History and Climate Change

A Eurocentric perspective

Neville Brown

London and New York

History and Climate Change

History and Climate Change is a balanced and comprehensive overview of the links between climate and man's advance from early to modern times. It draws upon demographic, economic, urban, religious and military perspectives. It is a synthesis of the many historical and scientific theories which have arisen regarding man's progress through the ages.

Central to the book is the question of whether climate variation is a fundamental trigger mechanism from which other historical sequences develop, or one amongst a number of other factors, decisive only when a regime/society is poised for change. Evidence for irreversible climate change is either partial or lacking entirely, but it is clear that climatic variation has regularly played a part in historical development. Particular attention is here paid to Europe since AD 211.

Cold and warmth, wetness and aridity can create contrary reactions within societies, which can be interpreted in different ways by scholars from different disciplines. Does climate change exacerbate famine and epidemics? Did climate fluctuation play a part in pivotal historical events such as the mass exodus of the Hsiung-nu from China, the pressure of the Huns on the Romans and the genesis of the Crusades. Did the bitter Finnish winter of 1939–40 ensure the ultimate defeat of Hitler? These events and many others are discussed throughout in the author's distinctive style, with maps and photographs to illustrate the examples given.

Neville Brown is Professorial Research Fellow at Mansfield College, Oxford University, and is attached to the Oxford Centre for the Environment, Ethics and Society.

Routledge Studies in Physical Geography and Environment

This series provides a platform for books which break new ground in the understanding of the physical environment. Individual titles will focus on developments within the main subdisciplines of physical geography and explore the physical characteristics of regions and countries. Titles will also explore the human/environment interface.

1. **Environmental Issues in the Mediterranean**
   J.B. Thornes and J. Wainwright

2. **The Environmental History of the World**
   Humankind's changing role in the community of life
   J. Donald Hughes

3. **History and Climate Change**
   A Eurocentric perspective
   Neville Brown

History and Climate Change

A Eurocentric perspective

Neville Brown

London and New York

First published 2001
by Routledge
11 New Fetter Lane, London EC4P 4EE

Simultaneously published in the USA and Canada
by Routledge
29 West 35th Street, New York, NY 10001

Routledge is an imprint of the Taylor & Francis Group

This edition published in the Taylor and Francis e-Library, 2005.

“To purchase your own copy of this or any of Taylor & Francis or Routledge’s collection of thousands of eBooks please go to www.eBookstore.tandf.co.uk.”

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
Brown, Neville.
History and climate change: a eurocentric perspective/Neville Brown.
p. cm.
Includes bibliographical references and index.
1. Climatic changes—Social aspects—Europe. 2. Human beings—Effect of climate on—Europe. 3. Europe—Civilization—History. I. Title.

QC989.A1 B76 2001
551.694—dc21

2001019473

ISBN 0-203-99568-6 Master e-book ISBN

ISBN 0–415–01959–1 (Print Edition)

Contents

Figures

Maps

Preface

This book is the first fruit of a conversion, that from a long-standing involvement in Strategic Studies – alias International Security Affairs. The most evident backdrop to this has been the strategic revolution of a decade ago and, above all, the end of the division of Germany and of Europe. History may conclude that Strategic Studies contributed to this benign *bouleversement*, particularly through its concern with how to cope with the quantum jump in firepower that nuclear weapons represented. But the result has been to leave the subject itself currently in limbo, with most of its customary themes either a sight less relevant or else analysed to exhaustion already.

Some of us have long argued – nay, pleaded – for its taking societal change, world resources and ecology properly on board as salient themes in the continuing quest for a true peace. But those who guard its inner sanctum have been much too resistant to this. Most would, in any case, be inwardly incapable of extending their remit that bit further to comprehend the threats to lasting peace posed not just externally but by the contradictions and instabilities within Western societies themselves. And in so far as other strategists may prove able to broaden their brief, they will thereby become generically less distinctive.

Yet this book is also the product of a reversion, one to my own youthful quest for identity and purpose. This quest boiled down early on to what the world might see as a stark alternative, that between history and physics. A country lad's fascination with the weather led me through meteorology towards general physics. But I always lacked confidence in my laboratory technique. Besides, the family precedents were towards reading history, precedents reinforced by the quasi-Churchillian sense of perpetual historic crisis many of my generation had imbibed from our wartime infancy. In addition, my home area – the Chiltern escarpment in the central Thames Valley – resonated with its remoter past more visibly then than it does now: with the Celts, the Romans, the Romano-British, the Anglo-Saxons and the Normans, not to mention Tudor and Stuart times. What brought everything full circle was the early acquisition of a riveting sense of shifting climate patterns, prehistorically as well as later.

The upshot was a decidedly unorthodox progression, one perhaps too much so to be admissible today. Grammar school majors in the physical sciences were followed by degrees in economics and history. Next, National service (i.e. military conscription) supervened, having previously been deferred (I had been led to believe for ever) by a sub-clinical attack of glandular fever or something like it that a Royal Air Force medical had uncovered.

So the question was how to respond to good effect. At that time, the Fleet Air Arm was advertising short-service commissions as meteorological forecasters. The said advertisement was explicitly directed at honours graduates in physics and mathematics. But swayed by maternal insistence, I rather desperately applied. I gained the last of the six new-entry places on the meteorological long course then being organised. Thus began the most diversified and stimulating three years in my whole career.

Not every interest or obligation pursued in the interim evokes nostalgia today. But I also look back with wistful gratification to my years (1965–73) as a defence correspondent, part-time but quite proactive. My most salutary experience was to discover in Saigon in 1966 how much erstwhile 'Kennedy liberals' – the 'best and the brightest' from Ivy League campuses – were feeding misguided official optimism about the war by applying their trite social science models to an alien culture via pathetically skimpy and corrupted databases. The troops in the field gave you a different story. This experience, in particular, has left me with abiding reservations about modish methodologies. Historical climatology is justified in part, in my view, as a corrective to forecasts of climate change and of its human impact that are entirely computer-driven. In that realm, computers are always essential but rarely sufficient.

About terminology, there is not a lot to say. For purposes of enumeration, Anglo-American units are used interchangeably with metric ones (Système Internationale) because that is how the relevant literature pans out still. As regards analytical terminology, 'erraticism' is preferred to 'variability' in allusions to acute fluctuations in climate at the interannual level. Also, the word 'secular' is used only how economists use it, as a synonym for 'long-term'. In economics, that tends to mean across several decades. Here it may mean a century or more. The term 'century' is, of course, a standard unit of time throughout though it has sometimes been imperative to insist that its employment cannot be tied too tightly to a timescale split into 100-year segments through our biological and cultural evolution. That sort of interval often proves very germane in history, whether human or ecological. But flexibility may be needed about when a particular century begins or ends for a given purpose. The romanisation of Chinese dynasties is in *pinyin*.

As regards the long timescales, the traditional 'BC v. AD' is generally used to locate events within the last two or three millennia. Otherwise one talks of years Before Present ('BP'). Occasionally, the names assigned to geologic spans are used. The Holocene is the last ten or maybe eleven millennia: back to when the last great glacial withdrawal was all but completed. The Pleistocene is from there to two million years BP; and the Pleistocene and Holocene epochs together constitute the Quaternary period. The one before it is the Tertiary, which begins 65 million years ago in the aftermath of the K/T episode: the catastrophic ending of the Mesozoic era. Where climatic comparisons with modern times are made, the statistical norms are mainly taken from the mid-twentieth century – that is to say, before anthropogenic 'greenhouse' warming began to accelerate so dramatically.

Territorially, the focus is very much on Europe, a preoccupation encouraged by the intricacy of its geography and the comparative richness of its database. Special attention is given to the period 211 to 1350 – i.e. from what some of us see (*pace* Gibbon) as the high water mark of the Roman Empire to the dawn of the Renaissance as it is as often still delimited. Excursions are regularly made to the Far East and the Near East: to the former chiefly for comparative purposes and to the latter because it is so interactive with Europe. The 'Near East' is cast widely – from Morocco to the Khyber Pass and from the Danube to the Horn of Africa.

Any presentation of this sort is bound to have a smack of the arbitrary about it. More than proportionate attention is paid to England as the mainspring of many of my own perspectives. Then again, academic affiliations are cited for quite a few of the specialist scholars quoted – this to generate a stronger sense of how the subject area has ramified. But it has been impossible to treat all concerned thus.

Likewise, a personal judgement has been made in favour of using the title ‘the Catholic Church’ to cover the institutional framework of Western European Christianity through the Middle Ages. That disposition is not uncommon in the modern world, especially the Protestant world. But what one needs to be satisfied about is that this or any other term selected allows of due recognition of the non-heretical pluralism (Celtic, Parisian, early Franciscan . . .) evident to an extent within medieval Western Christendom.

In the early centuries of the Church, the term ‘Catholic’ did tend to mean Rome-based orthodoxy. Nevertheless it seems to me that, on balance, it meets the stipulation just made better than ‘Roman’ does. All else apart, ‘Roman’ fails the elementary test of not encompassing the papacy’s ‘Babylonian exile’ in Avignon from 1309. Furthermore, to speak of the ‘Latin Church’ is unsatisfactory because it is not expressive of grass-roots support. Your Tuscan peasant, say, was never ‘Latinist’ the way his Eastern Orthodox counterpart, in the heartland of Byzantium at any rate, was Hellenic.

Warm thanks are due to many libraries. Those within Oxford I have relied on heavily include the Bodleian Map Room, the History Faculty Library, Mansfield College, Radcliffe Science, and the School of Geography. Those elsewhere in Britain I have likewise drawn on frequently include the British Library, the London Library, the National Meteorological Library, the Royal Astronomical Society, and the Wellcome Institute. Within Oxford, I have been glad to turn occasionally to the Ashmolean, the Faculty of Social Studies, the Oriental Reading Room of the Bodleian, Rhodes House and the Radcliffe Camera. Libraries elsewhere that have been most helpful on a ‘one-off’ or occasional basis include the Library of Congress in Washington, the National Diet Library in Tokyo, the Senate House at the University of London, the Society of Antiquaries, and Wabash College in Indiana.

Michael Brown, my cousin, is thanked no less warmly for reading draft scripts *en route*, as are Susan Bird, Graham Hutt, Ronald Long, Lawrence Measey, and Richard Washington for their thoughts on particular approaches. Jon Edmunds and Toby Purser are thanked likewise for reading the full draft through. So is Nigel James for the cartography. So is my wife, Yu-Ying, for her moral support at a time when she herself is poised to make a very singular contribution in Japanese art history.

For permission to reproduce illustrations, thanks are gratefully extended to the National Defence College in Helsinki; the President and Fellows of Corpus Christi College, Oxford; the Warden and Fellows of New College, Oxford; Ian Allan, publishers; AKG Photo, London; and the Mary Evans Picture Library.

This text is dedicated to Jill and Trevor Wells. Jill has been my Literary Secretary these past 27 years, unfailingly positive and dependable throughout. Trevor, too, has ever been in support if needed. More widely, we and all their friends appreciate their *joie de vivre* and generosity of spirit, qualities undimmed by their marked and merited success in the affairs of this world.

Neville Brown

About the author

As the Preface indicates, Neville Brown's career has been based on an unusual interaction between the humanities and geophysics; and also between global ecology and strategic studies. He read economics with geography at University College London, and then modern history at New College, Oxford. For about half of the time he then spent as a forecasting officer in the meteorological branch of the Fleet Air Arm (1957–60), he was involved in upper air analysis. He also had extensive experience on a coastal air station plus some in a gunnery-trials cruiser. He was a field meteorologist on two British Schools expeditions to sub-polar regions.

He was elected to a chair in International Security Affairs at the University of Birmingham in 1980. He has held Visiting Fellowships, or the equivalent, at the UK National Defence College, then at Latimer; the School of Physics and Astrophysics at the University of Leicester; the International Institute for Strategic Studies in London; the Stockholm International Peace Research Institute; and the Australian National University, Canberra. From 1965 to 1972 he worked as a defence correspondent around Afro-Asia, successively accredited to several leading Western journals.

He has authored ten books or major reports on strategic studies or contemporary history. With the award-winning *Future Global Challenge* (Crane Russak, New York, 1977), he began to stress the need to give economic, social and ecological factors some salience in a strategy for achieving a peaceable world in the decades ahead. This thrust continued with *New Strategy Through Space* (Leicester University Press, Leicester, 1990) and *The Strategic Revolution* (Brassey's, London, 1992).

From 1981 to 1986, he was the first chairman of the Council for Arms Control, a British all-party body drawn from a range of professions and dedicated to a multilateral approach to arms control and disarmament. He thus became involved in London, Washington and elsewhere in the debate about the Strategic Defense Initiative, alias Ballistic Missile Defence or 'Star Wars'. From 1994 to 1997 he was attached to the Directorate of Sensors and Electronic Systems within the UK Ministry of Defence as the academic consultant to the comprehensive official review of what our BMD policy should be. As its declassified version confirms,[1] the 87,000-word *Fundamental Issues Study* he wrote in this connection adopted a very low-key approach to that whole question and called, in particular, for a tighter arms control regime against the weaponisation of Space.

In 1990, he had moved to Oxford University to join the Environmental Change Unit. He is now a Professorial Associate Fellow of Mansfield College attached to the Oxford Centre for the Environment, Ethics and Society. He is also a Senior Research Associate at the Oxford Centre for Water Research. He and Professor Issar of the Ben-Gurion University of the Negev jointly edited the Proceedings of an International Workshop entitled *Water,* *Environment and Society in Times of Climate Change*. The subject matter extends across the Holocene. This project has been sponsored by the International Hydrological Programme of UNESCO, and the Proceedings were published in 1998.

Also in 1990, Professor Brown was elected a Fellow of the Royal Astronomical Society in recognition of *New Strategy Through Space*. In 1995, the University of Birmingham conferred on him an official Doctorate of Science in Applied Geophysics.

Part 1

The conceptual background

1 A confluence of disciplines

It has long been appreciated that, in relation to the ranges of temperature life forms tolerate, the climate of our planet has been remarkably 'uniform' the last billion years.[1] Viewed more closely, it is constantly inconstant. A burgeoning awareness of what this connotes could give 'historical climatology' wider currency. Customarily, it has covered the history of climate change, especially as revealed archivally in the pre-instrumental era.[2] In the future, it may routinely embrace the interaction with human history. Before the big expansion of coal production began 250 years ago, the balance was heavily towards climate cause and human consequence.

A particular contrast between the 'pre-industrial' era and today is that climate improvement then meant warming in most European minds. A warmer clime caused less clinical stress in wintertime for the very young or elderly. It usually connoted, too, a longer and more intensive growing season for crops and young animals. But caveats need be entered. Any secular trend in air temperature signifies a holistic adjustment involving sunshine, wind and – above all – rainfall patterns. Then again, the spread of diseases has a complex relationship with the prevailing weather.

Besides, we are today downright apprehensive about warming *per se*. For one thing, the technologies at our disposal facilitate adjustment to numbing cold better than to enervating warmth. For heat, being a randomised form of energy, is easier to add than extract. Still, apprehension stems mainly from the pace contemporary change could gather: not a degree or so movement in air temperature over several centuries, as per these last two millennia, but two or three degrees Celsius or Centigrade in one century. A further reality may be that our psychological roots predispose us to coping with coolness rather than heat. Maybe, too, with desiccation rather than profusion.

Children of the Wisconsin

Two million years ago (late in the Pliocene epoch), a warmish terrestrial climate turned much cooler though also, on millennial timescales, a lot more erratic. This mode has prevailed much of the interim, sustained by higher levels of atmospheric dust due to much more volcanic activity.[3] Other variables have most notably included the incidence of solar radiation. Indicative of the setting for the arrival of 'modern' humans in Europe may be a seabed core extracted from mid-Atlantic at 53°N. It reveals a summer sea-surface temperature peaking at 15°C in 122,000 Before Present (BP). Then erratic progress to 14°C in 75,000 BP led on to a plunge to 6°C around 72,000 BP. Recovery therefrom gave way to another peak-to-trough fall (from 12 to 7°C) between 54,000 and 46,000 BP.[4]

Tropical and subtropical regions extensively turn drier as climate zones edge towards the equator whenever polar ice extends much.[5] What was perhaps the greatest extension of northern hemisphere ice in the last 200,000 years climaxed in 18,000 BP. The glacial era between 72,000 and 10,000 BP has been known to European scholars as the Würm and in North America as the Wisconsin.

Our zoological family, the hominids within the primate order, had left a shrinking African rain forest during the equatorial aridity of the late Pliocene. Thenceforward it was little inclined to return to the jungle canopy. One recalls Joseph Conrad's alluring evocation in *Heart of Darkness* of an archetypal equatorial river, a description presented as 'an unrestful and noisy dream' about interaction with a historic past we jib at returning to.[6] The hominid predisposition when faced with recurrent drought was to extend across the steppic plains and other virgin lands.

For the greater part of the last million years, hominids have roamed much of the eastern hemispere. Lately, however, the balance of the genetic and morphological debate has been swinging towards acceptance of an 'out of Africa' thesis. It says that biologically 'modern' human beings, *homo sapiens*, evolved strictly within sub-Saharan Africa 200,000–400,000 years ago.[7] Something over 100,000 BP they crossed or circumvented the Sahara. Soon they were in south-west Asia; and 60–70,000 BP, on the latest evidence, already in west Australia. By 20,000 BP, they were entering the Americas in force.

At some point (i.e. mainly within a few millennia) they comprehensively replaced the Neanderthal proto-humans that had preceded them in Eurasia. My suspicion is that the transmission of disease, unwittingly and otherwise, was decisive. But maybe everything turned on more overt conflict and competition. A 1995 Stanford study concluded that much elimination took place from 50,000 BP, hard upon the renewal of hemispheric cooling. It was associated with a leap forward in the material culture of *homo sapiens*, concurrent with their spreading across temperate Eurasia. More efficient hearths were one aspect of this cultural transition; sewn skin clothes were another. Modern humans thus moved well ahead of the Neanderthals culturally; and probably registered further brain development as well.[8] To the end, Neanderthal proto-humans remained better attuned to the cold physiologically. But they had come to fit too closely a Toynbean-style model of 'arrested development' (see p. 33). Current genetic indications are that any interbreeding between them and *homo sapiens* was very belated and limited.

Predation by modern humans was also salient in the extinction virtually worldwide of the large mammals – i.e. those well over human body weight. In Australia this phase is effectively over by 35,000 BP.[9] In North America, over two-thirds of the megafaunal species were destroyed – very largely in the twelfth and eleventh millennia BP, hard upon the arrival there of *homo sapiens* and during a time of marked climate change.[10] In Africa, the isolated island of Madagascar conspicuously excepted, the extinctions come earlier (mainly between 110 and 70 millennia BP), but only two-fifths of the megafaunal species die out.[11]

In the higher latitudes, this behaviour is part and parcel of our ancestral response to glacial vicissitudes. Echoes abound in the dour celebrations of the far north in modern Western literature.[12] Some contributions ring very true. Witness the writings of Fridtjof Nansen (see Chapter 4) and of Vilhjalmur Stefansson (1879–1962), the Canadian Icelandic explorer-cum-scientist.[13] Witness, too, the experiential poetry and prose of Robert W. Service; and the empathy William Morris felt towards Iceland's pre-industrial society and artistic culture.[14] Conversely, some evocations of a Nordic or Teutonic past are altogether too mythical, and the political overtones either sinister or silly. Diabolically both was the 'World Ice Theory' apropos Nordic origins promulgated in the 1920s by the Thule Society of Munich, a group linked to the infant Nazi Party. Then in the realm of civilised literature, it would be hard to find anything more jejune than the rendering the poets W.H. Auden and Louis MacNeice gave of their pilgrimage in 1936 to what the former had foreseen as the 'holy ground' of Iceland. Auden, in particular, comes across as desperately incommoded by the whole experience. Even those vulcan landscapes, sternly enchanting to a sympathetic eye, he likened to the 'useless débris of an orgy'.[15,16]

Through the nineteenth century, those the Amerindians scornfully said were 'Eskimos' (eaters of raw flesh) came to occupy a 'conspicuously privileged' place in the imagination of a Western world fancifully 'fascinated by their position amidst the ice'.[17] But all over the globe there were encounters with 'primitive peoples' living in wildernesses that could be extolled by the *literati* as affording a chance to escape awhile. At first sight, there is nothing peculiarly human about ubiquity. Many other genera have spread round the world adaptively. But each has separated out into new species as it has done so. It is hard to think of another species that has spread so far and evenly on its own account.

By dint of their propensity to outreach, early human beings (and, indeed, the hominids as a whole) were a striking exception to what Charles Darwin saw in 1859 as the 'remarkable fact . . . that many more . . . forms have apparently migrated from the north to the south than in the reverse direction', the former connoting higher latitudes to lower. He presumed natural selection had endowed 'the northern forms' with 'dominating power'. But Elizabeth Vrba has proposed a hypothesis that better accords with logic and fact. It is that, during the late Tertiary and Quaternary periods (i.e. the last 15 million years or so), some crucial land bridges (notably, Suez and Panama) have been open whenever the ice caps have been bigger and sea levels therefore low. One particular consequence has been that far more species of mammals have migrated from Eurasia to Africa than vice versa.[18] Robert Ardrey suggested that the contrary thrust on the part of the hominids was a quest for prey 'naive' because unfamiliar with the innovatory battle tactics of 'our two-pint ancestor'.[19]

The most obvious expression from the more recent past of continuing outreach has been the settlement by the Europeans since the Renaissance, but especially between 1845 and 1900, of so much of the Americas, southern Africa and Australasia: a progression sometimes modulated by climate change, either within Europe or else in the new lands. It is salutary to recall that the abrupt curtailment of territorial extension around the turn of this last century has been among the many explanations advanced for the outbreak of the First World War: 'The very process of imperial activity had simultaneously furnished occasion for clashes and crises, and served the function of safety valve for the overflowing energy of Europe. There was, in 1914, no room left in the world for fresh conquests.'[20] Attributions of exceptionalism warrant the focus on Europe throughout this study. An argument for mainly concentrating on AD 211 to 1350 can be that aggressive tribal migration then figured repeatedly.

In many aspects of human ecology, the contrast with modern times is marked. Take the balance, as mediated through geographical space, between Humanity and Nature. Johan Huizinga, an eminent Dutch historian, observed in 1924 how, in the fourteenth century, a small town could experience a nocturnal peace more profound than was ever the case currently: 'The modern town hardly knows silence or darkness in their purity, nor the effect of a solitary light or a distant cry.'[21] Today the divergence is even starker almost everywhere. In such respects, the rural western Europe of 1924 was surely closer to that of 1324 than to that of 2000.

Modern geophysics, pre-modern history

The tempo and therefore the character of geophysical change are also different. When a forcing mechanism alters the circulation of the atmosphere and oceans, the basic components therein are liable to reach their new equilibria at quite different rates. Take adjustments to a sharp alteration in the thermal ambience. The characteristic time for effective 'equilibration' is given as a million seconds (*c.* 11 days) for the free atmosphere or surface soil. For sea ice, it varies between days and centuries. For mountain glaciers, 300 years is typical. With the bigger ice lobes, one must think in terms of millennia.[22] The same applies to the ocean deeps. In the middle of this last century, pioneering Swedish work on deep seabed cores showed that temperature trends in the bottom water of the equatorial Atlantic Ocean matched the secular variations at the surface, though with much smaller amplitudes and a delay of 'less than' a few thousand years.[23]

The significance thereof lies in this. If, as in Late Antiquity to the High Middle Ages, such a parameter as surface air temperature alters but one degree across several centuries, then almost every component will virtually synchronise throughout. But if, as per the standard 'business-as-usual' scenarios for contemporary 'greenhouse warming', one foresees a degree Celsius rise in air temperature every several decades, lag differentials must be anticipated. So the past climatic record could not proffer predictive analogues for the immediate future even were that record more complete in itself. A further complication is that the atmospheric carbon dioxide (CO_2) now so prominent as a climate forcing agent can, in addition, stimulate directly the growth of certain plants.

All of which cautions against climatologists attempting what both economic and military historians have sometimes essayed: treating the historical past as a database from which to distil a set of precepts of putatively enduring worth. As to whether this would be best practice in any case, the two most distinguished of Britain's current galaxy of military historians have proffered salutary advice. Sir John Keegan argued many years ago the futility of looking for timeless Principles of War, citing the distinctive *modus operandi* of medieval war to illustrate the point.[24] As late as the fourteenth century, after all, some adjudged it unchivalrous to look for topographic advantage in battle.[25] In similar vein, Sir Michael Howard has extolled the combining of a general awareness of how warfare has evolved with a rounded knowledge of a selected campaign. Thus may one acquire an understanding of this chaotic phenomenon richer than mere principles inculcate. He has endorsed in this context the dictum of the German-Swiss historian, Jacob Burckhardt (1818–97), that the 'true use of History is not to make men more clever for the next time but to make them wiser forever.'[26]

Addressing the era from Late Antiquity to the Early Renaissance, it is exceptionally important to study the past in its own right in every respect. This is because, in the eighteenth and nineteenth centuries, Protestant and secularist historians viewed this era as simply the Dark Ages, a long and cheerless night ahead of a transcendent Renaissance dawn.[27] Accordingly, the field was largely left to patriotic historians endeavouring to trace unilinearly the origins of their own nationhoods. Edward Freeman, Regius Professor at Oxford from 1884, gratified many compatriots by brusquely insisting (*pace* the Domesday Book) that the Normans merely modulated a process of nation building their West Saxon kingly predecessors had begun.[28] In France, Jules Michelet (1798–1874), sometime professor at Le Collège de France, had been more convoluted in his approach to the more involute emergence of France as *une personne*.[29]

By the time my generation of aspirant historians arrived on campus, the term 'Dark Ages' had virtually been confined to the fifth to ninth centuries and was coming to mean 'obscure' rather than 'atrocious'. Today, if used professionally at all, it is without prejudicial overtones. But that does not mean preconception has everywhere been vanquished. In workaday Anglophone parlance, terms like 'medieval tortures' or 'medieval obscurantism' are still generically applied: this regardless of time or place and careless, too, of the century we ourselves have just left behind being unsurpassed in the realms of brutality, disinformation and sheer unreason. So those medieval centuries need primarily to be studied for their own sake and with that blend of empathy and detachment that is the history ideal.

As regards the science of climate change, it could well be that over the next 20–30 years or so, the cutting edge will move to biogeography. As of the present, however, the most pressing issues are still in atmospheric physics with requisite inputs from elsewhere in geophysics and astrophysics. The term 'extended atmospheric science' is herein adopted to cover the sector as a whole.

The limits to confluence

To bring geophysics and human history together thus is to raise anew the 'Two Cultures' theme explored from 1959 by Sir Charles Snow, a divide between the arts and sciences seen as being a bit worse in England than elsewhere in the West.[30] However, the Snow model may have been unduly simplistic at the time and has proved the more so since. Surely there is no less of a dichotomy within science as between physics and the life sciences, this due to the latter encountering much greater complexity at the molecular level. Then on the other side of a supposedly binary scene, divergence often occurs between history and the mainstream social sciences or between it and cultural studies or literary appreciation. These days, too, any discipline within the humanities is liable to split between those who press for the extended use of mathematical data and techniques and those more conservative on this score. To which one might add that, in continental Europe, there has long been a more ready disposition to extend the bounds of science to encompass history than has obtained in the Anglophone world. Nor is this just a matter of semantics.

Perhaps, in any case, the similarities between history and extended atmosphere science are stronger than might be assumed. Take again the British experience. The interwar period was a time when both subject areas went far towards defining themselves in modern terms. It was also a time when each developed a felicity for communicating with a wider public without sacrifice of scholarly scruple. One may read the astrophysicist Sir James Jeans[31] (of Princeton and Oxford) or the meteorologist/climatologist Sir Napier Shaw.[32] One may then turn to such Whiggish historians of that generation as G.M. Trevelyan[33] or H.A.L. Fisher.[34] To make that switch is not to leap over a chasm. It is to stay within the same Aristotelian tradition of deductive empiricism.

None the less, everybody knows the two subject areas contrast to an extent. The philosopher Sir Karl Popper of the London School of Economics averred that one crucial test of a statement being scientific was its validity being testable definitively and by objective means. True, many of the more particular of the statements historians make likewise have that attribute. However, most of the more general ones do not.

Other distinctions were drawn by the late Sir Isaiah Berlin. Historians are, in the main, reluctant to set their specific conclusions within an overarching interpretation: 'Addiction to theory – being doctrinaire – is a term of abuse when applied to historians; yet it is not an insult if applied to a natural scientist.' Except where history has been enlisted by authoritarian ideologies or regimes to offer up a total explanation of everything (the aberration Popper dubbed 'historicism'), that difference is very evident.

By much the same token, historians seek multiple causes for a signal event, these often so disparate that they can plausibly be linked only via the idiom of everyday discourse. Berlin duly contended that 'A man who lacks common intelligence can be a physicist of genius but not even a mediocre historian.'[35] But what is 'common intelligence'? Some of the historians cited below – e.g. Edward Gibbon and Michael Postan – were not weighed down with humdrum common sense. Nor was Nansen, somebody who combined historical awareness and scientific excellence to a fault. Besides, some would rejoin that scientists routinely display an uncommon sense by isolating a particular effect and then ascertaining for it the simplest cause consistent with the evidence. In other words, they act in accordance with the 'razor' enunciated by William of Ockham (*c.* 1285–*c.* 1349): 'What can be done with fewer is done in vain with more.' With this crisp axiom, this late medieval Oxford logician (and rebel theologian) laid the cornerstone of modern scientific method.

All the same, such 'reductionism' is hard to apply to extended atmospheric science and to its environmental connotations. There are so many variables, each and every one difficult to abstract in the non-laboratory conditions that obtain. For instance, during these last two and a half centuries of global warming, no phase has caused so much professional consternation, both at the time and since, as the resumed cooling (in the northern hemisphere at least) between 1940 and 1965. Some 30 years ago, Reid Bryson of the University of Wisconsin essayed a multilateral explanation. It was that temperature trends before, during and after reflected an ever-shifting balance between several disparate influences upon the atmosphere – notably solar output, carbon dioxide, solid particles due to human activity and volcanic dust.[36] On the grander scale, the huge perturbations, physical and chemical, in the Earth's biosphere that effected the mass extinction not just of so many dinosaurs but of most other living things some 65 million years ago (thus constituting the Cretaceous–Tertiary [K/T] divide that ended the Mesozoic era) appear to have had a raft of primary and derivative causes.[37] Among them may well have been the solar system's encountering a giant molecular cloud, hydrogen from which caused a big draw-down of atmospheric oxygen by combining with it to form water.[38] Against that background, one can hear well the admonition in the 1988 President's Address to the British Ecological Society against being overly concerned with 'ontological' reductionism as applied to biological systems. This may lead to a neglect of variations, be these reactive or random, within a given system or in its ambience.[39]

Numeracy

Also, there are respects in which history and extended atmospheric science are becoming more akin. Recourse to theory is, in fact, one. Granted, the historicists (Plato, the Hegelians, the marxists, Toynbee . . .) have lost ground professionally of late. But the liberal mainstream of history is conceptualising particular themes (demography, economic take-off, crisis management, individual and mass psychology, ecology . . .) more regularly than before. Another exotic possibility, poised to enter via archaeology, is the catastrophe theory formulated by the French mathematician René Thom in 1972. It uses three-dimensional geometry to define the sudden changes of state that may occur (for good or ill) when the balance of forces acting on a situation flips. A standard instance is how critically an animal or, indeed, an army that is at once angry and frightened may be poised between fight and flight.[40] Many a long and hard-fought battle has ended very suddenly and conclusively. No less striking is the suddenness with which a community can switch either way as between tolerance and intolerance of some other social group.

The application of catastrophe theory to history and social science could become extensive, albeit more at a philosophic level than through esoteric mathematics. Take the sudden collapses of societies or regimes not seldom to be observed in pre-industrial times. Any such occurrence is deemed as likely to be the end result of a slow but insistent adverse trend in climate, or whatever, as it is to be the immediate consequence of an earthquake or a barbarian foray or some other abrupt event.[41] The view expressed in a 1922 demography classic that it seems inherently impossible 'to correlate the migrations of history, which are essentially rapid movements with slow changes of climate' would these days be seen as a non sequitur.[42]

A 1978 study of a peninsula on the southern Peloponnese revealed a marked shift in settlement towards higher altitudes sometime between AD 550 and 1250. Military insecurity was felt then to have been too ubiquitous throughout the eastern Mediterranean to have effected any such displacement. It was proposed that ecological decline involving an acute deterioration of the thin soils could be an explanation tolerably in accord with Ockham's razor.[43] Critical conjunctions of factors (military, ecological, epidemial . . .) may account for a long-enduring tendency for population to be distributed very unevenly as between different Mediterranean coastal plains.[44]

Of wider import is recourse to numeration in historical research. As far as Late Antiquity to Renaissance foreglow is concerned, this trend has owed a deal to field archaeology but some to social science. It can sometimes hamper exposition but has underpinned objectivity. Even the magisterial Burckhardt felt entirely free to lace insightful narrative with unscholarly jibes. Witness his dismissal of early Islam as a 'low religion of slight inwardness' that appealed to 'the very narrow Arab mind'.[45]

Yet it has long been evident from social science how soon one runs up against limits to numeracy. The last 30 years have seen occasional endeavours (notably by the UN and *The Economist*) to devise indices of national welfare in the round, these for purposes of international comparison. But the construction of any such index is admitted to be a highly subjective exercise.[46,47] In a 1972 league table, the USA was ranked fifth with a score of 56 if a high divorce rate was seen as a sign of social malaise. However, it was an easy first with 457 if acceptance of divorce was held to betoken tolerance and understanding. Since when, the decline of formalised marriage has compounded this particular ambiguity.

In that compilation, 15 criteria were brought together by simple addition with no weighting. Climate did not figure, no doubt because even so seemingly straightforward a parameter as mean temperature subsumed endless permutations.[48] Endeavours to quantify the human impact of climate variation have encountered similar problems. In Britain in the 1960s, attempts to delineate optimal summers for people and/or crops relied on linear equations with three basic variables: mean temperature, either overall or else daily maximum; sunshine totals; and rainfall or rain days.[49] Applied across the board, the results were somewhat banal. Nevertheless, this approach could assist in the interpretation of historical trends with staple crops.

When the direct impact on human beings is assessed, two issues arise. One is the effect of the weather on human energy, physical and mental; the other its influence on disease. Although this text concentrates rather on the meteorology of bubonic plague and its concomitants, a great variety of sickness correlations are germane.[50] Yet few are easy for the medical profession to elucidate. One tough case is whether it is low absolute humidity that makes respiratory infections so characteristic of the European winter.[51]

Reams have been written this last century about our basic metabolism and the weather. The literature reaches out to such ergonomic questions as the microclimate of an aircraft cockpit or a gold mine. No commanding overview has so far been achieved. Nevertheless, many writers since Antiquity have envisaged a climatic happy medium especially as between the terrestrial extremes for warmth and cold. The post-Pythagorean Greek thinker Parmenides (b. 515 BC or thereabouts) established an enduring convention by dividing the globe into five climatic zones: one torrid, two of moderation, and two polar. These last he knew to be inclement. The torrid he believed to be downright uninhabitable. The word 'climate' comes from the Greek for 'inclination' – i.e. of the Sun's rays.

A venturesome British contribution to the debate came, in the course of the Second World War, from the man who had been a firmly supportive Parliamentary Private Secretary to Prime Minister Ramsay MacDonald as the latter split the Labour Party asunder in 1931 by forming a coalition National government.[52] In a book taken up by schools and colleges, Frank Markham saw ambient heat as the key to the physical and mental energy of human societies. He averred that the ideal climate for outdoor work was (on the Fahrenheit scale) 'a daily temperature average of between 60° and 76° with moderate humidity, a gentle breeze and agreeable sunshine.'[53] It was a personal judgement but one many people might casually agree with. What would be helpful is a definitive analysis of weather trends in our ancestral home on the East African plains across the era when *homo sapiens* was completing its evolution, more or less, and making ready to move on – 'out of Africa', as things transpired. Pending this, one gets the impression that the annual temperature then and there was declining through 80 to 70°F (*c.* 26–21°C) as per the global sequence outlined above.

Any idea that this temperature range might be the human optimum would have been bad news for pre-industrial Europe. The International Standard Atmosphere (a schema devised for calibration and the like) gives mean sea-level temperature as 15°C on the 45th parallel: the latitude of Florence – a city which does, in fact, have close to that average. For Athens, the mean is near to 18°C but for Copenhagen only 9.5°C. What must also be allowed for is the 'lapse' of air temperature with altitude (see p. 15).

To his main thesis, Markham added a rider. In the eleventh century, the Normans had introduced the flue (i.e. smoke shaft) to western Europe in order to make the upper storeys of their stone keeps habitable. From the thirteenth, he said, Provence and north Italy apparently led a broader transformation in domestic heating. This involved the brick chimney and soon the grate; and was complemented by glazed windows. The dwellings thereby transformed included, in Lombardy and Tuscany, those of the urban bourgeoisie, not just the castles of the nobility (see Chapter 8). Frank Markham surmised that this was precursory to north Italy initially acting as a pacemaker to the Renaissance.[54] Modern textual research underpins this hypothesis in that it finds 1320 to 1390 to be the period when fireplaces proliferated across that region.[55]

But how well can excavation plus archival sources gauge such a trend, given the overlays of urban redevelopment? And how useful, in any case, are general enunciations of ideal climates? As human ecology and ergonomics have developed, the tendency has been to shy away from omnibus formulae. Today, we observe the city state of Singapore displaying intense vitality though not two degrees from the equator. Its daily maximum temperature averages 29°C and annual rainfall 240 cm. Air conditioning indoors helps sustain things now but did not aid much the initial economic take-off.

The difficulty of gauging the impact of climate variations is compounded by air flow. Incorporating the three parameters of temperature, humidity and wind speed, one finds a subtle divide between a coolish breeze being 'bracing' (i.e. invigorating) and its numbing the body and mind. The same applies to whether a light and warmish air is salubrious or enervating. Following remarks by C.E.P. Brooks, Melvyn Howe attempted to map the British Isles in these terms. Inevitably, the delineations were arbitrary.[56] Comparisons of wind chill are only unequivocally helpful across a widish range of values (see p. 36).

Chaos and antichaos

There is another novel branch of pure mathematics that bears directly on extended atmospheric science. From the early 1960s, Edward Lorenz of the Massachusetts Institute of Technology, a mathematician turned meteorologist by the exigencies of 1941–5, pioneered what became known as 'chaos theory', an account of how far initial conditions modulate a whole range of dynamic progressions. 'Now that Science is looking, "chaos" seems to be everywhere. A rising column of cigarette smoke breaks into wild swirls. A flag snaps back and forth in the wind.'[57] It does not seem as yet to loom large in the other sky science, astronomy – not over timescales that can easily be judged.[58] It may well transpire, however, that within 'chaos' and (p. 12) 'anti-chaos' lies a key to the early cosmos, particularly the streaming of exploding matter into galaxies.

On a terrestrial plane, a better understanding of cloud development (quite a critical dimension in climate change) may be afforded. Clouds epitomise the seeming randomness of the weather compared with the certainties of the heavenly round. For the West's *literati* from Aristotle onwards, they have betokened the insubstantial and elusive, even dissolution in death.[59] To landscape artists, they have been background features it has been unimportant to depict aright. Never bother, for instance, to give towering cumulus the flat base it so readily reveals when viewed obliquely. Sir Karl Popper contrasted clouds with clocks, the former betokening the limits of scientific prediction.[60]

The dimensions at which chaos operates are those of Newtonian physics. Nevertheless, it owes something to the Uncertainty Principle that Werner Heisenberg formulated in 1927 within the quantum mechanics revolution. This principle denies that anything can be measured with absolute exactitude. Thus two adjacent particles may be impossible to differentiate; and yet the contrast between their situations may soon lead them onto quite different paths of development, spatially or in such respects as energy level. The chaos theorists speak of the particles respectively being drawn to different 'attractors' in 'state space'. A famous exemplar of such divergence is the 'owl's mask' Lorenz derived from a three-dimensional study of convection currents in air.[61]

Chaos theory duly affirms that precise prediction indefinitely into the future or past of the weather or climate is ruled out in principle. It likewise underlines the dominance, in this whole sphere, of non-linearity. A chaos factor lies behind the irregularity in strength and timing that natural periodicities in climate (e.g., El Niño, discussed in Chapter 2) exhibit, even though well established and understood. Then there is the question of how 'chaos' bears upon the unwitting impact of humankind. About this, an interpretation has been put forward by T.N. Palmer of the European Centre for Medium-Range Weather Forecasts: 'the goal is not predicting an individual trajectory on the climate attractor; the goal is to determine the shape and position of the whole climate attractor itself when, for example, greenhouse gases increase.'[62] But that makes it no less important to get the initial conditions right. Take some experience in the Hadley Centre within Britain's Meteorological Office. A climate model had been predicting a 5°C warming from a doubling within the atmosphere of CO_2 equivalents. Then the ice in layer cloud was reduced. The prediction dropped to 2°C.

Timothy Palmer has inferred from the principles of 'chaos' certain likely outcomes of contemporary climate forcing. Among them are that the existing succession of climate zones will essentially be preserved. Moreover, the response in a given location will chiefly involve alterations in the relative frequencies of the pre-existing weather regimes. How the behaviour of El Niño may be affected is thus far unresolved.[63] All these considerations bear on the historical past as well as the secular future.

Lately, a new dimension has entered this debate: 'anti-chaos'.[64] It was inspired considerably by Erwin Schrödinger's reference to life's 'astonishing gift of concentrating a *stream of order* on itself and thus escaping the decay into atomic chaos.'[65] Among the inanimate repetitive patterns that result are snowflakes – formed as crystal accretions effected by the interaction between heat flux and surface tension in freezing droplets. Turbulence, too, readily assumes a degree of organisation. There may be clues to larger phenomena here, such as the way cumulus clouds may either cluster within or line up across an apparently uniform airstream.

At the same time, anti-chaos may help explain, let us say, the emergence of bargaining structures within a free market. Via such pathways, it feeds into history. Neither from antichaos nor chaos are definitive results in prospect for either history or extended atmospheric science. But again, the philosophic import could be considerable.

Delayed confluence

Yet to aver that history and geophysics have more in common than usually assumed cannot be to allow them simply to conflate. Admittedly one oft-quoted and, in many ways, highly informative study did just this, drawing on economic history in order to demonstrate an allegedly comprehensive flip-over to a less salubrious climate virtually throughout north Europe *c.* 1300.[66] As a general rule, however, historical climatologists have much preferred that the two streams of knowledge be brought together interactively only in the final analysis. Otherwise arguments too readily become circular.[67]

A cardinal question must always be how closely alterations in the pace or direction of economic and cultural development coincide with the climate changes deemed conducive to them. Many aspects of human behaviour militate against coincidence being exact. Often the most capricious will be the advent of new fashions in food, drink, clothing and architecture. Many manorial houses were built across central Europe between 1550 and 1600 as wealth diffused. Not a few had Italianate features even though the weather was then turning cooler. Witness the open loggias quite common in England. Over a century later, the poet Alexander Pope could still mock enthusiasts 'proud to catch cold' at a Venetian door.[68]

The evolution of fashion had likewise affected the geography of medieval wine production, something often treated as though simply climate-driven. Initially, the consumers of northern Europe had to be content with local ferments, thin and tart though sometimes spiced. By the fourteenth century, however, they were gaining access to strong, sweet wines from the Mediterranean – vernaccias and malmseys. In an age short on dietary sweetness, these became popular among those who could afford them.[69]

In similar vein, one has to say that, however conspicuous it may appear in retrospect, one cannot take artistic or intellectual virtuosity as indicative of progress in more prosaic realms. To cite a celebrated essay informed by the late medieval/early Renaissance era: 'There is no heap of riches and no depth of poverty that will automatically ensure or forbid artistic achievement. Intellectual developments must be traced primarily to intellectual roots.' Not seldom, investment in the fine arts or uplifting architecture rides high when more profitable avenues are hard to find.[70] Renaissance Venice has been cited as perhaps a case in point.[71] Its singular geography drew forth a townscape of evocative harmony.[72] Clearly, if the criteria of progress are disparate, they must all be used with caution when gauging an exogenous influence such as changing climate.

Soils, climate and hydrology

An interdisciplinary linkage of considerable import is that between climatology and soil science. A complication is that the ambience within soil differs profoundly from that in the free atmosphere, not least as regards temperature and the gaseous composition of air present. At a depth of 40 to 50 centimetres, daily variations in temperature usually count for little. Several metres down, the same applies season to season. A big question for historical climatology has been whether the Oxford economic historian Sir Michael Postan was right to interpret the high medieval socio-economic crisis as brought on by the inexorable interaction secularly of population pressure and soil exhaustion.[73]

Soil represents a chemical and physical weathering of the bedrock, and tends towards symbiotic equilibrium with the vegetation it supports. A strong vegetative cover much depends on the soil being well developed in depth, allowing of aeration and percolation and with nutrients in appropriate horizons. Plant nutrients include trace elements (e.g. iron, molybdenum . . .) that act catalytically. But the bulk foods are nitrates, phosphates and potash. In the Growmore fertiliser (developed in Britain for horticulture in the Second World War) the proportions of nitrogen, phosphorus and potassium are the same, 7 per cent in each case. However, nitrogen commands most attention. For one thing, it is especially prone to leaching. Obversely, many plants, vines included, are susceptible to nitrogen excess leading to growth distortions – e.g. undue leafiness. But the biggest problem historically, whether recognised at a given time or not, has been that the nitrogen a field under crop expends in a year may be several times the throughput via the natural cycle.[74] Nitrogen-fixing leguminous plants (e.g. the beans, peas and clover of medieval Europe) can help restore the balance as can manure. Medieval farmers were not even vaguely aware of any such benefit in either until quite late on.[75]

An overall measure of the quality of a soil is its location on the pH acid-to-alkalinity scale. It runs from 0 to 14, being acid below 7 and alkaline above. Many crops, including most fruits, seem happiest on mildly acid soil but others (e.g. peas, beans, vines and wheat) can appreciate to some degree the alkalinity associated with limestone bedrock. Towards either end of the scale plants tend to absorb nutrients less readily.

The systematic delineation of soil types was first addressed in nineteenth-century Czarist Russia.[76] It remains a daunting subject. All that can be offered here are a few indications of soils that mediate in a distinctive way between climate and vegetation in Europe. A good enough point of departure is the tundra, the ‘Arctic steppe’: the region within which the soil for some distance below a depth of a couple of metres, say, stays below 0°C for years on end.[77] It is not represented at all continuously in Europe (except in Iceland and along Arctic coasts), but high mountain soils can be akin.

Much more prevalent are the *podzols*. They are dominant across Russia to the north of 55°N; and preponderant around the Baltic. They result from fairly severe leaching of soluble salts: this derivative from a substantial rainfall, limited evapotranspiration and weak and disorganised surface drainage. It makes soil more acid by removing carbonates and other minerals while accumulating hydrogen ions. Acidity encourages but is also reinforced by the spread of conifers. Here as elsewhere, stands of trees can offer considerable resistance to change by virtue of mutual shielding.

In Russia, plus the Ukraine, there is an abrupt transition, bisecting the Middle Volga, from podzols to *chernozem*, the Russian term for black earth grassland. The chernozems are a form of weathered loess, material blown by the wind after glacial recession and deposited irregularly across central Eurasia from Germany as far as Manchuria. The calcareous origin of much loess tends to leave the chernozems with a pH of at least 7; and weathering helps make their top horizons humus-rich. They can yield bumper grain harvests. They may also prove more robust in the face of aridity changes than soils that are thin and humus-impoverished.

The vast loess deposits around the central Yellow River basin and other parts of north China tend in places (above all, in Manchuria) towards chernozem development. But the sheer thickness (up to 150 metres) of much of this non-compact material emphasises its porosity and proneness to erosion. These can be besetting weaknesses. It is an aspect to conjure when comparing droughtiness in Europe and east Asia.[78]

In the Mediterranean, thin and mildly alkaline soils occur widely because of aridity and the wide distribution of calcareous bedrock. Other features include (a) rich volcanic soils, (b) the *terra rossa* soils that result from the leaching then erosion of upland calcareous surfaces and (c) richly mixed clays and silts in the lower river valleys. The Nile affords the most striking example of the last, but the annual silting has tended to vitiate soil structuring.

Soil character is these days seen less than before as derivative from the bedrock. Nevertheless, it is a conservative factor that constrains ecological adjustment to climate change. Presumably, however, any discordance counted for less in the slower moving Late Antiquity and medieval climes than under present conditions. In Scotland and Wales, soil profiles from the last interglacial have been identified.[79] Agriculturalists have long cherished the belief that, in temperate latitudes (e.g. Atlantic Europe), good husbandry may often enhance across several centuries the potential of cultivated soil in relation to particular crops,[80,81] not least the grape. But improvement, or indeed impoverishment, across such extended time-frames is problematic (see Chapter 9).

Assessment of water in soil must encompass the bedrock below and the skies above. A key distinction in the science of hydrology is that between impermeable rock such as granite and the porous kinds – e.g. limestone and many sandstones. Most strata in either category develop cracks or jointed fissures which let rainwater trickle to lower levels. But the truly porous rocks (e.g. chalk limestone) may allow a high proportion of incident rain to seep extensively to a defined groundwater table.

The danger with groundwater is that it will be drawn on too liberally. The danger with run-off is that too little will be impounded. A cycle with high direct run-off is more vulnerable to a one-season drought. But reliance on groundwater can be singularly risky in the face of prolonged aridity.[82]

Marginal variations

Fluctuations in farm output were greater historically than in the Europe of today. The accumulation of capital and of scientific knowledge has sustained the evolution of a clutch of supportive strategies (hybrid seeds, advanced rotation, mechanised harvesting, fertilisers, pesticides, irrigation . . .). The stabilisation these proffer is illustrated by a study covering 1965–85 from near Stavropol in the European USSR. Better rotational management plus some application of fertiliser led to winter wheat yields in a very arid season being 80 per cent of what they would be with optimal weather. Otherwise the differential was 32 per cent.[83]

All the same, variations in the water cycle still are more pronounced in areas that are marginal in relation to rainfall averages. That can apply week to week or century to century. Basic comparisons are normally year to year. Nicholas Middleton of the Oxford School of Geography defines 'arid' lands as ones in which only nomadic pastoralism is possible because mean annual rainfall is between 80 and 350 mm and prone to fluctuate 50 to 100 per cent from the local norm in a given year. Within a parkland regime of grass and copses with rain-fed cultivation, the mean deviation is put at 25 per cent or less.[84]

Pretty much that distinction emerged from a survey of pre-modern British India. Reckoning in the most erratic 50 per cent of the years, 1890–1923, it found the standard deviation from the long-term mean was well under 15 per cent around the Ganges delta but well over 30 around the desertic lower Indus.[85] There are implications for the Near East periphery of the monsoonal circulation, notably the Hejaz (see Chapter 4).

Nor should alterations in mean temperature be discounted. In some situations, they are still prime movers. Comparisons are made in Chapter 2 of the vigour of the respective growing seasons on the coasts of Finnmark and of Denmark. Even on the Danish littoral, a lowering of mean temperature by 1°C throughout a season would decrease the growth potential (measured in the terms stipulated) by a sixth. In Finnmark, the decline would be a quarter.

More generally, temperature is a key determinant of the altitude up to which arable or grazing may be sustained. The global mean for the lapse of temperature with height throughout the troposphere (i.e. the air below the stratosphere) is put at 6.25°C per km (1°F per 275 feet).[86] Within two kilometres of sea level, the average may be a fifth slower. There can, in any case, be pronounced differences, especially at night, between the rates near topography and those in the free atmosphere. For observational reasons, the statistical data mainly relate to the former except higher up.

However, air mass differences are important. So, by extension, are regional norms. Over eastern Siberia in winter, the boundary layer (i.e. air near the surface) exhibits a negative lapse rate (i.e. actual warming with height) averaging as much as 18°C per km in December, a state of affairs that may lend some brittle robustness to the 'cold pool' anticyclone that through the twentieth century appeared so dominating a feature of northern Eurasia in mid- to late winter. Then again, evidence from Sicily points to a mid-Mediterranean positive lapse of only 4°C per km in high summer but 7°C in deep midwinter, a contrast largely reflecting seasonal differences in air mass origin. Each result bodes ill for Anatolia, a plateau of fulcral interest in the narrative that follows.

Meanwhile, the quasi-continental climate of north Germany shows a median value near to 7°C per km during five summer months falling to just below 5°C in midwinter. Britain would register a result very similar, albeit with the annual range diminished. To Gordon Manley, a pioneer of climatology across Britain,[87] the climate of the country was 'remarkably marginal'. Thus variations in mean temperature and, indeed, 'effective rainfall' such as have occurred over secular intervals have markedly affected the habitability of many districts.[88] Innumerable alternations in topography, relating to geological diversity, largely explain this. But lapse rates varying with air mass origins will also have been a consideration.

Professor Manley particularly addressed snow lie. He averred that, up to an altitude of 1,200 feet, the number of days in a calendar month with snow cover at 0900 hrs was essentially a function of that month's mean temperature. The connotations are indicated by comparing the years 1881–95 with those of 1921–35, thus bridging an interval in which England and Wales saw winter temperatures rise averagely 0.5°F. The consequences for a village 1,000 feet up in County Durham could have been a decrease from 57 to 38 in the average number of mornings with snow cover per year.[89]

Cover that is at all widespread and persistent generally correlates with air temperatures rising little above 34°F (1°C). That in turn means sharp nocturnal frosts beneficial to pest control, but with seeds in the topsoil below unshielded surfaces also dying as the freeze-up denies them moisture. Granted, extensive snow cover acts as a thermal blanket. But this cannot prevent the rupturing of leaves or blossoms above the ground as the aqueous solution within their cells freezes. Nor may it allow animals adequate grazing.

Weather and climate

Weather can be seen as a function of climate.[90] Obversely, climate may be seen as archetypal weather. A guide to the part each plays in our consciousness may be the space it commands in the 1989 edition of the *Oxford English Dictionary*. Over seven pages are given to 'weather' or directly derivative words. Less than one page is given to 'climate' and its derivatives.

Etymology illuminates things further. The word 'weather' crops up throughout the past millennium, its origins being Old Teutonic vernacular. The word 'climate' entered general currency in English and French in the late fourteenth century via the reapplication of classical learning. By 1661, the term 'climates of opinion' was being used, a departure which – taking the argument in reverse – underlines the notion of 'climate' as an ambient factor.[91]

Accepting the dichotomy implied, a British medievalist, Christopher Dyer, has lately protested that 'long term climatic shifts had considerable importance for a minority of people living in specialized environments' but elsewhere exercised 'an influence on economic change' that fell short of determining living standards. Contrariwise, 'short term fluctuations in weather had a profound effect on standards of living.' After all, a bounteous quarter of a century 'with five years of very poor harvests, would have been a miserable period for contemporaries . . . .' As Dyer acknowledged, however, an abnormal clustering of wet seasons in the early fourteenth century in western Europe (see Chapter 9) can properly be read as a determinate departure from the pre-existing norms.[92]

Statistical studies have demonstrated how gradual shifts in long-term average values may, even if other things remain equal, influence dramatically the frequency of a given extreme. Take the remarkably hot and dry summer the south of England experienced in 1976. That June was the warmest since 1658 at least. Were the secular mean temperature to remain stable, the statistical 'return period' for another June that warm was 330 years. But given a secular shift in the mean of 0.03°C a year (about what that region has experienced since), the return time could be 36 years.[93] Meanwhile, other analyses stress that short-term climate variability (what this study prefers to call 'erraticism') is itself a variable driven by climate change.[94]

In 1972, an Australian paper looked at displacements within the atmosphere of the principal 'centres of action', this in association with the temperature trend globally. It did sectoral reviews of how circulatory patterns had shifted in relation to the 0.5 or 0.6°C rise the previous century in northern hemisphere surface air temperatures. Most of the eight trajectories plotted were irregular; and no net displacements were great. The largest (from 61 to nearly 64°N) was in the North Atlantic, its sub-polar minimum in surface atmospheric pressure. Yet the movement of the corresponding Azorean maximum was 0.3° southwards towards 34°N. The Indian sector of the intertropical monsoonal trough moved northwards by slightly less, this through 27.5°N.[95]

Overall these are close to what one might expect. After all, the average difference in sea-level air temperature from equator to North Pole is *c.* 50°C or just over 0.5°C per degree of latitude. Therefore a rise in global temperature by half a degree might typically cause a latitudinal displacement of not more than one degree. On the other hand, the models of contemporary global warming tend on the whole to show more pronounced adjustments at higher latitudes. Hard to ascertain as yet is the linkage between such zonal tendencies and regional runs of weather. Nor will it be easy to translate current experience to past centuries. What can be noted *pro tem* is some resonance between this naive arithmetic and chaos theory prediction.

Individual occurrences

Allowing that the role of past weather in the critical minutiae of history is not yet gauged aright, the twentieth century alone is replete with instances waiting to be more closely considered. Attention is drawn by medical historians to the initial discovery of the antibiotic properties of penicillin by Sir Alexander Fleming in 1928. That summer, a microbe colony he was examining on a culture plate at St Mary's Hospital, London, died in the face of a contaminant mould, *Penicillium notatum*. For the latter's expansion to have begun had required several days with an ambient temperature not above 20°C – not longer, or else the contaminant might have weakened unduly. Apparently a door casually left open had afforded these preconditions against a background of unseasonable cold.[96] More generally, diplomatic conferences are a subject area that lends itself richly to exploration in the light of the weather along with the architecture, cuisine, information facilities, health of the principals and other contingent circumstances.

For pre-modern times, evidence on such events is hard to come by. But good and bad harvests are often individually recorded – usually with, particularly if a crop fails, a comment on the weather. Shipwrecks, too, are sometimes noted. Medieval English history was radically altered by two in the Channel. In obscure circumstances in 1064 or thereabouts, Harold Godwinsson went aground on the coast of Ponthieu, by the mouth of the Somme, and was ransomed to Duke William of Normandy. The results were fateful (see Chapter 6). In 1120, William Atheling, the only legitimate son Henry I ever had, was drowned crossing from Normandy. The upshot was England's being plunged into prolonged civil war on Henry's death in 1135.

Another sphere of knowledge in which the weather is too readily taken for granted is that of military history. It is so because logistics, technology, landscape and everything else is, too, out of deference to the qualities of generalship or a lack thereof. From AD 211 to 1350 most warfare was episodic and disparate. What with that and huge losses of information down the intervening centuries, many war leaders from then are (like their counterparts in the arts of peace) obscured for ever. But quite a number can be identified as having shaped, for good or ill, the course of hostilities and therefore of history in the round. Aurelian, Alaric, Attila, Arthur, Justinian, Heraclius, Harald Fairhair, Alfred the Great, William of Normandy, Seljuk, Richard the Lionheart, Saladin and Genghis Khan are among those who come to mind as strategists or battle commanders or both. They do so mainly by virtue of their perceived strengths in that realm. None the less, each and every one will have been considerably a creature of circumstance, the weather often included.

In the narrative below, Adrianople (AD 378) is recognised as a major encounter determined considerably by the weather on the day. The Norman campaign against England in 1066 is seen as conditioned by erraticism linked to climate change. The failure of the Mongol invasions of Japan, an outcome that shattered in the Far East any Mongol aura of invincibility, was capped by a 1281 typhoon – a singularity that perhaps bespoke a climate change (see Chapter 8, pp. 210–11).

Yet it is from the Near East that the most telling case studies can be drawn. That region is fulcral within Eurasia; and its largely desertic landscape regularly means that battles 'fought therein result in total victory or total defeat.'[97] Three episodes especially worthy of note are Muhammad's regaining of Mecca in 630; the Muslim Arab defeat of a large Byzantine army at the second Battle of the Yarmouk in 636; and the Crusaders' capturing Jerusalem in 1099. Clearly, Muhammad emerged as a prophet during a secular phase of aridity, aggravated in Mecca by a previous neglect of deep well digging. What has also been gleaned from Arab literary sources is that, before his triumphal return to Mecca in AD 630, the district had been visited by a year or two of drought so bad as to drive people to eat human flesh, grass, hair, and whatever. This episode had reinforced the effect of Muhammad's sporadic raiding of food convoys into Mecca and nearby villages from eastern Arabia and elsewhere. As the mercantile, artisan and cultic centre of the Hejaz, Mecca was absolutely pivotal to the Prophet's strategy. No doubt the warmth of his reception on return there (and then the explosive spread of Islam to embrace half of Arabia in the remaining two years of his life) owed something to a concurrent easement of the droughtiness.[98]

The pattern in respect of the fall of Jerusalem in July 1099 is both similar and different. The assault on the Holy City was by a force that was too weak using tactical opportunism to breach circumvallating ramparts that were too thinly held. Probably, too, the secular prevalence of a relatively cool, damp regime in the Levant in the eleventh century lessened the discomfort caused to the approaching Crusaders beforehand by the Fatimid defenders having felled the trees, scorched the earth and poisoned wells for quite a distance around the city walls.[99] The same stratagem was used a century later by a Saladin chastened by his defeat by Richard the Lionheart at Acre in September 1191. Yet Saladin not infrequently comes across down the centuries as a moderate and a moderator.[100] He might well have eschewed such ecological vandalism had he not been persuaded it alone could secure, in the situation prevailing, the Holy City he had lately regained. Others showed less compunction in the course of these divine campaigns.

The outcome of the 1099 battle for Jerusalem ultimately hinged on the besieging Crusaders constructing huge wooden towers in time to launch a decisive assault before a Moslem relief force from Egypt arrived. During much of the four weeks this took, a piercing 'sirocco' wind blew 'to deadly effect on the nerves of men unused to it.' The sirocco is drawn up from the south by low-pressure systems over the eastern Mediterranean. Through the twentieth century, it rarely blew anything like as long and hard in the summer months.[101] But this persistence may not have been as unusual in the more cyclonic regimen of the eleventh century.

Under these conditions, the Crusaders had to obtain water from beyond the Jordan, Muslim raids notwithstanding. The cumulative stress must have contributed to the wanton killing of all the city's Jews and virtually all its Muslims in the day or so after the final triumphant assault.[102] But long cycles of retributive violence will also have come into play. All too well remembered in legend was the killing or enslavement of all Jerusalem's Christians by rural Jews and Persian troops when the latter seized and sacked the Holy City in 614.[103] The rural Jew involvement can be read as exacting revenge for the oppressive circumstances of the droughty (see Chapter 5) Byzantine countryside.[104] And what we should remember, too, is (a) the Rhineland pogroms as the First Crusade was being launched and (b) the dreadful sacking of Christian Constantinople by Crusaders in 1204. Too often the sword or the cudgel too readily proved mightier than the pen. Peter the Hermit's ragamuffin Tafurs were especially blameworthy in 1099.

The second battle of the Yarmouk had been one the Muslim Arabs had to fight and had to win. Confronted by what was, in fact, a Byzantine–Armenian Christian army (much stronger numerically and more heavily equipped), they had lately fallen back to the desert fringe, abandoning such recent gains as Homs, Hama and Damascus. Had they continued to refuse a major battle, however, those tribal bands would quietly have melted away. Had they fought but lost, the morale effect on nascent Islam would have been disastrous. That they fought and won owed a great deal to the fact that a sirocco was whipping up the sand on the very day of decision. They advanced from the south-east against Christian defenders half-blinded by dust.[105]

The view that the weather factor is neglected in the voluminous literature on war is endorsed by the world's most eminent authority on the campaigns of Marlborough and Napoleon.[106] To cite a modern instance, let us return to Normandy, this time to the rough weather ahead of the scheduled D-Day of 5 June 1944. Forecasting for this Operation Overlord was done by telephonic conferencing between the several meteorological staffs, British and American. Mercifully, British caution tempered American sanguineness and secured a postponement from the fifth to the sixth. No less mercifully, American sanguineness bolstered British caution so that Eisenhower and his seniors were persuaded not to order another postponement: probably to 19 June, the next early morning low tide. Come the 19th, what was to prove the worst channel storm in that season for decades suddenly blew up.[107] Had the Allied assault waves then been storming in, the impact on them would have been catastrophic. All sides knew that a successful invasion was crucial to Anglo–American–Soviet cohesion; and that success or otherwise would largely be determined on the 'longest day', D-Day.

In short, the history of the world hung on judgements made about the weather by barely a dozen individuals, meteorologists and senior commanders. Yet come the fiftieth anniversary of the landings, only incidental recognition of this was shown by the military historical community. Take three studies, each brilliant according to its lights, that surmised how different command decisions at the time could have tilted the odds against the Allies. None adequately weighed the consequences of the Allied weather predictions being less finely honed or less judiciously responded to.[108,109,110] Significantly perhaps, it was left to a special atlas with commentaries to highlight not just the agonising difficulty of adjusting D-Day to tolerable weather but also to demonstrate just how close that storm of 19–23 June brought the Allies to logistic disaster, even a fortnight into a campaign then going tolerably well. A synoptic weather chart for 20 June clinched the point.[111]

Evidently, it remains necessary to bring weather more into our understanding of human affairs: in war and peace, in the past and in the future. Certainly weather must still be reckoned with in defence, not least because of (a) rising concern to ensure precision in targeting and (b) the extension of the operational zone through the high atmosphere. The relatively coherent level that separates the stratosphere from the troposphere is called the 'tropopause'. Its average height rises from 8 km over the North Pole to 16 km over the equator. Lay people tend to see that divide as between a weather-laden region below and the cloudless, weatherless stratosphere above. But as one extends up through the stratosphere, then the mesosphere to enter (at 80 km) the ionosphere, one observes a great deal of weather in terms of temperature and pressure patterns but also ionospheric electrical activity.[112]

Over and beyond the normal implications for radar and radio reception there are special consequences apropos a great bone of contention in military science at the present time – the interception of ballistic missiles maybe bearing warheads of mass destruction. Thus the explosion at 100 km, say, of a nuclear warhead (either pre-planned or as a result of its interception) gives rise to the electron surge known as electro-magnetic pulse (EMP). This can cause acute interference with electromagnetic radiation across a range of frequencies. Edward Teller, the hawkish 'father' of the American hydrogen bomb, regarded inadequate comprehension of this effect as a powerful reason why the West should not have agreed in 1963 to ban nuclear tests in the atmosphere.[113]

However, to anybody who has seen an aurora borealis at the latitudes (*c.* 70°N) at which it can be at its most lively, the notion that a few more such tests would have sorted that interaction out may sound optimistic. In any case, the situation has been fast evolving. Since the International Geophysical Year (1957–8), the mean temperature at 80 km has fallen 8 K, this probably as a negative feedback to greenhouse warming lower down.[114] All the parametric variations betokened by this signal fact must complicate, in the intricate Near Space ambience, forecasting EMP as well as the drift of lethal clouds – radioactive, biological or chemical. But this prospect ought further to discourage the extension into Space of the strategic arms race.[115] If it does, it will then be hard to demonstrate that the impact of weather on war matters as much operationally as it did in 1066 or 1944. All else apart, time-honoured manoeuvre warfare appears at last to be in decline.

Meanwhile agriculture, traditionally even more of a weather-prone occupation, was acknowledged above to be proving progressively more resilient in the face of weather adversity. At the same time it is quantitatively diminishing within the world economy. It is estimated to have occupied 72 per cent of the world's labour force in 1900, 61.5 in 1950, and 47.5 in 1988. Its share of the global aggregate of gross domestic products fell from 20 in 1948 to 6 in 1988.[116] The import of weather fluctuation and climate change is to that extent diminished. However, that diminution is transcended by the threatened pace of climate change and its interaction with other ambient trends.

On the morning of 2 June 1944 Group Captain Stagg, the senior meteorologist at the Overlord headquarters, looked at the current weather chart for the Atlantic. He found it to include more depressions than any synoptic chart for that area and season he could call to mind that century.[117] Even today, that maritime scenario does not lend itself to dynamic interpretation in terms of secular tendencies as readily as other weather extremes registered in the Europe of the 1940s (see Chapter 10). But many such blind spots should be remedied in due course. So, in anticipation, it may be more helpful to view weather as a derivative of climate than to view climate as the aggregation of weather.

Apocalypse then

This is not the place comprehensively to review the part consideration of climate change has played within the broader evolution of modern Western culture. That has recently been done well elsewhere.[118] But an early contradiction to explore is this. The great monotheistic religions of the Arabian desert fringe (Judaism, Christianity and Islam) each affirmed the notion of a natural order beneath the overarching firmament, an order stable until the end of time. Yet within them as well as without arose the legend of a dreadful climate catastrophe at the very dawn of human time.

In the Persian and Teutonic traditions, it was a winter of dreadful severity. The more general scenario, however, is of a deluge. It has been encountered among indigenous peoples from southern Africa to Mesopotamia, Australasia, Oceania and South America. Its salient features are strikingly consistent. There was a steep rise in sea levels, and, although the waters did soon subside, the effect was almost holocaustical. In some versions there are also hints of meteoritic impact with dust ejection, even though dustier skies would have caused expanding ice caps rather than rising seas. Natives of the Lower Congo have told of the deluge being preceded by a darkened Moon, while Assyro-Babylonian mythology has stressed six solid days of filth-laden torrents.[119]

Sometimes there will be conflation of folk memories. The cataclysmic eruption of the volcano Thira on the Aegean island of Santorini (now dated in 1628 BC) caused *tsunamis* in the eastern Mediterranean and spread a stratospheric pall of dust round the northern hemisphere. Not long thereafter, the Minoan civilisation on Crete went into irregular decline, absorption into the Mycenean orbit being part of this recession. In China the bronze culture Shang dynasty replaced the neolithic.[120] An earlier event was the surge of water across the Turkish Straits *c.* 5550 BC to create the Black Sea, a brackish extension of the Mediterranean 130 metres higher than the freshwater lake it subsumed.[121] This drama almost certainly shaped the Genesis/Dead Sea Scrolls story of Noah, not least his eventual landfall by Mount Ararat. Also, in 1996, Professor Alexander Tollmann of the Institute of Geology at the University of Vienna proposed that *c.* 12,000 BP (at the start of the Older Dryas cool phase) the Earth was hit by a shower of cometary fragments. He adduced debris and folk myth evidence but met with much scepticism. All the same, one may look for at least one input as overarching as that to account for indelible impressions of instant crisis as far afield as the Congo and Oceania.

Within the *homo sapiens* 'out of Africa' span, two pronounced elevations of the global sea surface have taken place. From 18,000 to 5000 years BP, there was a continual rise from a low point 125 metres below the present day to a high point slightly above today's mean sea level. Between 136,000 and 124,000 BP, virtually the same had happened.[122]

The earlier transition could be especially germane to legend forming. A global rise in sea level of two or three feet a century could have been under way as our immediate ancestors spread 'out of Africa' into south-west Asia. On gently shelving shores along the Persian Gulf, that much should have been noticeable. However, one should not assume that every change in sea level locally was simply eustatic – i.e. in line with the global trend. There are indications that crustal disturbance, temporary or permanent, can be a consequence of glaciation. Earthquakes and volcanic eruptions may be prominent among the manifestations. A case in point may be intense vulcanism *c.* 75,000 BP.[123] Also crustal movements may be revealed by isostatic (i.e. localised) sea level anomalies. Moreover, the Mediterranean twin basins show signs of being deeply disturbed geophysically *c.* 100,000 BP, early in the Wisconsin era and in the 'out of Africa' career of *homo sapiens*.[124]

The roots of historical climatology

The catastrophe legends served to complement the religious precept of a natural order stable beneath a symmetrical firmament. The synthesis was that this order never varies except drastically, and every drastic variation is a response by a just but jealous God to human sinfulness. In the mainstream of Catholic Christendom, the perception of pristine orderliness was consolidated during the intellectual stirrings of the twelfth and thirteenth centuries (see Chapter 9). The storms and downpours of the early fourteenth therefore struck those concerned as decidedly ominous. Comparisons with the Noahic flood were fearfully drawn.[125]

A measure of how the popular belief in a past 'universal deluge' had survived into pagan

Roman times had been its acceptance without demur by the cocksure young rationalist, Titus Lucretius Carus (*c.* 90 to 60 BC).[126] Otherwise the Classical *literati* come across as prosaically empirical regarding such matters. In *Meteorologica*, a book ascribed (probably correctly) to him, Aristotle (384–322 BC) observed how, since the Trojan War, some valleys in Greece had become moist enough for agriculture while others (e.g. Mycenae) had turned too dry.[127] Likewise, Pliny the Elder (*c.* AD 23 to 79) was among those who saw the shifting distribution of the beech, olive and vine as proof Italy and its environs were getting warmer and drier. But through Late Antiquity the *literati* were to find other themes to be more pressing.

For a good millennium after the fall of Rome, Europeans were very uncomprehending of gradual climate change across centennial timescales. As in other spheres, an interest the Classical world had episodically nurtured had to be reborn. Gestation began in the High Middle Ages. As regards the requisite physical science, however, solid progress had to wait upon the instrumental breakthroughs (telescope, barometer, thermometer, chronometer . . .) between 1600 and 1750. Only then was the scene set for a free-ranging debate about climate and society.

But the morning star thereof had been Jean Bodin (*c.* 1530–96), the French social philsopher best remembered for the quantity theory of monetary inflation. Where climate was concerned, he enunciated no strikingly new ideas. But he wove together the fragmentary comments of late medieval schoolmen to construct a studiedly pre-Copernican geocentric order attuned to astrological revelation. The arguments advanced about climate were enriched by evidence, however subjective. A cardinal theme was that the cool north-west of inhabited Christendom best nurtured social energy though maybe not individual acuity or artistic subtlety. A rider added was that windswept societies are prone to turbulence, political and cultural.[128]

Bodin's chief disciple in this subject area was Abbé du Bos; and his was Baron Charles de Montesquieu (1689–1755). David Hume of Scotland (1711–76) also stands out in this regard, as in others. These and the other members of the eighteenth-century philosophic 'Enlightenment' who engaged in such discourse varied in their emphases. But all were sure climate did affect both political culture and artistic expression, and, in particular, that the climate of Europe had warmed because of forest clearance.[129] Montesquieu, the best known to posterity, was the linchpin of this Franco-British community of scholars.[130]

The history adduced was not specific enough and the geophysics too confused for their endeavours to be of enduring intrinsic worth. But they did curb two misleading stereotypes, each of Classical origin. The prior one was still of an equatorial zone so 'torrid' that any indigenes would be fit only for enslavement. Then in part to counter it, there had been a chic revival of naive romance about a pre-existing 'golden age' in which 'noble savages' lived in a 'state of nature', perpetually and spontaneously suffused with integrity and contentment. Out of these cross-currents emerged Edward Gibbon (1737–94). He has been dubbed the first 'modern' ancient historian, not least on account of his Voltairean resolve to bridge the divide between religious history and the rest.[131] He could also be seen as the first historical climatologist, operationally speaking. No matter that the term 'climatology' was not to enter the English language until 1843.

Gibbon (see Figure 1.1) had read du Bos, Hume and, above all, Montesquieu. Also he was heir to the literary theme of secular decline, a theme traceable to the fifteenth century and which offset the sanguine 'smile of reason' of the *philosophe*. His mighty narrative about the Roman Empire necessarily presented the notion of decline as less complex than his generation well knew it to be.[132] He amplified the scornful indifference *philosophes* like

Figure 1.1 Edward Gibbon, *c.* 1790
Source: courtesy of AKG Photo, London

Montesquieu had evinced towards Byzantium: a pitch the most distinguished of his successive editors (the Dublin and Cambridge Hellenist-cum-liberal rationalist, J.B. Bury[133]) regretted and which a similarly eminent scholar later said 'killed Byzantine studies for nearly a century.'[134] For Gibbon himself that was but part and parcel of a general indictment of Christianity. Correspondingly, he too readily indulged paganism (Roman, Germanic, Arabian, Mongol . . .), not to mention an Islam he somehow persuaded himself was without any kind of priesthood and also schism-free.[135]

Still, he was never a set-piece *philosophe*. Hampered by his pudsy appearance, he evinced from his Oxford days onwards fierce hostility towards all intellectual establishments. The mental mobility he thus preserved yielded countless insights. He was in the literary circle of Samuel Johnson, another acute sceptic and *inter alia* the author of *Rasselas* – a satire directed in part against vainglorious scientists who might think they could soon do the 'multitudes' the kindness of controlling even the 'equinoctial tempests' while taking care never to 'rob other countries of rain to pour it on thine own.'[136]

Gibbon was interested in climate more than most. His database came to include jottings on local weather from as far afield as Iceland and Siberia.[137] He saw the barbarian tribes of Roman times as under the influence of 'food and climate' in a way which 'in a more improved state of society, is suspended or subdued by so many moral causes.' He further saw their elemental ruggedness and warlike proclivities as fired by how the chilliness and droughtiness they perennially experienced contrasted with the sun-soaked Mediterranean. Above all, he placed secular chilliness and periodic droughtiness squarely among the mix of causes that acted contingently to effect Rome's progressive decline and fall.

The twentieth century

For much of the twentieth century, historical climatology was dominated by people qualified in the Earth sciences. Most prominent initially was Ellsworth Huntington (1876–1947), a geologist and classicist by background and an ancillary Yale academician from 1905. He was said in 1972 to remain the most widely reviewed and read American geographer ever.[138] But to James Fleming he comes over as 'unrestrained and undisciplined', popular and prolix; someone whose 'basically unscientific' contributions cast 'a long shadow' over the repute of historical climatology.[139] Undeniably, his attitude to proof (be it logical or evidential) was too cavalier to survive in mainstream history or physics. Nevertheless, his personal fieldwork in south-west Asia between 1903 and 1906 afforded insights that led him to evolve, between then and 1924, a quasi-determinist thesis that remains of value dialectically as a counterpoint to Gibbon's causal relativism.

The axiom he started from was the overriding significance of rainfall variation. This he saw neither as random nor on an inexorable 'desiccation' path but as essentially cyclical, the cycles being more or less in phase across middle latitudes in the northern hemisphere. He perceived low turning points in Western Asia in 1200 and 125 BC, and in AD 650, 1200 and 1900. High points were deemed to occur in 950 BC and AD 0, then in 1000 and 1350.[140] He expressly saw the rise of the likes of Muhammad and Genghis Khan as facilitated by cyclical aridity.[141] Surely though, if so strong a cyclical tendency extends round the northern hemisphere, then each and every turning point is liable to be critical in a whole variety of locations widely spread. Huntington never marshalled materials to demonstrate so majestic a harmony. Nor has or will anybody else.

His attempts to account for cyclicity were likewise too simplistic. He and his colleague, Stephen Visher, sought to explain everything from short-term 'vacillations' to glacial epochs in terms of a 'solar cyclonic hypothesis' – i.e. variations in solar activity as revealed by sunspot periodicities. Their argument was insightful apropos the outflow from sunspots of charged particles. But much of their presentation consisted of hypotheses inherently implausible but also untestable with today's techniques, let alone those of 1924.[142] In short, they did not meet the Popperian criterion.

Where Ellsworth Huntington could have come across more persuasively was as his book *Civilization and Climate* drew to its conclusion. One says 'could have' advisedly in that by then he had allowed himself to assume great prominence in the national campaign in favour of eugenics.[143] Perhaps this digression was a reaction against the disinclination of the 'great and good' at Yale to consider him for professorial preferment.

If it was, it helped their case, not his. He was ill-accoutred for an intellectual evaluation of so loaded a subject. Instead, the role of the lobbyist atrophied that of the outreaching scholar. He failed to integrate at any level the two spheres of interest. Still, the saving grace was that *Civilization and Climate* contained little in the way of half-baked contributions to the eugenics debate.[144] What it did do was accept the modish argument that progress with indoor heating had allowed the foci of 'civilisation' gradually to edge polewards. To which Huntington pointedly added the rider that they were also drawn towards storminess.[145] An early critique was that, while both coldness and storminess stimulated primal energy and progressiveness, storminess was not a good setting for high culture. Charlemagne was more 'vigorous' than Harun ar-Rashid but not as 'civilised'.[146]

Huntington went on to argue that the supposedly 'hopeless' outlook for the tropics might soon be redeemed by (a) commuting from salubrious highlands, and (b) making building interiors cooler and drier.[147] In this latter regard, he was certainly ahead of the field. In the United States, air conditioning was installed in fine-thread textile factories *c.* 1920 but not more widely for another decade or so. Huntington's foresight well compares with the static determinism of the doyenne of Yale geography, Ellen Semple (1863–1932). Extolling climate as fundamental in 'all consideration of geographical influence', she unconditionally identified the temperate latitudes as 'the cradle and school of civilisation'.[148] She was dismissive of climate change. In the case of the Mediterranean, her main regional specialism, she discounted assertions of deterioration since ancient times as 'advanced chiefly by historians, archaeologists and other incompetent authorities . . . .' She cited sundry country-by-country studies plus her own findings about tillage dates etc. to infer little had changed over two or three millennia.[149] Yet to reason thus was to ignore the very real possibility that the climate of the Mediterranean had varied to and fro.

The Second World War was to witness a big, and considerably permanent, expansion in weather services. It was also to witness physicists and mathematicians taking over extensively from geographers in that subject area. The British historical climatologist Dr C.E.P. Brooks of the Meteorological Office library spanned this transition in his own career, *c.* 1926 to 1955. He followed Huntington in seeing the world as subject to several major 'fluctuations' in climate these last two millennia. Even so, he never tied himself to 'pulse of Asia' cyclicity, being exercised more by the 'positive feedback' (i.e. propensity to self-reinforcement) that characterises the expansion or contraction of ice caps (see Chapter 2).

Also, Brooks tried harder than Huntington had to explore geophysical causation. Paraphrasing Kipling on the construction of 'tribal lays', he quipped there 'are at least nine and sixty ways of constructing a theory of climate change, and there is probably some truth in quite a number of them.'[150] He, too, came to accept varying solar irradiance as the 'first favourite' cause of climate fluctuation while acknowledging there was still 'little or no evidence' to clinch any of the particular hypotheses.[151] In 1926, he had accepted the opinion of Huntington *et al.* (see Chapter 2) that increased sunspots often meant steeper gradients (i.e. stronger winds) in the Earth's atmosphere.[152] His own besetting weakness, even in relation to the methodologies he had regular access to, was dating. Eventually, he drew caustic scorn from Emmanuel Le Roy Ladurie for having *inter alia* used Toynbean speculations about nomadic eruptions to confirm the regional rainfall trends: 'What better example of a serpent biting its own tail?'[153,154]

Of Soviet/Russian climatologists, quite the best known in the West through the later Cold War years and beyond has been Mikhail Budyko of the Main Geophysical Laboratory in Leningrad/St Petersburg. For one thing, he was prepared on occasion (see Chapter 2) to query the way the Marxist mainstream extolled the 'drive for victory over the forces of Nature', portraying the latter as socialistically exploitable *ad infinitum*. That vision conspicuously found expression in how Albania, Cuba, the USSR itself and (pre-1969, let us say) Maoist China read Malthusian population pressure as a problem peculiar to capitalism. Likewise did it in proposals to transform Soviet climates either by warming the Arctic by controlling the flow of water through the Bering Strait or watering the arid southern territories by diverting towards them (over the next 50 years) maybe a third of the Siberian river flow. The latter strategy was explored the more determinedly, and was not, in fact, finally abandoned until 1986. As a study late on by the US National Center for Atmospheric Research at Boulder showed, the potential impact on the Arctic, and hence on planetary ecology, was probably not too drastic but remained very uncertain.[155]

Early on, Budyko himself had proposed melting the Arctic ice by spraying it aerially with soot.[156] Come 1971, he intimated he was still agnostic as to whether warming before 1940 would prove greater than the cooling discernible since. He gave pride of place to the cooling effect of atmospheric dust. He overplayed the extent to which comparison is vitiated by a shortage of data prior to 1875 or thereabouts.[157]

None the less, by 1978 he was anticipating that the cooling post-1940 would soon be reversed because the volcanic and man-made particle pollution he (much like Reid Bryson) attributed it to would be overridden by rising levels of CO_2.[158] Come 1985, he and colleagues were declaiming that, thanks to human activity, 'within only a few decades, the amount of atmospheric carbon dioxide is increasing by a value corresponding to its decrease previously over millions of years.' What he suggested, however, was that this 'restoration of the ancient chemical composition of the atmosphere' could effect 'an enhancement of photosynthetic productivity, warming in the countries with a cold climate, elimination of a possible glacial development.' Therefore, 'greater success might be achieved in the future by working out efficient methods to influence the atmosphere for the sake of the whole of mankind.'[159] The first of these propositions might charitably be read as a partially valid qualification of what would soon be in the world at large received greenhouse pessimism. The second was merely redolent of the spin the classical Marxists put on Victorian triumphalism.

Other Budyko traits have owed more to national culture than to ideology. One has been a disposition to compare predictions made by computer with those derived from historical analogues. Thus mean boundary latitudes for polar ice were calculated from shifts in mean temperature at 65°N for five phases covering between them a span of '232,400' years prior to AD 1800.[160] The relationship traced for the north polar region looks too linear to be convincing.

More ambitious though was his averration of quite a close link in the last 550 million years between major fluctuations in atmospheric CO_2 and the formation of rocks by volcanic action.[161] But in this instance above all, one is bound to ponder how accurate computation of the remote past can be. And can demonstration by analogy ever accommodate all the parametric variations? Arithmetic distillation of historical data similarly assumed prominence in Soviet thinking about future military conflict. In that domain, the Great Patriotic War (1941–5) was drawn on very particularly,[162] not always to good prognostic effect.

Excepting in the debate about the Gaia hypothesis (i.e. that terrestrial life acts collectively to sustain itself, not least by keeping the composition of the atmosphere relatively stable),[163] climatologists in the West have not been overly inclined to probe the pre-Wisconsin past. For one thing, their geologist colleagues lend little encouragement, finding recent climate trends trivial in relation to the infernal happenings they themselves routinely explore. By proceeding deep into such realms in order to illuminate the present, Budyko followed on from his fellow Slav – the great Serbian physicist, Milutin Milankovitch (see Chapter 2).

Among those who, since 1945, have contributed signally to the study of the climate of Europe and its environs over the last two millennia are Mike Baillie, Rudolf Brázdil, Keith Briffa, Willi Dansgaard, Jan De Vries, Hermann Flohn, M.K.E. Gottschalk, Jean Grove, Nikolaj Gumilëv, Fekri Hassan, C.U. Hammer, Arie Issar, Emmanuel Le Roy Ladurie, J. Neumann, Astrid Ogilvie, Martin Parry, Christian Pfister, Justin Schove, Leszek Starkel and Claudio Vita-Finzi. But standing more than *primus inter pares* is Hubert Lamb (1913–97). He does by dint of energy, vision, resourcefulness and commitment. He does, too, because of the encouragement he generously gave to many of us in the generation following on. He does not least through the breadth of his cultural horizons. Anybody who knows Iceland will find his account of a visit paid in 1938 far more empathetic and evocative than what Auden and MacNeice had proffered the previous year.[164] Lamb was heir to a British interwar genre that saw science as a solid grounding for non-esoteric philosophy – Arthur Eddington, James Jeans, J.B.S. Haldane, Julian Huxley, Charles Sherrington, H.G. Wells . . . .

But the ultimate yardstick is his scholarly works. The grandest, *Climate: Present, Past and Future*, has been adjudged by Professor Trevor Davies a synthesis 'of a scope and scale rarely seen in modern science' and one 'Many climatologists have claimed . . . fired their initial interest.'[165] As an overview of a big sector of applied physics as of 1977, it was an achievement of which Aristotle or Copernicus would have felt proud.

Prominent among many other contributions were those on (a) the climatic impact of volcanic eruptions, and (b) the frequencies of weather patterns as delineating climates. He was, in 1973, veritably the founding father of the Climate Research Unit at the University of East Anglia as a British counterpart to the Center for Climatic Research Reid Bryson had set up in the 1950s at Wisconsin. Under his successors as Director, Tom Wigley, Trevor Davies and now Mike Hulme, the CRU has carved a distinctive niche apropos the past and future of climate.

Hubert Lamb did more than anyone to engender among historical climatologists on this side of the Atlantic a feeling of common purpose. One could go further and divine something mildly Churchillian in his mien. Winston Churchill was less composed a person. In spite and also because of that, he operated in a much vaster arena. What the two men shared was a sense of being 'to the manner born' coupled with a heterodoxy fired, in Churchill's case, by Anglo-American parentage and, in Lamb's, by liberal Nonconformity. True, Winston the grand strategist would have scorned Hubert's acceptance, in July 1939, of transfer from the UK Meteorological Office to the Irish Meteorological Service rather than be obliged to study poison gas diffusion. The fact remains that a warrior and a conscientious objector *ipso facto* agree that war is a cardinal issue, just as an atheist and a religious devotee are at one about the importance of the God question. This writer has spent much of his career trying to grapple, mainly from a pragmatic standpoint, with the macabre problem of modern war. Yet in his early undergraduate days he very nearly declared for 'positive neutralism' because of (a) disgust at how the malign Senator Joseph McCarthy was fomenting 'anti-Communist' hysteria across the United States, and (b) disgust laced with trepidation over the book and film, *All Quiet on the Western Front*. The former reaction was fired by involvement in vicious clashes with the US Army in Austria while proceeding quite licitly as a student observer to a Communist 'peace rally' in East Berlin; but rejection of the overweening hatred fuelling that vast exercise in stage-managed hypocrisy proved the stronger response over time.

Gripped by urgent awareness of a world in dire crisis, both Churchill and Lamb evinced a strong will to lead proactively. But with the lonely eminence each thus assumed came a heightened propensity to err. Perhaps the most conspicuous instance in Churchill's grander scene was the endeavour he promoted to force the Turkish Straits in 1915 by committing an Allied army of such modest size that, had it debouched from the Dardanelles as planned, the defenders of Constantinople could then have devoured it several times over.

Nor are Lamb's analytical aberrations to be discounted. To imagine tidal floodings of evaporation pans causing a salt shortage in the Roman Empire seems surreal. Also he timed quite inaccurately whatever increase in storminess occurred while the medieval climatic optimum was peaking out (see Chapter 8).

Most contentious in his lifetime, however, was his scepticism about how quickly the 'greenhouse effect' (i.e. man-induced global warming) would build up. In the 1977 *magnum opus*, he saw no human contributions to warming or cooling as likely yet to have altered world mean temperature more than 0.2°C; increased atmospheric CO_2 as conducive to a temperature rise 'probably much smaller than the estimates which have commonly been accepted'; and the net effect of all the anthropogenic factors as 'probably very small'. Without 'stronger controls' than any so far considered, man-made heat would probably 'gain the upper hand' but only in the twenty-first century.[166] That aggregation Hubert Lamb always stuck by.

But in 1977, at least, scepticism was not atypical. That same year the then Director of the UK Meteorological Office alluded to 'the marginal effects of Man's intervention in climate', effects that 'may well be masked by natural variation.'[167] All concerned had been distracted by the cooling observable globally (and especially in the northern hemisphere) from 1940, a reversion that lasted through 1970 and which Lamb for one always insisted (*pace* Bryson) had never really been explained.[168]

Granted, Lamb's coolness towards computer prediction can be seen as a healthy corrective. He was also well aware that the net absorption of atmospheric CO_2 by plankton in sea water was actually greater at lower sea temperatures, a circumstance he felt made it that much harder to judge cause and effect. Another reason he found the greenhouse effect hard to gauge was because he divined the weather to be turning more erratic globally. Collation by Hermann Flohn and C.J.E. Schuurmans suggested extremes had increased since *c.* 1925 for monthly temperature, though only since *c.* 1940 for monthly rainfall.[169] But that disjunction surely enjoins caution. What is truly surprising, however, is Lamb's disregard of the anthropogenic inputs of other greenhouse gases. The 1972 and 1977 twin volumes positively consider only water vapour (see Chapter 2). Ozone is mentioned but immediately discounted.[170] Methane (CH_4) is not mentioned at all. Yet the part it plays today in greenhouse forcing is now nearly 30 per cent of that of CO_2.[171]

None the less, Hubert Lamb has left behind innumerable insights into the history of climate, not least from Late Antiquity to the Renaissance. Examples will be cited for decades. What is important is that these should not be treated as uncritically as, say, the maxims of Aristotle so often were through the High Middle Ages. That was quite contrary to the spirit in which Aristotle himself quested knowledge. The same would apply to Lamb.

The historians

Perspectives germane to the history and climate dialectic often come from historians under little or no professional obligation to extend their subject thus. A case in point is the thesis the University of Wisconsin historian Frederick Jackson Turner (1861–1932) enunciated in 1893. Its gist was that true democracy had been promoted across America by the 'moving frontier' of the Old West. The Turner thesis has attracted volumes of attention, a lot of it critical and some even psychoanalytical.[172]

Europe from Antiquity to the Renaissance was multiply enveloped by frontiers of settlement – maybe unsteadily advancing or intermittently receding, each tendency influenced by climate change. So if there is something in the Turner thesis (and provided the spatial dimensions, tempos and cultural settings are not too hopelessly different) that something may sometimes be translatable. However, it is salutary to bear in mind the contrary slant adopted by Georgii V. Plekhanov (1856–1918), the Russian Marxist philosopher and activist who became, in fact, a highly respected critic of Bolshevik sectarian violence. To him, the 'empty lands' of the Russian plain were a diversion from internal reform. Indeed, emptiness *per se* had negative connotations.[173]

The fact is that the frontier concept has never been explored adequately. Thus neither Turner nor Plekhanov addressed external frontier conditions so tough that breasting them has to be very much a collective enterprise, authority-led, as in the Christian *reconquista* of medieval Spain.[174] Nor did either tackle cyclical or secular climatic variation. Neither did they ecological degradation in the round. In the American situation, the poor and huddled masses had crossed the Atlantic Ocean not to conserve an unknown wilderness but to create circumstances in which their children could stand tall. As late as 1944, the then Chairman of the Tennessee Valley Authority spoke in such a vein about that great programme of interstate reconstruction pivoted on dam building. Granted, David Lilienthal extolled the TVA's achievements and potential in regard to erosion control, malaria eradication and lacustrine amenities. But he laid much more emphasis on 'democracy at the grass roots' via 'dreamers with shovels'.[175] Likewise, the big dam builders under the USSR's Five Year Plans were persuaded they were thereby creating 'Socialist Man'.

None the less, there were always those who celebrated Nature's true richness and yearned to see it preserved, not least on the limits of settlement. This applied in both these heartland nations emergent. Peter Kropotkin and Aleksandr Borodin (1833–87) helped evoke this spirit in Russia, as did the likes of John James Audubon (1785–1851) and Henry Thoreau (1817–62) in the United States.

Moreover, the rigid determinism so prevalent among American geographers in the early decades of this last century may gradually have been tempered by the waxing among historians of a consciousness of climate change and of varied responses to it. Several indications can be cited. In 1913, Ellsworth Huntington outlined in the *American Historical Review* the climate and history question as he interpreted it. He did so more acutely than on some occasions. Witness his insight that (as per what was said above) the 'genius of Mohammed' gained sway when a 'prolonged period of increasing aridity' in the Hejaz 'culminated with a sudden excess of dryness'. Both variations were, Huntington sensed, basic to the prospects for religious transformation.[176]

Since the High Plains 'dust bowls' of the 1930s, much attention has been paid to how far they were part of a recurrent drought cycle and what impact this has had. Oft-remarked, too, has been a 1966 study by Rhys Carpenter (b. 1889), a Classical archaeologist at Bryn Mawr. He well appreciated how climate changes that are limited globally can be acutely critical near zonal boundaries. He duly identified three historical crises in the eastern Mediterranean. Each he attributed primarily to climate change.

The first 'discontinuity' was *c.* 11,000 BP. Carpenter clearly found it hard to reconcile with ongoing post-glacial warming. Today, climatologists can link it to the Younger Dryas reversion (for a millennium) to colder conditions. The origins thereof were long enigmatic. But lately work by Wally Broecker and others has indicated that a huge overspill down the

St Lawrence (from a glacial meltwater lake in the North American interior) blocked out the North Atlantic Drift for an astonishing 700 years. At all events, Rhys Carpenter divined 'certain evidence of a great cultural recession' then.

Come 1200 BC, said Carpenter, 'Mediterranean man has begun to suffer the most severe cultural recession which history records or archaeology can determine.' Kingdoms like the Hittites in Anatolia collapse 'without apparent adequate reason'. Refugees surge onto the Mediterranean's eastern shores. The fortified palaces of Mycenae and Crete are burned by persons unknown. Throughout Greece communities revert to 'hand-to-mouth' subsistence. Egypt sinks 'into helpless apathy' for a full 400 years, following the 'nine plagues' and the Exodus of the Jews.[177] The common denominator of this 'Dark Age' was a deterioration much exacerbated by volcanic eruptions in the 1150s and 1140s. However, earthquakes figured too.[178] Apparently we have here ramifications of the Thira event, inaccurately dated.

In the Greek realm, historians discern the consequent emergence of a 'far bigger' cultural gap than any later in Antiquity. The Mycenean/Minoan ruling class disappeared. Syllabic script apparently went with it. The region entered upon an era that certainly looks 'dark' in retrospect and must have been considerably so intrinsically. Though wine making was resolutely upheld, much else will have been discarded. Then, in the eighth century BC, occurred – suddenly, it seems – a pronounced renaissance. Hence the Greeks' sense of their history being very abbreviated, save for vague images of a pre-Homer golden age. Notions of alternation, climatic and otherwise, likewise emerged.[179]

The said renaissance rested on an alphabetic script – i.e. one based on the distinction between consonants and vowels. It gave rise to Homer and soon after Hesiod, plus their rival schools of poetry. It much cultivated the pre-existing taste for geometric visual art as expressed in temples and other important buildings as well as in ornamental/monumental vases. Soon this new culture spread round the Mediterranean as the Greeks established colonies in Sicily, Italy, France, Spain and Africa. All in all, it was a remarkable dialectical reaction to ecological (not least climatic) disturbance, one all the more vibrant and brilliant for being delayed.[180]

The third crisis was in the seventh century AD. The Mediterranean littoral then appeared to Carpenter 'largely a blank', with low levels of population and activity. Nor could this slump be correlated with the Islamic conquest. In Anatolia, many churches were built in the fifth and sixth centuries. In the seventh no more were, and many existing ones fell into disrepair. Water shortages occurred. Yet Arab armies never reached that region. Nearby Syria they did occupy but as liberators. No towns had to be stormed. But here, too, a wave of church building died away.[181] In all this, Carpenter was closely in accord with an archaeological review of Syria that Howard Butler of Princeton had conducted in 1920 (see Chapter 4). The latter then claimed to have encountered the most exquisite pre-Gothic churches anywhere. Moreover, he took that opportunity to retract two things he had concluded earlier. The one was that AD 252 to 324 had been a time of building recession in Syria. The other was that there was clearly an Arab building boom early on. Alas those prior conclusions will have nudged Ellsworth Huntington towards his pulsation thesis.[182]

Acceptance of climate variation as something for history to encompass will usually progress alongside recognition of other ambient factors such as plague and bullion flow as well as of new methodologies such as psychological analysis. By the time Carpenter made his seminal contribution, articles in the *American Historical Review* had flagged a burgeoning awareness of (a) the history of disease[183] and (b) psycho-history. The latter looked towards links with climate fluctuation, citing a Soviet study of 1926 linking sunspots to mass excitement and insurrection.[184]

In 1976, the American Association for Environmental History was launched. What lags in the United States and almost everywhere else, however, is the integration of that subject into the historical mainstream. A qualified exception is afforded by the Annalistes, a prolific French school whose defining journal first appeared in 1929. Broadly leftist, they have sought never to be entrapped either in deterministic Marxism or by circumscribed academic disciplines. *Annales d'Histoire Économique et Sociale*, as it was initially called, was modelled on *Annales de Géographie* founded by Paul Vidal de la Blache,[185] a prophet of 'possibilism' while not – one should add – extending the perception of climate change beyond the alternation of clusters of several wet and several dry years.[186] This emulation reflected a desire to respond creatively to the ongoing advance of French geography. But the early Annalistes were no less keen to reach out to economics and sociology or even natural science. From 1970, Jacques Le Goff extended the remit into the interplay between psychology and culture. He averred, for instance, that in the course of the twelfth century, the medieval experience of dreams became much more prosaic, less mystical.[187] The Annaliste goal throughout has been *histoire totale et applicable*. In that aspiration, they have followed closely in the footsteps of the *philosophe*. The mathematician and philosopher Jean D'Alembert (1717–83) particularly invites comparison with them.[188]

Two eras of Annales specialisation have stood out. The one has been the Middle Ages – e.g. Marc Bloch, Georges Duby, Jacques Le Goff, Emmanuel Le Roy Ladurie and Henri Pirenne. The other is Early Modern History – e.g. Lucien Febvre, Fernand Braudel and Le Roy Ladurie. An abiding aim has been to break out of 'concern for the short time span' and seek synoptic views of several decades or centuries. The magisterial Fernand Braudel spoke of *la longue durée*: an interdisciplinary secular sweep (guided considerably by numeration) encompassing, in general, 1450 to 1750, the crucible of the modern world. Stress was laid on *la conjoncture* rather than the mere *événement*.[189]

In principle, this pitch could well accommodate secular climate change and its impact. Some Annalistes have addressed these issues, but their commitment has yet to progress beyond questing agnosticism. Le Roy Ladurie has put in most work and is considered later (see Chapters 7, 8 and 9). In 1968, Duby thought it 'not unlikely that *c.* 1300 Western Europe entered a long period of adverse climatic conditions which could, in part, explain the return of food shortages and the desertion of certain lands.'[190] Braudel saw the climatic unity of the Mediterranean Sea plus its immediate littoral as a prime driver of an ecological and social oneness, historically expressed in the 'eternal trinity: wheat, olives and vines' and countless other ways. He could have extolled climate unity more had he not (drafting the first edition of his *magnum opus*, published in 1949, as a wartime prisoner in Lübeck) overstated the extent to which Mediterranean depressions originate in the Atlantic (see Chapter 2). Yet while he was writing eloquently about Mediterranean weather vagaries, he was disposed to discount secular climate trends there. The vagaries he saw as part and parcel of the constancy and uniformity, *une histoire quasi immobile*.[191] In the second French edition (published 1966) he conceded that the Mediterranean was affected by such global alternations as the Little Ice Age.

He avowedly loved 'the Mediterranean with passion, no doubt because I am a northerner.' He also waxed passionate about how much French scholarship had done to awaken the world at large – eastern Europe, Islam, Black Africa . . . .[192] Many Annalistes have shared his pride. But their cumulative effect via the history-cum-geography side of the teaching profession has been to erode a French sense of exceptionalism,[193] this as part of the accelerating trend towards melded cultures worldwide. Yet erosion and melding were prospects Braudel was loath to accept. It does remain fair to ask, apropos all societies, whether melding

Map 1.1 Alps to Apennines

might not induce social crises liable to interact harmfully with ecological ones, climatic or whatever.

Someone who saw civilisations as too organic simply to dissolve into one another was Arnold Toynbee (1889–1975), a British historian whose career was centred at the Royal Institute of International Affairs. He is remembered with awe but affection. At the same time, his attempt to interpret the broad sweep of history in systemic terms (mainly in a ten-volume *Study of History*, 1934–54) has always drawn fierce criticism, not least from old friends.[194] The basic unit in his world-view was the 'full-blown civilisation', a discrete entity that is born, grows and decays – its last age usually sliding into inchoate violence. An extra dimension was formulated from 1938, this in response to family sadnesses and a frightful world scene. Roughly speaking, it was an underlying movement towards a better future under the guidance of a thoroughly ecumenical God.[195]

Yet he is less relevant here than his stature might have led one to expect. Temperamentally, he was more philosopher than historian. Youthful involvement left his interest in Europe overly focused on the Eastern Roman Empire/Byzantium. In a brilliant comparison with Huntington, O.H.K. Spate (later a Professor at the Australian National University) showed Toynbee's 'glance-at-the-map' handling of geographical specifics to have been all too often flawed.[196]

As an ecumenical proselyte, Toynbee was taken up more outside the West – above all, in Japan. Between 1971 and 1974, he held free-ranging dialogues with Daisaku Ikeda, head of Soka Gakkai – a Buddhist movement for political reform rooted in traditional national values. The two of them readily endorsed the Buddhist precept of Esho Funi – a perceptual blending of the whole environment with the life force. But only Ikeda raised the question of mankind's inadvertent interference with climate; and he was far from definitive about it.[197]

Elsewhere Toynbee flung a gauntlet down *vis-à-vis* the interpretation of nomadism. He saw the qualitative 'growth' of nomad societies as 'arrested' by their very success in adapting to desert margins, 'The formidable physical environment which they have succeeded in conquering has insidiously enslaved them, in ostensibly accepting them as its masters.'[198] Highly questionable, however, is his elaborate tabulation of nomadic incursions between 2025 BC and AD 2175 [*sic*]. With almost no cross-references, far too much has to be taken on trust. So what of the Toynbee claim that the 'overwhelming majority' of nomadic 'eruptions' could be grouped into 300-year phases starting forcefully at regular intervals of 600 years? He saw this as explicable only in terms of climate pulsations, thereby waxing Huntingtonian more categorically than Ellsworth himself.

None the less, he introduced caveats. A concurrence of widely separated incursions did not *ipso facto* prove an overriding aridity impulse. Thus the attack on China *c.* AD 300 and those on the Roman Empire (in central Europe, the Levant, Egypt and the Maghreb) *c.* AD 270 he relates rather to the internal state of each imperium. As regards the Franks in central Europe, less rain would have made their forests agreeably less dense. More generally, conversion to a higher religion may either encourage disparate tribes to erupt in unison or else act 'as a social solvent' relaxing 'the moral fibre of the converts' and ensuring their downfall. The conversion of the Arabian tribes to nascent Islam and of the seventeenth-century Kalmucks to Buddhism were seen as instances of the former reaction. The conversion of the Khazars to Judaism (see Chapter 4) or of the mongoloid Golden Horde to mature Islam were deemed examples of the latter.

In matters of allegiance and of strategy, towns and oases can be nodal within a nomadic orbit. To be noted as well is nomadic 'seepage into sedentary areas' for a century or two before a major eruption or simply in between the eruptive phases. For all that, Toynbee was curiously non-committal about the exact mechanics of climate determinism, particularly at the putative 600-year turning points towards eruption – e.g. AD 375 and 975. Nor did he convincingly explain why, for instance, the eruptive phase seen as ending in AD 675 can be said to have started in 375 rather than, say, 250. Nor does his tabulation properly encapsulate the tenth-century wave of desertic intrusions (Chapter 5).[199]

An oddity in Toynbee's position was his celebration of *Muqaddimah* – a treatise on human environments by the Arab scholar Ibn Khaldūn (1332–1406) – as 'undoubtedly the greatest work of its kind that has ever yet been created.' Odd this was in that Ibn Khaldūn was much more of a climate determinist. A strong if circumstantial case has been made for saying that Montesquieu, too, was directly influenced by *Muqaddimah*.[200]

So how far did Toynbee draw on it himself? A clue may lie in Ibn Khaldūn's rather contradictory attitude to the Bedouin. On the one hand, these desert dwellers were seen as 'closer to the first natural state and more remote from . . . numerous and ugly, blameworthy customs' than sedentaries with undue affluence and ease. Bedouin courage, fortitude and self-reliance were extolled as near absolute, as was their loyalty to kith and kin. On the other hand, such virtues were seen as dissipating within several generations whenever the Bedouin took over an alien and rich environment. Moreover, they are loath to stand and fight outside of the open desert. They prefer just to plunder because 'their existence is the negation of building . . . the basis of civilisation.'[201]

Maybe Ibn Khaldūn could be said thus to anticipate the Toynbean notion of 'arrest of growth': a people becoming so attuned to a harsh though, he might presume, changeless environment that nothing would impel them from it. What neither author explained was how, between Antiquity and the Renaissance in Europe and around the Mediterranean, tribal nomads were so often able to integrate into a pre-existing sedentary order as rulers or partners. Nor did their morale or morality overtly collapse. All that did diminish, as a rule, was belligerency, a quality of more contingent worth.

William McNeill of the University of Chicago tells how *A Study of History* persuaded him that one mind could conduct useful historical synthesis on millennial timescales. But he never did accept cyclical rise and fall, believing rather in abrupt shifts periodically. Moreover, he soon discarded the idea of discrete civilisations struggling autonomously for primacy. He highlighted instead intercontinental networking between societies.[202] Such a model is concordant enough with those for climate change. Even so, McNeill has never stressed that dimension. Instead, he has done more than anybody to make us aware of other ambient factors – notably technology diffusion and epidemic transmission.

To my mind, another good opportunity to achieve some confluence between the humanities and the environmental sciences was missed when Karl Wittfogel (b. 1896) recast 'oriental despotism', a theme aired by the European *literati* since the sixteenth century. Gibbon upbraided Montesquieu for describing the Orient (Christian Ethiopia excepted) as dominated by despotisms due to the 'torrid' climate travellers told of. But Gibbon himself saw the Roman Empire as moderate and inclusive compared with every regime to eastward. Marx and Engels were among many who argued episodically from much the same perspective.[203] For Michael Rostovtzeff, however, Constantine's accord with the Church finally changed the regime into an 'oriental despotism, Near Eastern style.'[204]

What Wittfogel did from 1938 was relate this preoccupation to the intriguing reality that early civilisation tended to arise on sun-baked but flood-prone terrain where agriculture might thrive dependably enough but only through area irrigation. That entailed, he would aver, a bureaucratic central autocracy. His failure to exploit this initiative probably stems from his insecurity as a footloose German Marxist: a concentration camp internee, 1933–4, but an American citizen from 1941. He was associated a long while with the Frankfurt school of Marxist cultural radicalism, and was more briefly, in the 1950s, on the fringe of McCarthyism. His bitter distrust of Soviet Communism brought him close to political despair.[205] It also led him to conclude that Mongol/Tartar rule destroyed 'the non-Oriental Kievan society' and laid 'the foundations for the despotic state of Muscovite and post-Muscovite Russia.'[206] But why should the 'non-hydraulic' Mongols have adopted a political culture allegedly peculiar to hydraulic management? And why should its introduction to a Russia considerably rain-fed have proved so enduring?

In the 1957 quasi-classic just cited, Wittfogel did regale us with sundry choice asides. Not least of them cited a surmise by Charles Haskins that the Domesday Book of 1086 owed something to what the Normans had learnt about Byzantine/Saracen hydraulic society since occupying north Sicily in 1072.[207] But as Wittfogel's critics on all sides have observed over the years, his overriding inclination was to impose the blanket interpretation, ignoring contrary evidence. Sri Lanka was a case in point. It gets no mention in *Oriental Despotism*. But a detailed analysis by Edmund Leach in a Marxian journal showed how the Sinhala regime thrived in the 'northern dry zone' of the island, from the third century BC to the twelfth century AD, on the basis of water control devolved very largely to village level.[208] Much the same applied in Central America and the Andes up to the European advent.[209] All else apart, devolution ensured more resilience in the face of invasion.

Yet the most serious indictment of Wittfogel (and, for that matter, of his critics) has to be their failure to address the physical dynamics of hydrological management. There are no indexed references in *Oriental Despotism* to soil quality, salination, river basin topographies, silting, climate change or, indeed, nomads. There is no discussion of the first steps towards large state creation or of the initial motives. Nor is there of the distinction Edward Hyams had drawn between (a) the natural provision of silt acting each summer within the riverine topography to make the Nile bread basket 'nearly man-proof' and (b) the Mesopotamian situation in which the very soil was man-made and vulnerable.[210] Ironically, one of Wittfogel's early studies had been geophysically related. It had been on inscriptive evidence confirming warming in north China during the late Shang (or Yin) – i.e. shortly prior to 1100 BC.[211]

In another Marxian neo-classical exposition, this time of 'world system analysis', Immanuel Wallerstein allowed climate deterioration a small part in aggravating a European high medieval crisis otherwise driven internally. That interpretation rested on the highly dubious double assumption that economic recession began pre-1300 whereas climate decline did not, and on the outright fallacy that the latter is likely *ipso facto* to have been uniform around the northern hemisphere.[212] Again, one encounters mental blockage. Those who would claim to be 'scientific socialists' are too little interested in the ecological natural sciences. To slice the argument another way, those who would assuredly endorse the Marcuse/Frankfurt critique of capitalistic 'one-dimensional man' are only two-dimensional themselves. They rely too much on maps, and their maps are too large of canvas, small of scale.[213] There may be here an open flank for the Annales school with its great talents, enduring *esprit de corps* and matchless prestige. In the ferment of the 1960s, they probably allowed the New Left to make the running unduly.[214] But they are much freer now to expand on their critique of capitalistic development, medieval and modern – not least in the ecological dimension.

Evidence and interpretation

It is extraordinary how much our knowledge of Late Antiquity to the Renaissance foreglow has deepened this last half century. A massive contribution has come from the much more extensive application to this era of archaeology, problems of settlement overlay notwithstanding. Enumeration has progressed, especially as regards proportional trends. Many field techniques and very many particular programmes could be cited. A few must suffice.

Coin assemblage has been important, not least for the eighth to eleventh centuries. Then again, the ability of aerial surveillance to detect subtle differences of warmth, colour and shadow was first utilised by archaeologists between the wars to map buried ditches, building foundations and the like. It has since proved efficacious at tracing the 'lost villages' of the late Middle Ages. At Duggleby in North Yorkshire a number of long houses stood opposite two of the courtyard farms that the better-off feudal tenants were building by a more prosperous thirteenth century. Soon after 1500, the entire village was abandoned.[215]

The discovery, between 1867 and 1903, of three ship burials in Oslo fjord gave a big lift to Viking archaeology. More generally, particular attention has been paid to urban archaeology; and the ongoing refinement of techniques has led to scaling down or up of the estimated sizes of population in various medieval cities. But the database remains so variegated yet patchy that the going has been tough, with bitter disputation easily engendered. Witness a severe attack on Josiah Russell's 'deplorable' methodology by a one-time reader in economic history at Oxford, one of the many sallies against this demographic pioneer that may have been at once substantial and unreasonable.[216] Nor have trends been much easier to establish than absolutes. Egypt into and through medieval times is one realm apropos which it has been especially difficult yet imperative to achieve a scholarly consensus (see Chapter 3). Meanwhile, urban populations still pose an especial problem.[217] Nevertheless the steady proliferation, across Europe at least, of observation points is beginning to create the possibility of systematic palaeoarchaeological mapping. That will aid medieval demographers, particularly since differences in current ecology and past history could produce marked population contrasts across quite short distances, this even before the Black Death.[218]

On the geophysics side, an account of the current status of palaeo-observations and derivative modelling is given in Appendix A. What will be important is so to combine techniques as to generate accounts of weather/climate parameters other than temperature and rainfall. Snow cover, wind speeds and directions, and sunlight come most readily to mind.

Thus in tougher climes, secular variations in the run of wind may be of more ominous significance than the problematic bracing-versus-relaxing divide. Take the Mongol homeland, the steppic fringes of the Gobi Desert. When the Siberian anticyclone is as strong there at ground level in wintertime as it mainly was this last century, it will maintain for much of that season (and especially late on) a savage north-easter. What this can mean in terms of discomfort to humans and animals is illustrated by a participant's account of a storm during the Sino-Swedish expedition to north-west China from 1927. It 'lasted the whole night and on the morning of the 14th November it roared and howled and raged still worse than on the day before . . . .' Millions of 'tiny flying particles lashed one's skin.' The sun was visible, if at all, as merely a locus of diffused light. The estimated wind speed on the 13th had been 30 metres per second or over 60 miles an hour. Only on the 15th did it abate appreciably.[219]

Deep midwinter temperatures in or near the Gobi tend to oscillate around freezing point. If at that temperature the wind speed is 15 metres a second, this is reckoned to chill people to the equivalent of –11°C in a light breeze, 2.23 metres per second. Lower the real temperature to –10°C while keeping the wind at 15 mps and the sensible temperature is said to be akin to –25°C in the light breeze.[220] But what if there is no wind? Everyone knows that a very chill air can feel equable in a flat calm under a sunny sky.

Evaluating the results, it is needful to avoid the temptation that perhaps both climate determinists and historicists fall for – that of extrapolating from the universal to the particular: 'situating an assessment' instead of 'assessing a situation'. So apropos whatever human historical developments one may be considering, was there any change in climate norms or erraticism? And if so, did it affect those developments materially?

If both answers appear affirmative, another choice presents itself. Was the impact of the climate variation akin to Huntington's 'pulse of Asia' model, a fundamental trigger mechanism from which other sequences developed? Or was it as Gibbon was disposed to view things, one among a number of operative factors – significant but not uniquely so? If one opts for the latter understanding, it logically follows that climate will be decisive only when a regime or society is critically poised for other reasons, in other words at *une conjoncture*.

2 Climate dynamics

The philosopher of the Scottish Enlightenment, David Hume (1711–76) observed that 'of all parts of the Earth, Europe is the most broken by seas, rivers and mountains . . . and most naturally divided into several distinct governments.'[1] Arguably, such devolution has been further encouraged by its climate exhibiting much variety but, thanks to oceanic influence, within moderate limits. One of Britain's many climate patriots felt that the creativity of his fellow countrymen had thereby been nurtured.[2]

An interesting though rough-hewn attempt has been made to depict liberal values as flourishing best where the mean temperature difference between the warmest month and the coldest is tolerably small – e.g. western Europe.[3] It is hard to believe there is nothing in this. Yet it is as hard to relate much of Europe's history in the twentieth century to post-Enlightenment liberal values. In a sense, the whole burden of this text is consideration of how far the influence of climate resolves the contradiction between Europe the devolved and Europe the atrocious, in modern times as well as earlier. Comprehension of the climate dimension has to start at planetary level and then zoom in on Europe and its environs.

Two basic realities govern the two fluid mediums addressed in extended atmospheric science: the atmosphere itself and the oceans. The one reality is that each, even the excitative atmosphere, is parcellated by boundaries (often called 'fronts') between masses with contrasting characteristics. Consider a tornado. Its circulation will typically be several kilometres wide towards the stratosphere but just a few metres at the Earth's surface. Inside this vortex, wind speeds may reach 350 km/hr. A few dozen metres away, 40 may be typical. Tornadoes occur occasionally throughout Europe as far north as southern Sweden.[4] But the point for now is simply how sharp transitions can be. If this be so spatially, it may apply across time as well.

The other reality was recognised seventy-odd years ago by a 'grand old man' of British meteorology, Sir Napier Shaw. He noted how an assumption usually made about any meteorological 'oscillation' was that it will be in phase with an ongoing outside influence. But it could as well represent a 'free vibration' continuing long after the initial impulse – e.g. a splurge of heat from the oceans, a spate of vulcanism or a solar eruption.[5]

One particular hypothesis has been that the anomalies whereby (a) the North Magnetic Pole has lately been located over north Canada (79°N, 70°W in 1988) and (b) a major loop in the magnetic lines of force extends axially across east Siberia may somehow bear upon the prominence of the cold pool 'anticyclones' that respectively develop in these locales in winter. It would follow that the elliptical revolution of the magnetic poles, over time-frames similar to those embraced herein, may influence pressure patterns.[6] There is, in fact, a westerly swing in the whole field of a degree every five years. This effect (discerned by Edmund Halley 1698–1700) has been traced back 2,000 years.[7]

The next question can be how far secular cycles in tidal strength (governed principally by the declination of the Moon to the Earth's equator) affect matters. The main declination cycle is close to 19 years. So was the mean of the alternation Simon Kuznets identified in 1930 in regard to American economic history. In fact, similar cycles have been discerned, albeit with varying definition, in a range of economic and social situations.[8] Longer-term ones can also be looked for, in the Middle Ages and earlier.

A high lunar declination should mean higher sea tides in high latitudes. In 1965, two Soviet scientists found that, in the Atlantic area, sea level at 75°N was 13 cm higher relative to that at 45°N when declination zenith was at its peak (28°40′) as compared with its low, 18°20′. Therefore, they surmised, a peaking could connote a less vigorous North Atlantic Drift (see also Chapter 9).[9] What anyone committed to any such interpretation needs to demonstrate, however, is that whatever cyclicity they observe in oceanic behaviour does not relate more to sunspots.[10]

Differential absorption

An important attribute of the atmospheric gases, not least in relation to past and future climate change, is how dependent their absorption of radiant heat is on the wavelength profile on which the radiation is taking place. A prior relationship is that between the wavelength at which the radiation is at peak intensity and the surface temperature of the emitting body, heavenly or terrestrial.

For this purpose, the temperature is read in accordance with the absolute measure afforded by the Kelvin scale. Calibrated in degrees equivalent to centigrade ones, it takes as zero what rates as 273 below zero (i.e. below the freezing point of water) on the Centigrade or Celsius scale. Minus 273 almost exactly coincides with the calculated point of absolute cold, a state in which matter has had all energy drained from it. From that extrapolation, one may infer that a rise of, say, one per cent in the net flow of energy to the Earth's surface could effect close to a two-degree rise in its mean temperature.

Colour is a complication. But with a classic 'black body', the peak wavelength at which heat radiates from its surface is in inverse proportion to the kelvin temperature of that surface. Therefore since the mean temperature of the Earth's surface is 287 K and that of the Sun's 6,000 K, the former can be expected to have a peak wavelength of emission over twenty times that of the former – close to 10,000 nanometres or nm (i.e. billionths of a metre) as opposed to 485. That poses the question of differential absorption by the atmosphere.

In 1802, a British astronomer, W.H. Woolaston, found sunlight to have pronounced absorption lines on certain wavelengths, ones that were to prove characteristic of gaseous hydrogen and helium, the substances of which the Sun's outer envelope is overwhelmingly composed. The study of electromagnetic absorption spectra was soon extended and popularised by Joseph von Fraunhofer (1787–1826), a Munich optician. In 1815, he produced a spectrum with no fewer than 324 gaseous absorption lines on it. Most of the chemical elements known to us on Earth have now been identified in this context. So have a variety of compounds, not least carbon dioxide (CO_2).

In 1827, the French mathematician Jean-Baptiste Fourier concluded that the mix of gases we know as 'air' acted, in these terms, like a glass cover. He warned this tendency would increase as more and more CO_2 was released into the atmosphere by the hydrocarbon combustion and decay required by economic development.

CO_2 and H_2O

Experiments later in the nineteenth century confirmed carbon dioxide and water (H_2O) as the gases mainly responsible for warming. Water has several absorption peaks between 940 and 6,300 nm. Carbon dioxide has a moderate peak just below 5,000 nm and a strong one at 15,000 nm.[11] Therefore they more readily absorb radiation from the Earth's surface than they do the much hotter radiation from the surface of the Sun. Otherwise, the Earth's mean surface temperature might have been, these last 10,000 years, say, some 30 kelvin degrees lower than it ever has.

Three-quarters of this 'greenhouse effect' has been due to water vapour, in fact. Nevertheless the H_2O dimension is not overtly included as a primary forcing factor in the current 'greenhouse' effect or in historical evaluations. It is customarily treated rather as a derivative and feedback factor, and is acknowledged to be more variable spatially and in the short term than it is secularly. Nevertheless, its feedback role in accelerating or retarding trends in surface air temperature was highlighted in a seminal University of Munich study in 1963. Variations in cloudiness also entered the argument.[12]

One consideration is that the amount of vapour the air can hold without condensation rises steeply with temperature. Over ice at –20°C, say, the pressure exerted by this saturation level of vapour is one millibar (mb), roughly what would be caused by a column of water a centimetre high. At 1°C the saturation vapour pressure (SVP) is 6.5 mb. It is 10 mb at 8°C and 50 mb at 32°C. Correspondingly, the actual vapour pressure recorded does vary with place and time markedly, whereas that of CO_2 does so only subtly. The former may be only 0.1 mb in dry polar air in midwinter but over 30 mb near the equator. Average vapour pressure worldwide is near to 10 mb, and the European mean may not be very different. Actual vapour pressure expressed as a percentage of SVP is the relative humidity at a particular place and time.

Neither the vapour pressure nor the relative humidity registered on a given occasion are by themselves indicative of the local likelihood of rain. Nor do they directly modify the barometric pressure field. But water in the atmosphere and oceans interacts with the rest of the geophysical ambience in manifold ways: chemical, mechanical and thermal.[13]

At least half the heat transfer from sea to air is effected via water vapour. Latent heat lost by the sea through evaporation (540 calories for each gram) is equivalently released as sensible heat when vapour within the atmosphere condenses into dew, fog or cloud. Calculations led by Budyko have been as follows. The average segment of ocean loses annually through evaporation a column of water 140 cm deep while receiving 127 cm as precipitation. The corresponding estimates for land are 49 and 80,[14] the former figure also covering transpiration – i.e. water loss through plants. But moisture exchange over the land is more variable than over the open sea. If soaked and warmed (as per rice paddy), the former may lose water to the air faster than does the latter.[15] Through the medieval optimum, mankind was converting wet wilderness to arable in both Europe and Asia. But it was still more extensively so converting woodland and scrub.

Therefore the probability is that, throughout the period AD 200 to 1350, humankind did appreciably alter atmospheric levels of CO_2 and, indeed, methane (CH_4), this mainly through arable extension. An early consequence of tree felling is the release of CO_2 into the atmosphere through burning and rotting. Obversely, in the longer term (two or three centuries hence?), this removal will lower the level of atmospheric CO_2 through a weakening of the carbon cycle (see Chapter 9). Something not easy to resolve at present is the pre-modern influence of humankind on the atmospheric presence of methane, a greenhouse gas that absorbs significantly at around 8,000 nanometres. Wet wilderness reduction will have diminished it. Paddy field expansion will have increased it.

Albedo

Next we may consider albedo, the ability of a segment of the Earth's surface or its cloud cover simply to reflect the solar radiation incident upon it. The albedo of a given surface varies with wavelength. Nevertheless, a compilation for the ultra-violet edge of the visible light spectrum may be representative enough. For the Earth as a whole, the proportion reflected (expressed as a decimal fraction) is presently 0.31. Thick cloud may reflect 0.6 to 0.9. For unfrozen sea the value is mostly in the 0.06 to 0.1 bracket, whereas the mean for dry land is 0.18 to 0.2. But 'burning' sands can reach 0.35. The spread for forest is from 0.07 to 0.18, and for grasses, 0.18 to 0.25.[16] Many surfaces exhibit higher albedos when the Sun is low. Calm water may exceed 0.5 when it is below 15°.

The albedo of stabilised snow may, at latitudes below 60°, average 0.7 but at high polar ones as much as 0.9.[17] Such values make the extent of polar ice all the more variable, even year to year. Since ice can thereby act so effectively as its own coolant, any area contraction will be reinforced. So, *pari passu*, will expansion. C.E.P. Brooks apprehended that once an expanding ice sheet had reached some critical extent, it might be unstoppable.[18] Six hundred million years ago, in fact, the Earth was almost completely encased in ice for some 10 million years. As much was confirmed by work done in the 1990s by Paul Hoffman and Daniel Sohrag at Harvard, Mikhail Budyko at St Petersburg, and Joseph Kirschvink at Caltec. Sea ice, mostly no more than several metres thick, is especially prone to 'ice-albedo positive feedback'.

In 1979, the late Carl Sagan and colleagues assessed the effect of anthropogenic albedo changes the last several thousand years, working from models showing that a change of 0.01 in a planetary albedo of 0.31 could alter mean surface temperature by two kelvin degrees. Averring that mankind will over time have caused much desertification, the team retrospectively predicted a net depression of temperature of one degree. Two-thirds was due to desert creation.[19]

Receipt of radiation

Implicit in everything just said is the truism that the Sun overwhelmingly supplies the energy received at the Earth's surface. The residual flux from the Earth's molten interior is not one part in 20,000 thereof. That from all other stars is negligible, too.

However, the solar flux per unit of surface area varies geographically. Broadly, lower latitudes receive most because their Sun ascends higher. But the highest average intensities of all occur towards the edge of the tropics, where very gradually the Sun progresses to then recedes from being overhead, at the tropical parallel, on midsummer's day.

Europe can be seen as bracketed between the Nile delta and the Svalbard archipelago. Upper Egypt averagely receives more solar energy per square metre than any other part of the Earth – some 200 watts. Just east of Svalbard the mean flux is 75 watts, less than for anywhere else.[20]

Coriolis and vorticity

The redistribution round this planet of heat energy heavily depends on the 'Coriolis force'. Named after the French mathematical physicist who delineated it in 1835, it acts to deflect any mass crossing a rotating surface,[21] a rolling ball following a curved path across a spinning turntable being an illustration often proffered. Air and water currents are subject to Coriolis, whatever their magnitude. Witness water spiralling into a drainpipe. The influence on horizontal vectors is greatest at the poles in that the rotation of the Earth there appears entirely horizontal. It is nil round the equator.

Gaspard Coriolis postulated the force acts at right angles to the direction a current is moving in. The deflective acceleration thus horizontally attained equals $2\,\omega\, V \sin\theta$. Here ω is the angular velocity of the Earth: a full circle per day, or 15° an hour. V is the horizontal velocity of the current – the wind or water flow as normally measured. Then there is the sine of the latitude at which the Coriolis force is registered, this being $\sin\theta$.

To define sine, one can take a minor angle of a right-angled triangle. The sine of that angle is the fraction obtained by dividing the side opposite the minor angle by the hypotenuse, the side opposite the right angle. At 0° north or south (i.e. on the equator) the sine of the latitude is therefore nil. At 90° (i.e. at either pole), it is 1. At intermediate parallels relevant to Europe the values are 0.5 at 30°, 0.69 at 45° and 0.87 at 60°.

In the atmosphere, the horizontal velocity of a current is mainly a function of horizontal differences in air pressure. On a non-rotating Earth, air would flow straight down the pressure gradient until this disappeared, thereby achieving an even energy field. Given terrestrial rotation, the situation will tend instead towards a dynamic equilibrium in which the pressure field is matched by the Coriolis force. Since the latter acts at right angles to the air flow, such a balance can be achieved (within a rectilinear pressure field) if the wind blows along the isobars. In the northern hemisphere, anybody with their back to the wind will have the lower pressure to their left. In the southern, it will be to their right. A Captain Buys Ballot formulated this rule in 1850, veritably at the dawn of synoptic meteorology.

An air flow thus sustained is termed a geostrophic or gradient wind. Its velocity is derived from the formula

$$2\omega\ V \sin\theta = \frac{dp}{dn} \times \frac{1}{q}$$

where dp/dn is the pressure gradient and q the air density.

Rendered thus, the algebra simply says that the Coriolis force will balance that induced by the pressure field. To focus on wind velocity the algebra can be recast as

$$V = \frac{1}{2\omega \sin\theta} \times \frac{dp}{dn} \times \frac{1}{q}.$$

One thing this format highlights is that the steeper the pressure gradient (i.e. the more tightly packed the isobars) the higher the wind. Another is the relationship between the sine of the latitude and the wind speed for a given pressure field. A field inducing a geostrophic wind of 28 km/hr on the 45th parallel would give rise to one of 23 on the 60th. At the equator, the zero value attained in the horizontal plane by the Coriolis parameter coupled with a diametric switch of direction 'leads to the breakdown of the geostrophic wind equation; the relationship between the pressure and wind fields is often uncertain with strong flow across the isobars.'[22]

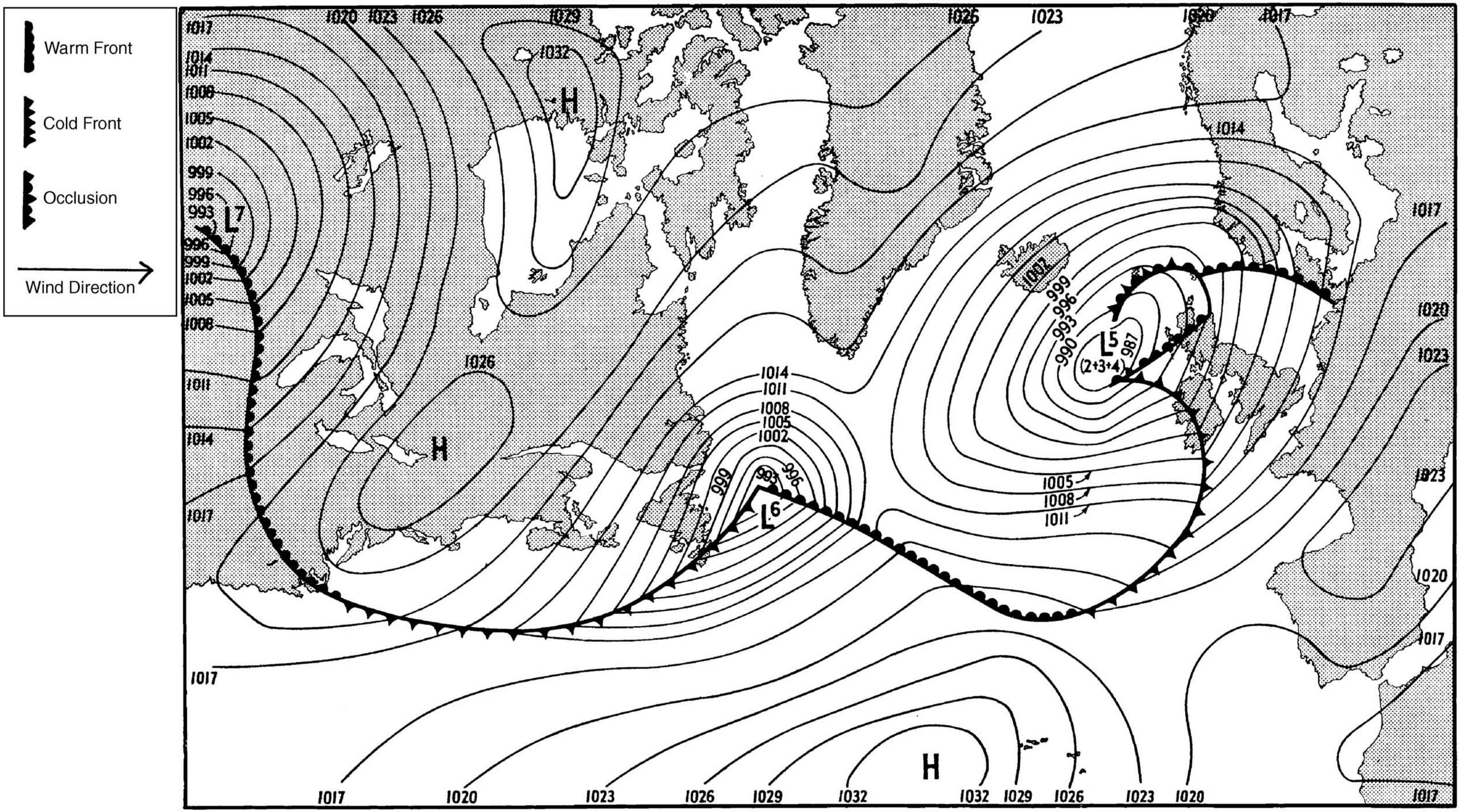
Across the rest of the world, the geostrophic wind is a close approximation to reality for much of the time. However, that is subject to qualifications. One concerns frictional drag near the surface, especially over land. By lessening the wind speed, it weakens the Coriolis deflection, and, as vector analysis readily shows, equilibrium is restored only through the wind inclining towards the lower pressure. This turning across the isobars is recognised in a refined version of Buys Ballot's law: 'If, in the northern hemisphere, you stand with your back to the wind, the lowest pressure is on your left-hand side but slightly in front.'

Early last century this cause of dislocation of geostrophic equilibrium was sometimes seen as a factor in the development of major weather systems, most notably the low-pressure circulations or 'cyclones' associated with wet weather and the high-pressure cells or 'anticyclones' that connote dryness. However, the 'boundary layer' of air affected rarely extends higher than 600 metres. Compare that with the 'tropopause', the irregular surface dividing the lower atmosphere or 'troposphere' (where virtually all the weather we normally observe is played out) from the virtually cloudless stratosphere above. Over central Europe, the tropopause is typically at an altitude of 12 to 14 kilometres. Granted, flows across isobars are integral to the development and decay of any system, but the evolution of pressure patterns these are part and parcel of tends to be largely internal and set in great depth. Quite often, the most decisive adjustments will occur not far below the tropopause.

Another effect to consider is the centrifugal or 'cyclostrophic' alteration of wind speed that may preserve equilibrium within an enclosed pressure field or 'vortex'. The altered speeds will be slower than gradient winds around cyclones (nowadays, in temperate latitudes, termed 'depressions') but faster round anticyclones. The literature occasionally suggests cyclostrophic action is of little meteorological consequence except in tornadoes and tropical revolving storms. Something being a weather forecaster around the coasts of Britain soon taught one, however, is that wind speeds may climb menacingly (e.g. by as much as a third) should isobars straighten out, however temporarily and locally, deep within the circulation of a vigorous depression.

The west-to-east rotation of the planet basically induces a westerly air flow as viewed from high above either pole. In other words, the depressions and anticyclones of each temperate zone are the successive segments of a band of cyclonic 'vorticity' extending round the Earth. A corollary will be that the stability limit for an anticyclone is set at the stage in its development when its vorticity counterbalances that of the Earth's rotation. Hence the observed tendency for anticyclonic circulations to be markedly less vigorous than cyclonic ones, though, as a rule, broader and slower moving. The surface pressure at the centre of a strong anticyclone in temperate latitudes may reach 1040 millibars; and that of a deep depression, 975. The mean air pressure globally at mean sea level is 1013 mb.

As applied to the atmosphere in particular, the Coriolis force is a conservative influence in an otherwise highly responsive medium. It diverts the translation of mass, energy and humidity. It preserves pressure patterns that, on a stationary planet, would have been too unstable ever to form. On the other hand, much meridional and intra-zonal transfer does take place, both within these patterns and through their displacement. Vorticity is salient throughout.[23]



Map 2.1 Normandy landings 1 (Weather chart for 1300 GMT, 4 June 1944)
Source: adapted from J.M. Stagg, *Forecast for Overlord*, Surrey, Ian Allan Ltd, 1971, reproduced with permission of the publishers

The high seas

The 'ice-albedo positive feedback' is the more significant because of a property of water that we take for granted but which is, in fact, exceptional. During its transition from liquid to solid, it expands. Other rather singular H_2O properties likewise shape the climate of our biosphere. An overall result is that, despite lowish albedo, sea surfaces warm up or cool more slowly than land over whatever time-frame. Water vapour in the air above works against heat transfers, particularly from the sea outwards. In most latitudes, cumuliform cloud is more prevalent over the oceans. The latent heat of evaporation or condensation is a further constraint.

Moreover, the specific heat of water is four or five times that of rock or dry soil. The 'specific heat' of a substance is the amount of energy (measured as a decimal fraction of a 'calorie') needed to raise the temperature of a gram by a degree Celsius. Pure water is the datum base with a specific heat of 1.00, the highest value for any solid or liquid bar ammonia. On the other hand, rock and, indeed, compacted soil are a deal heavier than water volume for volume. That can often more or less cancel out a specific heat differential.

However, a further aspect is that sea water more readily allows received heat to pass downwards some tens of metres. This spread is due to motion but also to the partial transparency of the sea to blue-green light. H.U. Sverdrup estimated that as much as 20 per cent of the sunlight incident on unmuddied water penetrates a good 40 metres. The boundary between the near-to-isothermal 'mixing layer' that may be established on top, seasonally at least, and the waters below is spoken of as the 'thermocline'. Usually it lies somewhere between 50 and 200 metres below the surface. Being also rich in dissolved gas, not least CO_2, the mixing layer is home to most of the plankton and much other marine life. It can store maybe 20 times as much energy as the entire atmosphere above.[24]

The general circulation of the ocean is very considerably 'thermohaline': that is to say, driven not by the winds but by density contrasts resulting from differences in temperature and salinity. However, the interactions are complex. As from a point just above freezing, water expands with rising temperature like other substances. Yet what the expansion rate is varies markedly with hydrostatic overpressure, salinity and start temperature.[25]

The fact that sea water is non-compressible and, in addition, much more viscous than air means its eddies are often orders of magnitude larger and more enduring. Correspondingly, the biggest of its dynamic surface features, the oceanic gyres, are a lot larger than most depressions or even anticyclones. Clearly the inertia that keeps these features going may also inhibit new ones. A corollary is that when the pattern does alter basically, the alteration will likely be sudden and major. Hermann Flohn of the University of Bonn has seen vertical oceanic adjustment as a prime cause of abrupt climate change (see Appendix A). Christian Pfister and colleagues have lately argued similarly with specific reference to fourteenth-century Europe (see Chapter 9). Correspondingly, the oceans seem more liable than the atmosphere to give rise to 'intransitive' climate sequences, ones capable of yielding more than one alternative outcome depending (as per catastrophe theory) on random perturbations *en route*. The North Atlantic thermohaline circulation has specifically been considered in this connection.[26]

Until the deployment, from 1920, of acoustic depth finders it was widely presumed the 'deep-sea bottom was a flat monotonous plain'[27] and the waters above lifeless and very still. What is now clear is that this zone is, certainly in the context of secular change, part of the general circulation. As noted in Chapter 1, the temperature of the bottom water of the equatorial Atlantic Ocean follows macro-variations at the sea surface but with a smaller amplitude and a time delay of perhaps one or two thousand years. Furthermore, the aggregate oceanic mass is 400 times that of the atmosphere. With the fourfold difference in mean specific heat, the oceans' total heat-bearing capacity is well over a thousand times that of the latter.

More emphasis is now placed, too, on the role of surface ocean currents, not least in regard to transfers of heat meridionally – i.e. from low latitudes to high. Without their contribution, the mean gradient in surface air temperature from the tropics to the polar regions might be twice as steep. But that view, a representative contemporary one, contrasts sharply with past received wisdom. An influential rendition of weather prognosis first published in 1943 quoted approvingly a comment by an ex-president of the Royal Meteorological Society: 'If it were possible to divide the Atlantic into sections . . . thus preventing any flow of water, it would cause very little change in the climatic conditions of North-West Europe.'[28] Since when, terrestrial energy emissions as measured by satellite reveal that ocean currents effect no less than 40 per cent of all heat transport between the equator and 70°N.[29]

The ocean currents form a massive global network. Thus, subject to the seasonal reversals of monsoon drift, the Agulhas Current past Natal and the Cape is sustained by the circulation in the Indian Ocean as reinforced by inflows from the equatorial Pacific. It itself feeds around half a billion megawatts of thermal energy into the Benguela Current of the South Atlantic. In due course, most of this water and energy flux crosses the equator. Steered by how the Americas are configured, the advancing water does a vorticity flip, emerging from the Florida Straits as the Gulf Stream. It widens into the North Atlantic Drift, part of which flows slowly on to lap in summer, as of the present time, Svalbard and even Novaya Zemlya. Quite the steepest regional gradient anywhere in mean sea-surface temperature (from 21 to 4°C in 600 miles along the 50°W meridian) occurs near Newfoundland as the Labrador Current undercuts the Gulf Stream more or less at right angles. It is a situation conducive to the formation within the atmosphere of frontal depressions destined to progress across the seaboard of north-west Europe.

This mechanism likewise accounts for 'the Gulf of Winter Warmth', a perennial tendency for a wide area centred on the Norwegian Sea to be much warmer (especially in winter) than one might otherwise expect. A definitive yardstick is afforded by contemporary (*c.* 1970) deviations from the latitudinal mean for annual air temperatures. On the Arctic Circle at 4°W (in the Norwegian Sea), there is a positive anomaly of 12°C. The anomaly isopleth (i.e. line of equal value) for 9°C on that scale cuts through Reykjavik, Belfast, Murmansk and the southernmost cape of Spitsbergen, the biggest island in Svalbard. No other part of the world registers an anomaly either way of more than 8°C.[30] To contrast this with an area near Svalbard being cited above as in direct receipt of less solar energy than anywhere else on Earth is to highlight the cardinal role of the oceans in extended atmospheric science. The rub is that we reputedly collect more geophysical data about the atmosphere every day than we ever have as yet about the ocean deeps.

The air circulation

A key fact about today's climate globally is that 90 per cent of the ice is on the Antarctic continent and the waters around it. One result is that the successive climate zones tend to be closer to the pole in the northern hemisphere than in the southern. Take, for instance, the lie of the 'thermal equator', the shifting and irregular line along which mean temperatures are at a maximum at a given time of year. In July, its median latitude may be 15 to 16 degrees north yet in January it is only 3 to 4 degrees south.

The associated atmospheric feature, the Inter-Tropical Convergence Zone (ITCZ), keeps pace quite closely with this oscillation. The ITCZ is a complex trough towards which winds obliquely flow to feed convection currents generated by surface warming, especially overland, but then further invigorated by the latent heat released through the condensation during ascent of water vapour. Over south Asia, the ITCZ becomes axial to the summer monsoon, a circulation that peripherally extends across a large part of the Near East.

Not more than 10 or 15 per cent of the tropics experiences atmospheric convection at any given time. Still, the result is huge uplift. In the upper troposphere, this spills polewards in each direction. However, mass and Coriolis deflection preclude its transiting straight to the poles. An early adjustment each side of the equator is a partial sinking that sustains the subtropical anticyclones, which in their turn engender largely cloudless skies and desertic landscapes. Evidently, the character and strength of this 'Hadley cell' circulation are counter to the strong convection that might also be expected overland around the Tropics of Cancer and Capricorn in their respective high summers (as previously related). What can be allowed, however, is that the big anticyclones are established more firmly over the sea, especially at low altitude. Notable for its direct influence on Europe is the 'Azores High'.

The fundamental place of the Hadley structure in the order of things is confirmed by its continuity over geological time. Even though the strength and positioning of its features alter, they rarely, if ever, disappear. Take the palaeoclimatic maps that Alfred Wegener produced, in collaboration with his colleague Wladimir Köppen, to promote the former's theory of continental drift, a theory now absolutely accepted though long bitterly contentious. The two zones of hot deserts (as revealed by sandstone deposits) fit the Wegener arrangement of the land masses for the Carboniferous Period as completely as do those other prime indicators, the coal seams and the ice caps. For the next of the geological periods, the Permian, the hot deserts match up as well as the glacial traces and better than the coal seams.[31]

Were our planet's surface entirely flat and of homogeneous composition, the 'planetary wind system' would produce a strong high-pressure centre at each pole (especially in the respective winters) as air from low latitudes advecting aloft cooled and descended. In practice, the winter anticyclonic centres are transferred, in the northern hemisphere, to the Yellowstone National Park, central Greenland and (for the 'Siberian High') Mongolia. This transference may, as noted above, be due in part to geomagnetic influence. But it must primarily be a consequence of strong cooling overland.

Just under 3,000 km north-east of the Mongolian high-pressure centre is Verkhoyansk, the 'cold pole' of the northern hemisphere winter. Yet since colder air is denser, it loses pressure more rapidly with height than does warmer. Therefore as one ascends beyond the boundary layer one finds this 'Siberian' circulation becomes not anticyclonic but cyclonic. In other words, the Siberian High that, for much of the twentieth century, has seemed so dominant and robust a winter influence in Eurasia is comparatively shallow. This may mean it has been, and will be, peculiarly susceptible to climate change.

Rossby waves

A further mechanism whereby air advecting to higher latitudes acquires anticyclonic vorticity is the Rossby wave. Carl-Gustaf Rossby (born in Stockholm in 1898) was nurtured within Scandinavia's peerless tradition of atmospheric science. But from 1926 to 1947 he had an illustrious career in the United States before returning to his *alma mater*, the University of Stockholm, as Professor of Meteorology.[32] The gist of wave theory as he developed it is as follows. As air travels polewards, its path acquires anticyclonic curvature. Ultimately that will direct it back towards the equator on a cyclonic track. And vice versa.

Such alternation is predominantly a feature of middle latitudes, its main influence being on the zonal wind in the high troposphere. In the light of what has just been said, that wind must otherwise be a product of (a) wind direction and speed at sea level and (b) a thermal vector derivative from how cooler air loses pressure with height comparatively quickly. Round the northern hemisphere, the mean zonal wind speed in winter at an altitude of 10 km is 26 metres a second along the 40° parallel and 12 along the 60°. For summer, estimates are 14 and 10.[33]

In principle, a Rossby wave will migrate within (though less rapidly than) the tropospheric zonal flow. In the free circulation of the middle latitudes of the southern hemisphere, such a pattern seems well sustained. But in the northern, and most conspicuously in winter, waves lock around the two great obstacles, the western cordillera of North America and the Tibetan massif. Even so, these 'standing' or 'stationary' Rossby waves are not regularly discernible on synoptic weather charts any more than their mobile counterparts are. But they show up better in seasonal averages. A Rossby propagation within the high seas may also be important. But the semi-parcellation by land masses of these waters compounds the analytical challenge.

One can predict that Rossby wavelengths (measured in angles of longitude) will increase with latitude and with the velocity of the upper zonal flow. Hubert Lamb more specifically proposed that this angular width increased in proportion to the square root of the zonal velocity.[34] His proposal is supported tolerably well by an independent estimate. It gives Rossby stationary wavelengths, for a zonal flow of 15 metres a second, as 72 degrees of longitude along the 40° parallel of latitude and 130 along the 60°. Increase the flow to 25 metres a second and those segments become 85 and 165 respectively.[35] Such considerations suggest that if very regularly there is one trough axis to the lee of the Rockies (medially down the 90°W meridian, say), plus another to the lee of Sinkiang and Tibet down 140°E, then a third is often to be expected with its axis through eastern Europe. In a quite separate study, Lamb himself postulated a weak ridging at the surface at 45°N that had averagely moved from 20°W in 1800 to 7°W in 1950. It was set between two trough lines in a sweep from 60°W to 20°E.[36]

There are still loose ends in the Rossby wave concept. Correspondingly, the salience accorded it in accounts of synoptic meteorology and contemporary climatology varies. To Henderson-Sellers and Robinson, these macro-modulations are 'probably the most important feature of the mid-latitude circulation.'[37] This understanding may well be vindicated in the context of historical climatology. But a critical question could be how to gauge secular variations in (a) wavelength and (b) amplitude. Lamb inclined to the view that, during the last big glaciation in the northern hemisphere, the waves in the upper westerlies (from the High Plains to the Balkans) were of reduced amplitude within a vigorous zonal flow confined between the expanded ice sheets and a constrained Hadley circulation.[38] But along with this amplitude reduction would have gone an increase in wavelength in that the steep temperature gradients beyond the ice would have strengthened the zonal flow. On the other hand, this effect could have been effectively offset by displacement of the whole circulation to a lower latitude.

Against the background of widespread medieval warming, these correlations may subtly have been manifest in reverse. Rossby amplitudes may have increased as the ice sheets receded. At the same time, slackening of this flow due to an easing of temperature gradients will have been liable to shorten Rossby wavelengths. Conversely, a displacement of the circulation polewards would have been conducive to wavelength extension in terms of the longitude covered. On this point, the mathematics is not easy to relate to topographical locking. However, for that scenario as for the 'ice age' one, the most important inference may be that concerning amplitude. It does bear on the geophysical side of this review, not least in the eleventh century.

The polar front

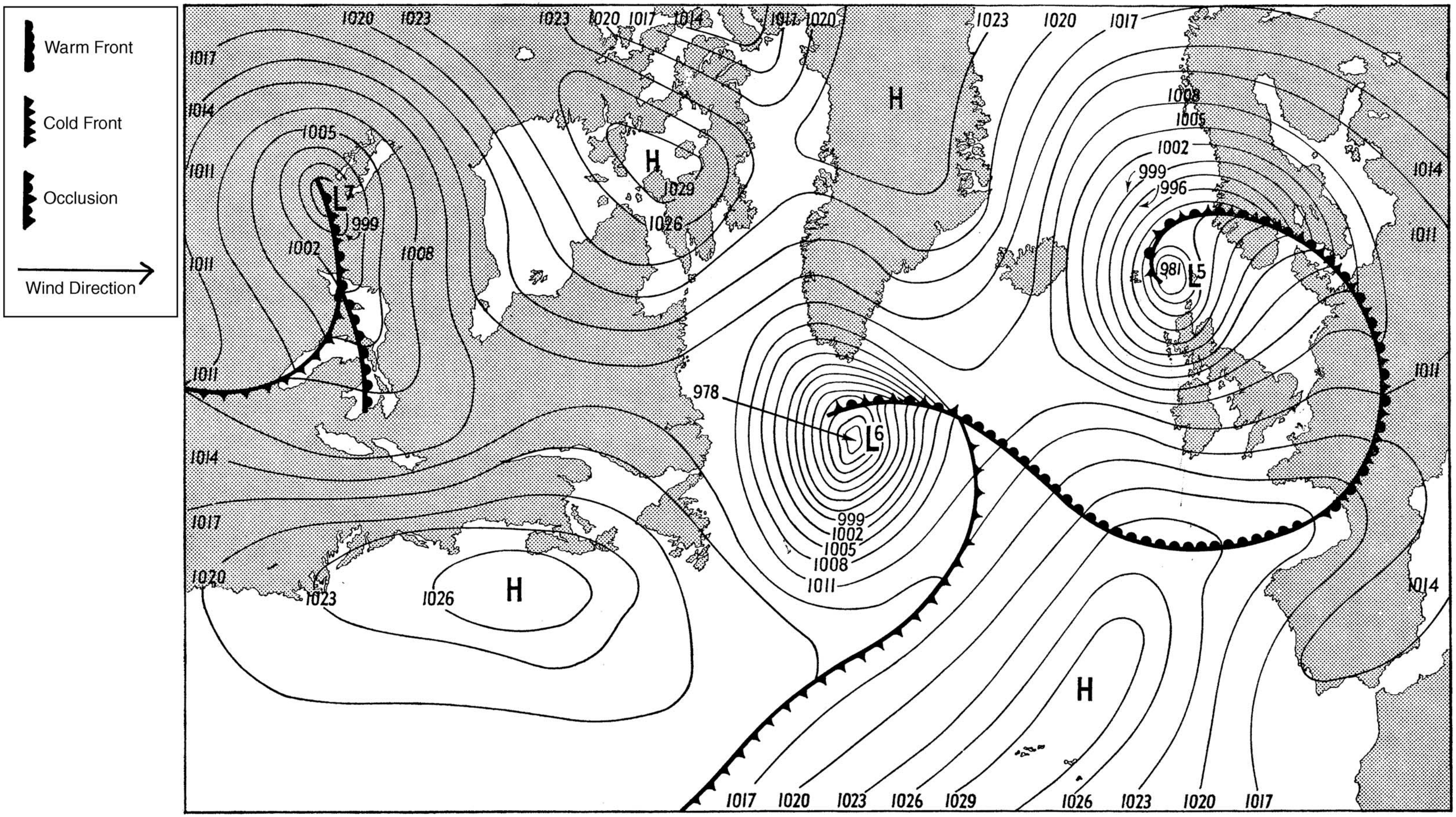
A concept yet more fundamental than Rossby waves, however, is the polar front. Often the latter is defined as the boundary surface, inclined upwards from sea level, where interaction occurs between (a) cold dry air advected from high latitudes under the influence of cyclonic vorticity, and (b) warm, moist air advected from low latitudes subject to anticyclonic vorticity. For density reasons, the cold air undercuts the warm. In an idealised account, this interactive confluence produces the middle westerlies.

Across the front the thermal contrast will be sharp. In the warm sector not far below the tropopause, the resultant wind vector tends to be acutely concentrated in 'jet streams': irregular ribbons of air turbulently flowing at tens of metres a second, their cores maybe only a few kilometres wide though hundreds or even thousands of kilometres long. In wintertime, a meridian across the North Atlantic, say, may be cut by two or three such jets, maybe one of them just polewards of the Hadley cells.

The lateral displacements of the jet stream or streams are nowadays seen as expressive of the migration, within a given season, of the polar front as such. Yet awareness of the jet stream phenomenon came well after the general acceptance of 'Bergen school' frontal theory. From the autumn of 1944, as the United States Army Air Force bombing offensive against Japan built up, aircrews were often distracted by what are now identified as jet streams. Such flows had rarely been registered categorically over the Atlantic or Europe because (a) operating altitudes had very generally been lower, (b) radiosonde balloon ascents were too few for synoptic continuity, (c) Japan was nearer in latitude to the mean winter lie of jet streams than was Germany, and (d) the singularly steep thermal gradients over north-east Asia/north-west Pacific afforded added energy. A representative speed at the core of a jet stream axis in the west Atlantic in January is 42 metres a second. In the north-west Pacific it is more like 55.[39]

Yet as we seek to comprehend the climate of Europe from Late Antiquity through the High Middle Ages, an absolute dearth of materials on the then jet stream is by no means the worst handicap. Much more limiting is a still piecemeal assemblage of variegated information at surface level. But in the interpretation of such data as is to hand, the Bergen frontal theory can basically assist.

For its formulation, too, war was the sombre setting. Early in this last century, a young Norwegian meteorologist, Vilhelm Bjerknes, was at the University of Stockholm analysing numerically atmospheric motion. From 1912 he furthered this interest as first director of the Geophysical Institute in Leipzig. But by 1917 many of his colleagues had been called to the colours, and five of the ten doctoral candidates were already dead. He returned to Norway, there to found the Bergen School. Since Norway's neutrality denied it weather observations from almost everywhere outside Scandinavia, Bjerknes assumed a lead role in building up a national network of reporting stations, densely so on land. These provided grist for the development (largely under the leadership of his son, Jacob) of the explanation of the genesis of depressions within the polar front zone. There the contrasting cold and warm air masses 'are in constant battle'.[40]



Map 2.2 Normandy landings 2 (Weather chart for 1300 GMT, 5 June 1944)
Source: adapted from J.M. Stagg, *Forecast for Overlord*, Surrey, Ian Allan Ltd, 1971, reproduced with permission of the publishers

The Bergen account of cyclogenesis is in essence as follows. An extended polar front accommodates the generation along itself of horizontal wave forms long enough (i.e. 1,000 km at least[41]) to be dynamically unstable. As such a wave acquires more amplitude, its leading edge becomes a 'warm front': a sloping surface where warmer, moister air both displaces and overrides that which is colder and drier. Its trailing edge duly becomes a 'cold front': a surface where colder, drier air both displaces and undercuts that which is warmer and moister. The common theme is the uplift of warm, moist air, an uplift that will be further sustained by the latent heat of condensation.[42]

This removal aloft of the uplifted air entails a fall of pressure at the apex of the wave. The resulting vortex evolves into a cyclonic circulation that goes on developing for several days more, moving the while broadly eastwards. Progressively, the 'warm sector' triangle on the surface will be 'occluded' as the cold front overtakes the warm. Close by the 'occlusion' line, there will be further frontal activity because (a) the two streams of cold air thus brought into contact will by then have had different histories, and (b) the warm air above will still be impelled upwards. But unless this whole circulation is rejuvenated (e.g. by passage over warm water), it will be near the end of its life after about ten days. It will gradually become slow moving, shallower and less active weather-wise.

As a warm front approaches, the clouds thicken and lower. Rain or snow begins and, rather unevenly, becomes heavier. Arrival of the warm sector is usually marked by wind veer and by the precipitation turning light and intermittent. At the cold front, blustery winds and showery rain are the general rule. But though very regularly observed, this latter transition is somewhat surprising. Showers are, after all, associated with a steep 'lapse rate', a steep fall off of temperature with height. Yet a vertical section through a cold front will show the relatively warm air aloft. In the cold sector proper, however, steep lapse rates will apply throughout, this because the advection of cold air towards the equator causes warming near the surface. A survey of rainfall between 1956 and 1960 at seven stations in northern England showed 21 per cent came from individual showers in 'maritime polar' (i.e. cold sector) air and another 10 per cent from the presence within cold air of 'polar lows' – i.e. local cyclonic circulations induced by convection.[43] An augmenting of the general pressure gradient by a local one on the western side of a polar low can produce stronger and gustier winds liable to catch fishing smacks and the like unawares.

Frontal depressions tend to cross the western European seaboard from the Atlantic sequentially, in families of three to five. The polar air behind each successive low centre tends to push that bit further towards the tropics until the end of the line is signified by a deep plunge of such air into lower latitudes. These plunges are essential to the completion of the planetary circulation.

Climate and landscape

Soil can be seen as the outcome of organic mediation, over decades or millennia, between (a) past and present climate, (b) bedrock composition, (c) topography and (d) plants and animals, *homo sapiens* included. Thus the creation of podzols in many sandy areas of western Europe has been ascribed to human intervention but may also be due to raininess in the Iron Age.[44] As regards bedrock, the Mediterranean, Black Sea and Caspian basins are largely dominated by Tertiary folding concurrent with that which has produced the Himalayas, the Japanese Alps and the cordillera of the Americas. Since the folding is geologically recent, and since the limestone extensively encountered does not weather rapidly, the resultant landscapes are 'immature', with steep though irregular gradients.

In contrast, much of northern Europe rests on a granitic 'shield', very ancient and, excepting the British and Scandinavian north-west, well ground down. But superimposed on this underlying geology across much of the north are the intricate consequences of Pleistocene glaciation. The well-defined boundary of the last glacial maximum stretches irregularly from the Bristol Channel to the big bend in the Dneiper, then still more irregularly into Russia. North of that line much soil was removed by advancing ice, particularly around the Baltic. Correspondingly, much coarse detritus was deposited – notably to form the long, low ridges we know as 'moraines', ridges liable to cut abruptly across the pre-existing drainage. Often their configuration and composition leave them infertile.

Not that the importance of soil in determining vegetation and of bedrock in determining soil has inhibited climatologists from seeking neat correlations between climatic transitions and botanical boundaries. Across Russia as far as 90°E, there is a close correlation between the core zone of northern frontal activity in high summer and what, to that longitude, is a well-defined divide between the tundra and the coniferous forest, alias *taiga*. Eastwards from there, the correlation breaks down because mountain terrain makes botanical zoning impossibly complex.[45]

Likewise, Wayne Wendland and Reid Bryson studied the annual dwell times in different locales of well-defined air masses. Very familiar in the mapping of Europe's natural forestry is a dividing line from the Skaggerak to the south Urals across which the *taiga* phases into the northern mixed forest to its south. Closely coincident with this is the authors' contour for dominance ten weeks a year by Arctic air.[46] East of the Urals (60°E) the concurrence breaks down due to aridity.

The early twentieth-century systems of climate classification (most famously by Köppen and then Thornthwaite) did define climate regimes in terms of the vegetation they could naturally support, the net water balance usually being seen as critical.[47,48] But as Kenneth Hare emphasised in 1968, causation may not be only a matter of climate affecting the emergence of a particular ecosystem. The implications of vegetative cover for such climate controls as albedo and surface roughness have to be considered.[49,50]

The climates of axial Europe

The concept of axial Europe is not unknown to historians.[51] It is no bad one for climatologists to follow. The climatic unity of these middle latitudes rests on the low and flattish terrain traceable from Galway Bay through the dragon's teeth of the Urals to the banks of the Yenisei. Sometimes in winter, ridging from the Siberian anticyclone is dominant as far as the Irish Sea. More often, however, Atlantic air spreads east. This is chiefly why the winter cold pole for the northern hemisphere is as far east as Verkhoyansk on the 124°E meridian. More generally, a continental–maritime gradation is manifest in the annual range of temperature measured as the mean for the coldest month subtracted from that for the warmest. It has lately averaged 70°C close to Verkhoyansk as against 24°C along the middle Dneister in Moldova.[52] At Valencia, in south-west Ireland, the norm has been but 8°C. Data gleaned by Kendrew from the early decades of the last century showed the number of days a year rivers in general were ice-bound. Near the Yenisei estuary, it was as many as 260 whereas along the Dneister but 75.[53]

Open though the 'North European Plain' may be throughout to air flows from Occident or Orient, one can trace across eastern Europe a meridional zone of swift transition, especially apparent in winter, between the maritime and the continental spheres. The region covered by Poland, Czechoslovakia and Hungary has been portrayed as an arena of perennial conflict between 'strongly contrasting' air masses respectively from nearby source regions.[54]

What is to be remarked on is how closely this climatic marchland coincides with that between (a) the mosaic geology and intricate topography of western Europe and (b) the more uniform geology and very even topography characteristic of European Russia.[55] No doubt the greater pluralism of the former in politics and culture has been encouraged further by this and by weather diversity. The Alps, in particular, can arrest or deflect the movement of depressions; cause secondary waves to form on cold fronts; induce 'orographic' precipitation as damp air is forced up steep slopes; occasionally, it seems, trigger tornado generation;[56] and give rise, in exceptional measure, to what the Swiss term 'föhn' winds (see Chapter 9). A moot point might be how this raft of strong traits may affect the profile of Alpine climate change.

Referring to the British Isles, Gordon Manley stressed the contrasts between one area and another in times of seasonal irregularity. Thus the winter of 1962/3, reckoned the worst regionally for over 200 years, was a lot more severe in southern England than in northern Scotland. Manley surmised that the explanation might lie in relocations of the upper ridges and troughs as between alternative 'preferred patterns'.[57]

This is pertinent to the genesis of cyclones and anticyclones. A favoured position for frontal depressions to form, in relation to upper troughing in the northern hemisphere, is shortly to eastward (i.e. leeward) of the trough's southernmost turning point. Obversely, anticyclones tend to generate once this flow has passed through the northernmost turning point. Lately they have often assumed a 'blocking' role in the weather of middle-latitude western Europe in springtime. They have done so by locating *c.* 0 to 20°W, maybe for five or ten days.[58]

The flanks of Europe

Historically speaking, Scandinavian Europe has periodically witnessed a sharpened contrast between a relatively clement south and a decidedly hostile north (see Chapters 4 and 9). No very acute dichotomy is apparent at present. By several criteria, however, the progressive deterioration northwards is quite pronounced.

Take the growing season as defined in terms of the number of days each year with a mean temperature of 6°C or more. From 1931 to 1960, it was 110 days in Finnmark and 210 in Denmark. Then where added warmth critically controls actual growth, the cumulative number of degrees above the 6°C threshold (as averaged per growing day) is a measure of this. A figure of 1,300 annually is typical near mean sea level in Denmark, whereas near North Cape the total may be 400 to 450. Yet important, too, is the potential for evaporation and transpiration annually. This may be 200 mm in Finnmark but three times that in Denmark. Parts of Denmark are designated arid.

In an average winter, the Baltic steadily freezes over except that, well out to sea, the ice may be ill-consolidated. If the weather is very severe, the freeze-up may encompass Oslo fjord.[59]

The Mediterranean twin basin also tends to be viewed as a climatic unity. Duly it is one of the ecological themes advanced by the Annales historian Fernand Braudel to underscore his contention that (even in the strife-torn sixteenth century) the region had a wholeness culturally. The historian is said 'to find almost everywhere . . . the same climate, the same seasonal rhythm, the same vegetation, the same colours and, when the geological architecture recurs, the same landscapes, identical to the point of obsession: in short, the same ways of life.'[60] The bounds are set, in terms of biogeography, between 'the northern limit of the olive tree and the northern limit of the palm grove.' Thanks largely to human intervention, there has long been much scrub as opposed to forest. 'True pastures' for cattle are scarce. Stock and draught animals have tended to be light in weight. Shallow but repeated ploughings have been the arable norm within a biennial crop rotation.

At sea, the unity theme was all too well sustained deep into the Middle Ages (see Chapters 3 and 7) by how absolutely a volatile threat of wet and windy weather precluded all but very local voyaging from October to March. Not infrequently in the summer half of the year as well, strong and gusting local winds could menace any ship in service. Among the named winds of the Mediterranean best known to the world at large are the mistral down the Rhône valley; the etesians of the Aegean; and the sirocco of the Levant or khamsin of Egypt. Many other local winds are likewise identified by name, not least in Spain.[61]

Around much of the Mediterranean drought is *the* climatic 'scourge'.[62] Near Córdoba, for instance, the potential evapotranspiration exceeds 1,000 mm a year – two or three times the rainfall.[63] Lately, droughtiness has been underlined by the judgement of the Intergovernmental Panel on Climate Change (IPCC) that over the coming century (a) certain parts of southern Europe will experience a continuation of the decrease in precipitation generally observed across that region this last century, and (b) water shortages already evident in the Middle East are 'unlikely to be reduced, and may be exacerbated, by climate change.'[64] All of which is consonant with the long-standing recognition that, during times of hemispheric warming, climate zones broadly tend to displace towards the poles and vice versa with cooling.

At the same time, however, there is awareness of the complexity of the Mediterranean's climatic experience, this a function of its bifocal structure and also of its being (a) virtually an inland sea, (b) marginally poised between desertic and temperate maritime regimes and (c) sculptured by Nature very intricately. Just how complex it can be has been evidenced from recent global warming. Between 1955 to 1974 and 1975 to 1994, the air temperature at sea level averagely rose globally by 0.15°C. Yet in north-west Africa the warming was by up to 0.35°. Meanwhile inner Anatolia cooled by a similar measure.[65] That measure of divergence across such a distance was by no means unique worldwide but hardly fits the Braudelian notion of an integrated twin basin.

Even apart from differential secular change, climate unity is an attribute really confined to the sea itself and to constricted coastal plains. The first thing said about 'mediterranean climates' the world over (Cape Town, Perth, Sacramento . . .) is that a high proportion of the rain falls during the winter, whereas the high summer is bone dry. But near the mountains or on the plateaux around the Mediterranean, convective-cum-orographic precipitation may be appreciable through the three summer months. It is 12 per cent of the annual total in Madrid and 23 per cent in Milan.

Ironically, however, Braudel understated the unity theme in regard to the autonomy of the Mediterranean Sea as a zone of cyclogenesis during the winter half of the year. In 1992, he again averred that, during those months,

> the anticyclone over the Azores lets in the Atlantic depressions that move one after another into the warm waters of the Mediterranean; they come in either from the Bay of Biscay, moving quickly over Aquitaine; or, like ships, they enter the Mediterranean by the Straits of Gibraltar and the Spanish coasts.[66]

Professional analysis has not endorsed so Atlanticist an interpretation. A review undertaken *c.* 1960 by Britain's Meteorological Office showed around 70 depressions transiting the Mediterranean in the course of the average year. A mere three would have cut across Aquitaine, and only four centres of low pressure come through the Straits of Gibraltar.[67]

Previously Kendrew, too, had spoken of many depressions coming 'from the Atlantic, often as secondaries.'[68] None the less, his description of the Mediterranean in winter as an atmospheric 'lake of low pressure' captured reality better.[69] No fewer than 60 of the 70 depressions just envisaged originated in, or else were revivified in or near, the Gulf of Genoa, mostly between autumn and spring. These 'Genoa lows' are the result of wave cyclogenesis as cold air, often continental in origin, sweeps over the Massif Central or else, of course, the Alps.

Cycles and teleconnections

An awareness that the climate is subject to quasi-cyclic alternations that ramify well beyond the more evident ones of the Sun and Moon can be traced back maybe three millennia to the Genesis story of how Joseph boldly interpreted the Pharoah's dream about seven fat cows and seven lean. He said it meant seven years of plenty would be followed by seven of deprivation. Clustering on some such timescale accords with much drought experience. But glaciers are liable to pulse over longer intervals because, every so often, the pressure from snow accumulating around the summit of the parent ice cap causes ice in basal contact with the rock below to melt. In due course, the meltwater will lubricate exceptional outward movement. Brúarjökull, an outlet glacier of the Vatnajökull ice sheet in south-east Iceland, has surged every 70 to 100 years for the last 350. Some Alpine glaciers behave very similarly.

It is ever more apparent how extensively 'weather cycles' proliferate. During and just after the Second World War, revisory studies were conducted in Germany[70] and Britain[71] into how certain intervals in the calendar (from several days to two or three weeks) experienced similar weather in a high proportion (maybe 75 to 90 per cent) of years. The respective results fairly closely concurred.

For extended atmospheric science, the delineation of such singularities affords case-studies of 'order on the edge of chaos'. How much they illuminate the historical past depends on how far they were recorded by contemporaries, assuming they were at all. But any idea that they counted for a lot in human history is undermined by the preoccupation of the folklore, not with cyclicity *per se* but with the meteorological counterpart of the alchemist's dream: the use of the weather on some particular day to forecast that for weeks or even months ahead.

However, a conspicuous exception is the period October 16th to 20th. It was identified in the British revisory study referred to above as often associated with calmly anticyclonic weather in and near the English Channel. Likewise, the folklore speaks of the fine and quiet St Luke's summer,[72] the Feast of St Luke being 18 October. So is it just possible that in 1066 Harold felt obliged to present his weary levies for the Battle of Hastings on 14 October (see Chapter 6) for fear of William's well-trained soldiers giving them the slip in the several days of good marching weather soon to be expected? The English levies were not cut out for manoeuvre warfare.

From the elusive intra-seasonal singularities one progresses, in the ultimate, to the epochal recurrence of impacts by heavenly bodies, cometary or meteoritic, not to mention the tectonic behaviour of the Earth itself. Not that one should be beguiled into thinking the circulation of the atmosphere and oceans is governed by alternations that are not only enduring but truly rhythmic. Many cyclical tendencies are regular in neither amplitude nor wavelength. Lately it has been proposed, apropos glacial advances, that this can be because an overarching cycle somehow induces frequency modulation.[73] Then again, periodicities may seemingly become imprinted yet soon afterwards fade. Bill Burroughs warns us that 'The history of meteorology is littered with whitened bones of claims to have demonstrated the existence of reliable cycles in the weather.'[74] Theories of chaos and catastrophe are germane.

One must treat with especial caution any perceived cycle that lacks explanation. Germane here is the distinction economists draw between 'exogenous' (i.e. external) and 'endogenous' (i.e. internal) causes of the putative trade cycle. The former covers divers possibilities: sunspots, wars, gold strikes, great inventions, etc.; the latter embraces those mechanisms at work within the economic system proper that induce fluctuations in investment, production, prices, employment, and so on.[75] A similar distinction should be drawn in climatology, as per the admonition by Sir Napier Shaw cited on p. 37. Certain causative variables (e.g. the Milankovitch cycles discussed on pp. 61–2, or solar intensity) stand outside the circulation of the Earth's atmosphere and oceans. Others (e.g. seasonal singularities, glacier surges and El Niño) derive from solar energy but only as mediated through terrestrial processes. They can therefore be deemed endogenous

Climatologists sometimes identify 'phase locks', two or more cycles quite different in character enhancing their combined impact by being in some measure in phase. Within the stratosphere, tropical latitudes perennially experience a regime whereby an average of 26 months of easterly winds are abruptly followed by westerlies for a similar interval. Then the easterlies supervene again. That this quasi-biennial oscillation (QBO) may so relate to the sunspot cycle as to affect weather right down to the Earth's surface was the inference from a statistical analysis covering 36 years conducted by Karin Labitske of the Free University in Berlin and Harry van Loon of the National Center for Atmospheric Research at Boulder. Their findings were that, at an altitude of 30 km (which means a pressure of *c.* 15 millibars), warm north polar winters (with –54°C as a typical temperature) occur in a QBO west phase only when the Sun is at its most active, and cold ones (typically at –78°C) only when it is least so. During the QBO east phase, the opposite applies. North polar winters are warm at the said altitude when the Sun is least active, and cold when it is most.

Further correlations were discerned, down to mean sea level: 'When the Sun is at its most active, it is very likely that, in the west years, the pressure will be higher than normal over North America, with lower pressure than usual over the waters on either side of the continent.' When the Sun is least active, the converse holds good. Though these perceived correlations still lacked a theoretical justification, the probability that they were pure chance was put at not more than four in one thousand.[76] Admittedly some analysts would say the characteristic temperatures cited are *c.* 20°C too low for the altitude stipulated.[77] Even so, this study is a salutary demonstration of how complex atmospheric cyclicity could turn out to be.

Two years can be a significant span in many a crisis situation (e.g. external war or internal revolution) in human history. Therefore it is pertinent to note that biennial fluctuations do occur, steadily or otherwise, in many meteorological time series. Burroughs cites the winter temperature graph for Marengo, Illinois, as showing a strong biennial oscillation between 1873 and 1886, yet neither before nor after.[78] Another intriguing case is a discernible biennial oscillation in the incidence of westerly winds over Britain from 1861 to 1979. This was even though, in secular perspective, their frequency was varying structurally – i.e. from a moving average low of 85 days a year *c.* 1885 to a peak of 108 around 1925, then 73 through 1970.[79] Gauging very short-term cyclicity in medieval times is difficult still and may long remain so. But current experience in this regard may still help us to view medieval climate impact more in the round.

The notion of cyclical modulations of the Earth's climate has become intertwined with that of 'teleconnections': the tendency of seasonal or longer-term anomalies in climate to relate (maybe with a defined time lag) to other regional fluctuations that may well (as per chaos theory) be quite distant. At the centre of what increasingly looks like a near-to-ubiquitous teleconnection web is the El Niño–Southern Oscillation (ENSO). Within the tropical Pacific, the displacement of surface water is heavily from east to west via a great gyre either side of the equator. In between, however, an equatorial counter-current moves the opposite way with its axis parallel to, though several degrees north of, the equator. Every year, usually from December, this current surges, inhibiting the upwelling near the coasts of Peru and Ecuador of deep water. Once or twice a decade, a reinforced surge, now universally known by its local Spanish name of El Niño ('the boy child', an allusion to Christmastide), is experienced. This occurs closely in phase with the 'Southern Oscillation', a tendency for the seasonal mean of atmospheric pressure around Tahiti to vary inversely with that around Darwin.[80] The nodal importance of this oscillation was confirmed by Sir Gilbert Walker (head of the India Meteorological Department, 1904–24) as he consolidated correlatory work undertaken by others since 1880.[81] The mean frequency and intensity of ENSO can vary sharply cycle to cycle but also over secular timescales.

ENSO derives from the recurrent disturbance (for maybe 12 to 18 months at a time) of the 'Walker circulation' within the atmosphere across the equatorial Pacific. Lowered air pressure 'around Tahiti' weakens the south-east trades. So does heightened air pressure 'around Darwin'. Normally these winds help sustain a sea level off Indonesia maybe 40 cm above the global average. With their weakening, much extra water may flow into the counter-current. The correlates ramify. In Ecuador, most of the years since 1951 with abnormally heavy rainfall have been El Niño ones. Likewise in eastern equatorial Africa, the central Pacific and the south-east of South America, precipitation rises above average. Usually it is well below average then over Papua New Guinea, much of Australia, the north-east of South America and south-east Africa. Affected, too, are tropical revolving storms. In the twentieth century, fewer hurricanes appeared in the North Atlantic during El Niño, while the median locus of Bay of Bengal cyclones tended to shift eastwards.[82] The 'teleconnected' concurrence of several such tendencies around the world has enabled the tracing of defined ENSO sequences back through 1475. There are also manifestations (notably in Nile flood records) many centuries earlier.

The Indian monsoon is liable to be most vigorous when the ENSO manifestation is not El Niño but La Niña, the 'feminine' ambience in which the equatorial counter-current surges less forcefully than normal, a year or two after an El Niño event. However, a lot will depend on whether the secular bias is towards higher all-India rainfall. If so, there could be phase locking with La Niña. If not, any lock will likely be with El Niño. However, ENSO will augment the secular propensity. Moreover, the circulation of the summer monsoon extends a deal further out, not least on the western side, than the bounds of the subcontinent. It regularly embraces the Persian Gulf and its environs, much of the Arabian peninsula, and, via the Horn of Africa, the Nile valley. In 1910 Sir Gilbert Walker recognised that, since Nile flood levels are largely determined by fluctuations in the Blue Nile, which rises in the Ethiopian highlands, there must be 'a tolerably close correspondence between the abundance of the Nile flood and that of the monsoon rains of northwest India.'[83] Recently an analysis of sea temperatures in the Arabian Sea has confirmed that the vigour of a monsoon in Arabia and the Horn of Africa is derivative not from local modulations but from the overall strength of its circulation that season.[84] Clearly that argument encompasses a vast region that, even before the early Greek writers acknowledged Egypt as 'the cradle of science',[85] was affecting how Europe developed.

Another way in which the El Niño climate syndrome may bear on Europe is through the behaviour of Arctic sea ice. Focal here is the East Greenland Current, which, emerging between Greenland and Spitzbergen, continues (on the surface and at depth) through the Denmark Strait before sinking below warmer water between there and Cape Farewell. It is thus the vehicle for the great bulk of the Arctic outflow.[86] Down one steep edge on the floor of the Denmark Strait, it plunges nearly four times as far as does any waterfall on land with a throughput nearly 400 times as great.[87] In springtime through the middle decades of the twentieth century, the associated pack ice encompassed Jan Mayen and also extended halfway across the Denmark Strait.

A study lately conducted at NASA's Goddard Space Flight Center has shown the north polar seas bearing nearly half a million square kilometres more pack ice in August during El Niño than during La Niña. Granted, this comparison covered only two ENSO cycles. All the same, the respective profiles did firmly point to a correlation. Any corroboration must be seen in relation to a mean annual fluctuation of this marine ice sheet from 14 million square kilometres in February to 7 million in August, as of the present. Worthy of concurrent investigation is possible ENSO *conjonctures* with a 60-year alternation in the ice cover in the Greenland Sea lately discerned by the Climate Research Unit at the University of Keele.[88]

Regardless of the exact modalities, however, the East Greenland Current is unlikely to have penetrated far enough south on the surface in the last two millennia to affect cyclogenesis near Newfoundland, though its strength may determine lesser developments, both air mass and Arctic frontal. Nevertheless, a study at the Universities of Provence and Oklahoma of the twentieth-century data suggested more winter 'cyclonicity' during an El Niño event, though the correlation was too weak to rule out randomness. More solid was an indication that, when it was springtime in Europe, El Niño correlated with a lowering of atmospheric pressure from the North Sea to the Caspian together with pressure rises over the central Atlantic and southern Mediterranean.[89] The most clear-cut ENSO correlation revealed by a University of Loughborough climatic review of Britain since 1880 concerned winter rainfall over England and Wales. It averagely showed a 12 per cent rise during mature El Niño events. During mature La Niñas, the norm was virtually unchanged.[90] Maybe ENSO as yet explains 'only a small amount' of the climate erraticism experienced in Europe in the twentieth century.[91] But a recent study by the Danish Meteorological Institute does point to a low-altitude oscillation in air temperatures being ENSO-related. It is as between the northern and southern extremities of Europe in both high summer and deep winter.[92]

A salient example of a widely set but very direct intra-regional teleconnection is the North Atlantic Oscillation (NAO). This has come to be defined as the varying steepness of the downward gradient in MSL atmospheric pressure along a near-to-meridional line (*c.* 24°W) from the Azores to Iceland. The NAO wintertime pressure differential lessened markedly, on 11-year moving averages, from 1908 until 1964.[93] That should have meant less storminess in the east Atlantic and axial Europe. Also revealed was a short-term oscillation with a mean length of two to three years. That coincided closely in wintertime with north European seasonal air temperatures.[94]

Steep gradients in sea and/or air temperature from the tropics to high latitudes are prone to accentuate collateral falls in mean atmospheric pressure. The NAO differential will therefore be greater when there is only a weakish advection of tropical water into the North Atlantic Drift via the Gulf Stream. This precept is consistent with the fact that it is in wintertime that storminess is most prevalent. Of late, the North Pole air temperature has averaged 68°C less than the equatorial mean in deep midwinter as against 32° in high summer. Yet in January the High Arctic is not the coldest region in the hemisphere, whereas in July, on sea-level temperatures, it is. Also to explore, of course, is any correlation between the variable advection of Atlantic tropical water and ENSO.

Solar variation

Any review of the most fundamental causes of climate change must accord the Sun pride of place. However, elucidation of just how our parent star behaves secularly still looks a tough proposition. Its inner mechanics are the subject of an ongoing debate lately intensified by data from orbital satellites – i.e. from outside the atmosphere. Nevertheless, a 'standard model' now accepted as the underlying explanation depicts the Sun as halfway through a 'main sequence' of 10 billion years as between initial consolidation into an energetic body and penultimate expansion into a 'red giant'. This formulation has the Sun growing 10 per cent brighter every billion years.[95]

The notion of a 'standard model' that outlines the life of many stars is confirmed by the more refined stellar observation from orbit and with computer enhancement. When the total luminosities of individual stars are plotted against their recorded temperature (a plot known as the 'Hertzsprung–Russell diagram') very many, our own included, are close to a 'main sequence' curve. In other words, similar mechanics do yield comparable results, size for size, across vast spans of time.

Meanwhile, surveillance of nearby stars has shown a high proportion to possess the equatorial gaseous discs from which planets may coalesce, as in the solar system. But if that parallel can be drawn may not another – one of more direct concern to extended atmospheric science? Recent measurements of irradiance in 33 stars closely akin in mass and temperature to ours have shown short-term oscillations up to one per cent, an amplitude several times what the Sun is currently exhibiting.[96] We feel less sure today than, say, 20 years ago about how solar radiation *in toto* can vary over decades and centuries. But just lately, cosmogenic isotopes have started to reveal much more about how it has varied historically.

Alongside esoteric enquiries about solar irradiance in galactic perspective runs the more prosaic one that has rumbled on for two or three centuries about the connotations of sunspot cycles across (it can with some confidence be said) the last half billion years and more.[97] Over a thousand studies have been published either to affirm or to deny a link between sunspots and terrestrial weather. Yet lacking throughout has been the sense of solid progress such outpouring ought to engender. Expressive of the resultant frustration is the extent to which direct empirical links have been sought between the popularly recognised sunspot cycle (averaging close to 11 years) and variables of a physiological or societal kind. Among many linkages proposed at a Soviet scientific conference held in Odessa in 1965 were ones with the 'reproduction of murid rodents' (p. 59) and 'the variation of blood coagulation' (pp. 215–17).[98]

In the West, the quest for such colourful concurrence has sometimes been as active.[99] Addressing the British Association in 1878, an eminent economist, W.S. Jevons, gave the mean interval between the troughs in the trade cycle (from 1721 to 1857) as 10.46 years. He duly claimed a near perfect correlation with a sunspot cycle he said medially recurred every 10.45 years. Acknowledging there to be no evident connection (e.g. corn prices) within the British economy, he presumed causation elsewhere, probably in the tropics. However, there are several parameters in the estimation of a sunspot peak: number, average size, largest sizes, latitudinal distribution . . . . Therefore a claim to have calculated the median cycle to 0.01 of a year (i.e. three days) was a classic false accuracy. Besides, Rudolf Wolf's celebrated Zurich sunspot series shows a mean of 10.9 years per cycle from 1723 to 1798, and then 11.3 from 1810 to 1878. Nor does the cycle-to-cycle correlation even as Jevons perceived it really hold up after 1797.

A contradictory aspect of sunspots is that, although they betoken intensified solar activity, each is a vortex of plasma that cools as it ascends to the surface. The fact that the spots are cooler than the rest of the solar surface (4,000 K as against 6,000) is not always offset by *faculae*, the very bright white streaks that occur in loose association with them. The Solar Max satellite, in near-Earth orbit from 1980 to 1989, found net solar radiation could fall by as much as 0.25 per cent when a revolving sunspot cluster was fully side on. Working Group I of the IPCC reported in 1990 that the high years of the sunspot cycle had registered more irradiance overall than the low, but only by one part in 1,400.[100]

At all events, there may be little correspondence either way between sunspot occurrence and erratic weather on Earth. In 1921 Huntington and Visher proposed that sunspots made storms 'more abundant' but also confined them more closely to certain tracks.[101] During the Spörer Minimum in sunspots (1410 to 1534), abnormal erraticism is evident in the Earth's climate. Yet during the Wolf and Maunder Minima (1280 to 1330 and 1645 to 1715) evenness prevailed more.[102]

Recently, Danish scientists have averred a close match, since 1870, between the length of the recognised solar cycle (which may, in fact, range from 8 to 14 years) and temperatures at the Earth's surface. When the former shortens, the latter are mainly higher.[103] Alas, a partial reconnoitre of one authoritative database does not well support such a linkage in relation to this current study. From 1600 to 1750, the nadir of the Little Ice Age, the mean time between maxima was 11.3 years. From 1100 to 1250, the zenith of medieval warming, it had been 11.16.[104]

There appear also to be solar cycles within cycles. Today the most basic as seen by astronomers is not 11 years or thereabouts but 22, the Hale cycle. This is because the lead spots of each 11-year phase always have a magnetic polarity opposite to that of their immediate precursors. Therefore the passage of two constitutes one alternation. Connections have been sought between this twinning and Kuznets-style periodicities, not least a drought cycle perceivable (on the High Plains of North America at any rate) the past four centuries. As with the nearly equivalent lunar cycle, however, firm and exclusive bonding is not easy to demonstrate over time.[105] For a Soviet enquiry quite closely akin, see Chapter 10.

Another cycle perceived is of 88 years or thereabouts. A 'secularly smoothed' series of sunspot numbers optimistically dating back to AD 400 gives a fairly steady alternation with a mean periodicity close to 90 years. Only twice does the sequence collapse into irregularity: 1150 to 1250 and 1580 to 1720.[106] But it may be no coincidence that the former brackets a warmth zenith and the latter the nadir of the Little Ice Age, two eras of critical readjustment. At all events, the sunspot incidence through the medieval warm phase was high overall. One proposal has been, in fact, that it was a maximum in a 800-year oscillation in solar activity.[107]

The themes currently emergent within the solar debate (see Chapter 11) are these. The Sun may be subject to vagaries outside the cycles here identified. In any case, fluctuations in that outpouring of sub-nuclear particles we know as the 'solar wind' could prove peculiarly important. Not least might this be so, in that one function of this wind can be to ward off considerably the 'cosmic radiation' from deep space. The solar wind blows especially strong from sunspots.

An Armagh University study lately published finds a tightly positive correlation from

1984 to 1994 between cosmic rays and low cloud cover globally, the latter then annually varying between 27 and 29 per cent of the sky.[108] A deduction might be that atmospheric atoms ionised by the rays serve as particles around which water vapour can condense. Always condensation takes place a lot more readily once particles of the right size and quality are sufficiently present. However, a leading cloud physicist has doubted whether this role can be fulfilled by material as insubstantial as ions – i.e. atomic nuclei deprived of their encircling electrons through ionisation.[109] Besides, a varied supply of 'condensation nuclei' is abundantly available in the modern world. Combustion alone is a major source. Moreover, atmospheric motion should usually ensure adequate particle uplift. The inhibition of condensation in clouds due to particle shortage is therefore estimated to be under one per cent.[110] In the Late Antiquity to eve of Renaissance era, things may at times have been different. But in the High Middle Ages deforestation must have been a major generator, assuming enough turbulence. A volcanic contribution may also have been significant.

Impacts and vulcanism

In 1784, the distinguished scientist and United States' 'founding father' Benjamin Franklin proposed a connection between a massive volcanic eruption in Iceland the previous summer and haze over the United States so weakening the Sun as to make that winter 'more severe than any that had happened for many years.' Demonstrably that effect can result from maybe tens of millions of tons of dust being discharged into the stratosphere either by an erupting volcano or else by the impact of an extra-terrestrial body, a meteorite, say. There is an inverse square relation between the diameter of a spheroid particle and its rate of descent through thin stratospheric air. One a millionth of a metre across ejected to a height of 30 km would take 2.8 years to descend to the tropopause at, say, 12 kilometres. Halve this width and that dwell time becomes 11.3 years.[111] Once dust has re-entered the troposphere it is normally washed out by rain or snow inside two weeks.

A belief entertained these days is that a reason why our *homo sapiens* ancestors, in every culture, gazed on the heavens so awestruck is that extra-terrestrial impacts have figured more in human history than was once assumed. About every 10,000 years on average a body some 100 metres across hits our planet with a force of the order of 10 megatons, ten million tons of high explosive or a large hydrogen bomb. An example was the 15-megaton asteroid (maybe 80 metres wide) that disintegrated over Tunguska in Siberia in 1908, levelling 2,000 square kilometres of *taiga* and causing fires far beyond. In July 1994, Comet Shoemaker-Levy 9 made multiple impacts on Jupiter. In December 1997, a Geminid bolide (i.e. meteoritic fireball) disintegrated after entering the atmosphere over Greenland.[112]

The supreme threat is that, every 100 million years or thereabouts, a comet or large asteroid will impact with a kinetic energy of a million megatons and savage the entire biosphere.[113] But in the interim, there will be a spread of lesser but non-trivial events. Of particular significance these last two millennia may have been a Taurid swarm of cometary and/or meteoritic debris that appears to revisit every two centuries or so.[114] More familiar, of course, is the Leonid swarm each November, a phenomenon that peaks every 33 to 34 years.

The long history of the Earth is also studded by extended intervals of enhanced vulcanism. Those of highest profile are often associated with the emergence of mountain chains, with repeated eruptions giving rise to persistent atmospheric palls. The last five or ten million years rate as the latest in a succession of glacial ages across geologic time to which vulcanism will signally have contributed. Even these last few centuries, eruptions have tended to cluster, sometimes geographically but more significantly time-wise. The sixteenth and eighteenth saw less activity; the seventeenth and nineteenth more. Much of the twentieth to 1975 was decidedly tranquil.[115] However, 1902 had seen three major eruptions in the Caribbean: La Soufrière and Mont Pelée, each in the Lesser Antilles; and then the mightiest, Santa Maria in Guatemala. Northern hemisphere temperatures soon fell 0.25°C below the secular warming trend. Thanks also to several eruptions elsewhere during the next dozen years, the trend line was not at all firmly resumed until 1920.[116]

It is often said that one big eruption ejecting into the stratosphere may depress global temperatures for up to seven years. Reality can be more complicated. The greatest single explosion this last century was of Pinatubo in the Philippines in June 1991. The veil it cast has been adjudged equivalent to that from Krakatoa in 1883.[117] For several months, insolation at the Earth's surface was down several per cent. By August 1992, mean tropospheric temperatures had dipped 0.7°C globally. Over the next three years, they reverted rather unsteadily to the 1979 to 1994 norm,[118] a reversion consistent enough with dust dwell times in the stratosphere.

Nevertheless, complications arise in relating the Pinatubo event (via successive anomalies in the circulation of the lower atmosphere) to abnormalities in regional climates. The study here cited from Tsukuba Science University in Japan notes a second strong peak in stratospheric dust over Tsukuba all but 600 days after the eruption (i.e. in February 1993). Coupled with a deep North Pacific plunge of Arctic air, the persistence of this dust veil for several months more at very similar intensities explains why that summer was abnormally cool over east Asia. Later on the Tibetan summer anticyclone waxed anomalously strong. In fact, it was enhanced for four summers more, though subject to QBO modulation. Between 1994 and 1996, some searing droughts occurred across east Asia.[119] A general inference may be that a prolonged vulcanic spell will induce cooling but also erraticism. In this particular instance, modulation by the mighty Tibetan plateau was probably very fundamental.[120]

Milutin Milankovitch

Long seen as basic to climate trends in general are rhythmic variations in the Earth's orbit and axial inclination, their respective periodicities being measured in tens of thousands of years. A causal link between their integrated effect and climate change was first explored over a hundred years ago. Then in the first four decades of this century, a thorough review of the data available across 600,000 years was carried out by Milutin Milankovitch, a Serbian physicist (1879–1958). A crucial phase in his labours was the time he spent at the Hungarian Academy of Sciences, on parole as a prisoner of war of Austria-Hungary.

He died convinced he had fully unravelled the truth of the matter. And he did establish beyond doubt that, for some thousands of years past, the underlying trend worldwide has been towards cooling. This is most basically because the 'astronomical' cycles Milankovitch was concerned with have reduced, particularly in high northern latitudes, the summer–winter insolation contrast. That reduction is conducive to icefield expansion. It is so because cooler summers mean less snow-melt while warmer winters (with the air able to bear more water vapour) yield more fresh snow.

What he failed to incorporate, however, is the positive feedback due to concurrent alterations in the concentrations within the atmosphere of carbon dioxide and the other 'greenhouse gases' – notably methane and, if you will, water vapour. In Helsinki in 1989, Mikhail Budyko expressed the view that the ice-albedo feedback could directly be credited with only a fifth of the five-degree Celsius fall in air temperature he judged had occurred during the last glaciation. The rest he attributed to a collateral fluctuation in atmospheric CO_2.[121] But he accepted that, while it was chiefly the astronomical cycles that had triggered this reverse 'greenhouse' effect, the latter had lagged behind the former, thus deferring the temperature low while making it that much lower. A cooling Earth would cool further as the carbon cycle retracted. A warming one would warm further as that cycle revived.

The latest modelling has borne this rider out while showing the greenhouse increment either way to be not as great as Budyko suggested. The correlation (as derived from ice core analysis across 160,000 years) is most finely expressed with methane, this because the average dwell time in the atmosphere of CH_4 is an order of magnitude (i.e. factor of 10) shorter than that of CO_2.[122]

Extended atmospheric science

A crucial question *vis-à-vis* this particular exercise in historical climatology is what import interactions so visible across several or many millennia may have had between AD 211 and 1350. An assessment by Hubert Lamb is germane. His reckoning was that, over the last 5,000 years, the astronomical cycles had quite steadily modulated mean temperatures as follows. At 35°N, a fall of 0.45°C per millennium applied in the summer half of the year and a similar rise in the winter half. At 65°N the summertime fall was 0.55°C per millennium and the wintertime rise 0.35°C.[123] Such rates of climate forcing are by no means negligible compared with others. But if they were so very consistent over time, that may have made them less crucial to impact analysis. Certainly they did nothing to dissuade medieval people from drawing a much sharper experiential contrast between summer and winter than we do today.[124]

Within decadal timescales, a variety of cycles may be important, most basically for precipitation and temperature. Identifying many cycles may be feasible over the land and in shallow waters, drawing on the existing mix of methodologies. Dating them will be trickier (see Appendix B). The accuracy achievable may vary between a year or two and a decade or two depending on (a) the apposite techniques and (b) the quantity and quality of the data to hand. It is very safe to assume that ENSO will regularly have influenced Europe's climate through Roman times, though the pattern of that influence may have evolved over the centuries. It is also reasonably safe to assume that biennial alternations as well as ones of around 20 years will have figured *c.* AD 211. But such longevity for most other cycles currently perceived cannot be assumed. Take the study of cosmic rays and cloudiness, 1984 to 1994, referred to above. The very neat concurrence established for low cloud throughout applies equally to higher cloud to 1991. Then it breaks down for the latter, suddenly and totally.[125] All the same, the temptation to presume too much will lessen as more fieldwork is done.

Peculiarly hard to advance, however, will be our understanding of the behaviour of the high seas the last two millennia. A shortage of specific data will remain an obvious impediment. But another difficulty could be that, because of their thermal inertia, the oceans have yet to adjust fully to the last great retreat of the ice sheets. That cannot but complicate retrospective modelling.

Yet there is no denying the salience of the sea in climatic variation. It is, for instance, probable that the occasional sharp short-term changes in mean air temperature globally relate to how anomalies in the sea's vertical motion specifically affect the concentration in the air above of carbon dioxide (see Appendix A). Besides which, any areal alterations in the spread of sea-surface temperatures are liable to have immediate effects on the weather –

immediate in the sense of being localised or regional as well as in that of being in close to real time.

If my memory serves me aright, it was the pioneer British geneticist and scientific philosopher, J.B.S. Haldane (1892–1964), who said, 'the Universe is not merely stranger than we realise; it is stranger than we can realise.' The same could almost be said of the terrestrial weather with all its chaotic vagaries. As with the cosmos, so with the climate, the strangeness does not preclude a goodly and increasing measure of prediction, retrospective and prospective. None the less, it is still desirable to bear this ultimate reality in mind when speculating about climate impact on a local situation without specific information as to what climate changes may actually have been registered here. Otherwise we may be too inclined to assume this change will be just a microcosm of whatever wider trends have been divined. That will be all too akin to how ignorance of the deep sea floor once fostered the presupposition that it was flat and in every way inert.*

* Temperature scales – in accordance with the *modus operandi* enunciated in the Preface, the metric and Fahrenheit scales are used interchangeably. The metric ones are the Celsius or Centigrade scale and its derivative (discussed above) the Kelvin scale. The freezing point of water is 0° on the Celsius scale and its boiling point, 100°. The equivalent Fahrenheit readings are 32° and 212° respectively. In Kelvin measurements the index ° is omitted; and, while a capital K is used to denote a specific temperature, a small k is employed for a temperature range – e.g. 'ten kelvins'.

Part 2

Late Antiquity to Renaissance foreglow, AD 211 to 1350

3 Empires and barbarians

Edward Gibbon's six-volume *Decline and Fall* (first published, 1776 to 1788) has so bestrode the study of the Roman Empire that his judgement as to when it was at its height tends to be taken as revealed truth. To him, its finest era was between AD 96 and 180: 'If a man were called to fix the period in the history of the world, during which the condition of the human race was most happy and prosperous he would, without hesitation, name that which elapsed from the death of Domitian to the accession of Commodus.'[1] The imperial reigns thus covered are those briefly of Nerva and then Trajan and Hadrian, followed by all bar the last of the four Antonine emperors.

Gibbon saw peace as then preserved by political and cultural unity at continental level. He saw that unity as upheld by a continental elite imbued with a philosophic agnosticism more encompassing and empathetic than the moral arrogance of his own day, whether emanating from the religious sectarians or the Voltairean atheists.[2] He felt this *Pax Romana* was everything the Enlightenment of the eighteenth century could have been.[3] Yet in almost the same breath, he recognised the inherent 'instability of a happiness which depended on the character of a single man' – whoever occupied the imperial throne at a given time.[4] The two that bracketed his 'golden age', Titus Domitian and Lucius Commodus, were summed up by Gibbon as timid yet cruel. Each fell to an assassin. Gibbon's confused attitude to arbitrary autocracy is epitomised by his modish celebration of 'the incomparable' Frederick the Great, modish in that the likes of Voltaire and Goethe similarly subscribed.

It was presumptous, in any case, to measure the progress of a bygone age by criteria as Olympian as the happiness and prosperity of 'the human race', particularly when 'prosperous' is evidently being extended to mean something less calculable than mere access to goods and services. Specific tests are more appropriate. Empires being what they are, the two most basic are territorial expansion and how civil government evolves. On both counts, Rome peaked half a century later than Gibbon asserted.

In campaigns waged between AD 102 and 117, Emperor Trajan had all but staked out the uttermost limits of Roman rule. Hadrian, his successor, had abandoned gains insecurely made in eastern Anatolia and Mesopotamia. Nevertheless, from *c.* 142 to *c.* 185, an Antonine Wall was to be maintained across central Scotland from the Firth of Clyde to the Firth of Forth. Then from 208, under Emperor Severus, a campaign was launched to conquer all Scotland. But this endeavour stopped on his death in 211. Rome's age of empire building thus came to a close. The very next year Emperor Caracalla extended Roman citizenship to all freemen within the Empire. That marked, however querulously, Rome's climax as a political experiment. So the beginning of the third century is a suitable point in time at which to start this core narrative. A suitable point thematically may be the influence of humankind on climate in the eleven centuries to follow.

Anthropogenic forcing

The most prominent, then, of the anthropogenic (i.e. man-made) factors will have been deforestation, its most immediate effect being the release into the atmosphere of much carbon dioxide. But a century or two after mass felling ceased, there could well have been a global reduction of atmospheric CO_2 because biomass depletion would have depressed the carbon cycle. More immediately, the albedo of the cleared farmland would have been almost twice as great as was that of the forest canopy. Maybe, too, atmospheric dust will have marginally increased in consequence. For all three reasons, deforestation in Europe or elsewhere may ultimately have had a cooling effect.

Over the east of Roman Britain, homesteads, hamlets or whatever were typically set 500 to 800 yards apart.[5] New clearance had slowed right down by the sixth century, the depth of the Burckhardt 'Dark Ages'. The seventh saw a resumption, there but elsewhere too. Witness deep inroads into primal forest in the Ardennes.[6] Among English historians, however, the current tendency is to stress how much woodland the Anglo-Saxons conserved,[7] for reasons ranging from home economics to ecology, from aesthetics to military security. Across Catholic Europe as a whole, the biggest surge of forest clearance was not until 1050 to 1250, this against the background of steep population growth. Italy may initially have been a pacemaker.[8]

China, too, effected much deforestation as its demographic frontier advanced southwards. But estimates of the relevant demography vary. According to Albert Kolb of the University of Hamburg, its population fluctuated within the 50 to 60 million bracket between the Han dynasty (206 BC to AD 220) and the year 1600. However, the percentage living in south China (the Yangtze and beyond) rose from maybe 8 in the Middle Han to an estimated 49 (including sinicised natives) around the year 1450. Even this restrained interpretation bespoke a vigorous and sustained colonisation of the south with much forest clearance, the peoples indigenous to its as yet leafy valleys sometimes being assimilated but more often displaced.[9] An alternative interpretation is that there was population take-off nationwide from 65 million in AD 750 to 110 in 1100. The fraction in the centre and south doubled from *c.* 30 million to *c.* 60,[10] that total being over half as much again as Kolb had suggested.

China is important to this narrative, and not just in terms of humans forcing climate change. It is invaluable for drawing general comparisons. It also interacts with Europe. Already by the first century AD, silk and much else was reaching Rome down the 'Silk Road' caravan routes. Thereafter silk goods, in particular, spread ever more widely among Romans.[11]

The climate of China

Therefore it may be appropriate first to scan the history of China's climate through to 1350. Precipitation trends are less likely to match the ones in Europe than are those of warmth. They are also easier to assess from the imperial archives. In 1926, the ratio of recorded droughts to floods was worked out century by century,[12] and the profile obtained was to be quoted by Joseph Needham in 1959 in his magisterial work on ancient Chinese science.[13] The compilation was based on as wide a sweep as possible across what in modern times has been termed China proper. The mean for the centuries from AD 200 to 1400 was 2.72. Therefore chronic aridity was indicated by the figure rising to 8.20 in the fourth century, and averaging 3.7 across the fifth and sixth. Wetness in the eighth, twelfth and fourteenth centuries was expressed by its dropping to 1.32, 1.04, and 1.05 respectively. Of these six, only the fifth and fourteenth seem in line with concurrent European experience.

However, a study of the Yangtze and the Yellow River presented in 1984 showed big disparities between these river basins. The Yangtze witnessed many droughts in the fourth, twelfth and thirteenth centuries but frequent bad floods in the fifth, eighth and fourteenth. The Yellow River often saw droughts in the fourth, sixth, eleventh, twelfth and thirteenth centuries but floods in the third and eighth.[14] The most indicative results have to be those for the Yellow River – alias the Hwang Ho. After all, that vast valley is the one which (a) has the most marginal water cycle, (b) is a pointer to tendencies in neighbouring Mongolia, (c) stood directly exposed to barbarian attack and (d) approximated closely to the core of old China. The only rider to add is that drier and/or cooler trends in an otherwise jungly lower Yangtze favoured colonisation by the Han, the Chinese ethnic mainstream.

Deductions from the historical archives, supplemented with archaeological and geological data, point to a drawn-out coolness between AD 0 and 600. Zhaodong Feng and colleagues perceive another such spell from AD 1000 to 1200. Ill in accord, however, is their apparent intimation that a contributory factor may have been a dustier atmosphere. The aerial transport of loess onto the plateaux of the Chinese north-west shows a pronounced upsurge, but only (as dated by magnetic orientation) from 1160 to 1270.[15] An explanation could be that, by then, the 'little climatic optimum' of the High Middle Ages was diminishing the effectiveness of the Siberian High in sustaining winds off the Gobi. At all events, an analysis of records from east Henan aligns with this dust-load profile better. Compilation in units of half a century indicates a cold phase from *c.* 900 to 1050. Hard upon it came a warm interlude from 1050 to 1100. But this was succeeded by a decidedly subdued rendering of the medieval optimum through 1200 and beyond.[16] All in all, this test case does not encourage one to attach importance to non-volcanic dust in the atmosphere as a cooling factor in China these last two millennia. But it is an indicator of air flow.

A key to the incomplete concurrence with European trends is that, down the eastern side of the Tien Shan range (*c.* 85°E), there is a climatic divide. This longitude is, after all, axial to a Rossby standing wave which, enveloping the Tibetan plateau, may well have persisted as long across geologic time. At the 1984 symposium alluded to above, it was claimed that a 3,000-year survey of climate variation in Sinkiang (into which the east Tien Shan extends) revealed a 100-year lag as compared with east China[17], particularly during the first millennium AD.

A pulse of Asia?

Though Gibbon still presides over the decline-and-fall debate viewed in the round, it was Ellsworth Huntington who promoted climate change as putatively of paramount importance. Unfortunately, he did protest too much. In 1930, a pioneering economic historian of Late Antiquity, Michael Rostovtzeff, crafted what is still cited as a seminal essay on the waning of that world.[18] In it, he waxed sceptical as ever about grand yet simplistic explanations, Marxian or geographic or whatever. None the less, he paid his Yale colleague Huntington the compliment of addressing his work closely. He found his analyses of lake varves and tree rings in California 'very convincing', speaking as a layman. He was less persuaded by the secular changes thus identified simply being superimposed on southern Europe. He was also doubtful about the archaeological inferences 'especially in Syria' (see Chapter 1).

Undeniably, Huntington's 1911 depiction of the climate of ancient Palestine was unsatisfactory. He assiduously mapped Dead Sea varves but could not date them properly. He fell back on biblical evidence, which could never yield definitive results for such a parameter as lake levels. He also presumed that the Dead Sea, the Caspian and the Lop Nur lake in Sinkiang were regularly coincident in phase.[19] That was not merely unproven, it was wildly improbable. Indeed, Lop Nur drastically relocated itself *c.* AD 330, this within a 1,600-year alternation (due to differential siltation and wind erosion) identified by the Swedish explorer Sven Hedin (1865–1952).[20]

Still Rostovtzeff was at his most forceful rejecting linkage between the pulsations of climate, as Ellsworth Huntington identified them, and the changing fortunes of Rome. He was adamant that Huntington had either failed to comprehend the intricacies of social and political development or else been plain wrong. He proffered instead his own interpretation. He accepted that 'periodical drives of nomads' out of steppe lands could be impelled by 'set(s) of dry years'. He agreed, too, that climate change may cause or aggravate soil impoverishment. He believed that 'in the late Roman Empire, exhaustion of the soil in some parts was a real calamity.' He further averred, very arbitrarily, that this instance 'must be ascribed to man, not to nature'. In which connection, he highlighted the singular strength of the *étatisme* political economy of Ptolemaic and Roman Egypt: 'its systematic agriculture, its refined and highly organised industry and commerce, its full and partial monopolies and its systematic use of labour . . . controlled and organised by the state.'

The fact remains, however, that the said province did share in a general collapse that took place in what is now believed widely to have been a droughty third century. As Rostovtzeff himself put it, 'All the borderlands . . . became waste and derelict; villages were abandoned; men were moving nearer the Nile.' Nevertheless, he saw in this 'all the marks of a sudden catastrophe', whereas he would himself have expected a gradual decline had such ambient factors as climate change been at all operative in Egypt itself or lands it traded with. It was a perspective consistent with a disposition to see climate fluctuation as quite manageable by any tolerably advanced material civilisation. His readers were reminded of the agricultural progress lately made by the Fascists in Italy as well as the Zionists in Palestine.

Yet here again, catastrophe theory will caution us against assuming gradual causation cannot effect sudden transformations. Nor is the pulse of Asia thesis affected either way by the fortunes of Egypt. Nor may those fortunes be too much related to climate tendencies elsewhere in the Mediterranean. After all, Egypt's own water comes very largely from the south. Conspicuously the case with the Nile valley, this is true below the surface of Kharga, 'the great oasis'. Across Egypt, the Romans were usually the first to tap the reserves of groundwater.[21] But in Kharga, many deep wells were sunk by the Persians in the fifth century BC, this to reach water that then flowed readily from artesian structures: that is to say, from porous rocks folding in such a way that, once the capping stratum had been penetrated, gravity fed water to the surface. Where such formations exist, it is usually as part of a much wider sandstone or limestone deposit. Percolation from the Nile in flood massively feeds into the Kharga site.[22,23] Otherwise the rain that charges the Kharga reservoir sandstones falls more towards the edge of the Chad basin.

If a prime cause of climate change to 1350 was forest removal, as mooted above, that precludes such change having been pulsatory. In any case, it is hard to interpret thus fluctuations that do not alternate regularly. Secular variations in the Caspian are hard to integrate even though a flattish topography allows any level alteration to be well expressed in shoreline movement. One might further presume *a priori* that any rise, say, betokens moister conditions in the Caspian's immediate vicinity. However, in the 1960s, L.N. Gumilëv, a University of Leningrad historical geographer, worked from the simple fact that by far the biggest source of Caspian water, the Volga, originates in the Valday Hills, between Moscow and St Petersburg. He persuasively inferred that the Caspian rises higher when rainfall increases in the upper reaches of the Volga as storm tracks are displaced to those latitudes. Such displacement leaves much of the Caspian littoral drier.

Looking at tribal migrations as well as climate proxies and extending his purview as far as Lake Aral and the Tarim, Gumilëv more particularly concluded that, from 200 BC to AD 400, cyclonic tracks were usually well north. Therefore, the Caspian rose even as its environs turned more arid.[24] This pattern reached a climax in the third century AD.[25] Around the time of Christ, a warm phase had peaked in the Black Sea basin with mean temperatures maybe half a degree above today's. That turning point is endorsed well by evidence from other temperate lands worldwide.[26]

Evidently Gumilëv was diametrically at variance with Huntington's deduction that the Caspian level fell continuously from 500 BC to AD 500, with an acceleration of this trend from the third century of the Christian era.[27] From that the latter had inferred extreme aridity locally and, by too careless an extension of his argument, across much of inner Eurasia. A variation on both his scenario and Gumilëv's can be that winter cyclonic storms occasionally switched to more southerly tracks. Corroboration might be read into a 1990 peat-bog analysis from the then Soviet Academy of Sciences. This found that, in a broad zone from Sweden through the Moscow region and also to Moravia, average annual precipitation in the fifth century was as much as 50 or 100 mm below the longer-term norms.[28]

On this score, however, the evidence is not merely skeletal but contradictory. Leszek Starkel of the Jagellonian University of Kraków is firm about his findings from geomorphological fieldwork that AD 450 to 575 was a time of flood clustering in the Vistula basin.[29] Nor is this to be explained in terms of accelerated run-off due to tree removal. On the Vistula–Elbe sector of the North European Plain, the botanical evidence does show a considerable extension of low intensity arable AD 0 to 500, but at the expense of grassland not forest.[30] Likewise, in the Bohemian rimlands a switch from forest to pasture only becomes pronounced in the seventh century.[31]

Here then is a contradiction that may best be handled at present by modelling. Through the mid-twentieth century, what is termed 'the Siberian High' was medially centred in January over the Khangai Shan region of Mongolia; and a westwards ridge was discernible, as a rule, to at least the Alps. That implies recurrent blocking patterns. What modelling now confirms is that only subtle changes in the alignment and profile of such atmospheric ridging can determine whether in a given phase these patterns block northerly cyclonic tracks in the main or more southerly ones. In those terms, this circulation is intransitive (see Chapter 2). For his part, Gumilëv went on to deduce that a mainly northward shift of the tracks in the tenth century and, the more so, in the thirteenth materially contributed to the decline of Khazaria: a fruit-growing, hunting and fishing polity that had dominated the Lower Volga-cum-Don region across the span AD 600 to 900 (see Chapter 5).[32]

To see how such climate shifts could influence tribal migrations, it may be helpful to turn to the Huns, the warrior nomads who were to be prime movers in the *Völkerwanderung* that, particularly via the Balkans, interacted so forcefully with an overstretched Roman Empire. They first alight on the stage of history in the third century BC. They do so reputedly as the Hsiung-nu, a people who once grazed vast herds and grew some crops across Dzungaria on the northern approaches to the Tien Shan. Though long-range transhumance (as between summer and winter pastures) kept them nomadic, their society evolved a diverse artistic culture.[33] They were prominent in the interplay between China and the 'barbarian' tribes. One kinship group that emerged therefrom was the Qin. They founded a dynasty (246 to

207 BC) that by the year 221 BC had established bureaucratic imperial government across much of what we today know as 'China'. They began a discontinuous line of earthen ramparts and watchtowers that was to be progressively revamped and extended to become, by the late sixteenth century, the Great Wall we know.

In the middle of the second century BC, the Hsiung-nu pushed well south of 'the Wall', contravening an agreement made in the year 162 with the Han dynasty in China (202 BC to AD 220). A Han counter-offensive from 128 to 127 BC regained the ground lost. Within several years, the Han started to extend the chain of forts around the north-east flank of the Nan Shan mountain range and towards the Tunhwang oasis.[34] It was part of a forward strategy of forging links down the Silk Road with the settled civilisations of central Asia, an urgent military purpose being to acquire war steeds of 'flying horse of Kansu' calibre. From 69 BC to AD 23, indeed, the Han maintained a protectorate with its capital at Wu-lei, a site on the south-east flank of the Tien Shan and 900 miles west-north-west of the end of the Wall. This thrust forward had been opportunistic in that, from the first century BC, the Hsiung-nu were oppressed by worsening drought and winter cold, as their traditions are said to confirm.

Therefore migration in a westerly direction, to lands that were moister, less bitter in winter and hopefully more peaceable, may well have appeared imperative to many of their clans. What has to be acknowledged, however, is that two modern experts on the Huns find unproven the Gibbonesque postulate that this people are of Hsiung-nu lineage. The late E.A. Thompson warned how difficult it was to trace their ancestry, given that they were illiterate, lacking a coinage and weak on oral tradition.[35] Likewise, about all Peter Heather of University College London feels we can say is that the Hun language was from the Altaic wing of the Uralic–Altaic language group.[36] The spread of that group from Manchuria to eastern Europe betokens successive migratory waves. The Altay mountains bestride the current international border between western Mongolia and Russia.

Arguably, of course, a general westward tendency is what matters analytically, not a specific ethnic linkage. In any case, the present writer is absolutely unqualified to challenge Edward Gibbon's inference that the Hsiung-nu did reappear as the Huns, having moved further and further west after their expansion southwards had been thwarted by Han national solidarity. Various authors have expressly cited the embryonic Wall as instrumental in such thwarting, facilitating as it did both defence and offence. The distinguished Sinologist, Owen Lattimore, stressed how it served as a benchmark by which the Chinese and the nomads could gauge their relative advantage. He was inclined to see it, too, as symbolic of an ethnic divide he judged to be more clear-cut, as a rule, than that between Rome and the barbarians.[37]

Still, it is hard to see how so discontinuous a feature could have exercised that much influence in the absence of other factors. Among those in play was climate fluctuation. The evidence, incomplete though it may be, appears to confirm two major trends in north-east Asia in the last two centuries BC, each probably linked to a waxing of the Siberian High. The one was a quite pronounced swing to lower temperatures, a state of affairs liable *inter alia* to limit the growth of grass on the barbarian steppes.[38] The other was the phasing out of several centuries of relatively high rainfall across much of China.[39] That trend would likely have extended to those steppes, too.

How much easement of the threat to China the Hsiung-nu exodus effected is problematic. Gibbon believed half of a Hsiung-nu population he put at 600,000 turned west.[40] Two Japanese estimates of the original Hsiung-nu warrior horde have recently been 60,000 and 300,000 respectively.[41] Though it could never have concentrated for pitched battle in these numbers, such a force could not have been contained just by discontinuous earthen ramparts.

The migrant mass would have proceeded north and then west out of the mountain grassland of the Dzungaria region into the steppes that today run continuously for 3,000 miles near the 50° parallel of latitude, thus affording a corridor between the *taiga* and the deserts. As delineated by the geographers, that corridor is typically 100 or 200 miles wide eastwards of longitude 85°E. To its west, the steppes broaden out to 300 to 500 miles, merging in due course into the black earth region of the Ukraine.[42] Throughout the centuries of which we are talking, their spread would probably have been similar. Nor may their axial latitude have varied much from now in or during Late Antiquity, even allowing for secular displacements of the storm tracks.

The inferred progress westwards of the Hsiung-nu/Huns was halting to say the least. Not till late in the fourth century of the Christian era did they proceed through the Caspian and Azov region. As Gibbon himself found, it is 'impossible to fill the dark interval of time which elapsed after the Huns of the Volga [*sic*] were lost to the eyes of the Chinese and before they showed themselves to those of the Romans.'[43] From then on the perceived pace of things quickened. Having forded the Volga in 370 to 372, the Huns broke the Alans, Ostrogoths and Visigoths; and thereby threw the whole region into migratory turmoil. Four years later, most of the Visigoths, again out to avoid them, fled into the Roman Empire. A couple of years of steppic adversity, climate or epidemial, might have sufficed to persuade the Huns to cross the Volga. Obversely, that advance westwards may have been induced by a burgeoning awareness that (a) internal weaknesses made Rome a more tempting prey than maybe the Chinese Empire had been or, indeed, the Persian one was, and (b) the climate was assuredly more agreeable to westward, being warmer in winter and moister in all seasons.

Certain Roman writers prominent in the late fourth century were convinced the Huns had chilly origins. Swamps 'near the Polar Sea' were mentioned.[44] However, this may have owed something to confusion with the Goths, who themselves claimed originally to have hailed from what is now south Sweden. Not every modern specialist *ipso facto* accepts that they did. But Gibbon had little doubt that both the Ostrogoths and Visigoths were from that 'extreme country of the North'. He envisaged their being set in motion by some *x* factor: 'Either a pestilence or a famine, a victory or a defeat, an oracle of the Gods or the eloquence of a daring leader were sufficient to impel the Gothic arms on the milder climates of the South.'[45] He saw them as still in Prussia in the Antonine period but as incursing into Dacia (the outlier of the Empire on the north bank of the Lower Danube) by the early third century. Soon the Goth's onslaught on Dacia grew more menacing, the upshot being that Emperor Aurelian (reigned 270–5) conceded the province.

Meanwhile a dramatic example was unfolding in China's northern borderlands of nomad belligerence in response to drought both in the pre-existing tribal grazing lands and among the settled communities being targeted. The Chinese chronicles indicate a strikingly high and consistent drought frequency over or near southern Mongolia, a phase neatly set between AD 280 and 500. There is a remarkably close match between that profile and the corresponding ones for nomad migration and armed conflict. All three sequences suggest a peak around 300, though not too much significance should be attached to that *conjoncture* since there may have been more reporting lapses in the tenser situation later on. Between the early third century and the mid-fourth, the administrative boundary between direct Han rule and nomad chieftain control receded (on the volatile 110°E meridian) from 40° to 30°N.[46]

The decline and fall: the climate contribution

To pursue the climate dimension further, we should look within the confines of the Empire at its zenith. The literature has tended to polarise between those who believe that climate change did affect Rome's decline and those who contend such change either never occurred or else was inconsequential. The latter have judged the climate of the Mediterranean to be much the same today as it was in the time of Christ, and have therefore inferred, however illogically, that the climate regime 'as a whole has remained unchanged since Greek and Roman times.'[47]

So the first question is whether the Mediterranean's present regime is comprehensively much the same as that two millennia ago. Soon after Israel gained its statehood, Yigael Yadin of the Hebrew University led the exploration of Masada, the Herodian fortified palace so awesomely built on a crag near the southern tip of the Dead Sea and which the Zealots made their last stronghold during the great Jewish revolt (AD 66 to 73). He found two aspects of the present ecology to be much as described by Flavius Josephus (AD 37–*c.* 95), the Jewish governor of Galilee turned historian. The one was proneness to flash-flooding; the other, the possibilities for cultivation on the flattish top of the crag. This persuaded Yadin not only of the veracity of Josephus but also of comparable runs of weather as between the AD 70s and the mid-twentieth century.[48] Back-up came in 1991 from the examination of fossil wood and solution channels within Mount Sedom, an eruptive salt-cum-karst formation near Masada. This found the first three centuries of the Christian era were moister than the several before and after or, for that matter, than the seven since the medieval 'little optimum'.[49] Now analyses of the seabed and littoral of the Dead Sea confirm the climate there was actually quite a bit moister than of late through the first couple of centuries of the Christian era.[50] The obsessive interest shown by Cleopatra (69 to 30 BC) in the balsam resins from those shores lends anecdotal support.

Sicilian experience likewise points towards the conclusion that climate across the central Mediterranean did not pitch drastically in any direction compared with today. By 215 BC, Sicily was fully under Roman control. For the next several centuries, economic and strategic importance attached to its agricultural exports, above all of grain.[51] Its chief physical advantages were (a) accessible groundwater reserves in limestone and tufa bedrock and (b) the tolerable consistency of the winter half-year rains.[52] Much of the interior afforded excellent summer grazing for sheep. Meanwhile, the fabled Leontini district regularly yielded an eightfold return on seed corn.[53]

Sicily's fair fortune, then and sometimes since, has probably related to its lying close to a mid-winter atmospheric trough extending through Toulouse out to Beirut. Its axis marks the median track of cyclonic depressions. Along or just southwards of it will be the most intense part of what may be quite a narrow band of increased rainfall. Subtle shifts in the axial lie could be critical for certain local climates, not least Palestine's. However, the probability that, at least for some decades before the Jewish revolt, the Holy Land was somewhat moister than today seems confirmed by isotopic analysis of the timbers the Romans used to make assault ramparts at Masada, timbers very likely to have been locally hewn.[54] Much of this moistness will have come from depressions that started life as 'Genoa lows'.

Drawing on Roman literary sources (e.g. Pliny the Elder and Strabo) for such indications as the extension northwards of beech copses, vineyards and olive groves, Hubert Lamb concluded that the climate of the Mediterranean and of axial Europe started to warm prior to 100 BC. He further inferred that Europe was getting drier over this span though Africa (as per p. 77) and Egypt retained, through the first century AD, a relatively strong water cycle. This was due to a longer rainy season, but may have been underscored by drawing down groundwater. Lamb believed the main climate tendencies continued until AD 400 or thereabouts.[55]

The sea-level changes do indicate a net warming trend globally. But as with China so with Europe, that tells us little *ipso facto* about regional experience. Certainly Hubert Lamb's perspective is at variance with that of the classicists, French and English, of the eighteenth century. Their consensus was that, throughout the decline of Rome, central Europe was appreciably colder than even their own chilly times. Edward Gibbon told how winter freeze-ups of the Rhine and of the Danube had often afforded the barbarian armies 'a vast and solid bridge of ice' across which to deploy. He believed reindeer had flourished in the forests of Germany and Poland. He saw Europe then as akin to the Canada of his own day, seemingly much colder than Europe now; and he presumed this was due to more forest cover in both cases. The barbarians he saw as 'hardy children of the North' who 'scarcely felt' the 'severity of a winter campaign that chilled the courage of the Roman troops'.[56]

Two generations later, Dr Thomas Arnold (famous as the headmaster who shaped, at Rugby, the English public school system but ranking, too, as a classical historian) described the Alps as far colder and more snowy in the Hannibal era than in his own day.[57] Judgement on this point is made harder by our still being uncertain through which pass Hannibal's army entered Italy in 218 BC, thus to take the Romans utterly by surprise. But tree-ring and glacial data studied by the late Professor Neumann indicated that around that date median temperatures were, if anything, slightly milder than today's.[58] Maybe this facilitated Hannibal's transit, complete with his elephantine heavy cavalry. Maybe, too, it helps explain why the stone-piered bridge Trajan built (in AD 101–6) over the Danube near the Iron Gate survived 170 years before being wilfully destroyed by the Dacian Goths. Hubert Lamb surmised that it would have been wrecked by ice floes had winters not been getting warmer.[59] But that surmise begged several questions best resolved via computer modelling.

Still, the Gibbonian contention that Late Antiquity was a cold era across Europe gains tangential support from a UNESCO-sponsored study by Arie Issar, a leading Israeli hydrologist. He identifies the first AD and, less acutely, the fifth as cold centuries in the eastern Mediterranean.[60] If so, this could connote that the climatic zones were sectorally displaced, however irregularly, towards the equator. The blocking anticyclones characteristic of the Scandinavian winter could therefore have extended more often southwards then, thereby drawing in more dry easterlies that limited precipitation where they prevailed. Signs of glacial recession across Scandinavia itself during the first two centuries of the Christian era and again during the fifth and sixth square with this interpretation.[61]

It may correlate, too, with archaeological observation of farming practice in Denmark. Take the keeping of cattle in enclosed stalls much of the year. By the Early Iron Age (*c*. 500 BC) the balance of advantage had apparently shifted towards this labour-intensive routine by dint of the advent of iron scythes to assist fodder collection, but also because the climate had turned colder and wetter. Come the first five centuries of the Christian era, things were drier and, for much of that span, warmer. Yet, contrary to what one might expect, the stalls continued in service and 'seem to get larger'.[62] Frosty anticyclonic winters may help explain this.

A British pioneer of modern climate change studies, C.E.P. Brooks of the Meteorological Office Library, concluded in 1925 that, in the fourth and fifth centuries, 'many German settlements were established on low ground, now swampy.'[63] In other words, he felt the regime was a drier one than in the early twentieth century. That judgement can probably be seen as corroborative even allowing for weaknesses in Brooks's methodologies, especially as regards dating.

For the British Isles, a few clues about water levels in aquifers indicate, on balance, wettish conditions.[64] Significantly, too, only one Roman villa has so far been identified in the south-west peninsula, the Devon and Cornwall of today.[65] On the other hand, the way the many villas elsewhere are aligned does not point to undue concern with south-westerly gales.[66] These slender strands of proxy evidence can be harmonised one with another and also with Gibbon, Arnold, Brooks and, subject to qualification, Gumilëv. It can be done by postulating that in winter anticyclonic ridging over Scandinavia caused fronts to become slow-moving across Great Britain and Ireland.

Admittedly, materials about aridity in Late Antiquity are still very thin for western Europe. But in central Italy there are few indications of really wet years between AD 100 and 500, whereas there are a number of chronically low lake levels.[67] A recent lacustrine review reaffirms these University of Perugia findings for the Arno–Tiber sector. A cool and wet first century AD was succeeded by generally dry and warmish conditions to 550.[68]

Singularly indicative for the eastern basin may be a Lake Van that was usually high between the years 250 and 800.[69] Maybe this is where the analyses for Europe and the eastern Mediterranean can mesh tolerably well with that for what we have known as the European USSR. Quite likely winter storms were sometimes deflected by anticyclonic ridging not north but well south, one track being through the Aegean then to southward of the Caucasus.

Granted, our climatic knowledge of the Roman world is still insufficiently synoptic or definitive. Yet this may not currently be the main sticking point when trying to register the historical impact of climate change; rather, this is the plethora of parallel or alternative explanations for Rome's decline and fall spawned since Gibbon's time. These cover *inter alia* soil depletion; a gold and silver shortage; outdated military science; lead poisoning from cooking pots and water pipes; sloth and sinfulness; and, in the Fascist era, genetic pollution by inferior races.[70]

Any explanation is going to rest on multiple causes in one permutation or another. Lamb even visualised shortages of salt in the city of Rome itself being aggravated by ice melt. Supposedly, that connection was made by a rise in mean sea level (MSL) due to net warming globally. The sea might have overrun coastal salt pans constructed at a time of low MSL.[71] The time when construction mainly took place (the seventh to the eighth century BC) did witness a major low in the Mediterranean sea level.[72] The MSL was 1.5 to 2.5 metres lower than it would be in, say, the fifth century AD.

With respect, however, acute scepticism is in order. At its zenith, Rome and its back country may have consumed 10,000 tons of salt a year. But although by AD 100 the Empire had some 75 distinct producing localities, little or no long-distance trade developed.[73] That surely implies that the metropolitan area remained self-sufficient. And is this surprising? After all, new pans could not have been that hard to construct.

Among the more cogent reasons advanced for Roman decline is the spread of pestilence, consequent upon contact being made with infected populations further afield. In the first century BC, Italy was already quite pestilence-prone. As the Empire extended, the Mediterranean was *ipso facto* more exposed. In AD 165, troops returning from active service in Mesopotamia unwittingly introduced a cocktail of diseases (mainly a form of smallpox) that by the year 180 had killed off up to 30 per cent of the population in parts of the twin basin and spread as far as the Rhine. Emperor Marcus Aurelius was fatally struck down. In 190, there was a fresh eruption of this 'Galen plague' (so named by posterity after the great Greek physician at the imperial court from 162). Population decline, accentuated by renewed plague outbreaks, was widespread for centuries. In particular, there was from 250 to 266 the pandemic St Cyprian described. This 'plague of Cyprian', which extended from Egypt to Britain, was another macabre cocktail: probably bubonic plague aggravated by such diseases as meningitis and acute dysentery.[74]

Also by the first century AD, malaria had become endemic over much of Italy itself. In a seminal study all but a century ago, W.H.S. Jones attributed this to the emergence of a mosquito-friendly ecology: unstable rivers, poor ventilation and drainage in ordinary houses, and general dislocation through warfare – Hannibal's campaign, and then the civil war Caesar and Pompey precipitated.[75]

Agricultural output

Susceptibility to sickness, localised or pandemic, could be heightened by malnutrition, perhaps brought on by climate anomalies. Marginal in very many places as regards the water cycle, the Mediterranean as a whole was susceptible (as it still is) to climatic zonal shifts or, indeed, increased erraticism. Across the Empire general famines were rare, but food shortages locally were not. To feed Rome itself, the emperors mainly looked across the Mediterranean. For well over a century, its southern hinterland has been somewhere to study the encroachment on Roman ruins of desert margins.[76] The cardinal questions have been (a) when did 'desertification' start, and (b) how far was it due to climate change, not just to war or overpopulation or plain mismanagement? Was it originally contained by the extensive Roman recourse to 'dry farming'? – meaning, in particular, continual attention to the arable, when crop-bearing but also when fallow.

Throughout, one should remember the Romans used the word 'Africa' to connote, strictly speaking, just one of their nine provinces on that continent. This 'Africa Proconsularis' corresponded closely to the Tunisia of today. Sometimes, however, 'Africa' was used more loosely to cover all the Maghreb plus the province of Cyrenaica, though not the four in the Nile valley.[77] Throughout this chapter that is the rendering employed.

Overall, the climate of Africa in the heyday of empire does seem to have been akin to what has obtained there of late.[78,79] Then as now, cereal production generally relied on 400 to 500 mm of rain distributed fairly evenly from September to May. In that fickle environment, however, the rainy season might shorten by several weeks at either end in a given year. The rainfall total could likewise be volatile, while the resultant problem of water access was often aggravated by thin soil and very deep strata of porous bedrock.[80]

The two biggest sources of corn for metropolitan Rome were Africa and Egypt, and, from AD 100 or so, Africa was the more important.[81] The export of corn (and also, from Africa, of much olive oil and timber) was facilitated, as in other situations historically, by an increasing polarisation across society of economic power. Africa's being the legatee of Carthage made this syndrome the more acute.[82] It set the scene for singularly tight and long-lasting imperial control over that particular nexus in the corn trade.[83]

In Egypt, a slow secular sinking of the Nile delta caused the outflow across it to be concentrated more in the central distributaries. On the other hand, there may also have been an underlying tendency, across the millennium from 500 BC to AD 500, for the Mediterranean near littoral (i.e. to 50 or 60 km inland) to turn moister as the broad zone of winter rain edged in from the north.[84] But on the all-important question of the Nile flood, we lack reliable data for these centuries. In any case, come the fourth, Egypt's corn trade started to divert from Rome to a burgeoning Constantinople.

Human folly?

Especially stark in the case of Africa is the 'apparent contrast between the extensive and impressive ruins of the Roman period, both cities and large rural villas, and the desolation of the countryside about them.'[85] The amphitheatre of El Djem, with seats for 60,000 people, now stands well and truly in the desert with but a few tiny settlements nearby. The Roman city of Timgad was abandoned *c.* AD 250. Beside its ruins is the channel of a now vanished river. Another city, Leptis Magna, is now an arid ruin near modern Tripoli. The birthplace of Severus, it was built up inordinately during his dynasty (to AD 235). Then it declined dramatically.[86] Yet there was also ecological continuity. In fact, a lot of primal deforestation has occurred only this last century or two. Those moisture-loving big cats, panthers and lions, still roamed wild in the Algeria of a hundred years ago. Roman deep wells have been used there in modern times.

All the same, there is no denying Africa had its share of the violent instability that racked the Roman Empire in a critical third century. It was in Africa that the revolt started which put the Gordians, father and son, briefly on a co-imperial throne in AD 238, ushering in several decades of unrest and pestilence. Yet in the fourth century, and even the fifth, the African situation was tolerably equable overall. The religious and cultural renaissance the sin-obsessed Tertullian and his more benign disciple St Cyprian had led in the early third century was followed through by the mighty St Augustine (354–430). True, some 80,000 Vandals landed in 429 and rapidly took the region over, Augustine himself dying during their siege of Hippo. However, the notion that they visited upon Africa boundless mayhem has now been discounted. Rather, these provinces became a very solid base from which the Vandal regime (nominally a Roman fief) harassed the rest of the western basin, Rome itself being plundered in 455. Vandal belligerence diminished with the death of their leader, Gaiseric, in 477, though their power was not finally broken (by the Byzantine general, Belisarius) until 533. That sequence is compatible with the notion that Africa's climate was still warmish and moist in the fifth century, by which time axial Europe had likely turned ominously cold and droughty.

As Rostovtzeff intimated, however, one gets a more pervasive sense of progressive decline from Roman Egypt. He was almost certainly right to exclude long-term soil exhaustion as a factor dragging down this Nilotic 'hydraulic civilisation'. On the other hand, the tight control exerted over the *fellahin*'s working life by exceptionally rigorous *étatisme* may indirectly have encouraged too rapid a population growth when harvests were good. Josiah Russell wrote of a population peak of 4.5 million in AD 100, a total he read as being a tenth of the population of the whole Empire as it approached its zenith.[87] In AD 99, a large quantity of corn exported from Egypt to Rome had to be sent back when starvation threatened the Nile valley in the wake of a poor flood. What must likely wait upon a better understanding of ENSO teleconnections in that era, however, is a definitive profile of secular trends in this regard. As things have thus far stood, even the resourceful Justin Schove felt able to identify but three short intervals as especially prone to weak floods: AD 53 to 63, 151 to 160, and 254 to 265. The 'plague of Cyprian' was closely concurrent with the last.[88]

In the second century, the Galen plague carried off perhaps a third of all Egyptians. Further instability culminated in the virtual destruction in 391 of the libraries of Alexandria, arguably the greatest collective wonder of the ancient world. Then in the fifth century, Egypt experienced a dramatic revival. There was an expansion of maybe a fifth in the cultivated area. Once again, too, there was overweening population growth. But the calculations thereof have varied chaotically. Hollingsworth's estimate has been that Egypt's population rose from a low of 7.5 million in AD 75 to a high around 30 million in 541.[89] That has to be a big overshoot. Russell has argued cogently for 3.6 million.[90]

It will suffice to make a preliminary judgement about the Nile floods, then, working from the premise that a strong summer monsoon over north India generally means plenty of rain in the Ethiopian highlands and so a good flood peak in Cairo that September. Under Chandragupta II (reigned *c.* 380 to *c.* 414), the Gupta Empire across north India excelled across the board: territorially, economically, culturally. . . . Witness the links with China mentioned below. Such prowess could not have been guaranteed by a lot of strong monsoons in, say, the century from 370. But it could have been precluded by many weak ones. After 470 or thereabouts, the Gupta Empire sharply declined in the face of the White Huns.

An urban-led crisis

To a considerable extent, the decline of the Empire is expressed in the travails of Rome itself. At its peak, the metropolis numbered perhaps a million free people plus 150,000 slaves. But it was always riven with tension. Emperor Augustus (reigned 28 BC to AD 14) claimed he had found a city of brick and left one of marble. But for all the brilliant engineering and all the emperor's extraordinary aplomb, this transformation impacted too little on the squalid lifestyle of the overcrowded poor. To the freeman majority within this underclass, Augustus offered *panem et circenses* as basic palliatives. But in the ensuing centuries, the arena spectaculars became ever more grotesque, more so in Rome than anywhere. There was massive sacrifice, for sadistic pleasure, of animals largely from Africa and slaves or prisoners from anywhere. If the Romans eventually lost pride and confidence in their imperial mission, such ghoulish celebration of it may have been a reason.

Granted, in Rome at least, the circus acquired another, somewhat more edified, function. In the absence of representative institutions, it was the recognised setting for clamorous protest direct to the emperor about current grievances. Yet this outlet did not preclude street demonstrations and riots, least of all when food shortages or some specific injustice had wound opinion up. In the third century, such events were endemic. During the imperial crisis of AD 238, indeed, a metropolitan civil war raged for several days with much death and destruction. In the fourth century, things worsened further, especially in the wake of Emperor Constantine's savage purge (*c.* AD 325) of the city's internal security.[91] In 330, he founded Constantinople to be the new capital.

During the third century, however, cities had plunged into crisis more or less throughout the Empire. That crisis can further be defined in philosophic terms. In the second century, the influence of sundry oriental cults had spread, notably among underprivileged urban dwellers. Then in the third, one of them – Christianity – had mushroomed remarkably. From the outset, it had singularly combined the hope of salvation in the next world with a concern for social justice in this. One earthly contradiction for it to grapple with was an accelerating polarisation of wealth, as reflected in conspicuous consumption, in and around the cities.[92]

Since the reign of Hadrian (AD 117–38), barbarians had periodically been invited to settle in the countryside to offset the drift to the cities: a drift induced by a mix of factors, putatively including chronic soil exhaustion.[93] Yet even allowing for urban industry, Roman cities appear heavily parasitic on the rest of the economy. If, like Edward Gibbon, one finds the attitude of their better-off to civic and military obligations too ambiguous, that domineering dependency will seem still more stark.[94]

The aqueduct (see Figure 3.1) was the ultimate expression of urban dependency as well as of Etruscan then Roman virtuosity. By AD 52 the network round Rome was all but complete, over 400 km in length of which 80 to 90 per cent was underground. About 150 aqueducts were eventually built in other parts of the Empire.[95]

Had they been more compact and solid hives of industry, the cities would still have been susceptible to trade disruptions by war or whatever. But such consolidation might have given each and every one more of a sense of identity and hence resolve to survive. Gibbon is caustic about how supine the citizenry even of Rome itself proved, in spite of the looming barbarian menace: 'the stately libraries and halls became useless to an indolent generation whose repose was seldom disturbed either by study or business.'[96]

Yet Roman Britain never seemed more 'happy and prosperous' than during the first three-quarters of the fourth century.[97] From there to Egypt, in fact, that time was perceived by contemporaries as *reparatio saeculi*, an 'age of restoration'. By many criteria, it was such – nowhere more so than within the cities of the Greek East. Some became veritable nodes of graciousness. Moreover, their commitment to imperial institutions remained stronger than was usual in the Western Empire. That situation was paradoxical in relation to Gibbon's thoughts on the part Christianity played in the Empire's decline and fall. Not that these thoughts hang well together. He was too uncertain whether to object to the Church militant or the Church otherworldly. His concern to distance himself no less visibly from the Voltairean atheists waxed too obsessive. Even so, he made enough allusions to subversive Christian proclivities to lead one to expect the Roman Empire to cave in first where that religion had sunk its roots deepest, around the eastern Mediterranean. That is not what happened. Peter Brown looks on stronger ground when he describes the Greek East as more resilient, thanks to greater economic sophistication with a less uneven spread of income and power.[98] Yet that is not unconnected with its coming less under barbarian pressure. Nor may it be with climatic tendencies. From the third century, Anatolia was satisfactorily moist whereas much of the Mediterranean was turning drier. On that argument, cities were in difficulties because their agrarian hinterlands were.

Not that a contrast in fortunes can neatly be drawn. In the 250s, more or less the entire Roman frontier from the Black Sea to the North Sea had collapsed as Visigoths, Alamanni and Franks surged across. In the 260s, the well-fortified Levant sector had likewise buckled and broken in the face of attack first from Persia and then from Palmyra – a quasi-autonomous city kingdom at the Syrian end of the comparatively 'fertile crescent' of steppe arching round into Mesopotamia. Palmyra's troops even reached Egypt. Not for several years were the imperial frontiers restored.

In general, however, the Empire in Asia Minor, the Levant and Egypt was shielded by the other settled kingdoms to eastward. This left Emperor Constantine (306–37) that much freer to build up the city to which he had given his name, not least to make it impregnable to assault from the north. Maybe its battlements inhibited the tribesmen from spilling across those straits, the way all those Vandals were to infiltrate in small boats across the Straits of Gibraltar a century later. In any case, neither the Anatolian plateau nor the Levant would have been as attractive as, say, Italy, Spain or even Roman Africa to nomads from the North European Plain.

The barbarian triumph

Whenever the barbarians put the pressure on, they much accentuated the imperial crisis, not least by consuming the attention of the emperors. The toleration – the 'Little Peace of the Church' – that Christianity found itself blessed by, so suddenly yet emphatically, from 260

Figure 3.1 Pont du Gard, famous Roman aqueduct in the lower Rhône valley, France
Source: courtesy of AKG Photo, London

to 302 owed much to official preoccupation with the frontiers.[99] One may therefore accent this authoritative but overly restrained 1964 judgement: 'the simple but rather unfashionable view that the barbarians played a considerable part in the decline and fall of the empire may have some truth in it.'[100]

So how far did the ebb and flow of barbarian pressure correlate with climate trends? On a year-by-year basis, we remain ill-equipped to respond. But in so far as anyone dare talk century by century, statements more refined than those of the Huntington–Brooks era can now be made. A measure of consensus has emerged that, across the lands out of which the tribes descended, the third century, and more so the fifth, was droughty. That matches well enough Rome's sequence of decline: the first major crisis in the third, a promising recovery in the fourth, then a complete collapse of the Empire in the West in the fifth. Yet however neatly these templates appear to fit, they do not obviate a need to gauge the impact of climate trends in relation to that of other causes: social and economic change within the Empire, its military posture, its military and political leadership . . . .

As the third century dawned, the military threat to the Empire was already looming. Your average Roman legionary was sometimes of measurably smaller build than his barbarian antagonists, 150 mm shorter than the Dacians for instance. But he was much better armed, armoured, trained and organised. One utterly basic advantage was that his army was not so desperately short of iron.[101] However, there were long and complicated fronts to defend with an army that amounted to well under one per cent of the population of the Empire. In Britain, the only land frontier to guard was that along Hadrian's Wall, a mere 120 km. Even so, the British garrison was built around three or four legions of some 5,000 men apiece. But just from the North Sea to the Black Sea, the frontier was 18,000 km in extent in the reign of Emperor Severus. The basic order of battle of the whole Roman army then was a mere 33 legions. So a 1,000 km front per legion deployed forward? It sounds hopeless.

Nor could the creation of stronger strategic reserves have resolved the overstretch problem. For one thing, the fractured geography of the Empire would have severely hampered their reactive deployment.[102] So would the fact that, as viewed from Rome, the North Sea–Black Sea frontier was essentially concave, forcing the Roman strategists to deploy on 'exterior lines', as their eighteenth-century neo-classical disciples would have said. Nor would a *masse de manoeuvre* have been, even at the tactical level, a defensive response appropriate to the kind of threat the barbarians posed best – a broad frontal surge in the form of a mêlée of guerrilla actions. A tempting analogy is with the final Maoist offensive in China, 1948–9.

Allowance must also be made for no rivers in axial Europe being as formidable an obstacle to barbarian forces as might be assumed; and, indeed, for their proving less so in the context of any trend towards either cold or drought. Throughout pre-modern times, even the Rhine and the Danube were braided extensively by sandbanks and islands. Ammianus Marcellinus, an intelligence officer in the fourth-century imperial army, cites two specific occasions when the Rhine proved fordable. One, near Angst, was actually during the spring, the meltwater season. Besides, the tribes were adept with watercraft and sometimes used Roman prisoners to build simple bridges. Many times, too, they availed themselves of winter freeze-ups.[103]

In the decades following Severus, the Roman army distracted itself by factional support for one aspirant to the throne or another, the 'barrack emperor' phase. One could regard that as enough to explain the near collapse of the frontiers just after mid-century. No need to invoke climate change. Entirely remarkable, however, is Rome's strategic recovery, particularly during the reign of Aurelian (270–5). Brilliant counter-offensives were launched. The army's strength was raised from 250,000 to perhaps half a million. Its cavalry proportion was increased somewhat and military politicking curbed. The tribes were bought off with either money or territory to a greater extent than ever.

In prospering though restless Britain, the defences of the south-east coast ('the Saxon shore') were soon to be much strengthened. Early in the century forts had been built at Reculver and Brancaster. In its last decade (290–9), ten or more were constructed from the Wash round to Southampton Water. At the same time, a fleet was built to rule the Narrow Seas.

This late third-century turnaround was a remarkable expression of the underlying resilience of the imperial regime. It set the scene for *reparatio saeculi*. Moreover, an easing of barbarian pressure by dint of a transitory climate improvement may well have contributed to this consolidation. But so, too, did a *volte-face* in the relationship between Christianity and the state. Constantine experienced Christian revelation on the field of battle in 312. He then promoted his new-found faith as the Empire's established religion in all but name, leaving it free to launch wave after wave of coercive conversion. This elevated profile did nothing for the principled concern of the early Church for the underdog, the end of war and suchlike causes. Nor did it help the position within it of women. What it did do was turn Christianity into a powerful agent for social cohesion, especially in the East.

The geopolitical stability of the early fourth century was bolstered as the tribes beyond the frontier came to share more of the evolving Roman lifestyle. As the Visigoths in the Danube basin turned towards Christianity, they acquired an alphabet to help them imbibe the biblical message. Meanwhile, their political and social structure was becoming more monarchical. Beyond them, the Ostrogoths, spread from the Pripet Marshes to the Black Sea, were turning more to farming.

Now began the final race against time. Yale Professor Ramsay MacMullen (incidentally, a sceptic about climate change as a factor in Rome's decline) notes how violence against non-Christian sects, already endemic in the more exposed provinces to the north and north-east, was decisively more prevalent from 380.[104] It betokened deepening insecurity as barbarian pressure resumed. The main driving force behind resumption was ultimately to be the Huns. But in 367 the Romans in Britain had been thrown off-balance by concerted offensives by a ring of enemies from Ireland to Scotland to the Low Countries. Morale on Hadrian's Wall sagged. Bands of deserters and of barbarian tribesmen roamed as far as the Thames valley. Yet once again, an impossible situation was expeditiously restored. Then in 383, a disaffected Magnus Maximus took a large part of the field army in Britain across to Gaul to usurp for five years the Empire in the West. This was the beginning of the end for that army. Its last units left Britain in 410, the same year the Visigoth king, Alaric, sacked Rome itself.

By 372, if not a decade or two earlier, the Huns had crossed the Volga in enough strength to confront the warlike Alani in the Don basin. That *démarche* cannot be explained in terms of the vaunting ambition of some heroic leader. Not until 434 did Attila, quite their most legendary figure, become even co-ruler. Once the Alani had been ethnically cleansed or subdued, the Huns began to harass the Ostrogoths and Visigoths. In 376, Valens, the emperor in the East (364–78), allowed the 200,000 Visigoth fugitives to cross the Danube into Roman territory, hoping thereby to win them as allies. Their treatment at the hands of venal and stupid officials made them instant dissidents instead.

The upshot was that, in sweltering August heat in AD 378, an all-too-confident Valens led 60,000 legionaries, his theatre reserve, against the Visigoths deployed about their huge wagon laager at Adrianople in northern Thrace. His men probably outnumbered the Goth fighters. They themselves fought as stoutly as ever. But the emperor's battle management was inept. He died and over half his troops were killed or captured in Rome's worst battlefield defeat since Cannae, almost 600 years earlier.[105]

Adrianople is a dramatic instance of a broad tendency being sharply accelerated by a specific event. The outcome bucked a recent tendency for the Romans to prevail in pitched battles.[106] It did so because an emperor in the field was inadequate on the day, but also unlucky. His men were too heavily accoutred for a spell of hot weather that does seem to have been very abnormal. Ineluctably this defeat will have hastened Rome's demise. That does not mean a victory would have precluded it.

Structural explanations

Therefore, one still seeks structural explanations for the fifth-century demise of the Western Empire, its last recognised emperor, Romulus Augustulus, being deposed by German Goths in 476. Evidently, the term 'structural' can embrace many possibilities, some quite remote thematically from matters ecological. Within its ambit can come military organisation.

Through the last century, military history was much under the sway of mobility buffs. Accordingly, the received notion was that the foot soldiers in the Roman legions were overwhelmed by mounted barbarian hordes in the flattish valley in which Adrianople was fought. On each side cavalry did assume ancillary prominence that day.[107] But the battle never resolved itself into an encounter between the 'powerful mounted forces' of the Goths[108] and the legionary Roman infantry, whatever cavalry apostles say.

In fact, as E.A. Thompson showed in 1958, the Germanic peoples never relied much on horse, a salient exception being some who by the sixth century were established amidst Mediterranean affluence.[109] Ten years beforehand Thompson himself had assumed the Huns 'all but lived on horseback'.[110] But subsequent research had found little sign of that customary image being validated in actual battle. In fact, it is doubtful how feasible it would have been for them to maintain adequate horsed armies as they extended into the intricate topography and diverse vegetation of Germany and Danubia. Even the Hungarian plain has been adjudged able to support only 15,000 cavalry, allowing for other pastoral needs.[111] Therefore one cannot say the Roman Empire fell apart because it neglected *l'arme blanche*. But its sorry plight in the decades after Adrianople points to structural weakness elsewhere. Ever since the reign of Diocletian (284–305), a standard response to the barbarian threat had been to split the Empire into several blocs, each under its own caesar. On the death of Emperor Theodosius in 395, the Eastern and Western Empires were formally separated along the Theodosius line – still the eastern boundary of Croatia. Illyria became a borderland in contention.

Henceforward Constantinople was under no formal obligation to aid Rome or, of course, vice versa. Nevertheless Flavius Stilicho, the Roman of Vandal ancestry who had been chief general to Theodosius, worked from a similar position in the West to forge anew a common West–East strategy of containment. But hamstrung by intrigue on all sides, he was unable to curb Alaric, king of the Visigoths. The latter switched his loyalties between the West and the East as well as between each of them and his own unilateral aims.

History has often condemned Stilicho for vacillation. Yet to judge from the atmosphere of paranoia and deceit that surrounded his execution in 408 for alleged treason, he had few options. A Julius Caesar, Hannibal, Wellington or Eisenhower might have fared no better. The Western Empire was by then deeply flawed, and even the Eastern Empire was strong only in relative terms. In 410, there was Alaric's sacking of Rome. Three years earlier, the

Huns had again crossed the Danube. Rome was to be sacked again in 455, this time by Gaiseric – the Vandal and Alani chieftain.

The Hunnish empire, as built up briefly by Attila (d. 453), covered 750,000 square miles from the Rhine to the Caucasus and therefore would have embraced some 5–10 million people. Though this population may only have been 10–20 per cent of that under Rome and Constantinople, it lent itself far better to military mobilisation, at any rate for short bursts of offensive action. It remained very multiethnic as, indeed, did the armies it fielded. Even so, it is permissible to infer that the Huns themselves were considerably more numerous than the presumed forebears who had turned westwards from the Tien Shan three centuries before. For most of a largely balmy fourth century, they will have grazed extensive steppe lands east of the Volga with rainfall averages then between 300 and 600 mm per year. One can imagine the numbers of animals and people rising steadily, only to stand the more exposed to a secular reversion to worse aridity and cold after 370, say. No doubt, too, Malthusian pressure would have been aggravated in this situation, as in so many similar, by ecological degradation caused by overgrazing against a background of droughtiness. The natural impact reinforced the human and vice versa.

One has to bear in mind, too, the obverse side of the reality that the tribes the Huns were liable to impel westwards were more sophisticated in structure and culture than a century or so before: more confederal, more hierarchical, more apprised of Roman skills. That convergence may have made them less inclined to war with Rome. But it could also make them able to wage war more cogently if they felt obliged to. By the fifth century (i.e. 372–476), the latter consequence was uppermost. Now interaction was continuous between the Empire's internal weaknesses and the external pressures it was subject to.[112]

Some consideration is given in Chapter 10 as to whether the sequence of Hunnish depredations in the late fourth century to early fifth lends itself to interpretation in terms of our modern knowledge of drought cycles in the south Russian/Ukrainian sectors. But the sharp decline of the Huns in Europe after Attila's death left other tribal groupings more freedom of action. Among them were the denizens of the Gothic heartland defined, from the first-century AD, by the Wielbark culture in Pomerania and the Vistula basin. In the interim, their population had continually risen as the low-intensity agriculture they practised on land with poor natural drainage benefited from the generally diminished rainfall. Accordingly, they regularly sent migratory war bands south and south-east. Come the fifth century, Gothic social and military organisation was well developed.[113] No doubt, too, the reversion to wetter conditions noted above will have precipitated an agrarian crisis in the old heartland just defined. Henceforward expansion from it took place in more or less all directions.[114] The *Völkerwanderung* was ramifying.

In assessing how far the Empire was compromised by internal climate change, one has to bear in mind how the pattern varied over time and from place to place. Take Mediterranean seafaring. A study of materials from the western basin concerning over 500 shipwrecks, between 450 BC and AD 450, shows a strong peak in the first century AD with the rate falling 75 to 80 per cent by the fourth to fifth. At first sight, this reflects a waning of commerce against the background of imperial decline. But improved navigational skills and facilities (e.g. the installation of more lighthouses) will have reduced the attrition rate progressively. Besides which, that early first-century peaking largely results from exceptional losses near the mouth of the Rhône and through the Ligurian Sea.[115] In a cool and moist first century, gales would *ipso facto* have been more prevalent, especially with the Rhône mistral and the Genoa lows (see Chapter 2). So what was then a vigorous export trade in wine from south Italy to France would have exposed many ships to danger. If that trade was diminishing by AD 100, physical hazard will have been one reason. But soon the climate would turn calmer in those waters.

A metropolitan obsession?

Most localities across the Empire will have been ecologically marginal in one respect or another at various times. On the other hand, the imperium as a whole will have been made progressively more resilient by the generation of a robust infrastructure, assisted by the development by the second century AD of a lime-based cement. Its roads and ports remain potent symbols of skill and determination. So do the aqueducts – to Gibbon, 'the noblest expression of Roman genius and power'. But why did local food shortages so readily develop? Part of the answer must be that, notwithstanding the strategic concern to safeguard grain supplies to Rome itself, the provision of staple foods elsewhere was largely left to city oligarchies given over to their indulgent interpretations of what the *res publica* was about.[116]

Nor does the contrast between Rome and all other cities and towns stop there. Until Constantinople emerged in the fourth century, Rome was favoured more singularly than most capitals have historically been. Moreover Constantinople was a stark example of the exception that proves the rule. It was similarly privileged, grew similarly large and assumed a similar role. It was never more than partially successful in engendering a universal sense of imperial identity, *cives Romanus sum*. It remains a moot point whether another overweening metropolis itself was on balance an asset in terms of containment strategy. Not if Gibbon was right about urban mightiness leading to a 'leakage of reality' (see Chapter 4).

At all events, the rather ill-cast endeavour to stabilise Rome through civil expenditure, as indicated above, had long undermined a proper securing of the imperial borders. As early as the reign of Augustus, a conflict of fiscal priorities became acute, despite a shift in geo-political emphasis from expansion to retrenchment. Sound enough in itself, the shift was accompanied by undue curtailment of military strength. After losing two legions in an offensive into Germany in AD 9, Augustus failed to raise replacements even though 'forty years before, the Roman world had supported three times the number of legions then in being.'[117] Instead he lavished resources on civil infrastructure, a precedent others followed.

Granted, quite a proportion of this expenditure took place outside Rome. Furthermore, quite a bit of that (e.g. allocations to trunk roads, bridges[118] and postal facilities) had military utility. Nevertheless, the metropolis itself received privileged treatment, the aim being to head off the mob unrest always latent there.[119] In no sector was imbalanced appropriation more blatant than in the provision made for the supply of water. The capacity flow to metropolitan Rome at its imperial zenith has been put at 600 litres (*c.* 130 gallons) per head per day, about five times as much as Londoners currently consume.[120] Still, average inflow will have been a very minor fraction of that.

What is unclear is how equitably the water was distributed.[121] Manifestly, it was not sufficiently so as to assuage social tension, any more than the welfare handouts were. All in all, the distribution of income became less equal over time. Come the fourth century, the annual income of a Roman senator could be as much as 120,000 gold pieces; of a court official at Constantinople, 1,000; of a town merchant, only 200; and of a peasant, five pieces. Retrogressive taxation was a prime cause of this polarisation. Thus, the 'land tax had trebled within living memory by 350.'[122]

The negative effect of financial stringency on imperial defence likewise became more acute over time. Niggardliness undermined military morale, cohesion and professionalism in manifold ways. The willingness of young Romans to serve as soldiers an Empire 'too big to stimulate devotion' diminished still further,[123] a signal aspect of the syndrome of self-concern Gibbon was to wax scornful about.[124] All this encouraged reliance on barbarian support. Nor was it just a matter of offers of land inside the frontier. It also meant recruiting many barbarians into the legions; paying bounties to chieftains to keep the peace; and, as time went by, persuading some of them to be overt allies. By the start of the fourth century, reliance on this barbarian involvement was considerable. Towards its end, under Theodosius, it turned desperate. The more Rome needed to look to its own resources, the less it felt able to. At least in the Greek East, the rural social structure and the military geography allowed of greater reliance, as of the fifth century, on local peasant levies; and that is customarily understood to have been a good thing. Up to a point, it was.

A Eurasian dimension

An analysis against which hypotheses of climate determinism can usefully be tested is a 'world system' one conducted by Andre Gunder Frank of the University of Amsterdam and Barry Gills of the University of Newcastle. Their 'theoretical approach' is broadly Marxian. Its gist is that the 'fundamental cyclical rhythms and secular trends of the world system should be recognised as having existed for some 5000 years, rather than the 500 years . . . conventional in other world-system and long-wave approaches. . . . Our focus is upon accumulation . . . as continuous but cyclical over several thousand years.' In a cyclical down phase, 'there is usually . . . a series of social and political conflicts and wars related to this contraction and hegemonic disintegration. . . . Nonetheless we do find the development of some hegemonic powers also in an otherwise generalized down phase.' Indeed, such 'out-of-phase' behaviour is crucial to the development thus of the 'world-historical rhythm, the world-system cycle'.[125]

In particular, the period AD 150 to 500 is identified as a down phase throughout Eurasia, with the fourth and fifth centuries being times of especially acute contraction. The nub of the argument is that 'first the rise and then the decline of Han China (and their Central Asian Hsiung-nu neighbours), Kushan India, Parthian Persia and western Imperial Rome occurred at very much the same time.' There was 'a notable simultaneous decline of Central Asian and maritime trade among them.'[126]

Stimulating though so synoptic an overview is, difficulties are evident. How well do the facts fit? The Han Empire ended 250 years earlier than did the Roman. It makes little sense to cite Kushan India but not its brilliant Gupta successor. And what of the irregularity of the 'rhythms' identified? Seven complete ones are identified as between 1400 BC and AD 1450, some 400 years on average. But the shortest (550 to 350 BC) is under half that while the longest (AD 150 to 800) is nearly double. That irregularity must cast doubt on internal mechanics, thereby inviting one to look for extrinsic causes that may be manifest more randomly. Maybe, too, the Gunder Frank–Gills thesis overly stresses the importance, in pre-modern times, of trade between imperial hegemonies. Nor, in any case, is any explanation adduced for the recurrent interdiction of trade routes by bellicose barbarians and associated onslaughts on the hegemonies themselves. Was there a dynamic connection between, for instance, the Black Huns advancing across the Volga in 372 and the White Huns overthrowing the Gupta Empire a century later? May not climate stress be a common factor here and elsewhere? Have Gunder Frank and Gills been right to discount it *a priori* the way they have seemed to?[127]

China and Europe compared

The putative commonality of the Hun factor underlines the case for drawing comparisons with China. What is striking about it is the thoroughness with which the precept of imperial rule was applied so early on, and its resilience in subsequent centuries. Albert Kolb claimed that there is 'scarcely a parallel in the whole of history for the achievements' of the Qin dynasty, notably as regards the standardisation of everything from script to cart axles.[128] That extreme *étatisme* was consolidated under the Han (206 BC to AD 220).

In AD 2, the year of the first census for which we have textual evidence, the Han writ extended, loosely at least, over territory closely coincident with what has been known in modern times as China proper. But the ethnic Chinese were still concentrated heavily on the north China alluvial plain). Water management there and, maybe prior to that, in the loess valleys of the upper Yellow River basin was a major motive for imperial hegemony. There is no doubt that, by the year 1000, Chinese civilisation was to be much more hydraulic than ever the Roman had been. Partly for this reason, though also because its physical geography was far less fragmented, it could sustain social and administrative unity that much more readily. A glance at the line of China's coast as compared with that of Europe's suffices to confirm this.

With its more homogeneous culture, the Han Empire never relied on slavery as much as did the Roman as a nexus for social control. That alone must have given China more resilience in the face of alien threats. An ability to thwart or absorb such threats has been a salient attribute ever since.

By AD 160, weak imperial rule coupled with tribal incursions on the north-west frontier had undermined Han control. Soon a wave of agrarian unrest was to culminate in the religious uprising of the Yellow Turbans, which engulfed the country from 184. Well before the Han dynasty finally ended in 220, effective power had passed to regional warlords, the scene thus being set for the subsequent division of the Empire into three separate states. This transitional phase has the hallmarks of being shaped by climatic adversity. Though the data to test this thoroughly are lacking, the preliminary indications point to undue aridity in the Yellow River basin.

But a much bigger crisis broke in north China in the desperately droughty fourth century. Early on, the remaining Hsiung-nu nomads surged across the Great Wall to establish a state in Shansi-Shensi. In 311 and 316 respectively, they sacked Loyang and Ch'ang-an (Sian), the two customary capitals near the middle reaches of the Yellow River. Meanwhile, tribes from Mongolia and the Manchurian plain were similarly active. The result was that north China became subject to a succession of short-lived dynasties, headed by families with barbarian backgrounds. In the resultant confusion, the region experienced not only much destruction and loss of life but also the southward emigration of many of its inhabitants. But from 386 to 534, unity and stability were reimposed by the Toba (northern) Wei, a Turkic people from Manchuria. They achieved this through land redistribution as droughtiness diminished, and also by becoming heavily sinicised themselves.

A key to the balance of advantage on the Mongolian front will have been the perennial fluctuations of the Gobi Desert. Even a small encroachment of the sands could make the nomads desperate enough to attack, though a deeper one might leave them too weak to do so. The grassy plains of Manchuria were a wider nomad base.

Still, although their fourth century was especially grim, the Chinese were ultimately to preserve through the erstwhile 'Dark Ages' more continuity than did Roman Europe. Their political geography was never completely torn asunder. Cultural development likewise proceeded more smoothly. Taoism had first emerged indigenously *c.* 250 BC; and Buddhism had arrived on the trade routes from India in the first century AD. In the fifth and sixth centuries, both were to flourish in interaction with each other in philosophy and art. Meanwhile, the communication of Indian advances in fields like medicine, mathematics and astronomy helped lay the foundations for great scientific and cultural progress as China became reunited once more under the Sui dynasty (581 to 618) and then the Tang (618 to 907).

Karl Wittfogel characterised the Roman Empire as a 'loose' hydraulic society in contrast to the 'compact' hydraulic societies of the ancient Near East. He attributed this to the latter having defined core areas whereas the former did not.[129] But one of these Near East centres of compaction – namely, Egypt – was long under the *Pax Romana*. By hallowed dynastic tradition, however, operational decisions on irrigation management were taken locally in Egypt, not centrally.[130] The Roman emphasis on well digging within the province was compatible with this.

The moral would appear to be that the disparate geography of the Roman realm accentuated the impact of any ambient variables, climate included. The first century or two of the Christian era were cool and wet across much of the Mediterranean. Then, by early in the third century when this narrative begins, things are warmer there. But they are turning a bit too dry across much of the twin basin and also of axial Europe. Anatolia appears to have been an important exception to this trend. Egypt was not, despite the singularity of its water cycle. By the fifth century, a tendency towards higher pressure over Scandinavia was driving a stronger aridity trend there and across much of axial Europe. It would appear, however, that the southern Mediterranean had an agreeably moist fifth century. So did Anatolia and probably the Levant.

In the final analysis, however, decadal drought clusters may be as significant as those century by century (see Chapter 9). Besides, when reckoning the impact of drought on, say, pasturage in and around Europe or in and around north China, one must not neglect altogether other climatic factors. Temperature variations can be important in their own right. Then of great consequence in Mongolia at least will be the likely frequency and strength of dust-laden winds. For China and its borderlands, we need more climate data on these centuries. Yet that applies the more to Europe and its environs. More scientific fieldwork, in particular, is both feasible and needful for the first half of the first Christian millennium. This especially applies apropos drought cycles in eastern Europe and migratory rainfall patterns in the Mediterranean.

4 Antiquity melds

Historians have moved well beyond the preconception that the Empire in the West collapsed into brutish and destructive anarchy. At the heart of the reappraisal has been demography. How much did population fall? How far was this fall directly due to armed violence as opposed to generalised disruption and disease? How far did climate flux, secular or temporary, exacerbate famines and epidemics? When did Europe's climate start to move towards the 'little climatic optimum' that was closely conjoint with the High Middle Ages?

The ruin of Britain

Received wisdom once said the population of Roman Britain reached somewhere between two and six million; and that, whatever the actual total, it had almost halved by the year 650. Writing in 1973, however, Leslie Alcock, Professor of Archaeology at the University of Glasgow, gave the *c.* AD 200 peak as 'at least a million' while still perceiving a steep decline by the fifth century.[1] In 1985, Josiah Russell put the figure for AD 350 as low as 300,000.[2] Now the post-Roman demographic decline is under continual review, albeit with information that is still patchy and confusing.[3]

Sometimes it looks plain contradictory. Take Gildas, a sixth-century Romano-British monk who apparently resided in the south-west peninsula or Wales and who was steeped in the Graeco-Roman classics. His overriding concern was with the divine wrath any society could face that failed to respond morally to the beneficence of God. In his tract *De Excidio Britanniae* ('The Ruin of Britain'), the historical section starts with a sweet account of the possibilities inherent in his native land:

> Poised in the divine scales that (we are told) weigh the whole Earth, it stretches from the south-west towards the northern pole. It has a length of 800 miles . . . . It is fortified on all sides by a vast and more or less uncrossable ring of sea apart from the straits on the south where one can cross to Belgic Gaul, but it has the benefit of the estuaries of a number of streams, and especially two splendid rivers, the Thames and the Severn . . . . It is ornamented with 28 cities and a number of castles, and well-equipped with fortifications – walls, castellated towers, gates and homes, whose sturdily built roofs rear menacingly skyward. Like a chosen bride arrayed in a variety of jewellery, the island is decorated with wide plains and agreeably set hills, excellent for vigorous agriculture and mountains especially suited to varying the pastures for animals. Flowers of different hues underfoot make them a delightful picture.[4]

Yet so rhapsodic a celebration relates awkwardly to the author's avowed aim of delivering himself, not a moment too soon, of a jeremiad against the 'general loss of good, a heaping up of bad' within society.[5]

It is even more awkwardly precursive to the account he rendered of the coming of the English. Gildas stressed (as do historians today) the strain the Romano-British confederation under Vortigern had been under from the continual raids, many of them amphibious, by the Picts and Scots. Nevertheless he insisted it had been a terrible mistake to invite over the Saxons under Hengist and Horsa to help defend the south-east coast. He saw them as treacherous interlopers somehow responsible for a more generalised conflagration engulfing the whole island:

> In just punishment for the crimes that had gone before, a fire heaped up and nurtured by the hand of the impious easterners spread from sea to sea. It devastated town and country round about and, once it was alight, it did not die down until it had burned almost the whole surface of the island and was licking the western ocean with its fierce red tongue . . . . All the major towns were laid low by the repeated battering of enemy rams . . . as the swords glinted all around and the flames crackled.[6]

It is an arresting narrative, not least because allegory seems not to be intended. Though original blame is attributed to the Saxons, they are not referred to overtly again. The enemy that wielded those battering rams may have been the Picts and Scots, exploiting some temporary weakening of an embattled Britain. The way the narrative is constructed suggests some such relationship between cause and consequence. Victor Clube and Bill Napier are disposed to see the background cause as cosmic, a meteor stream or fragmented comet that the British Isles passed directly under.[7] The migration of thousands of people from the south of Britain to what, by the mid-fifth century, was identified as 'Brittany' points to a sudden trauma particularly affecting Britain. The migrants came in spite of the Huns still posing a continual threat to the whole of Gaul, this until their defeat in 451 at the battle of Catalaunian Fields (near Troyes).

Arguably, cosmic causation gains support from traditions that speak of the death then of Vortigern and of the elimination of a leadership cadre, quite possibly his confederal council. There is also an ominous entry in the *Annales Cambriae*, a compilation that covers the period 444 to 954. It speaks of 'darkened skies' in 444 or thereabouts; and this could refer to a dust veil maybe destined to spread globally and unsettle the weather for several years. Gildas spoke, too, of a 'dreadful and notorious' famine that suddenly capped a general food shortage caused by armed strife. He indicated it was raging around the time of a plea for assistance made to Aetius, the Roman commander in Gaul. That must mean in 446 or thereabouts. A Gallic commentator had indicated in 442 that a general English offensive was under way.[8] That year the Chinese registered a 'new comet'.

The course of events may have been like this. In 442, a heavy meteoritic shower caused attrition across Britain, maybe including a direct hit on the confederal council in session. Just possibly, too, enough dust was projected into the stratosphere to induce climatic perturbation worldwide. Witness abrupt tree-line recession in Canada and Scandinavia. The English quickly moved against their British hosts, acting to extend their own domain opportunistically though also in desperation. If such an astronomic factor did come instantly into play, a disposition evident of late to dismiss Gildas as rhetorical and confused[9] loses its justification. Instead, he can still be seen as the modest and truthful personality that comes over in the Preface to *De Excidio*.

In 1966, the journal *Acta Astronomica Sinica* reviewed 147 major meteor showers observed over China since 1575 BC. Ten were recorded in the fifth century AD: two being in 443 and 447, respectively, with all but one of the remainder between 461 and 466. That pattern looks compatible enough with the interpretation just rendered. It may the more so in that the fifth represents a climax in this regard across eight centuries. Thus the sequence across the millennial AD 100 to 1100 is nil in the second century, two in the third, one in the fourth, ten in the fifth, five in the sixth, nil in the seventh, six in the eighth, nine in the ninth, eleven in the tenth, and six in the eleventh.[10]

The five episodes in the sixth century are recorded in 530, 532, 551 twice, and 585. However, recent research has well confirmed 10 to 20 years of irregular but very pronounced coolness and aridity around the northern hemisphere and beyond, this consequent upon a major dust veil event from 535 or 536 sometimes ascribed to volcanic action but at other times to a cometary or meteoritic impact.[11] Famines occurred soon thereafter in Ireland and Britain, the Mediterranean and China.[12] Dry fogs (i.e. dust veils) are also recorded in Europe in 536 and 537. A Greenland ice-core two-stroke acidity signal detected in 1978 (and at that time located within a decade of 540[13]) raised the possibility that an extra-terrestrial impact triggered a volcanic eruption as a subsidiary effect. However it may be explained, 540 comes across very consistently in the tree-ring analyses as almost the poorest year for growth these last two millennia.

As of 1999, it did rather look as though the hesitations had been resolved in favour of a single autonomous occurrence, an eruption of Krakatau rating as about the biggest event of its kind throughout the Wisconsin–Holocene era. The evidence, inspirationally researched by David Keys, pieces together thus. A strong Antarctic ice-core acidity signal combined with a weaker Greenland one suggests a location just south of the equator. The Chinese chronicle *Nan shi* ('History of the Southern Dynasties') refers, quite abnormally, to a strangely double roll of 'thunder' in 'February 535', a sound coming from the south-west towards Nanjing. The said acoustic profile fits well enough the refraction and reflection of low-frequency sound waves across a few thousand miles. An eye-witness account of a Krakatau upheaval was transcribed (from a medieval manuscript) in the nineteenth century. The dating thereof is problematic but the substance persuasive. Moreover, Krakatau has a huge caldera of about the right age.[14] Given all the circumstances, it is not surprising that a nadir in tree growth came in 540, five years after the event. Temperatures may then have been at their lowest and forests at their most enfeebled.

Meanwhile, plague (predominantly, it would seem, bubonic) advanced up the Nile valley from some 'inveterate focus' (i.e. reservoir area) in the Uganda–Kenya region. The resultant epidemic was to take its name from Justinian I, the emperor in Constantinople from 527 to 565, whose territorial reconquests transiently turned the Mediterranean into a 'Byzantine lake'. Progressing through Egypt and then Palestine, the 'Justinian plague' proved savagely virulent in Constantinople, killing perhaps 40 per cent of the population through the winter of 541–2. From the metropolis, it spread across Anatolia into the Fertile Crescent. It did so within the context of several decades of climatic erraticism (see pp. 105–7) and of successive earthquakes, one of which had reportedly killed *c.* 250,000 in the Antioch area in 526.[15] Modern scholars have commented on how the population losses, especially those in Anatolia, left Justinian's empire more open to invasion,[16] especially from such desertic landscapes of Islam as may have escaped more lightly.[17] One could have expected this to make the Byzantine authorities less keen to invoke the Eastern Empire tradition of militia defence, always a piecemeal way to utilise manpower. They reacted in the opposite direction.

Soon the contagion(s) extended into Persia and on to other parts of central and south Asia. Arabia Felix was likewise affected. Meanwhile, morbidity spread through the Mediterranean, to devastating effect in Italy, southern France and Iberia, where it lingered through the autumn of 544. By the time the pandemic was finally spent, a fifth to a quarter of Europe's population south of the Alps had perished. It had extended as far north as Denmark and as far west as Ireland, where mortality was especially severe. It had reached Ireland from Arles (near Marseilles) in 543–4.

It then adopted the Mediterranean region as an intermediate focus. Outbreaks from there recurred in 10- to 24-year cycles for the next 200 years, albeit with less virulence after the sixth century. Sometimes (as in 541–4) smallpox epidemics occurred concurrently. It is estimated that 50 to 60 per cent of the baseline population of southern and western Europe had succumbed by the year 700.[18] Some of this increased mortality will have been due to a greater prevalence of tuberculosis.[19] Across axial Europe, one general result in the medium term could have been a diminution of warfare.[20] However, the Byzantines were soon to lose vital ground in Italy against Ostrogoths less acutely plague-stricken.[21]

If the advent of this plague can be linked to a Krakatoan upheaval, it will be a dramatic example of climatic cause and epidemal effect. What has to be admitted, however, is that plague ecology is not yet fully elucidated. Perhaps the most pertinent point thus far established is that *Xenopsylla cheopis*, a rat flea prominent in plague transmission at least since the fourteenth century (see Chapter 8), best thrives in temperatures between 59 and 68°F and requires an ambient relative humidity of 70 per cent or above. Hence in much of Europe, plague outbreaks were more prone to begin in the autumn or early winter.[22]

Fenno-Scandinavian tree-ring data indicate mean summer temperatures during the 535 to 542 period very consistently to be 1.0 to 1.5° Celsius below the 1951–70 norm, the 536 readings being the most acutely so in fact.[23] But when that downward tendency in temperature profiles for those two decades is applied to representative places in Mediterranean Europe, it seems to make little difference to the continent's exposure to flea intrusion. Take the number of months a year with a mean temperature within the 59 to 68°F bracket (15 to 20°C). When a 3°F decrease is fed in, that number drops from four to two in Marseilles; stays at two in Athens and Madrid; and rises from four to five in Gibraltar.[24]

Obversely the advance of the plague up the Nile valley during the winter season must have been assisted by lowered temperatures. After all, from Lake Victoria to the White Nile–Blue Nile confluence January mean temperatures are currently 68 to 70°F or a little above. Then down the middle Nile, through the Libyan and Nubian deserts, the rise in relative humidity that would probably be a corollary of a lowering of temperature would have been no less welcome by the *X. cheopis* flea. Even so, it is likely that the main factor conducive to an upsurge of the plague would have been the debilitation of human populations as a result of harvest shortfalls due to cold and diminished sunlight. What is more, once the plague had gained a foothold in new regions it became cyclically endemic for a century or two. Tuberculosis will similarly have been favoured.

The 536 event could cast further kindly light on whether Gildas was sound of judgement. Whether it actually does will depend on when *De Excidio* is thought to have been written. One opinion has assigned it 'at the latest to the 520s'.[25] Much more general, however, is the view that it belongs to 540 or just before.[26] If so, this Celtic monk was putting quill to parchment in the throes of a sudden spell of irregular but abnormal cold. It will have made the more vivid his sense of divine retribution for sinfulness, past and present. This effect will have been the stronger since, while people of that generation fervently sought to satisfy themselves their weather normally derived from the utter orderliness of a cyclical cosmos, the Noahic flood had shown there were no limits to God's intervention should He feel obliged so to act. So far as Britain was concerned, however, this eruptive episode impacted on human affairs less immediately than the previous one had. For one thing, the strategic situation appeared more stable in 536 than it had been *c.* 445.

The hinge of fate

The key to that perception lay in a crushing British victory over the English around the turn of the sixth century at Mons Badonicus. The location thereof is unknown but is generally assumed to have been in the West Country. Some have thought Dorset.[27] In 1973, John Morris proposed somewhere near Bath, and also that a large force of English infantry had penetrated deep into Romano-British territory to destroy King Arthur's cavalry together with its logistic infrastructure.[28] But under those circumstances, it would have been difficult to oblige that cavalry to fight from any position of tactical disadvantage. Nor would its infrastructure have been sufficiently tangible and centralised to constitute a suitable target. Nor would it have been sensible thus to denude English territory of infantry cover for any length of time. We do well not to be swayed by English intimations that this encounter took place well to the west. There are sensitivities here. The *Anglo-Saxon Chronicles* do not allude to Mons Badonicus at all. Nor did Bede.

The point about location is not unimportant to the analysis here being pursued. The further east the site, the more the result confirmed Romano-British ascendancy; and so the more there was for the English to recover from as and when circumstances altered due to climate flux or whatever. To me, the military logic is that battle will have been joined well east, perhaps on or near the Chiltern Hills.[29] It would have been the culmination of a British punitive sweep by a mounted *masse de manoeuvre* led by a *dux bellorum*, a sweep menacing enough to oblige the English to present themselves in strength. Gildas says this *dux bellorum* was Ambrosius Aurelianus, but it was probably his presumed successor, Arthur.

The outcome was a gridlock, the nub of which was the Romano-British enclave in the Chilterns with its many villas and the Roman city of Verulamium (near modern St Albans), 'large by the international standards of its day'.[30] An extensive West Saxon colony in the Hampshire basin was thereby contained. English colonies in the upper Thames and across to the Ouse basin were fragmented politically and bound to make local accommodations with the British. Further to the north and west, the Romano-British writ still ran firmly.

Normally, so intricate a balance would have been liable to snap suddenly. What long precluded that in this case, one can confidently assume, was English apprehension of any repeats of Mons Badonicus. Hence this brittle peace survived the climatic perturbation of 536 and its immediate aftermath. The question that remains, none the less, is whether the Justinian plague was ultimately to hit the British that much harder, thereby encouraging the renewal of English encroachment from 552.

In entries for 545 and onwards, the Romano-British archives report a succession of epidemics in Ireland and Britain. There is presently a general consensus among the historians that the British did suffer more than the English since they were regularly in contact with Gaul. More reasons might be adduced. A possible tendency for British settlement patterns to be more dispersive than English could have served to facilitate plague transmission by the rat – a rather solitary and strongly territorial animal bearing a few fleas apiece. Moreover, the fact that British population densities were lower overall could have meant, in the judgement of Russell, that more percentagewise would succumb.[31] Then again, coldish summers would hit food production hardest beyond the fertile lowlands the English then farmed.

There may have been a disposition, however, to exaggerate the differential effects. A reason for dwelling on them is the absence of any allusion to plague in the earliest surviving literature of the English people. There is nothing until a typically prosaic reference to 'much pestilence on the island of Britain' in the entry in the *Anglo-Saxon Chronicles* for 664:[32] an outbreak confirmed by Bede and others as the next major visitation of the plague on Britain and Ireland, this time with the English badly affected. But here again one has to remember how arbitrary the said chronicles can be, especially early on, in regard to subjects covered. Human ecology, in all its aspects, gets short shrift.[33] In fact, the total surviving coverage of the critical 540s is only sixty words.

There are other complications. The notion of the English concentrating from the outset in larger settlements may not gel with the positive approach they are credited with to woodland preservation (see Chapter 3). Besides, the evidence for artefact trade between the British and the English in this era simply confirms what one might, in any case, expect: namely, that two peoples situated so much side by side had to interact peaceably, to quite an extent, or else to be endlessly at one another's throats. Yet just minimal interaction would surely have involved a high risk of plague transmission. It is hard to accept the double contention that 'what trade there was between the rival camps was probably conducted by itinerant pedlars. Such men were unlikely to provide a sufficient channel for widespread epidemics to break out.'[34] What can perhaps be allowed is that, in the more solid English enclaves in the more fertile parts of East Anglia and the Hampshire basin, mortality could have been kept comparatively low. Soon, too, Malthusian pressure might have been tempting those English to take advantage of any British weakening. Any analysis must also allow that males of or approaching arms-bearing age (i.e. 10 to 30 years) were everywhere more susceptible to the plague than most other people.

In 552, the West Saxons under King Cynric struck north, defeating the British at Old Sarum. Cynric then moved down on the Thames valley via the White Horse escarpment. According to the *Chronicles*, another strategic defeat was to be inflicted on the British by Cuthwulf at 'Bidcanford' (most likely, Bedford) in 571. This secured once again for the English such South Midlands locales as Aylesbury, Benson and Eynsham. Bath was overrun by the West Saxons six years later. By then, too, the genesis of the Anglian kingdom of Mercia was under way in the Trent valley. Though still divided, the English were now decisively ascendant. Moreover, their ascendancy was reinforced by the weather across much of the British Isles turning damper awhile from *c.* AD 600: a trend revealed in peat humification from Ireland to north Yorkshire. All five of the sites examined were north-west of a line from the Severn estuary to Whitby. Such a trend would have been liable, in any case, to favour differentially the dryish English-held areas.[35] The arrival of another St Augustine in 597, to bring Christianity to the English direct from Rome, bespoke recognition of a new reality.

Irish exceptionalism

Ireland commands attention, not least as a contrary example of how climate may shape history. Adventurous idealism may be inspired by an ambience that avoids numbing cold but is remote, rugged and storm-swept. Further, Ireland is a sublime illustration of the axiom that a country's progress cannot always be gauged in some all-inclusive way; that it is possible to be well advanced in certain aspects of human existence while visibly backward in others.

The Romans visited Ireland little, and the discovery some years ago of an encampment 20 miles from modern Dublin is the only indication to date of their ever sojourning long.

Map 4.1 Ireland

Even so, there was enough contact between the two peoples for the Irish to acquire, probably in the relatively benign fourth century, iron coulters (i.e. vertical knives) in their ploughshares. This led to 'a dramatic expansion in agriculture . . . probably in quite a short time all the land from which a living could be wrested was occupied.' As the sixth century dawned, Ireland was well peopled and tolerably prosperous.[36] It was much more so, for instance, than more northerly Scotland.

Yet agrarian and demographic advance notwithstanding, the political and social structures remained very devolved, no doubt in part because (a) Ireland's topography was akin to a saucer with a notched rim, its surface well laced with water – i.e. rivers, lakes and marsh, and

(b) the Irish felt little urge, in the absence of barbarian invasions, to forge a wider political unity. Security was sought locally through two distinctive innovations in defensible domestic architecture. The one was the 'ring fort', the other the *crannóg*.

The ring fort was a homestead within a wide circular wall, such a unit being known as a *ráth* if the wall were just earthen or a *cashel* were it made of stone. The *crannóg* was, and is, an artificial island in a lake. Several thousand were built, particularly between the fifth and seventh centuries. Several tens of thousands of ring forts were constructed, too.[37] Society remained clannish, with allegiances to kingship being shadowy to say the least. No towns evolved nor did coinage. To which one might add that the thesis that devolved settlement can lead to heavy plague mortality is, in fact, borne out all too well by Ireland. Its people suffered grievously in 544 and again in 664.

Within this rather basic pattern of culture a remarkable revival of Christianity peaceably took hold, under the leadership of St Patrick, in the first half of the fifth century. It did not dissent from Rome's theology or much (as we would see things today) from its ritual. But organisationally and in terms of spiritual uplift, personal and pentecostal, a radical departure was made. Its psychic mainspring was located in a mystic sense, druidic and bardic, of ancestral place. It had been vitalised by the receipt, via Gaul and Brittany, of twinned concepts originated by the 'desert fathers' of the Christian East. The one was the monastery, the other the hermit. The former evolved from the latter with physical seclusion, fierce asceticism and literacy among the common traits. The results could range from the sublime[38] to, in the case of certain hermits, the atavistic.[39]

In the Ireland of the sixth century, 'the Age of the Saints', these desertic themes were recast with singular purity. From what is known of the eighth century, Donald Matthew has identified 75 'important monasteries'.[40] They and very many lesser foundations had emerged in close association with clan geography. Meanwhile the eremetically inclined lived out their solitude in tiny beehive cells. Sometimes these two modes of devotional living were confluent (in Ireland and across north and west Britain) in island sanctuaries – e.g. Skellig Michael, Iona, St Kilda and Lindisfarne – free from spectator gaze, unlike the locales of the desert fathers. Often the islands selected became nodes of evangelism, scholarship and artistic expression. In Ireland, the term 'saint' connotes these aspirations as much as it does godliness *per se*.

The most celebrated missions abroad were those of St Columba (521–97) and St Columban (*c.* 540–615), each a scholarly aristocrat. The former converted Scotland via Iona. The latter spent the last half of his life assisting or encouraging the founding of some 40 monasteries amidst what he had found to be a very demoralised continental Christendom. Kenneth Clark, the art historian, was oversimplifying and therefore overstating when he opined that it was in Celtic Britain that Christian civilisation itself in that era 'hung on by the skin of its teeth'.[41] All the same, there is no denying the religious upsurge in Ireland made a difference continentally.

Fairly soon, however, its influence began to wane. St Gregory I (lived *c.* 540–604, and Pope from 590) began to bring monasticism under Rome's control, utilising the Rule (i.e. set of precepts for monastic living) of St Benedict of Nursia. At the Synod of Whitby in 663 (an event not covered in the *Anglo-Saxon Chronicles*) a decidedly fractious Celtic team was constrained to accept Rome's practices on the ritual points at issue – the form of tonsure and the dating of Easter. During the eighth century, a quasi-feudal order began to emerge across Ireland as a trend towards monastic federalism fused with one towards secular overlordship involving tenancy or vassalage.

Across northern seas

So what bearing may climatic tendencies have had on what was soon revealed as the propensity of the bolder Irish monks to rove the seas in search of converts if not of Paradise itself? From the mid-sixth century to the late tenth, it was comparatively warm over Greenland, save for cool intermissions from 660 to 710 and 820 to 870.[42] One is tempted to presume that a relatively salubrious climate would have helped St Brendan and his brethren sail their open boats not just to Iceland but, in all likelihood, on to Greenland (though not the American mainland).[43] However, the relationship between temperature and run of wind is not a matter for simple abstraction. A tentative comparison of gale frequency as between the warmish years 1930–5 and the coolish 1945–9 shows little difference overall, either in the Denmark Strait or around Cape Farewell.[44] Obversely, an earlier statistical analysis suggested that summer anticyclones are more evident in the Greenland–Iceland sector when pack ice is persisting well south.[45] The argument is, in any case, turned on its head as regards St Brendan's transatlantic epic if, as is quite possible, this took place in the Krakatoan cool years between 536 and 540. He may have followed migrant birds to the Faeroes and Iceland in the early summer, then picked up anticyclonic easterlies to carry him towards Greenland. Apparently he sailed, on a later trip, into the calmer seas of the trade wind belt at least as far as Madeira.[46] He was lucky as well as deserving to die back home, *c.* 577.

Around the British Isles, storminess may have been the norm in that era. Arguably, high wind and heavier rain were there experienced most frequently in cold centuries like the fifth. This will have been because anticyclones extending across Scandinavia in winter caused active fronts to be slow-moving across Britain and, of course, Ireland. Even allowing for data paucity, it is to be remarked how, around the North Sea and English Channel coasts, surviving records of severe sea floods peak in the fifth and sixth centuries.[47] However, two queries must be raised. Was more attention paid to marine storms on account of the ramifying *Völkerwanderung*? And how much does any deduction about winter storms tell us about storminess in summer?

Besides, an abnormally adverse climate, if that is what it really was, might have stimulated the more the cult of the sea that proved so strong a trait of the Celtic monks, doing much to galvanise their missionary zeal. A quarter of the 'important' Irish monasteries identified by Donald Matthew were off, on or very close to a western seaboard that will have been storm-beaten, whatever the modalities of climate change.

Thanks to the ice-albedo feedback, the eventual onset of medieval warming will have been at its most emphatic on the receding margins of the polar pack ice. Writing in 1926, C.E.P. Brooks surmised that, with the arrival of medieval 'maximum warmth and dryness, in about the 7th century, . . . the permanent floating ice-cap round the pole had almost or entirely disappeared.'[48] That arresting conclusion, or something akin, passed into general currency for a while.[49] But nothing of the sort would now be entertained. None the less, close study of glacial moraines on Baffin Island has confirmed an era of relative warmth regionally from AD 350 to 1000.[50]

So what does that connote for Europe's climate? Here one is indebted to the Geophysical Isotope Laboratory of the University of Copenhagen. Willi Dansgaard and his colleagues have discovered a marked longitudinal lag in the waxing and waning of the 'little climatic optimum'. When core analysis from the Greenland ice cap is set alongside evidence from England between 850 and 1900, an uncannily neat match is found in the profile of major temperature trends (i.e. those in excess of 200 years) provided England is set 250 or so years behind. Iceland is intermediate, not always inclined more towards the Greenland timings.[51]

Through the extended trough

Another understanding used to be that, in one way or another, the climate of Europe 'troughed out' before the sixth century. In 1912, Otto Pettersson had placed the sixth century alongside the thirteenth and fourteenth in terms of being 'an epoch of violent disturbance' in the climate of continental Europe.[52] In 1932, Sir Napier Shaw saw AD 400 as the point of cross-over to more warmth and less rain in the climate of the Mediterranean.[53] Later on, however, data from the Alpine glaciers indicated (assuming no great changes in the precipitation regime) a cold phase from AD 300 to 700.[54]

The current disposition is to extend the cold and wetness into the eighth century as far as axial Europe is concerned. Outside the Mediterranean added rain or snow will almost always have posed a problem. It strengthened the forests, and limited the extent and diversity of grain cultivation. In northern France, for instance, the peasantry came to differentiate arable soils as 'warm' or 'cold'. The former had light, readily drained humus, and, though often less productive, were easier to till. Bolton Fell Moss is a peat bog in north-west England close by the Scottish border. Its index of surface wetness goes through a high in the early eighth century then a low during the ninth.[55] More generally, pollen analysis and so on indicates a continual retreat of plant life from the fifth century through the eighth; and, on the alpine foreland, some fall in the tree line.

Farming apart, the ecological and human impact of bad weather was tangible. The French bishop and historian, St Gregory of Tours (538–94), noted at one point how 'the winters were grievous . . . so that streams were held in chains of frost and furnished a path for people like dry ground. Birds, too, were affected by the cold and hunger, and were caught in the hand without any snare when the snow was deep.' Witness how, in the Irish annals, notices of disease and famine during the late seventh and early eighth centuries 'far exceed' those for the Justinian plague of the 540s.[56] The view that temperature recovery set in by 750 to 800 would today be the most representative.[57] Accordingly, W.G. Hoskins, the Leicester University pioneer of landscape history, may have been wrong to intimate that climate improvement cannot be adduced to help explain the very general reorganisation of the English agrarian landscape (between 700 and 1150) into manorial 'open field' villages with strip holdings farmed in rotation.[58] Was not this the *modus operandi* for a leap forward in cereal production made possible by the warmer and drier weather?

What then of the maritime flanks of Europe, the Mediterranean twin basin and Scandinavia? Two analyses from the Galilee area (the one seabed core and the other speleothem) show temperature lift-off from *c.* AD 300 and *c.* AD 700 respectively.[59] That discordance could fairly be read as reflecting how subtle any secular changes in mean temperature were in the Levant from the fourth to seventh centuries. It is well established that across central Europe both the secular fall as from Late Antiquity and the secular rise from AD 750 to the optimum *c.* 1250 were only of the order of 1° Celsius. In the Mediterranean twin basin, long-term movements of temperature will probably have been still less pronounced.

As usual, a synoptic assessment will hinge on how pressure and rainfall patterns may have realigned. From the ninth century, with warming assuredly under way, there could regularly have been a strong ridging across Europe, even in winter, of the Azores anticyclone. The long north-easterly fetches of air that would thus be generated across the eastern basin of the Mediterranean could explain what might otherwise be the anomalous incidence of freeze-ups in that region as the little optimum approached. Going up to the year 1250, one observes a freezing over of the Venetian lagoon in 853, 859?, 860, 864?, 1118, 1122 and 1234; and of the River Po in 1116, 1133, 1216 and 1234.[60] Likewise 829 and 1010–11 saw freeze-ups on the Nile. The latter winter marked the onset of a year of severe cold across much of Europe north of the Alps.[61]

One corollary of this Azorean ridging could be a weakening of the Siberian High, apparently strong in winter quite often through Late Antiquity. Another could be a strengthening (between Scotland and Iceland, say) of the North Atlantic Drift coupled with a displacement of the polar front medially towards the Norwegian Sea. Not confirmed as yet, however, is the status in winter of the Scandinavian High as secular warming resumed at the continental level. How strong was it as a rule? And was it usually organised as a ridging from Siberia or as part of a reassertion of a circumpolar anticyclonic regime? There seems to have been some glacial advance in Norway, due either to more snow or less melting, that may in places have extended beyond the AD 700 turning point discernible in the Alps as per the above. Likewise, Leo Koutaniemi of the University of Oulu has written of 'numerous signs of contemporary cooling' in northern Finland for the centuries preceding AD 800.[62] An argument to pursue further in Chapter 5 is that the Viking era owed something to a secular dip in summer temperatures of perhaps 3° Celsius that had made grain cultivation difficult in central Norway and impossible in northern. Increased pastoralism could not fully correct the consequent food deficit.[63]

Illumination can be sought from post-AD 1000. In September 1993, Keith Briffa of the Climate Research Unit at the University of East Anglia gave a paper at the Durham meeting of Britain's Quaternary Research Association. From an analysis of quasi-fossil tree rings, he inferred that the medieval optimum, 1100 to 1300, was actually rather cold in northern Scandinavia. Granted, summer temperatures tend there to be the most critical factor as regards growth. But it is possible also to envisage a significant effect from the longer, colder and drier winters that could have resulted from a building up of the circumpolar High. That could be reconciled with what was said above about anticyclonic tendencies in the Greenland–Iceland sector against a background of warming, and also with what was said in the previous chapter in relation to Khazaria and, indeed, Mongolia. Also with the perception that the eighth to twelfth centuries were drier across Europe as a whole, this not only in summertime.[64]

On the whole, this dryness was good for arable agriculture. But even as the trend was getting under way through the eighth century there were years of excessive aridity across western Europe if not beyond: 719, 737, 764, 772, 783, 794, 797. . . . The 764 summer drought followed a long and ferociously hard winter throughout Europe. Many village, urban and monastic fires broke out across England. Even in Ireland it was 'a great drought beyond measure'.[65]

To vanquish or to meld?

It is sardonically observed that the thing everyone knows about the Roman Empire is that it declined and fell. As part of an ongoing revaluation of the 'Dark Ages', however, historians have lately laid more stress on the continuities (cultural, institutional and demographic) between the Empire in the West and its barbarian legatees. Widespread devastation (as per the Vandal, Alan and Sueve rampaging in Gaul, 406–9) was not that common during the transition. Accommodation leading on to assimilation was. Granted, this revisionary view proves nothing, in itself, about climatic cause and historical effect. But it would be consonant with the weather deteriorating through the year 700 or thereabouts, though never so precipitately as to induce a frenzy of belligerence as a kind of Malthusian 'natural check'.

Beyond that, it is still far from clear how the situation unfolded. A recent historical geography cites an estimate that, even in the sixth century, the population of Gaul was but a quarter of what it had been in the second. Around 700 came the nadir, a mere eighth of the second-century maximum. But this study also stresses how strongly certain districts bucked the general trend. In Limagne, agricultural margins extended continually from Late Antiquity to the time of Charlemagne. In Picardy those margins did recede when the tribes moved in but were soon to advance anew.[66]

Where a big fall in population is indicated, the inclination nowadays is to explain it not so much in terms of wilful slaughter as of the disruption inherent in a transition such as this and, above all, the extra purchase afforded for epidemial spread. Yet in these dimensions, too, assessment is problematic. Take the Celtic side of the British Isles, a decidedly oceanic zone where appreciable climate improvement may have come slowly. K.R. Dark has lately insisted that, while 'there may have been a plague in mid-6th century Britain, there is no acceptable British evidence for it.'[67] But noting the sparsity of settlement remains or of artefacts in general, he surmises that Ireland and Celtic Britain could have experienced a collapse of agriculture and long-distance trade through the eighth century extending well into the ninth. He sees its likelihood as strengthened by the annals entries alluded to above.[68]

More generally, limited bulk transport meant that famines (be they brought on by war, drought or floods) could still occur regionally or locally without a wider food shortage. Gregory of Tours told of several Burgundian crises from 530 to 570. Food shortage drove Germanic Lombards south into Italy in the 550s and again in the 590s. Overall, the second half of the sixth century comes across as much subject to famine, dislocation and epidemics – including the recurrences of the Justinian plague.

The eighth century witnessed a marked decline in the incidence of plague across much of Europe. Yet the ninth to eleventh were to see more malnutrition than had the fourth to eighth, the new climatic regimen notwithstanding. This was partly because of population growth and warfare but also on account of wide diffusion of new or unusual plant diseases. Heavy rains were associated with harvest failure across France and Germany in 809, 821 and 835. In 821 at least, there were food surpluses in England but little capacity to hand for relief shipment. Then in 857, the northern European rye crop was ravaged by a fungal disease characterised by the formation of pink/purple nodules or ergots. These proved poisonous to livestock and also to people since they induced corrosion of the central nervous system and arterial constriction leading to haunting visions, fits, dry gangrene and other maladies. Ergotism thus became endemic in Europe for several centuries. The worst outbreaks followed upon warmer but wetter springs and summers. Needless to say, they were concentrated most in districts where rye was dominant, the soil being too poor or the weather too cold for wheat – e.g. the Ardennes, the Jura and the upper Rhône.

Between 857 and 950 there were at least another twenty severe European famines, raising mortality and depressing fertility enough to reverse regionally the century-long rise in population. In the Iberian peninsula in 915 and again in 929, a parasitic fungus in the rust group ruined the entire wheat crop. An Aragonese chronicler wrote: 'Destitution at last reached such a pitch that men began to devour each other and the flesh of a son was preferred to his love.' All around Europe, 'two-legged mutton' went on sale in famine years. In the late tenth century, the frequency and severity of famines diminished. But in the early eleventh, they were to increase once more awhile.[69] Something to explore is whether climate erraticism was then on the increase.

Grim as the accounts sound, however, they do not gainsay the general amelioration of the climate from the eighth century onwards, a trend well reflected in population growth continentally. Nor was political and cultural progress precluded. But one argument against simplistic climatic determinism would be that progress gathered pace in these respects during the seventh century – before the troughing out. A view expressed over sixty years ago was that the emergence in seventh-century England of a 'new Anglo-Saxon culture' was 'perhaps the most important event between the age of Justinian and that of Charlemagne for it reacted with profound effect on the whole continental development', not least through missionary work. The north-east of England became a creative interface between the disparate Celtic Christianity and the more unified Rome–Canterbury mainstream.[70] The latter secured a formal ascendancy at the Synod of Whitby, a consummation in line with the hegemonic emergence from that time of Mercia, the kingdom of the English Midlands. Then out of this Whitby accord dawned a splendid artistic (and, not least, architectural) renaissance as Celtic localism interacted with Roman cosmopolitanism. This ecumenical outcome also eased English–British tension since the main English kingdoms (Northumbria, Mercia and Kent) were Christian-led by the time of the Synod. Celtic Britain was all but unique in the seventh century in that it encompassed lands formerly within the Western Roman Empire that had still not come under 'barbarian' control.

What can be discerned meantime is a cultural revolution throughout Gaul/Frankia, Italy, Spain and Africa. It involved a more thorough 'de-romanisation' than heretofore. In buildings, arts and crafts, settlement patterns and language, the tribal vernacular took over more completely everywhere. Dark well observes a lack of close concurrence with 'environmental' (meaning, above all, climatic) changes but wonders if more exact knowledge of the time profile across the Mediterranean of the Younger Fill (see pp. 114–15) just might reduce the discordance.[71]

The question is fair but sanguine. After all, it was around the Mediterranean that Roman culture had persisted most strongly. Take the linguistic and legal divide that appeared across France, roughly along a line trending eastwards from l'Ile d'Oléron. The *langue d'oil* to the north was more Celtic and Frankish (and hence less classical) than the *langue d'oc* to the south, a difference traceable into the twentieth century. To the north, the *droit coûtoumier* was rooted more in custom as confirmed by legal precedent than was the more codified *loi écrit* to the south. What was happening throughout was, in essence, the creation of a patchwork of proto-states as comparative peace descended across axial Europe. These states were needed to curb, through their capping of emergent systems of feudal obligation, an endemic problem of lawlessness at local level. They were very particularly needed to encourage long-distance transit in luxury goods and by pilgrims. An underlying impetus was there already. The Frisians assumed a lead role in a growth of North Sea trade (and inshore fishing) discernible in the sixth century and gathering pace in the seventh.[72,73] Indicatively, the seventh century saw a general introduction of national currencies. In most of Europe beyond Byzantium, these soon came to be based on less scarce silver rather than more scarce gold (see Chapter 5).[74]

Seeking to interpret this era more in terms of the philosophy of government, Peter Brown has insightfully explored the Gibbonesque notion that (for both cultural and spatial reasons) these proto-states were less prone to flights from realism (Gibbon's 'leakage of reality') than a 'city swelled into an Empire' with its 'natural and inevitable effect of immoderate greatness'.[75] In the wake of this forging of new Romano-barbarian national cultures and the resurgence of Catholic Christianity came the virtual abandonment by Constantinople of its lingering aspiration to dominate the northern Mediterranean and thus confront Islam's extension over the southern.[76] Meanwhile the said resurgence, especially pronounced in the seventh century, at once furthered and benefited from the cultural fusion the proto-states were kneading. Most of the distinct languages of Europe as we know them today were generated as vulgar Latin merged with the respective native tongues of the different barbarian societies.

So how much room is left for the role of climate change? No doubt, as research progresses, sundry correlations will be presented. Some may concern the viability of waterways, judged in relation to the water cycle. Thus Archibald Lewis concluded that, particularly in the *langue d'oil*, there was a big switch to transportation by river as opposed to Roman road.[77] That may have been hard to affect unless rainfall norms were at least as high as today. Otherwise rivers might too often have been impassable on account of a tendency to braid, meander and silt. On the eve of the pre-modern wave of engineering improvements (to be precise, in 1825), the mighty Rhine had 2,155 identified islets on the 150-km stretch from Basel to Baden-Baden.[78]

More generally, this truism needs to be nailed. For cultural melding to take place as comprehensively as it did, the conflict between Roman and barbarian cannot have been incessant. Indeed, we know full well it was not. Witness the *foederati* deals for alliance and settlement from the third century onwards. One inference can be that the climatic stress that periodically impelled the tribes forward was never so vexing as to override the other factors here adduced. The climate decline was fairly steady (see pp. 122–4) and very gradual and will have become the more so as AD 750 approached. For that reason alone, we should not be too surprised that reconstitution (political, cultural and even economic) began ahead of the climate upturn.

What must be admitted, on the other hand, is that for two or three centuries the economic revival was hesitant. A slow rate of forest clearance bespeaks this. Also, there are indications of the trading crisis in the mid-eighth century being a very general one, a state of affairs perhaps owing something to the geopolitical situation in the Mediterranean but more to bullion shortage (see Chapter 5).[79] In fact, Richard Hodges concludes that no truly systemic change (in terms of urbanisation and so on) took place in western Europe (Scandinavia included) until the middle decades of the ninth century. But at the same time, he stresses the inadequacy of the oft-aired view that this lift-off was essentially a by-product of Viking expansion. He calls on us to think in terms of a multivariate multiplier that centrally incorporates a societal plus an energy dimension and embraces, too, an 'ecological' perspective.[80]

By 'ecological', one has still to mean, first and foremost, 'climatological'. However, that cannot be held to connote an a smooth unilinear progression. Seasons of drought within the context of a broadly positive trend to drier conditions will have caused or contributed to many of the periodic famines. There is, too, the question of when secular warming decisively set in. The freezing over of the Venice lagoon in several winters between 850 and 864 will have correlated quite closely with cold winters across western Europe. Furthermore, though northern Scandinavia was in the process of becoming awhile a distinct climate region, it is striking how neatly those same dates delimit a cluster of cold summers as per the Briffa tree-ring analysis.[81] Even more portentously, the acidity trace in a Greenland ice core reveals a dramatic contrast between the two halves of the ninth century, as regards the registration of vulcanism throughout the northern hemisphere. The second was easily the least active half century between AD 750 and 1000. But the first had been easily the most so, especially from 820 to 854.[82] Since vulcanism can be an important cause of decadal cooling globally, we may conclude that medieval warming was widely interrupted in the mid-ninth century. Viking experience in England and Iceland is in line with this conclusion. So, indeed, is geophysical evidence as far-flung as Greenland, the Near East, the Yucatan and China (see Chapter 5).

Yet this leaves little time for markedly warmer weather to induce the economic lift-off

Hodges identifies. Two remedies present themselves, perhaps in combination. The one is to say that it was actually a transitory renewal of cold that drove men to consolidate the statehoods better, even to effect 'the massive injections of capital'[83] the associated urbanisation required. Richard Hodges comes close to proposing this, and, interestingly, adduces climate deterioration as a possible reason for the early (seventh century?) spread of the heavy wheeled plough in Carolingian lands.[84]

The other approach is to insist that, in north-west Europe at least, the Vikings were a crucial catalyst after all. In research on Ireland, the trend has lately been to gainsay the idea that the five townships they famously created from the ninth century (Dublin, Cork, Waterford, Wexford and Limerick) were but 'parasitic' alien enclaves.[85] At all events, the Vikings themselves are classically seen as supreme exemplars of response to climate stimulus, a precept examined at length below. In other words, the rebuilding of post-Roman axial Europe was influenced by climate change at one stage removed as well as directly.

The wetlands

Through the discipline of historical geography runs a propensity to juxtapose land and sea as contrasting realms that set the bounds of social and political conduct.[86] This can lead to insufficient regard for the variety of seascapes and, still more so, landscapes that present themselves. A big contrast between pre-industrial times and now is the extent then of wetlands, even in temperate zones. These admixtures of river, lake, marsh and woodland proffered good security, coupled with waterborne travel, and an exacting but adequate livelihood for low-density populations. Across Europe in the seventh century, most fish were caught inland; and in central and eastern Europe this still applied through early modern times.[87]

From the Zuider Zee to the west Ukraine and out to the Arctic coast, wetlands were once particularly extensive. This whole zone, having been subject to Quaternary glacial deposition, still rests on a chaotic landscape. In the Polesie region of the upper Pripet basin (alias 'the Pripet Marshes') there was an especially distinctive ecology: huge morasses usually covered in reeds and rushes; peat typically 'eighteen feet in depth'; innumerable streams, often diverted by water lilies, a landscape perhaps 'shaped largely by the beaver'.[88] All of which helps explain why the heathen gap in between the two great Christian obediences, to Rome and to Constantinople, closed less readily in that sector than in the Balkans. In the latter, the process was almost completed in the ninth century, this with a good deal of overlap, especially towards the Adriatic. Further north, Poland opted for Rome officially in 966, while from 867 there had been an Eastern church at Kiev. Yet not until 1387 was the then Prince of Lithuania, the last remaining heathen state, converted, in his case to Rome so as to succeed to the Polish throne. Throughout that region the Christianising process had been tough and often martial. So the eventual interfacing between the obediences was brittle, a state of affairs that will have contributed to the split between Rome and Constantinople becoming absolute in 1054. The posture of exclusivity assumed on each side was reinforced by geopolitics.[89]

More research is needed on how the hydrology varied in north-central Europe over the centuries in question. Evidence from south Finland suggests it was similar to recent times in AD 400. But further evidence from there and nearby territories tentatively suggests things got wetter during the last several centuries of the first Christian millennium,[90] a conclusion in line with the onset of an aridity crisis around the lower Volga. By AD 900, too, milder conditions may have made the wetlands more viable for their established human communities, not least because they might have been less healthy in high summer for unacclimatised intruders. That, too, will have slowed the closure of the heathen gap.

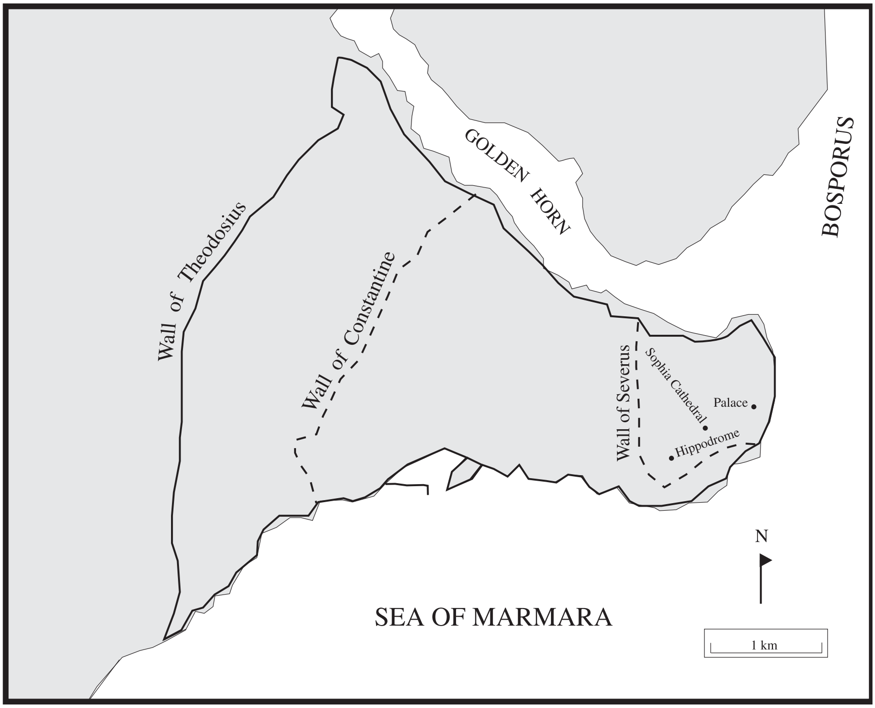
The survival of Byzantium

Ironically, a European polity that several times came close to eclipse in the sixth and seventh centuries is the one widely thought of since then as a great survivor: the Eastern Roman Empire, alias Byzantium. In so far as climate change may have figured in this, it could have done so through Justinian's plague but, more generally, through rainfall alternations. In 1997 Issar went firmer than ever before about a switch in the Levant between AD 500 and 700, a switch to warm-dry from cool-moist conditions.[91] At the same time, Amos Frumkin and his colleagues at the Hebrew University had measured drainage channels in bedrock in the northern Negev, ascertaining that *c.* AD 600 the water cycle got much weaker remarkably quickly.[92] All of which can square with Lake Van in eastern Anatolia being abnormally high from 250 through 600; and also with the evidence from Italy indicating a sudden peaking in moistness around 550, this being succeeded by another moistness trough *c.* 800.[93] The general inference is that a signal turning point came 150 years earlier around the eastern Mediterranean than in western Europe. That turnabout may have been sharper as well, at least as regards precipitation.

On the mountainous border between Anatolia and Persia, harsher conditions for winter warfare (more cloud, rain and fog, and sometimes much more snow) may have been experienced through the sixth century. During the fourth, the Persians had launched winter offensives periodically. But for the sixth, archival references to one side or the other calling offensive action off before the onset of winter are numerous enough to convey the firm impression that contemporaries sensed the ambience had worsened. What is remarkable though is how Emperor Heraclius (ruled 610–41), renowned already as a bold strategist, responded to Constantinople being invested in 626. The following September he launched an offensive into Persian Mesopotamia. Before the first snows fell on them in February 628, his troops had annihilated a Persian field army near Nineveh[94] and marched on Ctesiphon, the capital city, on the Tigris 60 km (as the crow flies) downstream from where Baghdad stands today. So had Heraclius vaguely perceived the incipient onset of the regional warming and drying tendency, or was he just foolhardy but lucky? Either way, the Byzantine progress was to precipitate the penultimate crisis within Persia's Sassanid dynasty. Shah Khusro II was murdered as one of his sons usurped the throne in 628; and by 632 the next six or more shahs had all met violent ends. Ctesiphon fell readily to the Muslim Arabs in 637.

The previous century, Justinian I had reconquered vast areas once ruled by Rome: North Africa, south Spain and much of southern Italy. But the distress of those territories in the face of plague outbreaks was aggravated by the centralising proclivities of Constantinople. In the period 613 to 620 Khusro II seized North Africa as well as Palestine. Soon afterwards, the Arabs did so more permanently. In any case, lands held in that quarter never afforded protection against the threat perennially posed to the metropolis from closer in. The investment of 626 was effected by Avars and Slavs aided by Persian diversionary action.

Having enjoyed rising prosperity in the fifth century, Byzantium had widely been smitten from *c.* AD 500 by 'a remarkable succession of droughts, plagues of locusts, earthquakes and other calamities',[95] and these may well have debilitated society ahead of Justinian's plague. With the ensuing demoralisation came religious factiousness, millenarian excesses included.



Map 4.2 Medieval Constantinople

Meanwhile, a continual fall in population was most manifest in an urban crisis, the cities or townships worst affected being those exposed to enemy forays and, in due course, Constantinople.

Constantinople was the biggest city in Christendom in AD 540, in terms of people as well as spatial extent. It was shielded in its peninsular location by two lines of battlements: the last and outermost, the Theodosius Wall, completed *c.* 390. Within that compass were six square miles. Although much of this area was not built on, that made it considerably bigger than Córdoba in Spain, its nearest rival and a place usually credited with 250,000 inhabitants then. Maybe Constantinople never quite achieved in that era the 500,000 often allowed it in the historical literature. With a hippodrome able to accommodate 60,000 at once, it cannot have been far short.

Then came its exceptionally severe experience of Justinian's plague. But through the seventh century (*c.* 610–717), its fortunes were restored awhile, this via a radical transformation in political culture adjudged by a member of Birmingham University's prestigious programme for Byzantine studies to be far more consequential than any 'natural and usually very gradual shifts' in the geophysical climate.[96] To the detriment of other centres, Constantinople was made more emphatically than ever the king-pin of a Byzantium shrinking in the face of Arab and Balkan pressure. A revivified imperial bureaucracy imposed afresh state fealties, undermining the senatorial landowning elite. Steven Runciman reckoned that, by 650, some 800,000 people resided within the capital's mural bounds.[97] That makes all the more arresting the current understanding that, within two centuries, it had reverted to a cluster of enclaves separated by dismal stretches of dereliction. A population below 250,000 in AD 800 is inferred in *The Times* historical atlas.[98]

Unfortunately, Edward Gibbon reinforced a Latinist disposition to view Constantinople as simply a microcosm of Byzantine experience as a whole.[99] Yet the general recession in city life (and in the regional trade associated with it) was offset by the resilience of the quasi-independent peasantry, cardinal element in the East. Let us recall how, during the strategic crisis the former Roman Empire as a whole faced in the fifth century, the Eastern Empire had still felt able to place more reliance than the Western on territorial levies, *limitanei*, and correspondingly less on mobile field forces, *comitatenses*.[100] Whatever may fairly be said about the inherent limitations of *limitanei*, the barbarian probes through the Caucasus were thereby constrained.

The bureaucrats of sixth- and seventh-century Constantinople furthered this reliance on what Gibbon extolled as 'rustic and martial simplicity'.[101] A Farmers' Law enhanced peasant rights as regards, for example, land disposal. The settlement of peasant farmers in militarily significant territories underlined their importance. The peasants' self-sufficiency was in line with the prevailing ethos. Arguably, their low rate of agricultural innovation mattered less against a background of high mortality. Above all, the bureaucrats often countervailed against the aristocrats in specific disputes. Granted, the invincibility of Byzantium ultimately rested on (a) the near-impregnable battlements of Constantinople, (b) many good ships and anchorages and (c) a monopoly of 'Greek fire', an incendiary mix based on Black Sea naphtha and used for projection from forts and ships. But the territorial levies (now called *themes*) shielding the fulcral region of Anatolia, in particular, still helped to underpin stability.

The seventh century also saw a big drive towards Hellenism, a reaffirmation of the Greek roots of Byzantium as opposed to any Latin ones. A prime aim was to foster a surer sense of national identity and purpose, at any rate in the core area. The same applied to the encouragement of the arts and of scholarship, most notably across a span of 100 years that knew several emperors of unusual vision and ability. This span started with the forceful assumption of power in 867 by Basil I, a much-larger-than-life personality of Macedonian peasant stock. Where the imperial quest for national identity had already proved decidedly unsure, however, had been in its promotion of a Church supposedly purified by the general destruction of sacred pictures and statues. The Iconoclast Movement (730 to *c.* 845) brought violent discord to Constantinople itself; made the split with Rome all but final; and ultimately collapsed in the face of a rural, clerical and artistic backlash. Nevertheless, by the time of Basil I, regional commerce was reviving. A milestone in the metropolitan recovery had been the repair in 766 of the Valens aqueduct, a main conduit the Avars had wrecked in 626.[102]

However, a mild regional boom based on the sound gold coinage was to the benefit of large landowners producing for sale as against the self-subsisting peasantry. By 700, in fact, weather changes on the Anatolian plateau were interacting with the national economic recovery to favour there a development of ranching underwritten by a modicum of capital investment on water control coupled with the wider installation of watermills. At the present time, January temperatures on the plateau (typically 1,000 metres above sea level) average 5°C. A rise of, say, half a degree above any such pre-existing mean in the eighth century could have reduced midwinter snow-lie appreciably. That and the lower rainfall will have reduced the competitiveness of the labour-intensive agriculture practised by the peasantry. The succour thus given to the ranching interest will *ipso facto* have disadvantaged, too, a Constantinople deep in the throes of iconoclasm.

Be that as it may, not until the twelfth century do the Byzantine chronicles drop silent on the subject of periodic dearth.[103] The long and bitter Anatolian winter of 927–8 had caused 'the great famine', with many peasants finally selling out to rich landowners. Undoubtedly, too, the susceptibility of Byzantium to climatic 'acts of God' had been aggravated by military encounters the previous quarter of a century. A particular setback had been the total loss of the granary island of Sicily to the Muslim Arabs in 902. The tenth century as a whole was continually punctuated by warfare against Arabs, Bulgarians and rebellious provincial landlords. The fortunes of war swung wildly, albeit within certain limits.

In essaying even a provisional overview of the part climate change may have played in the strategic fortunes of early Byzantium, one has to bear in mind that (a) we await more research on weather fluctuation on the decadal timescales that may here be quite critical, and (b) climate change around the Mediterranean can be very uneven across lines of longitude as well as those of latitude. There is also the particular question of how compatible the climate analysis pursued above is with the Vita-Finzi thesis outlined on pp. 114–15, and, of course, the collateral issue of how compatible it needs to be at this stage in our understanding. All that said, one may tentatively infer that, through Late Antiquity, a secular rise in rainfall between the Aegean and the Caspian had contributed to the resilience of Byzantium, though maybe, too, of their Sassanid adversaries in Persia. But later falls of population due to plague and, eventually, economic and social restructuring, against the background of climate change, will have left Anatolia, in particular, more open to attack. What can more specifically be allowed is that the Justinian plague, along with the post-Krakatoan weather, cramped on both sides the campaigning triggered off by what might otherwise have been the critical Persian invasion of 542.[104]

The launch of Islam

The Islamic Arab expansion is generally deemed to have taken off with the death of the Prophet Muhammad in 632 and to have peaked out in Europe, militarily speaking, when Charles Martel defeated a Muslim army at Tours in central France a century later to the very year. However, the wider impact of the new faith was only starting to register. One of the great services of Islam to European culture was to act as a sanctuary for original editions of the classics of Greek Antiquity. The transfers were mainly negotiated through Jewish mediation, in the tenth century, with a Byzantium wearied by the Iconoclast disaster and other travails.

By 632, Islam had achieved an insecure ascendancy over the west side of the Arabian peninsula. Twelve years later, it had firmly extended through Arabia, Mesopotamia, the Levant and the Lower Nile. Its 632 core area had been the Hejaz, a region that bestrides the north and centre of the mountain axis extending from near the Gulf of Aqaba into the Yemen. Rain is very largely confined to the summer. The Hejaz lies within the outer circulation of the south Asian monsoonal low, a troughing from which usually extends deep into the Sahara more or less along (as of the present) the 20°N parallel. The mean annual rainfall at a given location will much depend on topography and aspect.

In upland parts of the Yemen to Hadramaut sector, yearly norms nowadays are very generally between 100 and 500 mm. This may yield adequate supplies of water, as long as irrigation is in place. But from the Hejaz to Oman, sharp fluctuations in rainfall – annual or secular – figure throughout history. Crucial, too, is how much the historical responses are conditioned by cultural and political factors. Islam's emergence in the Hejaz may be seen as a response to an adverse turn in the climate. But Islam was also a legatee of cultural and political developments the previous several centuries.

The Yemen–Hadramaut sector had risen to prominence during the last pre-Christian millennium. It was *c.* 950 BC that the Queen of Sheba (or, probably, Saba) had led a resplendent caravan to visit King Solomon. Two centuries later, a stone-faced dam was built close by Marib, the capital of Saba. Two thousand feet wide, the main section of this centrepiece of Saban irrigation impounded flash-floods sufficiently to irrigate 24,000 acres. Greek and Roman scholars of the first and second centuries BC acclaimed the wealth of south-west Arabia. The Greek historian and geographer Strabo (*c.* 63 BC to *c.* AD 25) lauded the 'costly magnificence' of its palaces with their interiors reputedly studded with jewels. Such imagery may have nurtured his conviction that the culture of people was never just a straight response to its ecological ambience. Then, in the second century AD, Claudius Ptolemy of Alexandria mapped the known world. He labelled much of the Arabian peninsula 'Arabia Felix'. However, the allusion was, above all, to its south-west.[105] It is to that segment the term will here be applied.

A less enduring but more descriptive rendering was Arabia Odorifera. What this celebrated was not just the grip south-west Arabia had secured on the trade across the Indian Ocean in exotic commodities – it was also its lead in the production of perfumes/medicines in the frankincense and myrrh family of tree resins. However, through assuming this central role, the region lost the security of obscurity. That its political unification *c.* AD 300 could not offset. Instead, decline set in. Cultural and religious cross-currents (Jewish, Persian Christian . . .) surged from without, the precursors of political takeovers. Ethiopia ruled over the erstwhile Arabia Felix from 525 to 575; then Persia did until its dynastic crisis of 628. The Ethiopian occupation looks disastrous in terms of disruption and neglect. In the 540s a flood breached the Marib dam for the first time since 450. A decade later the same happened again, with silting so severe that half the irrigable capacity was permanently lost. After a third breach in 590, the dam was abandoned. Social fatigue was too far gone.[106]

So what part may climate change have played in this precipitate decline? *Prima facie* David Keys links a marked regional rise from the 530s in erraticism (severe floods and droughts) with the big Krakatoan event. Certainly aggregate levels of silting, 540 to 590, were remarkably high. Against this background tens of thousands emigrated, especially to a Medina already suffering from a collateral decline in trans-Arabian traffic.[107]

Also to bear in mind, however, is the probability that the median lie of the Inter-Tropical Convergence Zone (ITCZ) in summer was already well to southwards in the Afro-Arabian sector because of a tendency that was to culminate in the twelfth century or thereabouts (see p. 319). In modern times, ITCZ location has fluctuated considerably, not least from year to year. A median August lie will virtually bisect Arabia Felix.[108]

Broadly speaking, 'moist conditions prevail equatorwards from the ITCZ and dry conditions occur poleward from it.'[109] Besides which, there will have been convective showers along the ITCZ itself. Arabia Felix should therefore have become drier, an inference that gels well enough with the wider Holocene experience that, on millennial timescales, more rain across the Anatolia–Persia arc is often associated with less in the Indo-Arabian and vice versa.[110] Granted, a converse argument could be that Arabia Felix might thus have come more completely under the influence of the Indian summer monsoon. Depending on the upper air structure, that could occasionally have allowed of 'orographic' (i.e. mountain-induced) downpours as air from a northerly quarter, sometimes recharged with moisture over the Red Sea, struck Yemeni mountains rising near to 10,000 feet. On balance, however, southward displacement of the ITCZ must have been a climatic source of economic weakness.

To it should be added a shortfall related to rites of passage. As their witness spread, the

Christians discouraged embalming the dead. They thereby much reduced the demand for frankincense. No doubt this is why the small but resplendent frankincense market of Ubar in Dhofar proved unable to recover from a major earth movement half way through the first Christian millennium.

This reduction must also have affected the oasis towns of Mecca and Medina, as well as other staging posts on the caravan trail from the Yemen through the Hejaz to Petra and Jerusalem. On the other hand, the Hejaz may have been less directly susceptible than Arabia Felix to climate shifts on a centuries timescale: little influenced rainfall-wise by the exact position of the ITCZ and more able, in any case, to sustain its thin population with fossil groundwater available via the oasis springs. But whether discomfited by ambient change or not, the Hejaz, and especially Mecca, had enjoyed something of a cultural uplift from the third century AD as, led by the Quraysh tribe, the Bedouin communities drew on an *esprit de corps* born of hundreds of years of martial horsemanship. As a moral bulwark against encroachments from whatever direction, classical Arabic was refined and enriched with poetic artistry. Towards the end of the fourth century, an Arabic script had emerged, apparently as a Nabataean derivative.[111] A metric notation was developed, too, as was an elaborate code of chivalry.

Tradition further indicates that the Quraysh embraced a quasi-biblical monotheism, not pagan polytheism. That confronts one with a theme in the geography of Holy Land history George Adam Smith wrote in 1894. Smith appears oblivious to climate change. Instead, he was enthralled by the impact of climate as supposedly invariable; and, in particular, by the idea that the stark bareness of the desert encouraged single tribal gods that could, at a certain stage of cultural development, translate to an all-encompassing monotheism. This notion he had gleaned, somewhat equivocally, from Ernest Renan (1823–92), the French historian of early Judaeo-Christianity.

The religious culture of the Indian subcontinent invites comparison. Agreed, a Hindu pantheon could hardly emerge against too austere a background. Nor might such a god as Vishnu with his four arms and diverse incarnations. Nor, indeed, would a Buddha figure forever seeking benign harmony with a regenerative natural order. However, the presumptive corollary that monotheism abhors the rain forest holds less true. Over a third of the people on the subcontinent today are Muslim, a good half of them in areas subject to monsoonal downpours. None the less, the Renan thesis as here presented has resonated from his day till now. Lawrence of Arabia is a case in point.[112]

Resonant, too, is Smith's own opinion that the desert or near-desert breeds 'seers, martyrs and fanatics'.[113] In this realm, however, causal relationships are intricate and contingent. During the Islamic expansion, its horsemen regularly fought with fervour against the infidels or, if none were to hand, one another. Yet in the wake of conquest they just as regularly turned to co-existence in one mode or other.

To see how far ambient factors conditioned the emergence of Islam, we must turn again to Mecca and Medina. The latter had languished badly within the context of regional decline, due no doubt in part to the refugee influx but also to tensions between Arab merchants and the locally powerful Jewish ones. But the Quraysh of Mecca, the lineage the Prophet Muhammad himself came from, had been building their town's trade up despite the waning of Arabia Felix. Yet to Muhammad and a growing band of revivalist adherents, the spiritual cost was too high in terms of material indulgence, economic polarisation and lapses into primitive idolatry. What they sought, in effect, was a return to the enlightenment of the third century.

Hence their flight to Medina in 622, to secure it as an offset to Mecca, through a combination of (a) urban acumen and caravan raiding, and (b) popular submission to Allah, a local tribal deity now elevated through the prophesying of Muhammad to be the one and only God. That elevation was in tune with a marked internationalisation of Mecca's trade (under Muhammad's great grandfather) from AD 550. The upshot was the Prophet's triumphal return to Mecca in 630, a denouement played out against a background of a trade recession his campaign had deepened.[114] Certainly it will have been worsened by the elimination (through death, expulsion and enslavement) of Medina's Jews. But, as was intimated in Chapter 1, an acute drought also came into play.

Historians in the West have long debated how far secular droughtiness across the Hejaz was a catalyst for Islam. Two famous orientalists, Leone Principe di Caetani of Italy and Carl Becker, then Professor of Oriental History in the Colonial Institute in Hamburg, argued early on it was a prime driver. Caetani saw this climacteric as the latest of six such crises in the Arabian Desert in the last 7,000 years as demographic expansion ran up against water shortage, large-scale migratory movement being either trigger or consequence. In rather similar vein, Becker wrote in 1912: 'The sudden surging forward of the Arabs was only apparently sudden. For centuries previously the Arab migration had been in preparation. It was the last great Semitic migration connected with the economical decline of Arabia.' Oral legends and rock inscriptions affirm that 'for a long period the conditions of life in the southern part of the Arabian peninsula had been growing worse.'[115] By 1925, the concept of drought cycles of millennial length was part of received wisdom.[116]

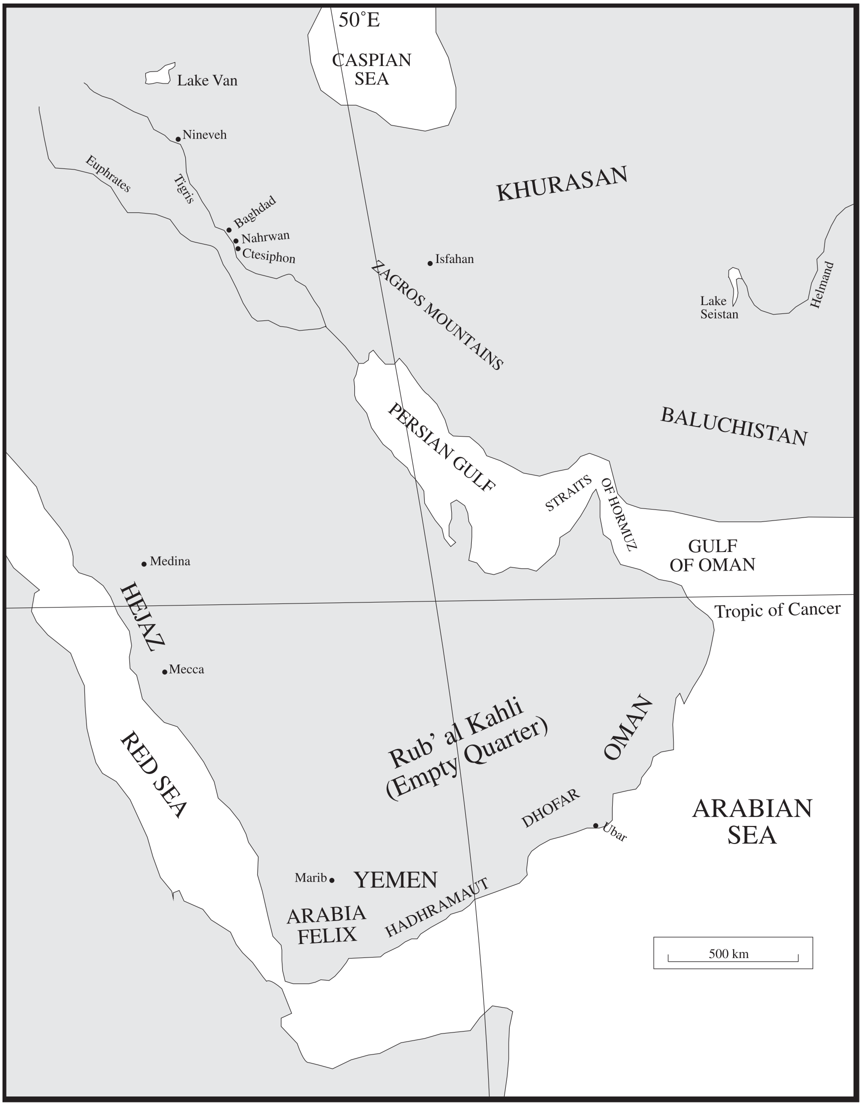
A priori, however, it is easier to comprehend the impact on marginally placed pastoralists of oscillations sharp enough to be registered in the course of their individual working lives. There is room, too, for further debate about the significance for nascent Islam of fluctuations from one year to the next.[117] Moreover, modern rainfall records confirm something like a 20 per cent variation in rainfall from one decade to another in so marginal a setting (see Chapter 1).

The folk tales of the local Sherarat tribe are very explicit about how much more numerous its people had once been. Then, in the time just before Muhammad, no rain fell for seven years. So the great majority migrated via Egypt to Tunis. Scores of other tribes were obliged to react similarly.[118]

The Islamic expansion

Yet in this instance it is especially hard to draw the neat distinction always sought between the migration of a whole people (usually enforced by famine or war) and the movement into newly conquered land of a ruling class. At first sight, the expansion out of Arabia was a cadre one involving language and religion but not entire peoples. Nevertheless, the exiting from the Hejaz of maybe 10,000 or 20,000 warriors plus their dependants will have been, in Arabian terms, a major demographic displacement. Obversely, in target territories like Egypt they would still appear as a military elite equivalent to only 1 or 2 per cent of the existing inhabitants.

Nor may this illustration be unrepresentative. The population of Egypt early in the seventh century (in the near aftermath of the Justinian plague) has been conservatively guestimated at 2.6 million.[119] The extent of the Hejaz, customarily given as 150,000 square miles, could connote a population of 250,000 under the conditions obtaining. That in its turn might allow of a warrior host of 30,000. In fact, armies 5,000–10,000 strong often figure in accounts of Islam's early decades. The first wave to gallop into Egypt may have been a mere 3,000.



Map 4.3 The Gulf and Arabia

The sequence was probably like this. The Muslim conquest of Arabia in the two years following the Prophet's death in 632 did not involve major demographic transfer. It was a process of cultural and geopolitical consolidation under 'the one God, Allah', undertaken partly to contain the disintegrative tendencies in and around Mecca itself, tendencies apprehended the more because of the suddenness of the Prophet's demise. With the capture of Damascus in 635 and Jerusalem in 637, things entered a phase involving the emigration from Arabia of elites led mainly by the Ummayads, the most powerful Quraysh clan. Expansion then acquired an ongoing momentum as these Muslims fused, however factiously, new-found courtly lifestyles and traditional desert mores.

Throughout the Middle East and North Africa, conquest and assimilation were facilitated by the supineness of the target regimes. Climate adversity may have contributed to this, too. It does seem that, in the seventh century, the secular dryness trend identified above was under way throughout the 'Fertile Crescent' from Palestine round to Upper Mesopotamia. Previously, this broad swathe of steppe land had extended deeper into Syria's desertic interior, Badiet esh Sham, than it thenceforward did or, indeed, does today; this circumstance had been abundantly reflected in the economic and cultural achievements cited below, but also in political geography. Thus Palmyra had been at its zenith in the third century as a quasi-autonomous city-state within the Roman Empire. Then the overweening ambition of its Queen Zenobia led to its being sacked by Emperor Aurelian in 272–3. It proved unable to recover. Today only a small village occupies this site.

Widely across the 'Crescent' there is evidence (e.g. in church architecture, olive plantations, and agricultural terracing) of a peaking out in the sixth century. Then from 610 onwards came the very destructive Persian invasion, followed by an extensive Arab conquest 20 years later. Civilisation declined regionally with little new development taking place until the castle building and restoration of the Crusader era. A Princeton study published in 1920 concluded that extreme paucity of rain must have figured in so sudden and comprehensive a decline. It had observed to 38°E across northern Syria, sixth-century churches 'more ornate than any Christian buildings before the Gothic period in Europe'. Public baths, 'sumptuous villas' and grand mausoleums similarly abound.[120]

This swing towards drier conditions is visible as far as the Negev. The study from northern Israel cited above can be adduced. So, too, can one in which Issar and Haim Tsoar reject the pre-existing understanding that settlement retracted in the Negev during the second half of the first millennium AD entirely because of the Islamic takeover. They argue that this retraction (which involved the abandonment of six cities) was considerably the result of a climate flip to a warmer, drier trend.[121]

On any sensible interpretation, judgement as to how far Islam was responsible for the regional decline has no bearing on the competing claims of Israelis and Palestinians to the Holy Land of our day. That simple truth is one much of Israel's present academe unreservedly accepts. The fact is, however, that linkage was presumed, during and just after the Second World War, as Zionism became a highly charged subject, not least within Anglo-America. Some rhetorically enquired what the Arabs had ever done to 'make the desert bloom'. Particular attention was paid to the conquest era and also to the centuries that immediately followed it. What of the further retraction from the ninth century of the frontiers of settlement in the Hejaz and East Bank Jordan as well as across Syria?[122] Was this due to cultural or maybe strategic factors or had the seventh-century aridity been the *entrée* to several hundred years of exceptional dryness across a wider region? *Prima facie*, recent research on the annual Nile floods lends support to the latter hypothesis. It is from 622 (during the brief Persian occupation) that flood readings are systematic and regular. Analysis of them shows that the Nile's full flood, measured at what became the site of Cairo, has to be described as 'weak' for 28 per cent of all years between 622 and 999, as against for only 8 per cent of those between 1000 and 1290.[123]

To establish a connection with the weather in and around Arabia, one reasons thus. The chief variable in the Nilotic summer flood is the flow of the Blue Nile off the Ethiopian highlands. This topography lies within the outer circulation of the south Asian summer monsoon, like Arabia and much of the Fertile Crescent. Accordingly the strength of a Nile flood is a good indication of the seasonal rainfall tendency in the Hejaz and the Yemen.

The criticality of the Blue Nile derives, first and foremost, from basic geography. The

White Nile flows through 15° of latitude whereas the Blue Nile traverses but six. Therefore the former is exposed to a spread of climatic tendencies, these sometimes contrary one to another. Moreover, the White Nile passes through the swamps of El Sudd. These have exercised a modulating influence ever since their evolution in the aftermath of the radical adjustment the Nilotic drainage system went through *c.* 12,000 BP as the equatorial climate turned moister within that zone of longitude. The river further downstream ceased to be extensively braided with an erratic flow and became what it has since remained, a well-incised feature with a strong though seasonally accented flow. That adjustment coincided with the Older Dryas, a defined cool interlude, lasting two centuries, in the post-glacial warming of Europe.[124] From 11,000 to 10,300 BP, there was to be the similar Younger Dryas. That time round, a good half of Europe was largely given over to tundra.

When assessing what part the White Nile may have played these last 2,000 years in determining fluctuations downstream, there has been a disposition to look at variations in the extent of Lake Chad. The lake's catchment area is outside the river's but seems broadly comparable with it. For the centuries one is here concerned with, however, there have been conflicting interpretations. In 1972, Hubert Lamb depicted a general extension of Lake Chad from *c.* AD 250 to 1000.[125] But in 1981, Fekri Hassan perceived overall shrinkage at least during the ninth and tenth centuries. Accepting Lake Chad as a good proxy for the White Nile, Hassan was further persuaded that the latter was then the prime source of interannual fluctuation in the Nile proper.[126] Nevertheless he freely acknowledged that, during the flooding season (July to September), the Blue Nile's flow of water is usually over three times as rapid as its annual average. Correspondingly, that tributary's contribution to the supply downstream averagely rises from one-quarter in the minimum water month of June to well over three-quarters in August.[127]

Not that this *ipso facto* means Nilotic flood fluctuation is infallibly a reflection, year on year, of aridity across Arabia. One complication will be how rainfall in the source region of Ethiopia is affected by shifts in the axial lie of the ITCZ. Take a graph drawn by Lamb on the basis of a data compilation Sharon Nicolson had undertaken at the University of Wisconsin. This shows a consistent inverse relationship, schematically on secular timescales, between the maximum height of the Nile at Cairo and the level of Lake Rudolph in Kenya. The latter is positively responsive to southward displacement of the convergence zone. But when such translation is at all pronounced, it must leave the Ethiopian highlands that much drier. The fact of the matter is, however, that the Nicolson graph shows Rudolph as very high from AD 300 to 1100.[128] That does not exclude ITCZ mobility intra-annually, seasonally or, indeed, week to week. But it does underpin the assumption that, for the era that concerns us here, the positive correlation observed early in the last century between the Indian monsoon and the Nile flood (see Chapter 2) applies with emphasis.

Not surprisingly, there is no concurrence (up to the year 1000) between the Nile's vagaries and the incidence of famine elsewhere around the Mediterranean. With east of the Jordan, there is some linkage. Abnormal mortality from starvation and related epidemics are recorded for Seistan in 836; Iraq and Syria together with Egypt in 939; and Baghdad in 944–5.[129] All coincide with what are indicated as weaker than average Nilotic floods. However, in no case is the perceived weakness pronounced; and only in 945 is the Nile reading viewed with high confidence.[130]

Also to reckon with is a hypothesis Claudio Vita-Finzi, a geographer at University College London, first presented in 1969. He found that, within a wide zone of latitude axially extending from Iberia to Persia, the redistribution by rivers of eroded material from their upper reaches to their flood plains underwent a systematic succession of transient increases between Late Antiquity and the High Middle Ages. This was because the paths of winter depressions were progressively displaced southwards.[131] In 1976 he inferred a displacement of the median cyclonic track from the 45° parallel of latitude *c.* AD 500 to that of 30° a thousand years later – i.e. from the latitude of Zagreb to that of Cairo.[132] The band of moister conditions associated with this track is deemed successively to lead to increasing erosion in the upper valleys, hence to more deposition downstream.

His analysis drew upon field studies in just eight locations, barely enough to confirm a thesis so arresting. Still, frontal lows traversing the Mediterranean twin basin will nearly all have originated within its bounds. Moreover, it is likely that they did become less closely aligned with systems further north as medieval warming developed. The Vita-Finzi thesis is now very much part of the ongoing discourse about historical climatology in the Mediterranean. As it stands, it lends extra credence to the Anatolian progression as depicted above.

The Holy Land

In consideration of the advent of Islam against a background of climate change, particular attention has been paid, especially since the Holocaust, to Palestine and the lands around. Ritchie Calder emerged in the 1940s as a pioneer of British science journalism. He inveighed, via UNESCO, against contemporary desertification. Impressed by the Zionist reclamation drive, and suffused with a conviction that any desert that once bloomed can do so again, he discounted climate change as a historical influence in Mesopotamia and disregarded it apropos Palestine.[133] More insightful are the comments of one of his contemporaries, Walter Clay Lowdermilk. This former Assistant Director of the US Soil Conservation Service became Chairman of the Commission on the Arid Zone, a body established by UNESCO early on. He was, too, a devout Christian and biblical student who, much like Albert Einstein,[134] saw Zionism as a means of affording the Jewish people more security but also as a way to revitalise the Holy Land via Jewish–Arab partnership, its crowning triumph perhaps being a Jordan Valley Authority.

Though rather contradictory, this judgement by Professor Lowdermilk has to carry weight:

> The decline of Palestine's land and of the people began with the first Arab invasion during the 7th century of our era. However, several centuries were to elapse before the country reached the stage of utter desolation. Although the nomads destroyed many cities and overran cultivated areas with their destructive herds, much of Palestine seems to have escaped the full effects of this first wave out of the desert. The country still was fertile and many of the native population were allowed to remain and to continue their traditional ways of farming or carry on their former trades. It was not until the wars of the Crusaders during the 12th and 13th centuries, and the second Arab invasion which drove them out, that Palestine was plunged into its age of darkness.

He saw Bedouin destructiveness as largely confined to the Sinai and Negev initially. He cited Mukaddasi, a tenth-century Arab traveller, as extolling the bounteous diversity of Palestinian agriculture. Obversely, Ishtakhri, another tenth-century Arab traveller, was quoted as describing Moab (an upland region east of the Dead Sea) as potentially rich except that Bedouin ascendancy had ruined it.[135]

Writing in the fraught years after the 1973 Arab–Israeli war, Eliyahu Ashtor laid stress on the soil erosion in Syria and elsewhere in the Fertile Crescent caused by 'semi-nomadic' Arabs preferring haphazard cereal growing and pastoral overgrazing to maintaining terraced olive groves. In the Plain of Sharon, many villages were abandoned between the Arab conquest and the First Crusade – at any rate along a coast exposed to Byzantine forays. He drew on geomorphological evidence of up to 8,000 square kilometres being lost to agriculture, in that era, in west Judaea alone. He took note of Vita-Finzi but dismissed any idea of sharp alterations in precipitation regimes being causative here or elsewhere in the Near East. Nevertheless, he thought it 'erroneous to believe that after the Muslim conquests there was a real cataclysm in the agricultural history of this region. In fact, there was rather a progressive decline' over time, with some new settlements being built the while.[136]

Lately the Nabataean nationhood centred on the 'rose-red city' of Petra in the lower Jordan valley has proved singularly revealing. A study for the Jacob Blaustein Institute of Desert Research at Ben-Gurion University inferred from contemporary documents discovered in 1937 at Nizzana (close by the present Egyptian–Israeli border) that multi-crop agriculture peaked in the Negev in the sixth and early seventh centuries, sustained by terracing and other techniques for managing rainfall run-off. Then things progressively declined, the more in the eastern Negev, where the Arab conquest involved some destruction – e.g. the firing of churches.[137]

Earlier a still tribal and nomadic Negev had been subject to a determined 'Romanisation' by first Rome then Constantinople: a process involving many strands including the Greek language, Christianity and urbanisation. This was against a background of comparatively moist conditions. Six small cities could hardly have been established *c.* AD 500–625 within 35 km of Sede Boker (today a realm of awesome desert wastes) had the water cycle not been stronger than ever since.[138] The total number of settlements in the Beer Sheba plain was around sixty in the middle of the first millennium. At the beginning and again towards the end, it was about fifteen.[139]

The heyday of Nabataean civilisation proper had been from the fourth century BC to AD 106, when it was subjugated by Rome. The alienation that this must have induced will have been a backdrop to the decline of Petra as a nodal link between the *via odorifera* across the Hejaz and the Mediterranean. This Roman takeover will have coincided closely with a climatic peaking out, precipitation being the key parameter. One should recall the evidence adduced in Chapter 3 for dubbing the first century AD a good one climatically in Palestine, not least in the marginal Dead Sea region.

In northern Syria, Ashtor perceived hard proof of a flourishing civilisation being, in effect, discarded by intruding Bedouin in the seventh century. He quoted Lowdermilk as concluding that good *terra rosa* soil was widely washed away to depths of several feet. But as regards Mesopotamia, he deploys a more interactive interpretation. Long before the Arab Islamic advent in 637, a bursting of dams had caused much of the Tigris-cum-Euphrates basin to become flooded or swampy. Then around the time of the conquest 'things went from bad to worse, and the Great Swamp was formed, covering an immense area between the two great rivers, from Kufa to the environs of Basra. The Tigris shifted from the eastern (present) bed to the western and flowed into the Swamp. This change turned all the country bordering on the old channel into a desert.' None the less, within a century of the conquest, much restoration work had been effected.[140] There was also technology transfer to Al-Andalus.

The common-sense argument for restoring the *status quo ante* was even more compelling on the Mesopotamian flood plain than elsewhere in the Fertile Crescent. Similarly, Arab sources on the Abbasid regime in Persia tell of 10,000 people being subordinate to the Merv water office. Four hundred guarded the main storage dam and the distribution of water was finely calculated.[141]

Clearly, one must always separate the question of what occurs at the time of conquest from what transpires in the decades and centuries thereafter, and also allow that any forceful takeover may be the more disruptive in the context of ecological adversity. Regarding the Fertile Crescent, one ought also to be cognisant of there being two distinct conquests in quick succession. Preceding the Islamic advance had been that last and very dreadful campaign by Sassanid Persia into Anatolia, but also down the Fertile Crescent to Egypt. In 613, Damascus fell; and the following year Jerusalem did, some 60,000 there being massacred as Christians by the Persian soldiers or, the more so, in the ensuing communal conflict between the Christians and Jews. The 'devastation in and round the city was so vast that to this day the countryside has never fully recovered.'[142] Likewise, Howard Butler saw 610 as a climacteric year in Syria.[143] The subsequent Arab takeover of Palestine (635–9) seems mild by comparison, in terms of the suffering and environmental degradation imposed. But maybe both episodes were aggravated by the simple fact that the climate was already getting droughtier. What must be remembered, in any case, is that 639 witnessed an outbreak of plague throughout Palestine.[144]

North Africa and Iberia

The polemics have also extended to the Arab takeover west of the isthmus of Suez. Writing about North Africa in 1950, Rhoads Murphey of Ohio State University noted an apparent contraction of agricultural land under Byzantine rule (i.e. to 638), as well as 'intermittent' Arab references to climatic deterioration. However, he reasonably observed that in modern times the climate had been no worse than in the first century AD. Throughout the historical period, he less reasonably insisted, one finds 'only minor and conflicting evidence of even slight changes' of climate regionally, this in sharp contrast with, say, the Neolithic.

Next he arbitrarily asserted that, within a century or two of the conquest, of the order of a million [*sic*] Arabian nomads had arrived in North Africa, blindly committed to a pastoralism that involved heavy reliance on the omnivorous goat coupled with a generalised disdain for trees except as firewood. Town life, too, was despised. Disintegration, he duly inferred, was soon the consequence, in spite of putative climate stability.[145]

All else apart, visions that lurid do not easily relate to the ease of the initial Arab advance. From the Nile delta to Tripoli took but two years, and from Gibraltar to Toulouse under ten. The weakness of the opposition everywhere was a follow-through of the late Roman urban syndrome. The decay yet again of Carthage 'to a shadow of its former self . . . appears to be typical of cities large and small, all over the Mediterranean'[146] in the century or two before Muhammad. This is at one with how each and every walled city of the Fertile Crescent fell inside four years (635–9) to smallish contingents of Arab irregular light horse with no heavy equipment. Bringing to bear his expertise on Byzantium, Cyril Mango noted how readily 'walled cities fell to an enemy who was often neither very numerous nor very skilled in siege warfare, and the absence of any urban resurgence after the enemy had withdrawn shows . . . that military hostilities were merely the last shock that brought down a tottering edifice.'[147] In similar vein, Sir Steven Runciman stressed the alienation of Syria and Egypt from an ever more centralised administration taxing high in order to sustain itself and keep all the denizens of Constantinople 'well fed and contented'.[148] Egypt was further aggravated by the way its corn trade to the metropolis was losing out to Anatolian suppliers still well sustained by the secular moistness tendency. In short, the Byzantine recovery looks to have been very shallow on the Empire's exposed peripheries.

Accordingly, one should ponder how far climate adversity had already sapped the material strength and psychological stamina of vulnerable territories. The climate situation remains more obscure in North Africa than in the Near East. Quite possibly, Egypt's corn crisis owed something to local environmental trends as well as to Ethiopian ones. The Nile valley had been developed by the Romans as a wheat bowl which quintessentially matched their notion of a 'heavy, rich, treeless soil' (as Cato the Elder put it) being the right medium for that grain.[149] But the *modus operandi* may have had to be so intensive that a fall in the labour force of 25 per cent with the onset of the Justinian plague in the 540s perforce resulted in a similar proportion of arable being abandoned. Also the sixth century, or maybe the seventh, witnessed major breaches of the delta perimeter by the sea, replacing fecund flood plain with brackish lagoons.[150] Moreover, a combination of backward extrapolation and forward examination suggests a trend from a peak of high Nile floods in perhaps the sixth century into a trough of low floods which passed through *c.* AD 700 to judge from informal inspection of the tabular evidence, or maybe *c.* AD 850 if decadal moving averages are calculated instead.[151,152]

What cannot be said is that the particular decade that encompassed the Arab invasion of Egypt (i.e. 635 to 645) was abnormally prone to flood deficiency. More specifically, there is no record of a crisis of this kind during the actual takeover of the lower Nile, 640–2.[153] Nor is a stronger winter ridging of the Azorean High likely to have been under way in the eastern Mediterranean before the second half of the eighth century. On the other hand, the Justinian plague was to erupt periodically through the seventh and beyond. What is not clear is how susceptible intruders newly arrived from out of Arabia were to this climate-related pathology. In principle, the probabilities could be argued either way.

Between the Sinai and Gibraltar, only the Berber tribes in the Atlas Mountains offered the Arabs serious resistance. Soon thereafter, these martial peoples made up a high proportion of the 30,000, all more or less Islamicised, that took over two-thirds of Iberia in the course of the eighth century. How far was the adaptive resilience of the Berbers a function of the near-impregnable topography of their mountain fastnesses? How far was it due to these mountains being subject to winter rains that were unlikely to be diminished at all critically by regional climate trends?

The Arab impact

Any assessment of the seventh-century Arab conquests should be conducted sector by sector but within the context of broader tendencies. Christianity had become fissiparous, not least in Syria and in the Iberia of the Visigoths. In general, the new nationhoods arising out of the ruins of the old Western Empire were as yet insufficiently consolidated, while Byzantium, alias the Eastern Empire, was still immoderately large. Nor were endeavours by Constantinople to create a national consciousness through a revival of Hellenism ever liable to resonate much beyond the Aegean. Elsewhere it came over as an alien urban fad.

What the specialist commentaries stress, however, is that the faith Muhammad propagated was urban-centred: able to 'multiply cities at will' even if these commonly lacked individuality and autonomy.[154] For an invasive philosophy this anti-rural inclination was perhaps no bad thing if spatial constraints were thereby set on how much it might impinge. At all events, the austere monotheism that made Islam fearsome on the battlefield also enabled it to accommodate other faiths in the wake of victory. Gibbon's appreciation was to exercise great influence. He well divined Islam's primordial appeal but depicted it as rooted in Enlightenment virtues to an extent that appears naive as regards its history and downright absurd in respect of its origins.[155] At the same time, there was one theme in early Islam that Gibbon and his Enlightenment peers failed to pick up: the sanctity of Jerusalem and the

'Holy Land' of Palestine.[156] This may have made the Islamic takeover there the more respecting and respectable. But it was still not so orderly as to preclude the plague outbreak.

Nor should one forget that not even Islam's Bedouin element was pure nomad in lifestyle the way that, say, the Mongols would later reveal themselves to be. None the less, in situations where the marginality of the local agriculture was already being made the more acute by climatic change, the forceful arrival of this creed was bound to be somewhat destabilising, a proclivity specifically reinforced by discordance between its lunar calendar and any agricultural cycle. As and when ecological circumstances were positive, however, Islam was to prove adequately adaptive or, if one prefers, adoptive, including apropos the calculation of the seasons.[157]

It was in Muslim Spain (Al-Andalus, alias Andalusia) that this adaptive/adoptive propensity was most dramatically expressed. Roman irrigation networks were restored and much extended, thanks to technology transfers from Egypt and Mesopotamia. Around Córdoba alone some 5,000 waterwheels would eventually be installed. Over a hundred kinds of fruit and vegetable were cultivated, including rice and sugar – each figuring in Iberia for the first time. Emphasis was placed on grapes for wine, the Qu'ran notwithstanding. So was it, too, on the oil from olive trees, a good substitute for the fat in the pork the Qu'ran proscribed. In that era woodland cover reached what was perhaps its greatest Iberian extent these last two millennia.[158] So much for any idea that Islam was unconditionally contemptuous of agriculture and arboriculture[159] or, indeed, that the fatalistic resignation very characteristic of the creed made it appropriate only for life under the desert stars. One can never say religious culture has no bearing on climatic adaptation. One can always say the linkages between precept and practice are too criss-crossed to allow of trite cultural determinism.

Accepting that, one still has to resolve the contrast between what received wisdom used to say was the misery the Arab conquest brought to Africa and the undeniable bounteousness of Al-Andalus, the Spanish garden of Islam. Had Michael Rostovtzeff, for instance, any objective grounds for concluding that 'When, after the passing of Roman, Vandal and Byzantine rule, Africa fell under the sway of the Arabs, it reverted, like the Syrian lands, to very primitive conditions of life similar to those that had prevailed before its colonisation by the Carthaginians'?[160]

A key may lie in the cumulative evidence that, from Egypt through to Spain, much of the population long remained, under Arab rule, overtly Christian, especially in the countryside. Even in Andalusia, a majority may have done through the tenth century.[161] As for the Berbers, the same tribal mores as had sustained their initial resistance to Islam soon facilitated their acceptance of it.[162]

Gradual or delayed conversions confirm a relatively benign and often peaceable takeover by a regime not driven by purblind bigotry or over-stressed by a secular worsening of the geophysical climate. What comes across is an Arab willingness to build on the pre-existing culture, utilising in the process the urban entrepreneurial skills extolled by the Prophet and in the Qu'ran. In Africa, unlike Andalusia, this disposition effected no economic miracle. Nor did it ever achieve there a cultural renaissance such as the Maghreb and even Egypt had experienced in Late Antiquity. Witness then the cities of Hippo and Alexandria respectively. Differential shifts in rainfall patterns, on the Saharan fringe or in the Nile catchment area, bear on this contrast. As was intimated above, more fieldwork is needed on this point. So is more dialogue between historical climatologists and regional historians, especially those on each side specialising in territories outside the Levant. In the meantime, the options that were open to contemporaries are best understood within the wider dialectic between Islam and Christendom.

5 Northerly engagement

The new Islamic zone created and retained a large measure of cultural unity. Yet a corresponding political unity, derivative from the one caliphate located in Damascus or Baghdad, did not properly survive the eighth century. The absence of a theory of universal statehood is often adduced to explain why. The theological split between Sunni and Shi'ite does this more directly. The disparate character of the zonal geography of the Mediterranean and Near East does so structurally.

None the less, the Shi'ite-aligned caliphs of the Abbasid dynasty proved able to sustain in Mesopotamia, in effect from the founding of Baghdad in 762, a civilisation with scintillating aspects. Under the fifth caliph, Harun ar-Rashid (ruled 786–809), Baghdad

> was the richest city in the world . . . Arab merchants did business in China, Indonesia, India and East Africa. Their ships were by far the largest and best appointed in Chinese waters or in the Indian Ocean. Under their highly developed banking system, an Arab business man could cash a cheque in Canton on his bank account in Baghdad. In Baghdad everything was plastered with gold. Not only was it used to adorn the women but also the pillars and the roof-beams . . . Intellectual, and even theological, discussions were among the recreations of the educated classes.[1]

Of special importance to the Arab world militarily was the import of up to 10,000 tons annually of superior iron produced by thousands of small blast furnaces in Sri Lanka, all of them facing the south-westerly winds that blew there strong and constant for perhaps ten weeks at the height of the summer. Any tendency towards a weakened monsoon through AD 999 may not have affected that aspect much.

The Mesopotamian basin is too low-lying and eccentrically located to benefit much from the south Asian monsoon. But since its twin rivers, the Tigris and Euphrates, rise in the Taurus–Zagros Mountains on the southern side of Anatolia, they will have been affected by the secular diminution of rainfall on that plateau land from the eighth century. Also in the winter half of the year, Mediterranean depressions not infrequently cross those mountains into the Persian Gulf, directly depositing moisture on the Mesopotamian flood plain (25 to 75 mm a season) as they do so. Judgement as to how this modest contribution may have been affected by early medieval warming could hinge on an evaluation of the Vita-Finzi hypothesis.

All in all, the Harun ar-Rashid years were the culmination of a hydraulic civilisation rebuilt in defiance of the ecological tendencies – this under alien rulers unversed in relevant technical skills but inspired by one of the great monotheisms. Yet still, it was in a weak situation ecologically. Given the contradictions inherent in the caliphate concept, the resulting political tensions were especially liable to cause unrest in the more peripheral territories within its obedience. By the last decade of Harun's reign this was conspicuously the case.

Muhammad and Charlemagne

A theme to explore as an alternative to climate-shaped theories about the impact of Islam on Europe is one enunciated shortly before his death in 1935 by Henri Pirenne, a scholar whom one can still acknowledge as a titanic presence in the economic and social historiography of medieval Europe. A measure of the standing he achieved within his lifetime is that, although himself Belgian, he was on at least two occasions invited to become the editor of *Annales*.[2] The Pirenne thesis here alluded to has given rise to antithesis; and hence to a synthesis in which the Abbasids centrally figure.

The gist of the thesis itself was that, deep into the Dark Ages, the Mediterranean remained, even for Germanic tribes, 'the very centre of Europe, not least as a *mare nostrum* across which international commerce was preserved and within which it regenerated.' Then came the expansion of the Muslim Arabs. By 720 they held the southern coastline of the Mediterranean from the Levant round to the Pyrenees. By 850, they held some key islands: the Balearics and most of Sicily, plus Malta and Crete, though not Corsica, Sardinia or Cyprus. With the Mediterranean thereby reduced to 'a Muslim lake', so the argument ran, the centre of gravity of Catholic Europe was displaced well northwards. It was most visibly with the creation of a Frankish Empire, centred in Aachen, that in 800 (the year its ruler, Charlemagne, was crowned by the Pope in Rome as 'Holy Roman Emperor') stretched from the Elbe to the Pyrenees: 'Without Islam the Frankish Empire would never have existed and Charlemagne without Muhammad would have been inconceivable.'[3]

In 1951 and again in 1979, this bold declamation was to be endorsed by a distinguished Lebanese Christian professor at the University of Michigan.[4] Conversely, it had early on been dismissed on what now may seem the unsatisfactory grounds that the anti-town bias of the Germanic tribes perpetuated into the ninth century an urban and commercial malaise first manifest in late Roman times.[5] A more trenchant line of attack was to insist that the strategic grip the Arabs secured on the trade routes through the Near East did not exclude from the West such commodities as papyrus, oriental ornaments, spices and gold currency. Any disappearances were (a) not that complete, (b) not coincident with the Arab advance and (c) more the product of cultural change.[6]

What is depressing is the prejudicial fervour of Henri Pirenne's exposition of the consequences he claimed followed from the western basin of the Mediterranean being secured by Islam:

> the coast from the Gulf of Lyons and the Riviera to the mouth of the Tiber was now merely a solitude and a prey to piracy. The ports and the cities were deserted. The link with the Orient was severed, and there was no communication with the Saracen coasts. There was nothing but death. The Carolingian Empire . . . was purely an inland power for it had no outlets . . . . For the first time in history, the axis of Occidental civilisation was displaced towards the North; and for many centuries it remained between the Seine and the Rhine.[7]

Even so, he did allow that, by the ninth century, several Christian ports in Italy were trading with Islam extensively, Jewish communities being well placed throughout to bridge the divide.[8] Since when, a specialist study has confirmed such traffic, very generally through Jewish mediation, from the eighth century. Even Byzantium was engaged in this inter-faith commerce a bit.[9] By the early ninth, the city-state of Amalfi had assumed especial prominence through its pragmatic dealings with all comers.[10] Over the next century, its urban population mushroomed to 70,000. Harun ar-Rashid's decision to admit his pen friend Charlemagne to the status of protector of Jerusalem was a gesture in tune with the times.

Nevertheless, Eliyahu Ashtor may not have been far wrong when he said Mediterranean maritime commerce had disappeared 'almost altogether' during the course of the eighth century.[11] Certainly the eastern basin saw repeated forays by Muslims and Byzantines against one another from 700 to 925. Added to which, Byzantium regularly applied economic sanctions. Throughout, Constantinople proved militarily impregnable with its outer walls and Greek fire. The most menacing of three Arab expeditions against this metropolis had its morale shattered in the winter of 717–18 when 'above a hundred days the ground was covered in deep snow.'[12] The besiegers' retreat the following spring turned into their all-but-comprehensive rout. Thenceforward, neither Arabs nor Greeks stood a chance of outright victory but neither felt able to admit as much.

All the same, there is little here to sustain Pirenne's broader inference that north-west Europe arose in natural compensation for the Mediterranean's eclipse. History is no zero-sum game in which the decline of one realm is *ipso facto* offset by the ascent of another. Neither, for that matter, is economics. A nodal region in decline is as liable to tug peripheral areas down as it is to leave them free to rise up.

A sickle-led advance

One must therefore look to the indigenous roots of economic change in the lands encompassed by the lower Rhine, Meuse and Seine valleys. Pirenne saw the export of Flemish woollens as booming from the early ninth century, this because of the dislocation of the embryonic silk trade due to the Mediterranean impasse.[13] That explanation is debatable specifically because (a) in 552, it seems, Emperor Justinian had set up the smuggling out of China of silkworm eggs and mulberry seeds, and (b) in the eighth century, the Arabs had introduced to Spain and Italy silk culture and weaving. So one may do better to look to agriculture in general as a pacemaker. For information on this score, one of the richest sources is the 'polyptyque' (i.e. inventory) undertaken by Norman Pounds for eight of the larger monasteries in the ninth century in that part of Europe. This revealed an agriculture highly diversified in the sense that it was still largely geared to local self-sufficiency. At the same time, there were marked local variations in population level and, indeed, income *per capita*. An irregular incidence of disease, armed conflict and famine might reasonably be inferred.[14] That in its turn could help explain the early manifestations of social fluidity in the lower Rhine–Meuse sector.

Through western Europe as a whole, most of the land 'cleared and cultivated in the age of Charlemagne, had first been brought under cultivation in the period of the Roman Empire or even earlier.'[15] In other words, it was essentially a matter of recovery on the extensive arable margins. Demonstrably, however, a real breakthrough was being achieved in intensive farming. By the early ninth century, all its elements had been developed: the open fields, the heavy plough, the modern harness, the triennial rotation – everything except nailed horse-shoes, which appear a century later.[16] Wheeled ploughs suited the deepish soils of axial western Europe, while the production of oats favoured more recourse to horse power.

In France, the divide between the new agriculture and the old closely corresponded to that between the *langue d'oil* and the *langue d'oc* (see Chapter 4). But the balance of advantage was inverted by comparison with Late Antiquity. Writing in 1967, Peter Brown, now a doyen among the scholars of that classical twilight, saw the latter-day upper classes of the Western Empire as entrapped in the rigidities of a Mediterranean urban lifestyle as their world fell apart around them. He noted how, 25 years earlier, the Empire's 'technological failure to develop a Northern agrarian society, as an alternative to that of the Mediterranean', had been remarked on in the *Cambridge Economic History*.[17] It will be conceded below that the Romans never thought expansively on certain pertinent issues – e.g. the waterwheel and forest management. But it would be fair also to say that through Late Antiquity their ambience will too often have been discouraging climatically as well as in other respects.

A good comparison to draw may be the northward bounds of viticulture, hamstrung though an ecological interpretation this early on is by the sheer paucity of data as well as by economic and cultural variables. The Paris area – what, by the twelfth century, would be identified as the Île de France – had assumed more prominence by the Charlemagne era than in Roman times. Belgian wine, too, figured more. In the Rhineland the limits were extending beyond the Roman even by the seventh century (see Chapter 9). Granted, quite the heaviest concentrations of production appear to have been around Paris and, to a lesser extent, near Koblenz.[18] But, all in all, the signs are of vigorous viticultural promotion beyond Roman limits and ahead of secular warming.[19]

Anticipatory, too, of the climate turning point was the early Carolingian (i.e. linked to the Frankish dynasty dating from the seventh century) proliferation of markets. Yet while very many were eventually founded, the overriding emphasis was on the local retailing of farm produce and craft products. Pirenne saw whatever existed early on in the way of longer-range trading as proceeding *ad hoc* and independently and as being concerned with valuables (cattle sometimes included) but not staple food.[20] His judgement on this score matches what Pounds was to say about the localisation of famine. This behoves us not to discuss in overly bold sweeps the effect then of flux in climate or, indeed, any ambient factor.

Having said that, a general tendency does set in towards weather that was drier and sunnier. The realignment of the atmospheric circulation that will have been effecting this would ultimately lead to secular cooling over northern Scandinavia in summertime and, in all probability, through the winter as well. Biological evidence (tree rings and glacial debris) from around Rinkojietna (inside the Swedish border near Narvik) bespeaks a trend towards cooler summers that started as early as AD 600 but bottomed out two centuries later.[21] Also on the continental canvas, as one might say, stronger and more regular extensions north-eastwards of the Azorean High will have ushered in across much of axial western Europe a sunnier and warmer regime, especially in summer. Maybe it was during this time that the die was cast for the perception, set so deep in medieval vernacular culture, of the contrast between the two well-recognised seasons, joyous summer and fearsome winter (see also Chapter 2).[22]

In the Mediterranean lands, however, one material result of Azorean dominance could have been regularly to aggravate the customary water shortages: a provisional deduction that draws support from a compilation by Hubert Lamb of Italian rainfall/flooding records which show *inter alia* the seventh and eighth centuries to have turned fairly dry.[23] Elsewhere in western Europe, indeed, the commonest cause of harvest failure will by then have been an unduly arid summer associated with overly strong Azorean ridging. Among the signal contributions to historical climatology of Justin Schove was his review of drought in north-west Europe, 714 to 835, cited in Chapter 4. Likewise, the folk legends of north-west Europe (and especially of the Celtic communities) 'are strongly suggestive of drier conditions, if not actually of a water shortage.'[24] Yet nowhere across the said span do the *Anglo-Saxon Chronicles* refer to drought. Even allowing for idiosyncratic editorial objectives, that surely rules it out as a major threat in the English south.

What enters intriguingly into this scheme of things are the archival indications that, by the early ninth century, farmers in, for instance, the upper Rhône much feared destructive storms, especially hailstorms, supernaturally contrived by malevolent individuals. Both Church and Empire were bound to combat any such superstition because of the challenge the alleged storm-makers posed to institutionalised authority. But why the accent on hail? Was it due, as Paul Dutton has proposed,[25] to increased reliance on cereals, a crop genre always fragile in high summer? Or were the anticyclonic ridgings from the Azorean Hadley cell especially prone, in places well inland, to end in thundery breakdowns with hail as a concomitant? How well, in any case, can we gauge levels of public anxiety so long ago? For whatever the comparison may connote, in terms of either meteorology or human history, there is a remarkably low incidence of hail reports from east Henan in China during that time (see p. 141).[26]

At all events, by 750 axial western Europe was entering, haltingly but insistently, a more benign phase weatherwise. The societal and political response can well be seen in the further development around their northerly core areas of two proto-states referred to earlier: the central English kingdom of Mercia and the Frankish Empire. Mercia reached its zenith under Offa, king from 757 to 796. It can be viewed as the intermediate stage in the transfer of the English spotlight from Northumbria to Wessex. This translation southwards was in the opposite direction to what continental warming might lead one to expect. But the potential inherent in the location of Wessex was always liable to count in due course. Moreover, that prospect became more immediate as the better weather favoured wheat growing on the alkaline soils of its chalky downlands. In the interim came the English cultural and, indeed, spiritual renaissance in the wake of the Whitby Synod, a fusion of Celtic and Roman traditions catalysed by a migration of scholars from a strife-torn Mediterranean.[27] Despite the fractious nature of Northumbrian politics, much of this renaissance (from Cuthbert and Bede to Alcuin, *c.* 735–804) stemmed from the English north-east.

Meanwhile, from 768 to 814 Charlemagne created an imperium that eventually bestrode the Pyrenees, extended halfway down the Italian peninsula, and had a toehold on the Baltic coast – not 'purely an inland power' *pace* Pirenne. Charlemagne made his court at Aachen a centre of cultural revival. In ecclesiastical architecture, metalwork and – not least – writing, the leadership afforded was seminal to Europe's cultural identity.[28]

The old Frankish heartland (extending from the Seine to the Rhine and upper Rhône) was well positioned to benefit agriculturally from Azorean ridging. Duly, its infant industries (cloth, glass, metalwork . . .) led the recovery from the arrest of trade development much of western Europe had been experiencing by 750, a state of affairs gradually alleviated by a widespread switch from gold to silver coin. The trade in question relied considerably on river traffic. However, certain Alpine passes served to reforge Mediterranean links to an extent. Meanwhile, Mercia extended to the Thames estuary as North Sea commerce flourished as never before. From the Frisians to Finisterre, long fetches of moderate sea will have aided the mariners often. Everywhere the growth of industrial production and trade depended heavily on arable development. Not least was this the case on the new frontiers of settlement in Germany.[29]

The Magyars

Charlemagne's imperium failed to survive his demise in one piece. Perhaps it had simply waxed too larged. Maybe, too, this undue progress had been furthered by the extra infusions of balmy Azorean air. One can further surmise that climate fluctuation was the ultimate cause of the Holy Roman Empire's moving in the tenth century from the Francophone world to the Germanic, there to remain for the next 800 years as a Mittel European entity.[30] The last Carolingian emperor, Arnulf, died in 899. The first authentically German one, Otto I, was not crowned in Rome until 962. In between, the title was a cipher.

The fluctuation envisaged will have made itself felt via the Hungarians, alias the Magyars. From 833, this nomadic people had been harassing Khazaria as well as Byzantine colonies around the Sea of Azov. This and their subsequent migration westwards were probably a reaction to persistent drought, a prelude to the aridity crisis that was to afflict Khazaria more directly by the tenth century. Weight is lent to this interpretation by the Hungarians being forced westwards by recurrent pressure from the Pechenegs, a Turkic people who had emerged from beyond the Urals. A domino effect was again at work. In 862, the Hungarians began raiding parts of Germany, and in 899 the Po valley. Soon afterwards they descended on France. But they were to settle down on the Pannonian Plain (the area long since regarded as their ancestral home) once their strength had been broken by Otto at the battle of Lechfeld in 955.

For several decades prior to this dénouement, however, Hungarian depredations had been on the wane. Growing defensive resilience, especially in the German lands, was making short, sharp forays harder to execute. Yet incursions that were large and drawn out meant great exposure to disease and – always worrisome, this – fodder shortages. Suggestions that a Magyar tribal host of mounted archers-cum-lancers could ever have mustered, for offensive action, anywhere near the 200,000 customarily conjectured are now given little credence.[31] Any such muster for home defence will have been largely unmounted.

The Pope's crowning of Charlemagne as the first Holy Roman Emperor, on Christmas Day in the year 800, had confirmed how much Islam had undermined the credibility of Byzantium as leader of Christendom. But the lift this event gave to Carolingian charisma tends to be exaggerated. Maybe all it really did was highlight that domain's overextension. Of more tangible consequence for the renascent north-west Europe was the import via the Viking Baltic of large amounts of Abbasid silver from the mines of Persia, Afghanistan and Transoxiana. This inflow, largely used for bullion conversion, initially peaked around 800.[32] For Charlemagne and Offa, it served to strengthen the royal writs through the management of money supply. Offa eventually had something approaching ten million silver pennies in circulation.[33] In those terms, Offa and Charlemagne would have been inconceivable without Muhammad or, indeed, without the Vikings.

The Viking ambience

All the same, the Viking expansion out of Scandinavia encompasses far more than bullion shipments. In assessing what part climate change played in triggering it off and in its unfolding, a basic question is how much hinges on global or hemispheric warming usually being more pronounced at higher latitudes, a differential seen as veritably axiomatic in the current debate about greenhouse warming. The first response must be to reiterate that, during this era, there was no simple climate trend across Scandinavian Europe. Nor was there throughout high northern latitudes. The longitudinal time lags were one complication. Witness the very previous (i.e. just post-550) warming of Greenland discerned by Willi Dansgaard and his colleagues.[34] Witness, too, the strong resumption of warming there through the tenth century.[35]

These anomalies respectively show warming to be under way across the northern face of the pronounced Rossby standing wave that, with its axis more or less down the 130°W line of longitude, forms as an air flow response to the cordillera mountain chains that stretch down the western side of North America. That interpretation can help explain a major migratory revolution within pre-European North America, a revolution that started in northern Alaska but was eventually to bear hard upon the presence the Vikings were to establish on the eastern maritime rim of that continent. It was a case of radical response to a marginal yet critical change in the ambient ecology.

According to observations revised some 35 years ago, the stubby Barrow peninsula then just clipped the northern limit of the beluga toothed-whale population, a community locally at the apex of the marine food chain. Actually, the said limit was not 200 kilometres south of the median edge of the pack ice in high summer, an edge 600 kilometres further south there than at the apex of the 'gulf of winter warmth' near Spitzbergen.[36] The Eskimo (alias Inuit) inhabitants of a location so finely poised – this a millennium ago no less than nowadays – had to be ready to respond to even small alterations in their ecological parameters.

Their responsiveness found dramatic expression after AD 900. Several centuries of cultural evolution in the very isolated Barrow area had produced a distinctive 'Birnick' way of life. With local modifications, this would soon spread throughout Eskimo Alaska, then progressively eastwards and, in due course, into Greenland: an island that had had settlements around its coasts 3,000 years earlier (the most northerly at 82°N) but which was less extensively occupied, even littorally, in 900. Apparently the belugas were likewise spreading east. However, Vilhjamur Stefansson believed that, through the early stages of their own progression, the Birnick were following the musk ox more than the harvest of the sea. This hardy ruminant will also have been on the move because its preferred habitat (the tundra short grass) was losing ground to the forest to the south and south-west while gaining ground to the north and north-east (albeit more slowly) against the bare rock and ice.[37]

The human outcome was a comprehensive cultural transformation and hence a geopolitical one. Absorbing the pre-existing Dorset culture, Birnick metamorphosed into a new Thule culture. All Inuit from Alaska through Thule and around the Greenland coast came to speak, subject to local dialect, the same Thule language. Correspondingly, much of the technological virtuosity in what 'every schoolboy' used to know as 'Eskimo society' was superimposed by the ascendant Thule: kayaks and umiaks, advanced harpoons, bows and arrows, built-up dog sleds, whale-oil lamps, snow igloos . . . .[38] The significance of all this in European terms is that the Thule culture was essentially the one that by the thirteenth century the Greenland Vikings were closely interactive with.[39]

Turning next to Iceland's climate, one acknowledges the paucity and unreliability of sea ice reports prior to AD 1300. That makes it all the more important to aim off against pre-existing notions about what medieval warming might entail. Hubert Lamb averred in 1966, albeit without demonstration, that drift ice had become 'rare' in Icelandic waters by 800 and 'apparently unknown' between 1020 and 1200.[40] However, he did concede four years later that the near absence of reports of 'polar ice' near Iceland between 800 and 960 proved little in itself.[41]

Perhaps this much can currently be said. The reversion to warmer, moister weather observable over Greenland so early on would have been matched over Iceland, subject to a time lag of perhaps a century. Shorter-term fluctuations may or may not have exhibited the lag, depending on their character. Take the cool intermission recorded by the Dansgaard team as having occurred in Greenland from 820 to 870. Iceland's singularly severe 'famine winter' of 975–6 could fit the pattern, allowing for the stipulated lag. Conversely, the hard Icelandic winters of 850 to 865 are very directly concurrent with the cold tendencies in Greenland but also much further afield.

An added complication just might have been the 60-year cycle discernible nowadays in ice build-ups from the Arctic Ocean feeding into the Greenland Sea and thence down the Denmark Strait.[42] However, high-resolution marine sediment cores extracted in Nansen fjord in 1991 do indicate relatively warm and stable sea temperatures in the Denmark Strait from AD 730 to 1100. In other words, sea ice will have largely been absent.[43] Likewise, Icelandic farmsteads did prosper during the 'saga times' (AD 930 to 1030) in locations that, seven centuries later, had been engulfed by the Breidamerkurjökull glacier.[44] Lamb in 1966 may not have been too far wrong.

Singular significance may attach to the first major event in the Viking onslaught against England. It was in January 793 that Lindisfarne monastery was sacked. Most of the later Viking raids were staged either in spring or autumn. January has a smack of desperation about it. Skeletal though the evidence is, this raid could have taken place within a several-year cluster of Norwegian harvest failures as from 792–3. It was earlier 'the same year', according to the *Anglo-Saxon Chronicles*, that the people of Northumbria had been 'wretchedly terrified' by 'excessive whirlwinds, lightning storms, and fiery dragons . . . flying in the sky.' For 'the same year' read the previous twelve months? We are told the raid took place after a 'great famine' in England. Does that relate cyclically to the severe west European droughts recorded for 794 and 797 (see Chapter 4)? Victor Clube and Bill Napier note that the Chinese records show a rising incidence in this era of heavy meteor showers. Is there a material connection? Should we be envisaging a meteoritic salvo or two casting up harvest-spoiling dust veils? Worthy of consideration, too, is the fairly high volcanic activity in the northern hemisphere (as revealed in the Greenland ice sheet) in the period 787–90.[45] That could well have cast a pall more or less worldwide, 787–798.

However, the archaeological evidence for acute ecological disturbance is thin.[46] Nor should one forget that, before the Viking onslaught was fully under way, the Anglo-Saxon chroniclers were inclined to enliven their narrative by talking up freakish stories. Witness the 'strange adders seen in Sussex' in 776.[47] Once the 'Northmen' were rampant, there was no lack of more substantial copy.

Looking towards the Scandinavian heartland, the North Sea and Denmark are the simplest areas to assess. Between AD 600 and 1000, the record of severe North Sea floods is minimal, well below that for the centuries before and much less than for those to follow.[48] Attention is further paid in Chapter 8 and Appendix A to the difficulty of evaluating archival sequences so far back. All the same, that stretch of time covered considerable maritime and coastal activity, warlike and commercial. Really dramatic natural events should have been recorded.

In AD 500, or soon thereafter, according to Klavs Randsborg, Denmark moved out of a cold and wet regime and towards its medieval optimum. Cereal crops gained against pasture, while rye gained ground on barley. More emphasis on vegetable protein allowed of a larger population even though the ratio of farmed land to forest was little different in 800 to what it had been at the turn of the millennium. Farmsteads were set within orderly villages, and their living quarters and stables were normally under the one roof. Then in the tenth century, magnate farms evolved in western Denmark with living quarters set apart. These betokened both economic growth and social differentiation.[49]

Up to the 64th parallel, Norway and Sweden matched the general trend towards warmer winters and drier summers observable throughout axial Europe by 750. Through the sixth century, the Justinian plague had accentuated a sharp fall in the regional population with the weather drear and dank. But between the eighth century and the eleventh, the number of farmsteads was to treble in south-east Sweden.[50] However, low rates of plant growth across the span 770 to 900 are revealed by the varved sediments of the small Lake Judesjön (at about 63°N) in Ångermanland. A critical factor was probably reduced sunshine,[51] a consequence of frontal activity along a climate divide.

Further north, there likely was the early medieval tendency towards a wintertime 'cold pool' high examined further in Chapter 6. But what happened in summertime? In 1990, Keith Briffa and his pan-European team published their review of Scots pine data from Lake Torneträsk, a locale in Sweden hard against the border near Narvik. Their dual baseline was the mean summer temperature in 1930–49 (0.31°C) and for 1880–1929 (–0.20°C). Twenty-year running means no less warm than the former appear in 750–80, 920–40 and 960–1000. Ones at least as cold as the latter occurred from 780 to 830 and (much as in Greenland, Iceland, England and China) 850 to 870.[52]

Viewed more dynamically, the Torneträsk sequence shows a sharp mean fall (of the order of 2.0 to 2.5°C) from 750 to 800 though a similar mean rise from 800 to 845.[53] The sharp fall, in particular, is a more definitive rendering of indications first remarked some decades ago.[54] It has lately been intimated that, across the medieval span, the differential movement in mean summer temperature as between northern Scandinavia and southern may have been close to one degree Celsius.[55] This accentuation of the thermal gradient will have made the transition zone more stormy. A measure of human sensitivity to temperature contrast may be seen in the Norse colonisation of Finland. Through the second half of the first millennium, settlement progressively edges east from Turku to Lake Ladoga, rather than northwards. The largely nomadic Lapps excepted, humanity virtually confined itself to south of 62°N.[56]

In one significant respect, however, a north-versus-south divide had almost disappeared by the start of the first millennium. This was post-glacial isostatic rises in the level of the land mass. Northern Scandinavia, having been depressed by more ice and for longer, had recovered later but then more rapidly. At one time in the early Holocene, northern Finland had been rising in places as much as ten metres a century.[57] With the near completion of this adjustment, drainage would gradually have become more smooth and regular in the North, for a given rainfall pattern. That would have favoured eventual colonisation.

The salient questions remain these. Do the peatbogs and moraines or lake varves of southern Scandinavia reveal climate events or tendencies acutely enough to explain how Viking expansion developed in the first place? And why did it so suddenly acquire an added dynamic *c.* AD 835 or 865? At whatever stage, might climate anomalies have pitched human society across a threshold of instability? Or should we envisage something still more elementary and elemental? Might the 'outburst of energy that carried the secluded inhabitants of the creeks forward to Constantinople . . . have been the mere force of example and fashion, the cumulative power of a ball, once set rolling by the casual success of a few adventurers'?[58] Was emulation encouraged by the common Norse language group, *dönsk tunga*? Is it a question of raiding overseas as the assertion of royal authority made raiding at home more difficult? Did the Vikings strike out across the seas and up the Russian rivers simply because northern Scandinavia was still uninviting?

The Viking sequence

Viking armed forays began in the 750s with Danish raids on the Frisian island chain: a feature of the seascape then being absorbed into the Carolingian Empire but which may not yet have recovered from the population crash it had suffered during drought around AD 500. A leap forward in strategic mobility westwards came with a Norwegian probing of the Dorset coast of England in 786 and then, seven years later, the Lindisfarne sacking. The next ten years saw a succession of Viking strikes around the British Isles. Celtic monastic foundations by isolated coasts were obvious targets. In 836 the Norwegians founded Dublin, and, eight years later, were to appear before Moorish Lisbon and even up-river Seville.

Around 865, during the hemispheric cold interlude, a Norwegian farmer, Floke Vilgerdason, tried to settle in Iceland. He gave up, after losing his cattle and seeing 'a fjord filled up with sea ice. Therefore he called the country Iceland' (*The Landman Saga*, *c.* AD 1200). Then in 874, Ingolf Arnarson arrived and did manage to establish himself. By 930, against a more salubrious background, 20,000 Norwegians had migrated thence and had distributed themselves extensively in workable lodgements.[59] About a half, it is generally thought, were from in or near Bergen,[60] and these presumptively had left under pressure from Harald Fairhair (see p. 138). There are, too, cultural signs of an east Scandinavian influence.[61] One may add that a few Irish monks who had preceded the Norse in Iceland somehow vanished very early on.

Thirty years ago, the American legal historian, James Bryce, wrote of medieval Iceland as

> an almost unique instance of a community whose culture and creative power flourished independently of any favouring material conditions . . . . Nor ought it to be less interesting to the student of politics and laws as having produced a Constitution unlike any other whereof records remain, and a body of law so elaborate and complex that it is hard to believe it existed among men whose chief occupation was to kill one another.[62]

If the murder rate was that bad, this was a function of ambient conditions. Its coasts nowadays are very generally colder, cloudier and windier than those of the Skagerrak, say. One consequence is that, coupled with the extent of the high central plateau, they preclude much production of quality timber. A thousand years ago this particular constraint applied after deforestation and regardless of decadal climate trends. It will have limited the exploitation, except by small boats working inshore, of cod fisheries even richer in *c.* AD 900 than today. But maybe inshore operations could suffice.

The allegedly blood-lusting settlers soon evolved confederacies of neighbouring estates each loosely knit under the leadership of the foremost resident, a chieftain who had assumed the role of *godi* – that is, priest of the temple. He would rank first among the local landowners.[63] In 930, with the influx of immigrants more or less over, the leading *godi* came together at Thingvellir or the Plain of the Thing, a flattish rift valley of heroic aspect yet still accessible, 50 kilometres inland from Reykjavik. They did so to launch the Althing, the legislative and juridical national assembly that was to meet there almost every midsummer till 1798. Neither the body of law it enacted nor its specific decisions could have been imposed nationwide without a solid consensus at the grass roots. The same applied to the Althing's carefully judged decision, in the year 1000, to endorse Christianity as a unifying national religion.

Informing the whole process was a peculiarly strong reformulation in law and through representative assemblies of the Norse–Germanic tradition of the democratic prerogatives of all freemen.[64] The attitude to slavery was likewise relatively benign. Slaves receive frequent mention in the Icelandic sagas. Nearly all of them were of Irish extraction as were not a few of the wives that accompanied the Viking settlers. Duly, the Nordic precept of according slaves certain rights was well upheld in Christian Iceland; and, in any case, slavery had died out there by 1100 or so, a century or two ahead of the rest of Scandinavia.[65] Nor, of course, was Iceland ever involved in a transcontinental slave trade. In short, what seems to have evolved within a century is a good frontier society, one cohesive yet tolerably relaxed. The absence of an alien presence or of an external threat (except, at long range, from mother Norway) will have helped this evolution. But to what extent did climate flux do so as well?

So far as the economic base was concerned, the most important sector will have been farming. But the inshore fishing was strongly complementary. If ice-bearing currents were in some measure in retreat, that would have favoured the cod. This fish prefers sea temperatures between 4 and 7°C. It does not normally survive in sea temperatures below 2.0°C for then its kidneys fail.[66] At the present time, the mean annual sea temperatures around Iceland are between 4 and 6.0°C. Bottom temperatures on the famous Grand Banks off Newfoundland can be as low as −1.4°C. It helps explain why, for instance, these Canadian stocks proved very susceptible to overfishing in the 1990s.[67]

It would be tempting to presume that the Icelandic weather would readily have ameliorated all round in harmony with a rise in sea temperatures regionally. As has long been recognised,[68] however, the rock and ice plateau of Greenland (2,000 m high) tends to divert the path of frontal depressions, inducing many of them eventually to proceed north-east up the Denmark Strait, sustained by the steep thermal gradient near the icefield. That is a gridlock situation unlikely to alter except abruptly and after some considerable delay. Besides which, stronger Azorean ridging may have been associated with anomalously low pressure near Cape Farewell, the North Atlantic Oscillation. What is very noticeable is how consistently, through the turn of the millennium, new Icelandic farmsteads were located in inland valley sites, well sheltered from the storms.

What must also be said is that, in other respects, the pre-existing ecology went unstable rapidly and drastically in the face of human intrusion. The destruction of the scrubby woodland to smelt iron was a critical reason. A general one was individualism waxing too careless against the background of a climate that was tough but improving. Before the Vikings arrived, 65 per cent of the landscape was vegetated, over a third of this fraction being covered in birch woodland of whatever calibre. Very soon the situation came much closer to what it is today: just one per cent of the total area forested and only 25 per cent vegetated.[69] The Icelanders thereby left themselves much more susceptible to climate deterioration as and when this set in.

Not that a ‘great famine winter’ in 975–6 conspicuously altered the course of history. Perhaps, though, it did serve finally to undermine the authority of the pre-Christian gods. For this was the terrible dearth ‘in heathen days, the severest there has been in Iceland. Men ate ravens then and foxes, and many abominable things were eaten which ought not to be eaten, and some had the old and helpless killed and thrown over the cliffs.’[70] A few Christians, such as Aud the Deep-Minded, had been numbered among the very first settlers. But a turning point for Christian witness came in 981 when Thorvald Kodransson returned to his native Iceland to lead what proved a highly successful mission.

Also in 981 or maybe 982, the boisterous Erik the Red was exiled from Iceland for three years for blood feuding, a sequence he had already been through once in his native Norway. He and his band of adventurers sailed west to explore a land first spoken of a century before. They spent the three exile winters close by Cape Desolation on the south Greenland coast, a location characterised in modern times by solid pack ice in late winter and no trees save dwarf birch and stunted willow. The three years up, Erik returned to Iceland and persuaded enough people that what he, with studied optimism, had dubbed 'Greenland' was worth colonising. He led an expedition back there, in 985 or 986, to found a scattered eastern settlement not far from Cape Desolation and a western one close to the present site of Godthaab. Both locales were actually on Greenland's western seaboard, where good fjord harbours, reminiscent of Norway's, existed while the open sea was less storm-swept. No doubt, too, an amelioration of climate, by then well advanced, facilitated not only living there but passage to and from. The many cod bones in the settlements' middens confirm higher sea temperatures. So, perhaps, does a saga tale of a cousin of Erik the Red swimming several miles in a fjord. Certainly, ice core analysis of air temperatures indicates AD 975 as the peak of medieval warming in the Greenland sector.[71]

What should be avoided, however, is treating such Viking sea-rovings as proof of decreased storminess. To do so might be to lapse into tautology. Certainly it would be to discount the hazards they, almost matching the Irish before them, were so often willing to accept. Of the fleet of 25 crowded ships Erik led back from Iceland, only 14 actually reached Greenland. Several of the rest foundered amidst the floes.

Naturally, the early settlers will soon have made landfalls further up the Davis Strait, if only while whaling and fishing. Nevertheless, the dozens of Norse artefacts since found well scattered up to 79°N appear to have been imported by the Inuit through bartering. In that some of these items can be dated, they mostly belong to the High Middle Ages, notably the thirteenth century. In other words, the trade flourished well after medieval warming peaked in that longitude, this a consequence of the gradual consolidation across the region of the Thule-led Inuit culture.

The idea that the Vikings ever roved deep within North America proper has owed all to 'cult archaeology'.[72] In his inspirational study of the Viking centuries published in 1911, Fridtjof Nansen (polar explorer, zoologist, oceanographer and international statesman) well identified two territories named in the sagas as having been reached, *Helluland* (i.e. the slate or stone land) and *Markland* (i.e. the woodland). He guessed the former must have been Labrador and the latter Newfoundland.[73] Since when, an eight-building Icelandic-style site from the late tenth century has been found and excavated at L'Anse aux Meadows in Newfoundland. It was a staging post where up to 30 ships' crews could winter. However, it was occupied for not more than 20 years,[74] and maybe only one or two.[75]

What Nansen dismissed as mythical was Vinland, the most famous of all the landfalls – actual or supposed. He felt the image thus conjured of a frost-free American land endowed with wild grapes and self-sown wheat was too obviously in line with a paradisal tradition in mythology stretching back via Homer to ancient Egypt and Babylon. Classical myths have likewise been invoked against the notion that St Brendan or colleagues set foot on the North American mainland.[76] The fact remains, however, that nowadays at least two black grape varieties of American wild vine, *vitis labrusca* and *vitis riparia*, grow as far north as the New England–St Lawrence region.[77] Granted, wheat is not indigenous to North America. So for 'wheat' read 'maize'? Suffice to note that the Icelandic sagas evince a commitment to historical truth high for their generation. Nor was classicism, Aristotle excepted, much in vogue when the sagas were completed. But did 'vin' just mean 'pasture'?

If, in the north-east of mainland North America, medieval warming was then near its peak, it is entirely possible that Viking explorations southwards from Cape Farewell were facilitated by some displacement and/or diminution of the ambient weather hazards, not least the combination of sea fog and icebergs off Newfoundland. At the same time, however, whatever resistance the Vikings encountered to attempted landings will have drawn strength from indigenous economic advance within the context of a warmer and moister climate. L'Anse aux Meadows shows every sign (the large storage and accommodation blocks, shoreline location, no pastoralism . . .) of having been a launch pad for ambitious amphibious forays that soon proved unrewarding.

An inference just drawn is that the Vikings never colonised further up the Davis Strait. Within Scandinavian Europe, the contrast between a south they settled and a north they eschewed was every bit as stark. Several reasons may there be adduced. A cardinal one was the emergent tendency in the north for cold pool anticyclones to be more dominant, particularly in the winter half. Derivative from this was the steeper south–north temperature gradient discernible in tree growth. Perhaps the view was that icy high latitudes were, like the 'torrid' equatorial zone, all but uninhabitable. One authority who believed this legend flourished well into the twentieth century was Stefansson.[78] Yet the original zonal formulation was not by Aristotle[79] but by Parmenides (see Chapter 1), someone surely little known in medieval Scandinavia. Interestingly Greeks of his father's generation, led by Pytheas, had made a landfall *c.* 65°N in 325 BC. Similarly, Norse whaling voyages went well north of Norse settlements even in early Viking days. Northward settlement as such may have been discouraged by folk myths that inner Lapland was a haven for evil trolls and other creatures from a hostile supernatural. Winter darkness, aurorae and accentuated cold, apparently the year round, will have been grist to the mills of superstition. Also, that post-glacial adjustment in natural drainage was not yet fully complete.

The Norwegians are not known to have reached the Svalbard archipelago (Spitzbergen etc.) until 1194. But they had entered the White Sea as early as 875. Intermittently they resumed a presence there, either trading with the Lapps or fighting them. In a punitive/plunder campaign *c.* 965, they devastated much land around the River Dvina.[80] However, they were never to settle anywhere in Finnmark (the furthermost province of modern Norway) until the thirteenth century.[81] Nor did the Norwegians, either in Viking times or during the High Middle Ages, urbanise far up the coast. Only eleven settlements in medieval Norway were ever accorded the legal status of townships. Of these, the northernmost (at latitude 63°20′) was Trondheim.[82]

The Rus

In Sweden in the early ninth century, what was to become the national core area around Lake Malaren was already emerging in terms of urban settlement and commercial activity. The main town then was Birka, though by AD 1000 Sigtuna had displaced it.[83] Either way, the key trade routes were to the east and south.[84] Something of the settlement progress through Finland has already been indicated.

In some ways, the most amazing dimension in the whole Viking phenomenon was the Swedish. Having refined their boat handling on the rich though inclement herring grounds of the Baltic, these eastern Vikings (alias the 'Rus') projected themselves along the system of natural waterways that, more than any other feature, bestowed a basic unity on what evolved into Russia. Early in the ninth century, the Rus established their first settlement by the shores of Lake Ladoga. Around 840, a proto-state was forged around the southern city of Kiev; and primary manuscripts show the Rus to have been raiding the southern shore of the Black Sea. In 860, a Rus fleet of 200 boats bore down on the Golden Horn at Constantinople; the city was only saved, its inhabitants averred, by a storm conjured by the Virgin

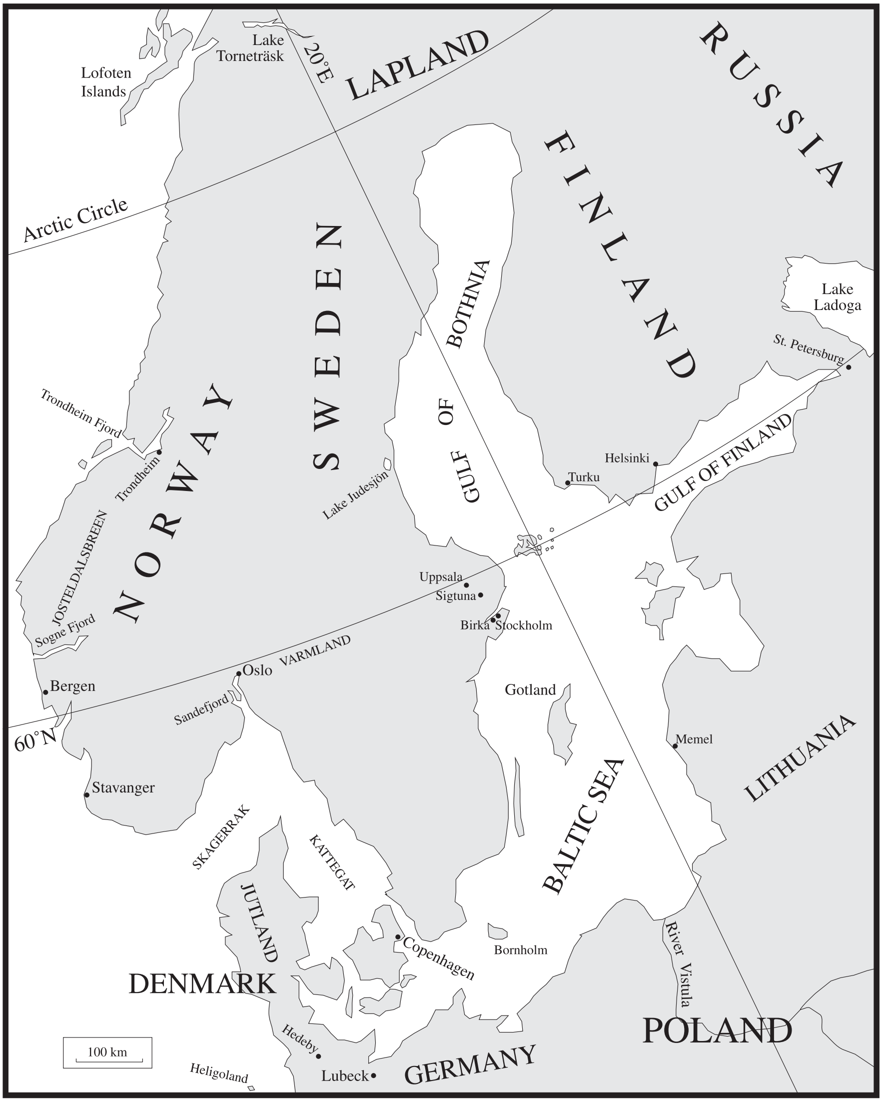
Mary. Novgorod became the Rus capital in 862. Twenty years later, Rus pirates appeared on the Caspian.

About that time, too, the quasi-legendary Oleg made Kiev the capital of a Rus confederacy. In 907, this Grand Prince of Kiev appeared before Constantinople with no fewer than 2,000 boats bearing 80,000 men, and with cavalry support on land. The peaceable outcome was the wide-ranging commercial and cultural treaty of 911. But in 941 and 944, Igor, the then Grand Prince of Kiev, led two further expeditions against the same objective. The first was devastated by 'Greek fire' but the second was peaceably accommodated with the signing the next year of a new treaty. To the Kievan Rus as to the Arabs, Constantinople was physically irreducible. Where the Rus succeeded much more than the Arabs could have was in locking Byzantium into partnership, commercial and strategic, based on effective parity. The acceptance of Orthodox Christianity by Grand Prince Vladimir of Kiev in 988 more or less put the seal on this.

Ever since the eighteenth century, an acrid debate has intermittently proceeded as between the 'Normanists' and their adversaries, the former being those who attach overriding importance to the Viking role in the incipient creation of what we loosely term Russia. This debate needs to become less polarised through being better informed. An important element in the extra information could be climate change. One complication is that 'Viking trade with Russia only began in earnest *c.* 840', shortly before what is here being identified (see Chapter 4) as the onset of a hemispheric cooling interlude.[85] And what are we to make of the suggestion that, before 900, Arabic coinage was largely confined to the south-east side of the Baltic?[86] Was longer-distance trade still in recession? If so, did the Vikings encourage instead more local trading networks focused on new market towns? Will archaeology uncover evidence of extensive rural settlement by the Vikings in the Russian lands? And were not these Scandinavians effectively the creators of Novgorod as a city nodal in terms of waterways, though set secure midst forest and swamp? Maybe, but the Russian Primary Chronicle insisted its roots were slavic.[87]

The Volga was a routeway of great interest to the Rus. Having discovered it early in the ninth century, they found it to be (a) free from a long succession of rapids such as compromised navigation of the Dneiper below Kiev and (b) the most direct route to Abbasid silver. Yet notwithstanding the Caspian piracy alluded to above, they were never able through the Volga basin to be 'much more than traders and supplicants at court' with the Bulgars long in control of the river's middle reaches and the Khazars of the lower.[88] Even great rivers are almost always controlled from their banks, not their midstream.

The key to the situation will have been Khazaria: the polity identified in the last chapter as having dominated the lower Volga-cum-Don region until a northward displacement of storm tracks, under way by the tenth century, undermined its rainfall regime. This displacement might fairly be seen as a concomitant of Eurasian warming, perhaps through accentuation of the western limb of the Rossby standing wave enveloping the Himalayas and Tibet (see Chapters 7 and 8). At all events, it induced a menacing rise in the Caspian sea level from AD 1000 to 1250.[89] In 914 or thereabouts, a Kievan amphibious expedition some 50,000 men strong was annihilated about the Volga delta by a Khazarian–Islamic alliance. Sundry other attacks were to be driven back, the sharpest encounters being in 943, 969 and 1041.[90] From then on, however, Khazaria declined steeply as rainfall displacement and inundation paradoxically combined.



Map 5.1 The Baltic region

The Danes

Within the overarching compass of the Norwegians and the Rus, the Danes, too, were pushing forward. By the year 830, they had resumed raids on Frisia and were also harrying the coasts of the English Channel. So far as England was concerned, sporadic raiding was secondary from 865 to the heavy settlement of the east centre of the country by Danish Vikings, Lincolnshire being the county area most densely affected. Then early in the tenth century Vikings (largely of Danish extraction) were to establish the very robust Duchy of Normandy. After which, there were for 60 years (920 to 980) no more berserker onslaughts, a break which set the seal on the Viking era proper. The impact of the Scandinavian state system on the political geography of the eleventh century (the Anglo-Danish kingdom about the North Sea; Norman England; the Norman kingdom of Sicily; a flourishing Kievan state . . .) is qualitatively different.

Throughout the first decade of their offensive against England the Danes exploited to effect the fragmentation of the country into several different kingdoms, and by 876, only the southern kingdom of Wessex stood out against them. That it survived the next two years seems remarkable. The *Anglo-Saxon Chronicles* tell us that by Easter 878, the writ of King Alfred ran firm only over a 'little company' beleaguered in the Somerset fens. Yet several weeks later he was to win the battle of Ethandune and thereby oblige the Danes to sign the Peace of Chippenham. Under its terms, the Danish leader Guthrum accepted Christianity and apparently agreed to the division of England into two acknowledged spheres of influence. Another treaty was concluded with Guthrum in 886, following Alfred's seizure of London. This delimited the 'Danelaw' to the territory east and north of the Thames estuary, the River Lea and Watling Street.

The nadir of Wessex fortunes cannot have been quite as low as the chroniclers would have us believe. Nevertheless, a key factor in any account has to be the resilience in adversity of the man who has come down to us as Alfred the Great. So, too, does luck, not least on Alfred's own part. However, behind all the particular considerations that can be adduced is a rather involuted sequence of climate change. Ironically, it was the Danes who had turned the warmer winters that marked the passing of the cold interlude of the mid-ninth century to operational advantage. For thirteen years in succession from 866, the main Danish 'host' was able to over winter in hostile or contested territory, always 'slipping into' a township for this purpose, though still exposing itself more to the elements as well as to disease or malnutrition than if it had retired to a secure base area. That this innovation was, indeed, concurrent with the advent of warmer European winters is confirmed by varied evidence. Freeze-ups of the Venice lagoon occurred in four or five winters between 850 and 864, including that of 860, when the Frankish annalists record 'continual snowfalls and hard frosts from November to April'. Moreover, both the Frankish and the Irish annals record hard winters from 855 to 857,[91] years during which the lagoon appears not to have frozen. Then again the Briffa series shows Torneträsk summers (April to October) to be significantly warmer for the period 865–88 than for the previous two decades.[92] No more lagoon freeze-ups occurred until 1118.

However, a warrior 'host' that might winter on the basis of requisitioning one or more small towns cannot have been large itself. In fact, the likelihood is that the order of battle of such a Danish field force never exceeded several thousand. No doubt, too, this helps explain why, within several years from 878, Alfred proved able to deter this billeting in Wessex towns by organising local militias within them.[93] A wider connotation is that most of the energy of the Danes, above all of their young menfolk, was now going into the development of where in England they had already settled solidly, basically Yorkshire, Lincolnshire and around the Fens.[94] Many Danish villages had been established alongside English ones, the two populations coming more or less into balance numerically. An evolving philosophy of live and let live leading on to assimiliation was consonant with (a) the readiness with which peace was made in 878 and again in 886, (b) what seems to have been the peaceable settlement by the Norwegians of what we know as the north-west of England, and (c) the progressive reabsorption of the Danelaw by the English crown through the first half of the tenth century.[95] It all bespeaks the discovery by both sides of a spirit of accommodation, something that will have come the more easily through the extending of agricultural horizons as a consequence of climate improvement. Granted, the Danelaw Vikings did lend active support to a 300-ship amphibious offensive launched against Wessex in the 890s by their (mainly Danish) cousins from the Seine and the Loire. However, this could be seen as but a blip in the convergence process.

Root causes

Still, the chief question posed down the century now past has not been how the Vikings found things climate-wise in their target areas. A fascination with Greenland apart, the big issue has remained what factors within their homeland region stirred adventurism in the first place? To address it, we may best take in turn the core Scandinavian nationhoods forming up in Viking times – Denmark, Sweden and Norway.

The raids the Danes launched down the southern coast of the North Sea in the eighth century perhaps served to impede the eastward expansion of the Frankish Empire as well as to cripple the Frisians, thus far the leaders in the development of commerce in northern waters. Around 800, Charlemagne began to create a matrix of coastal and naval defence centred on Boulogne. Apparently, too, his son and heir, Louis the Pious, fostered, successfully for a while, a peace party in Denmark. Even so, there was the general resumption of raids, heavier and cast more widely, from 835; and by 850, Danish settlement had begun in Frisia. Granted, allowance has to be made for the way the Frankish Empire progressively lost its cohesion, and therefore its deterrent power, in the decades following Charlemagne's death in 814. Yet it would be hard to deny the inner dynamic Danish expansionism had attained even before the great descent on England from 865.

So was this simply the result of a follow-through of the climate amelioration located for Denmark as early as AD 500 to 800 in the 1980 study by Klavs Randsborg previously cited? Or did it owe much, as Randsborg himself then suggested, to interruption of the secular improvement by the mid-ninth-century cooling? Inclining towards the latter understanding, Randsborg incorporated the downturn, troughing out by 875, revealed in the Greenland ice core data. Nevertheless he accepted the advice of Willi Dansgaard and his colleagues that time lags of 250 years must usually be allowed for in low-frequency temperature alternations as between Greenland and western Europe. Oddly, however, that acceptance is rendered somewhat otiose by his seeing the weather alternations in each region as then being subject to a 250-year cycle.[96]

The effect of the mid-ninth-century perturbation will have been the greater if Denmark was already entering upon an ecological downturn of longer duration. This could have been the case if (a) the secular advance into a warmer and drier regime was faltering or (b) the population growth this advance had stimulated was leading to a Malthusian 'land hunger' problem. In that era a secular trend towards less humid peat deposits (as revealed by higher sand content) will have been negative if it had resulted from temperature decline, not from easing rainfall and cloudiness. Transections of the Draved peat bog in south-west Jutland show that, around AD 900, three centuries of decreasing humification were giving way to what proved to be three of increase. Around AD 200, a similar turning point had led to the abandonment of 'a large number of early Iron Age settlements, especially on the poor lands to the West.'[97] Soil analyses show that, in the ninth century, decidedly marginal land was brought under cultivation to match population growth. There was still a trend towards high-protein food[98] in line with rising expectations. All the same, the country was drawing close to a crisis of non-sustainable development.

Writing in 1989, Klavs Randsborg still saw crisis in the mid-ninth century but set causation more within the Near East. Archaeological surveys of the Mesopotamian flood plain had revealed about an 80 per cent fall in the rate of settlement expansion between 840 and 870, about the most representative time-frame for the cold anomaly in the climate of the northern hemisphere. The regional background climatically was the secular decrease (AD 600 to 1100) in rainfall over Anatolia indicated by varves from Lake Van.[99] All of which must be set against the general decline from *c.* 800 of the insecure Abbasid caliphate. Symptomatic was the transfer of its capital from Baghdad to Samarra in 836.

This crisis at the very heart of the caliphate soon induced a collapse of some 80 per cent in Viking imports of bullion from the Near East.[100] Denmark was immediately affected because its port of Hedeby had been emerging as a nodal trans-shipment point between Sweden and western Europe. Then at the start of the tenth century, a sharp recovery in the Baltic bullion trade was registered – if only for three decades. During that time as well, Denmark's improving agriculture was again poised to exploit the scope for cereal expansion afforded by a still warm and dryish climate. In that century, too, Denmark acquired more of the infrastructure, institutional and material, of an integrative kingdom. The ultimate result was modal change. The forceful pressure that was eventually (i.e. in 1013–14) to oblige England to accept the suzerainty of the Danish King Sweyn and of his son Canute was of a style belonging more to the world of medieval dynastic rivalries than to the opportunistic sea-roving of the Viking berserkers.

Initially the Swedes may simply have felt tempted to emulate the belligerent adventurism of their Danish and Norwegian cousins. Their own internal feuding apart, this could explain their first expedition into Russia in 859. Three years later, according to the Kievan twelfth-century *Nestor Chronicle*, several native peoples asked them to stay on to rule in the interests of stability.

Also southern Sweden will considerably have shared in the climate amelioration Denmark putatively experienced so early. Advancement in a wider sense has been portrayed thus by the then Director of the British Museum, himself a Viking specialist:

> Although never free from internal trouble – as many a violently destroyed farm dramatically relates in the archaeological record – the Scandinavians were building up a self-confident civilisation of their own between 400 and 800 . . . . In Sweden the Migration period and the period of 200 years before the Viking adventure began (the Vendel period) have been described as an age of gold.[101]

Sweden was the chief fount of a brilliant Scandinavian tradition of, mainly abstract, ornamental metalwork – this very predominantly in bronze and tenuously reaching back to the Bronze Age from 1500 to 500 BC.[102] Though such decorative art was also applied to wood and to horn, metallic glitter clearly had a special appeal, no doubt as an offset to the agoraphobic bleakness of the North. If the Rus were consciously or otherwise the more attracted to the bullion trade on this account, it is a remarkable example of an expansive but austere landscape spreading its influence further afield.

In societies emerging out of tribalism, the correlation between rising productivity and population growth may be very close. The latter tendency is one that historians of the Viking period have, for over a century past, seen as conducive to the overseas expansion, particularly in the Norwegian case. Social mores will have played a part. Primogeniture will for sure. So will a disposition to measure manhood in terms of the number of sons sired. So will the practice of polygamy, at any rate by the better-off.

Meanwhile, in Norway the prospect was made the more fraught by an acute scarcity of tillable land coupled with agrarian backwardness. So was it by the way a deeply indented coastline and generally tortuous landscape impeded endeavours to consolidate peaceably the writ of central government. From his ancestral seat in Oslo Fjord, and following up his father's ambitions, Harald Fairhair (lived *c.* 860 to *c.* 940) forcefully insisted he was king of Norway. After a savage triumph at the Battle of Jafsfjord near Stavanger in 900 or thereabouts, he imposed his will ruthlessly. Many of his opponents fled to the British Isles only to be harried further. Some duly moved on to Iceland. This exiting had largely been by disaffected local aristocrats. What is unclear is how far east Scandinavians were involved in this showdown, though a sizeable community may have sojourned awhile in west Norway around this time.[103]

At its most basic, this whole episode can be read as Malthusian overspill triggered by climate change but modulated by political and cultural factors. Nevertheless, it is still tempting to surmise that Viking expansion may have crucially depended on some technological leap forward that was either pure serendipity or else the product of incremental advances in scientific and technical knowledge owing little to other tendencies. However, there is no sign of this in respect of weaponry. Nor would it be easy to make a case *vis-à-vis* maritime science. Take the two boats from Kvalsund in Norway (the larger, 60 feet long), which are usually, albeit tentatively, dated as from the late seventh century AD. It was to this kind of vessel, beautifully constructed with 'unpainted oak and clinched with iron nails, broad and shallow, of easy entrance and run, with a deep rockered keel and a steep sheer, that the Viking shipbuilder always remained faithful.'[104] In due course, more adequately ocean-going versions began to appear. Take the 'longship' (i.e. man-of-war) from the late ninth century discovered at Gokstad in Sandefjord in 1880. Its length is all but 80 feet, and its displacement 30 tons. Its kind ruled the waves until, in 896, Alfred the Great deployed to effect warships claimed by the *Anglo-Saxon Chronicles* to be nearly twice as long.[105] Often with Frisian captains, these 'dreadnoughts' could well have represented an Anglo-Saxon constructional breakthrough.[106]

In general, however, boats may be 'the most conservative' genre of artefacts found around the North Sea for the period AD 300 to 1000.[107] The Viking longship has been interpreted as a linear evolution from the dugout canoes numerous around the Danish coast *c.* 7000 BP. By the Bronze Age what would always remain the high end-posts, often with dragons' heads, were evolving. By then, too, planking was regularly used to elevate the freeboard.

In a double-beaked war canoe from Hjortspring, Denmark, dated *c.* 2350 BP, the shell consists almost entirely of overlapping planking (known as 'clinker' or 'lapstrake' construction), the dug-out bottom being reduced, in effect, to a rudimentary keel. A thousand years later the true 'longship' had evolved, possessed of the attributes that made it so suitable for high-speed rows across open water to attack coastal or riverine targets. Its features included slender design, light but sturdy construction, shallow draught, and the ability to reverse readily without turning. Then, more or less concurrently, *c.* AD 700, the two clinching innovations came in. The one was the further development of the keel to accommodate a rudder. The other was sails. These were intended initially to supplement longship propulsion by oar, though the broad-beamed *knörr* or *knarr* (being introduced in Scandinavia for deep-sea cargo trips) already relied on sails almost completely.[108] All the Vikings were really doing here was belatedly applying to their warships something utilised in the southern North Sea in Roman times, and adopted by the Saxons and then the Angles during the sixth and seventh centuries.[109] Similarly, in their routine use of heavenly bodies (above all, of the Sun and the Pole Star) to obtain navigational fixes, the Vikings were applying well-established geodetic science.[110]

Almost by definition, pre-existing techniques adopted as and when a demand arises cannot rate as prime movers in historical development. It is therefore not easy to go beyond the view that 'better ships and improved methods of navigation were absolutely fundamental to the success of Viking activity . . . but they were one of its instruments, not its cause.'[111] Nevertheless, an urgent concern from around the year 700 to enhance nautical capability is to be remarked on. By then marine ice and snowfields may have been receding visibly enough around the North Sea and Baltic to make long-distance navigation over sea and up river more appealing. The fact is, however, that if this dating is not too early,[112] the said concern is expressed a century before the Viking era begins in earnest. The keel and the sail thus count as longship adaptations destined for full exploitation, but only when the time was ripe in all respects.

As regards the opening moves, one objection has been that there is no hard evidence from peat bogs of critical climate change in the Viking homelands in southern Scandinavia through the beginning of the ninth century.[113] What may here be prayed in aid, however, is Torneträsk, no matter that it is firmly on the northern side of the climate divide identified above. The argument would run that, despite the background of a sharp contrast in secular mean temperature, decadal fluctuations were liable to be similar each side. If so, the 780 to 830 cold spell will also have been experienced in southern Scandinavia with its nadir *c.* 795 throughout. Correspondingly, the south will have shared in, more or less, the very steady 2°C rise observable at Torneträsk between 795 and 850, just as it assuredly did the two cold decades that immediately followed. The inference might be that the nadir of cold triggered Viking adventurism but then amelioration did not curtail it. Any such hypothesis needs to be tested by further fieldwork. Should it fail such testing, the possibility will still remain that, around that time, population increase associated with climate improvement passed through a critical threshold.

A further complication is that varves from Lake Judesjön show cool and cloudy weather as dominant right from 770 to 900.[114] However, that can be seen as expressive of frontal activity along an acute climate divide.

The underlying anomaly of regional cold in north Scandinavia will have related to a tendency towards a polar anticyclonic circulation emergent as an offset to an incipient weakening of the Siberian High. Strictly the Torneträsk data relate not to winter but to the long summer days. However, the seasons interact. Take Karesuando, a town on the Swedish–Finnish border at a recording altitude of 1,080 feet, and virtually the same latitude at Torneträsk. Some decades ago, 10 May was the median date at which the mean air temperature climbed above freezing point,[115] a threshold often quite critical for plant growth. Rapid change during the Scandinavian spring will have accented the winter–summer dichotomy medieval people were so desperately conscious of.[116]

Outside Scandinavia, the secular trends in climate on balance favoured Viking progress. But the mid-ninth-century cold anomaly had mixed consequences. It frustrated Vilgerdason's attempt to effect a lodgement in Iceland. It will likely have contributed to ecological recession on the Mesopotamian flood plain. Obversely, there was a mass Danish emigration across the Narrow Seas at that time.

With the Viking expansion, even more than with the earlier *Völkerwanderung*, one is struck by how readily aggressive warfare could give way to convergence with indigenous populations: to intermarriage, to the adoption of Christianity and, above all, to bilateral trade. G.M. Trevelyan remarked of the Vikings that they 'combined the pride of the merchant with the very different pride of the warrior, as few people have done.'[117] Casting the interpretation wider, a number of commentators have averred that, into the twentieth century, Anglophone democracy has sustained this 'sokeman' legacy.[118] Yet things were never that simple. Reaction to the Viking menace must have accentuated the tendencies towards land-based feudal vassalage under way by the eighth century, most notably in the Frankish realm. There, in fact, the tendency was further strengthened as central government fell apart after Charlemagne's death in 814. Then from 911 the Vikings themselves established in Normandy the most stringent of feudal modes. For most, feudalism represented a relinquishing of personal freedom in a quest for manorial security. Yet maybe even that choice was less stark during an era of moderate if irregular economic growth.

The proposition that the secular economic uplift of the eighth and ninth centuries in west and north Europe owed a lot to climate amelioration is not gainsayed by signs that the former commenced a short interval (one might say half a century) ahead of the latter. That relationship is what one might expect at a time of technical and institutional progress with capital accumulation. What should be further addressed is how far Denmark was a special case in terms of soil and hydrology.

East Asia

Again, an excursion into east Asian history may put European experience in clearer perspective An assessment of the Rossby standing wave enveloping the Himalayas and Tibet may be especially instructive. Otherwise comparison can still revolve around how susceptible Europe and China respectively were to steppe nomad depredations. Never mind that China's demographic centre of gravity was now edging steadily southwards.

In the Cold War years, Owen Lattimore was the USA's best-known interpreter of China's political culture, historically considered. He was by virtue of his incisive scholarship though also for having withstood (from 1950 to 1955) a McCarthyist 'anti-Communist' witch-hunt. In 1951, Lattimore portrayed all the Chinese dynasties as subject in their turn to an organic progression of rise and fall: emergence of a strong man; mass mobilisation for water control; apparent stability; cheap supply of labour; agrarian depression; yearning for next strong man. . . .[119] It is pertinent now to ask how climate change may alter the profile of whatever cyclicity is built in. As usual, proxy measurement of mean air temperature will proffer the sharpest indication. Across east Asia, its special significance will lie in its being a yardstick of the current progress of the eternal conflict between the Siberian and Pacific circulations. As a rule, the secular sequence is even more intricate than in Europe. The reactiveness of the Tibetan plateau is one reason why.

A 1993 study cited in Chapter 4 concluded that by AD 600 a longish cool phase was ending in China; and the ensuing warm one lasted through the turn of the millennium.[120] Those findings were well corroborated by a nearly concurrent study by Jin-Qi Fang, a study focusing on east Henan. Additionally, however, he registered a sharp though transient reversal in temperature in the ninth century, especially the second half.[121] Consistent with this, as far as it goes, is the tabulation of severe winters in the other study of Chinese historical climatology noted in the previous chapter, the one Cho-Ching Chu completed in 1926.[122]

It is unlikely that this transient cooling was caused by extra loess dust in suspension regionally[123] or by any other factor more or less specific to China. Rather it should be read as another manifestation of the anomaly widely registered across temperate northern latitudes about that time. At present it seems difficult, however, to identify a general cause that seems sufficiently coincident with this event. Traces of volcanic dust from the Crête core, Greenland, show moderately high levels from 820 to 854 but then minimal registration until the huge Eldgjá eruption in Iceland in 934.[124] An exhaustive study of sunspots by Justin Schove showed three strongish cycles quite tightly grouped between 829 and 850.[125] But even if the timing had been that bit better there would still be the usual uncertainty about the terrestrial connotations. Besides, although the anomaly in question seems very consistent inter-regionally, it is not absolutely so. That suggests to me a thermal splurge in either the North Atlantic or the North Pacific oceans. As a matter of interest, however, Co-Ching Chu did claim to observe a positive correlation, century by century, between winter cold in China and sunspot numbers through the second half of the first millennium AD.[126]

As regards droughtiness across China as a whole, the worst of an arid era was over by AD 650. The next 300 years were moister.[127] In other words, there was a turning point in precipitation closely coincident with that in axial Europe, though in the opposite direction. The switch in China generally augured well for rice, just as that in Europe did for wheat and other hard grains. However, China's weather in general appears to get more erratic across the span AD 500 to 1000. Yet here, too, caution needs be exercised. Take the incidence of droughts and floods. According to the 1926 survey, their combined frequency more or less doubled over this interval. But could this not largely be a function of more intensive recording as China waxed more competent in both science and government? That reading of the data draws extra credibility from an analysis of the censuses of population. This found that the number registered, expressed as a percentage of the total modern demographers have deduced, rises from 12 in 775 to 95 in 1100.[128] On the other hand, those east Henan records of hailstones look strictly consistent with the temperature profile for those centuries. No adjustment for intensity of recording is called for. Certainly that holds true if one associates hail mainly with the southward advection of cool but moist and unstable air. Reports of hail are actually quite infrequent from AD 550 to 1200.[129]

What is more, the secular shift towards moister conditions appears very uniform spatially, coastal locations excepted. That comes out of the survey by Jin-Qi Fang, cited above, of lake evolution the last two millennia.[130] Usually the combination of extra rain and higher temperatures will have invigorated and extended both monsoonal forest and marshland, features liable to impede the southward progress of the Han. At the same time, this moister and warmer pitch should in itself have encouraged (much as in Han Empire times) the northward extension of rice cultivation with a corresponding recession of the northern hard grains, notably millet and wheat. In practice, however, the introduction during the Tang of the stone roller to 'tiller' the young wheat shoots (i.e. make them spread horizontally) enabled wheat literally to gain much ground against rice on the north China plain.[131] This was in spite of the moistness trend being accented in the eighth century by frequent flooding by both the Yangtze and the Yellow River (see Chapter 3).

The tribal peoples, sedentary or nomadic, each side of China's northern border will have been stabilised by incremental warmth and moisture, even if the sequences were irregular. In a parallel study, Fang found AD 650–1050 to have the fewest records of direct migration of any secular interval in the period 190 BC to AD 1880. Nor was this to be explained by any abnormal shortfalls in collation.[132]

Although southward colonisation by the Han started, in the fourth century, as a movement of refugees to locales beyond the reach of famine-stricken barbarians, it in due course became a positively successful exercise in the redistribution of population, this success deriving from a new culture based on rice and tea. Under the eastern Jin dynasty, centred in the lower Yangtze, the ancestral grazing lands of the indigenous Thai were turned into plantations and bamboo groves or into parks with artificial mountains and scenic conduits. Putting to one side the question of ethnic injustice, Professor Albert Kolb of the University of Hamburg averred 'No other people have achieved a comparable transformation or shown themselves so adaptable.'[133]

Nevertheless, the reunification of China was achieved, in 589, through the defeat from the north of the eastern Jin and the deletion of their capital, Jiankang. The pedigree of the successor dynasty, the Sui, was therefore northern. To be precise, it was a Sino-Turkish aristocracy formed through assimilation in the wake of forceful incursions. Once in charge of the country, the Sui launched huge programmes of public works carried out by dint of *corvée*-style conscription and providing the infrastructure for a forward strategy against the nomadic tribes. Between 605 and 610, the Grand Canal was dug as a trunk route linking the Yangtze and Yellow River. Likewise, millions worked on strengthening the Great Wall, incurring during the exceptionally long and parched summer of 607 (i.e. close to the climate turning point) a death rate of at least 50 per cent.

Cultural advance was also sustained. The creative interaction between Taoism and Buddhism observable in the fifth century continued into the sixth. At the same time, the diffusion (via Turkestan and Sinkiang) of Indian advances in fields like medicine, mathematics and astronomy paved the way for marked scientific progress as China was united once more. Nevertheless, anxiety persisted about the security of the northern border, particularly as regards its more verdant north-east approaches. Hence in 611, the first of three campaigns was launched against the Koguryõ, a Manchurian–Korean regime. All were costly failures. A resultant backlash found expression in hundreds of local uprisings all round China culminating in the assassination of the emperor himself in 618.

Neither the next dynasty, the Tang (618 to 907), nor indeed its successor, the Song (960 to 1279), saw any need to extend the Great Wall.[134] Quite early on the Tang had effected the break-up of the Koguryõ barbarian state by engineering the secession of the Korean peninsula. Likewise from 648 (after the Turkish tribes had been broken by large-scale massacres in the course of punitive forays), China systematically advanced down the Kansu corridor, across the Tarim basin and into Turkestan, thereby creating for itself an outlier which it proved able to sustain until 763. Across China proper, the Tang ushered in a still more vigorous era, stimulated the more by an inflow of goods, people and ideas through Turkestan. The principle of scholastic examination, open to all as a preliminary to entry into the imperial civil service, was fully embraced. A comprehensive network of good post roads was established. The ancient city of Ch'ang-an very likely now attained, with its suburbs, a population of two million. No fewer than 14 other urban prefectures embraced at least 100,000 households apiece.[135]

Within the penumbra of Chinese influence, two kingdoms emerged which invite comparison with those arising in western Europe. On and around the Tibetan plateau, a modicum of relative warmth is always liable to be of critical importance, not least apropos the swards of mountain grass. Furthermore, there are indications that warmer spells can last rather longer there than in China proper, the intervening cold spells being correspondingly shorter though very acute. The year 800 was the middle point in one warmish cycle extending across four centuries.[136] In 635 the Tibetan kingdom had consolidated around its new capital at Lhasa. This sheltered Brahmaputran valley site (at 3,500 metres and facing south) nowadays enjoys a July mean temperature of 14.6°C and has peach trees blossoming in early April.[137]

Over the remainder of the seventh century and on through most of the eighth, Tibet expanded in more or less all directions. The coast of Bengal was broached, while Nepal became a satellite of Lhasa as did part of Turkestan and, more loosely, the Thai Empire. South Asian influences duly affected Lhasa more. But concurrently Tibetan troops deployed northwards, cutting across the Kansu corridor. Then between 840 and 900, this Greater Tibet collapsed back to the plateau and Lhasa's valley. This collapse was followed by prolonged feudal strife internally. In the meantime, in 668, the Silla kingdom in Korea had been able, with China's military and cultural support, firmly to unify that peninsula, and then to distance itself from the Chinese enough to be functionally independent. The unified Silla regime, based on Kyongju, became awhile a veritable fount of creative artistic expression.[138]

The Tang dynasty had itself lapsed into a crisis of instability by the mid-eighth century, its being marked by a civil war from 755 to 763. One response was the abandonment by the regime of the imperial role it had lately assumed in central Asia. Another was to launch a further wave of peasant resettlement in the Yangtze valley and beyond. However, the conflicting demands for free enterprise and imperial involvement on this moving frontier exacerbated tensions over such peasant obligations as *corvée* and conscription. These were duly eased, but that presented the authorities with bottlenecks in manpower. Massive peasant risings towards the end of the ninth century precipitated the terminal dynastic crisis. The immediate aftermath (906–60) was even more chaotic, the period of the Five Dynasties and Ten Kingdoms.

A question is what the relationship was, in terms of geophysical dynamics, between the halcyon era in Tibet (*c.* 630 to 840) and climate fluctuations in China proper and also central Asia. The basic concept, as enunciated by Reid Bryson, is that a more vigorous and extensive summer monsoon will normally be associated with the Tibetan plateau being comparatively balmy; and also that strong southerly vectoring of the run of wind will bring welcome extra rain to the Chinese heartland. But over central Asia, the same air currents, having backed north-east, may connote aridity.[139] But their vigour will still yield orographic rain when they transit the Ethiopian highlands.

As much is corroborated by the Nile flood records, used as a monsoonal proxy. William Quinn has found, for the first half millennium (629 to 1129) of the keeping of regular records, 33 seasons in which the Cairo nilometer peak reading was more than 0.8 metres below the norm – i.e. 3 or above on his scale (0 to 5) of deficit severity. Yet only one of these weak floods (i.e. that of 782) occurred between 714 and 801.[140] The high point of the Tang penetration into central Asia can be taken as 751, the year the Chinese are finally checked, though not by the Turks but by the Arabs at the battle of Talas, south-west of Lake Balkhash.

As always, the Chinese 'were successful in controlling the steppe and the steppe nomads only when internal steppe politics had drastically weakened the nomadic empire',[141] a situation most likely to be induced by climate erraticism. Among their prime concerns had been to acquire fleet and strong Turkish horses to supplement the squat Chinese variety. The Tang military had built up in the seventh century (in pursuance of the forward policy in inner Asia) an equine inventory of no less than 700,000 mounts but now wanted to enhance stock quality. So proactive a Chinese interest in the cavalry arm was a function of what richer pastures and an expanded imperial budget might allow. It also owed something to recollection of a most menacing incursion by Turkish cavalry *c.* 620.[142]

The question thus posed is whether the course of events can basically be explained in terms of the Lattimore cycle or whether climate change supervened decisively. Might not the coldish interlude in the middle or late ninth century have turned other instabilities critical in both China proper and Tibet? More generally, did not climate flux bear considerably on agricultural development and therefore on the perennially delicate strategic balance along China's northern border?

From shortly before the inception of the Tang dynasty, Japan began to emulate China closely and systematically. The latter was adopted as the model for almost everything from watermills to lacquerwork, from Buddhism to the tea ceremony. In 710, the first acknowledged capital of Japan was established at Nara. It was built to a chessboard ground plan akin to that of intra-mural Ch'ang-an. The same applied to the new capital built from 794, also in the nodal Kansai area of west Honshu. It was called Heian-kyo, alias Kyoto. This translation of the imperial seat was for reasons factional not ecological.[143]

The previous two centuries had seen Japanese Buddhism transformed into a popular religion. This helped to forge a nationhood that, apart from ferocious campaigns against the Ainu aboriginals, was initially free from warfare, and which, by the ninth century, was evincing within its upper strata singular elegance and sensibility. These cultural traits were especially associated with the dominant Fujiwara clan based in Kyoto.

Still, government was no more than clannish confederation. The first traces of manorial feudalism did not appear until the eighth century. So in that respect Japan remained very different from China. The difference stemmed from its offshore climate and tortuous topography. The individual family rice fields tended to stay well scattered.[144] The climate allowed that this could be so. The topography meant it had to be. Likewise the landscape did not lend itself to wide areas of common grazing, each one to be managed as a whole. Nor were the Ainu aboriginals strong enough to necessitate comprehensive feudal bonding for mutual protection. When, from 1185, a quasi-feudal order was systematically created, it was because the ruling shogunal military wished to curb violent strife among aristocratic factions.

Analyses of tree rings point to the weather getting warmer and maybe drier, through the ninth century at least.[145] Similarly, the date in April of the first cherry blossom at Kyoto averaged out at 11.3 and 11.8 in the ninth and tenth centuries respectively. Those results may be compared with a mean of 17.2 for the next four.[146] Once again, one must ponder how indicative a seasonal tendency is of an annual one. One can further ask if the ninth-century figure admits of a cool interval from *c.* 850.

The answer to the first question may be that early blooming betokens the early collapse of the wintertime Siberian High. The second one can, of course, be related to the firm indications elsewhere of such an interval. A further consideration to adduce apropos Japan are possible alterations, as the medieval climatic optimum approached, in the lie and amplitude of the Rossby standing wave enveloping the Tibetan–Himalayan massif and of the corresponding trough axis of late lying longitudinally just east of Japan. This double feature will have been liable to increase in amplitude and maybe ease somewhat to westward, thereby locking in more tightly to the said massif. That prediction is in line with what Lamb tentatively proposed. It is also consistent with other authoritative advice that, even on weekly to seasonal timescales, Rossby long waves may be discerned subtly shifting westwards – i.e. against the zonal flow.[147] That may have made the Japanese climate more oceanic for two or three centuries.

The temple states

A primary effect of such a standing wave accentuation could have been to plunge colder conditions down the maritime flank of continental east Asia. That in its turn could have engendered a drier surface regime over much of Indo-China and Thailand. Therefore the rain forest would have thinned. The ultimate human link in the chain of causation will have been the emergence of the Khmer Empire. Initially this was centred on Angkor Wat with its magnificent temples and bas-reliefs. Later on its capital was Angkor Thom, a temple city of maybe 250,000. The empire was at its height between the tenth and fourteenth centuries.

How far the climatic setting for so remarkable an emergence lends itself to Rossby wave analysis is of added interest because of the influence south-east Asia had on the outside world in medieval and early modern times, not least its indirect influence on Europe through interaction with the Arabs and with China. Clearly, too, it sheds light on Rossby waves and climate change as considered in the round. In 1977, Hubert Lamb was disposed to attribute lighter rains over Indo-China to more limited migration by the Inter-Tropical Convergence Zone.[148] By 1995, however, his surmise was that a progressive extension southwards of a trough over east Asia (offsetting a ridging 'over the Indian sector') had 'introduced an anticyclonic tendency over Thailand and northern Indo-China.'[149] That was tantamount to saying that the Rossby wave factor was coming into play.

Seeing the rise of Khmer civilisation as dependent on an easing of the water cycle is supported by field research. Originally (i.e. AD 0–300), its incipient prosperity derived from the 'flooded savannah' rice fields of the broad Mekong delta. In the seventh century, the temple architecture began to evolve. Then between the eighth and tenth centuries, as state institutions consolidated, the surplus wealth slowly accumulated was directed towards two disparate objectives. The one, 'a feat of tremendous magnitude', was to switch most of the agricultural base to tens of millions of plots newly created out of the rain-forest slopes about the delta proper. This has been read as a response to 'a change in the flood pattern'. It was certainly in reaction to a thinning of the forest.

The other transformation involved investment in very water-consuming 'theocratic hydraulics'. The Angkor cities (and, less completely, the rural hamlets) were turned into replicas of Heaven as per Indian cosmology. Remarkably, no instance is known to the specialist here cited 'where a temple pond was equipped with a distribution system to water the fields.'[150] One thing this probably connotes is that any secular decrease in mean rainfall is unlikely to have been pronounced.

Over and beyond the exposure to climate flux inherent in all hydraulic civilisations, this bold departure was peculiarly susceptible on two counts. The one was the failure of the Khmers properly to master the art of dam-building. The other was the very seasonal character, by equatorial standards, of the regional precipitation. In Hué, just the other side of the Annamese mountain axis, less than a fifth of the rain nowadays falls in the six spring and summer months as against two-thirds in the three autumn.

Nevertheless, the Khmer experiment flourished for close to half a millennium. Yet that makes a geophysical explanation no easier to tie up. Several objections can be levelled against the Rossby wave approach. Waves generated in the temperate zone are not understood to extend readily towards the equator. Instead, oscillations in the upper westerlies tend to generate within the tropics independently of those more to polewards. Besides which, the trough displacement to westward would have had to have been very considerable. Nor can the upward trends in warmth and precipitation across early medieval China easily be accommodated thus.

Moreover, these difficulties are accentuated if one tries to relate the analysis to other Buddhist–Hindu temple states that waxed impressive in south-east Asia in those early medieval times. The chief were the highly refined Pagan in central Burma from the eleventh to the thirteenth centuries; and the Borobudur and Prambanan in Java from the eighth to eleventh. From the tenth, Arab merchantmen voyaged to Java,[151] drawn no doubt to the nutmeg, cloves etc. of the nearby lava-rich Moluccas – alias the fabled 'Spice Islands'.

Another explanation that might fit such a geographical spread is that of a secular weakness of the south Asian monsoon. The tabulation of Nile floods by Quinn points to the frequency of weak monsoons troughing out *c.* 775, and then to a contrary trend the next few centuries.[152] Moreover, weak monsoons are associated with El Niños rather than La Niñas; and the former also correlates with decreased rainfall across the Indonesian archipelago south of the equator (see Chapter 2). Here again, more fieldwork, analysis and debate are needed. But on the evidence to date one can with more confidence deploy the explanation of plunging cold waves later in the medieval warming process. Arguably this mechanism bears on the English crisis of 1066. Assuredly it sets the climatic scene for Genghis Khan.

Suffice to observe that this is not the only instance of the climate history of north temperate latitudes in the first Christian millennium being illuminated by the burgeoning study of tropical palaeoclimatology. Another concerns the tightly defined cold decades of the mid-ninth century. Closely coincident with them was a terminal crisis in the classic Mayan civilisation flourishing until then on and around the Yucatan peninsula. That event is most visibly evidenced in two refugee migrations, the last and biggest in 889. Until recently the cause of crisis was mysterious. But now it is confirmed that the said locale had suddenly lapsed into what was to prove its most prolonged and savage drought these last thousand years. Very likely the aridity was associated with cooler conditions, taking day and night together. But the essential point for the moment is just that this transient, but acute, climatic perturbation was more or less concurrent with the cold interlude identified herein as affecting several far-flung regions.

6 Towards the optimum

THE CLIMATE IN TEMPERATE EURASIA

Affirmation that, in and around Europe, a salubrious warming trend was well sustained from sometime in the 'Dark Ages' to the thirteenth century has long been a *sine qua non* for scholars concerned with climate change. What basically occurred was a moderate rate of evolutionary progression over an extended time span. Secular changes in mean temperature were markedly slower than what was characteristic of the onset or conclusion of the Older or Younger Dryas events, or is of contemporary global warming.

Hubert Lamb saw the northward limits of vine cultivation attained in western and central Europe in the High Middle Ages as indicating mean summer temperatures a modest 0.7 to 1.4°C warmer than in the twentieth century.[1] A recasting of this could be a rise of near to one degree above the annual mean several centuries before. That or something akin has long been received wisdom within the climatological fraternity,[2] due not least to Lamb. What also seems generally agreed is that, at sometime near the temperature optimum, a slow and irregular trend towards dryness gave way to a moister tendency.

Among historians proper, on the other hand, the very idea that climate variation contributed to the waxing and waning of medieval civilisation has tended to receive shortish shrift, though not with the monolithic consistency climatologists usually assume.[3] Take the pitches respectively adopted in the decade from 1962 by three celebrated students of the economic and social history of the Middle Ages – one Dutch and the other two Annaliste French. B.H. Slicher van Bath in fact perceived a wet interlude from about AD 1000 to 1300. Yet to him, it did 'not appear likely that the periodic ups and downs observed in the economic life of western Europe after 1200 are the result of climatic changes', notwithstanding sundry attempts to link weather periodicity to sunspot cycles.[4] Next, Georges Duby, addressing the period from 1300 onwards, called for more research into how far climate fluctuation effected economic and social change.[5] A few years later, Emmanuel Le Roy Ladurie suggested that at what he saw as its medieval peak (*c.* 1080–1180) the mean annual temperature in western Europe was 'perhaps a few tenths of a degree Centigrade more' than in the late Middle Ages.[6]

Lately there has been a renewed disposition to play down the thematic prominence of medieval warming *per se*. Fluctuations on decadal timescales have been stressed more, those across centuries less. In the main this has been a matter of reinterpreting the dynamics – geophysical, ecological and human. But questions of veracity also arise. Not least has attention been directed to how stories of sea floods may gain in extravagance what they lose in authenticity as they are passed down the generations (see Chapter 8).[7] Profiles constructed by Lamb that will need ongoing reassessment include (a) summer wetness indices for

England, AD 1200–1350, and (b) English winter severity indices for 1100 to 1400. In a 1978 review, the former stood up to scrutiny. The latter did not.[8]

What must also be remembered is that, at global level, transient medieval warming was by no means synchronous or even ubiquitous. In various parts of the world (e.g. much of China and also of the Pacific cordilleras of North America) average temperatures stood higher than in the centuries to follow. In other regions (e.g. the south-east of the United States and much of South America) the norms, as measured to date, differed little from more recent times. That applied, indeed, to much of Mediterranean Europe.[9] Nor is so involuted a pattern surprising bearing in mind our contemporary experience. The change in mean air temperature as between 1955–74 and 1975–94 varied, across the world, from – 0.6 to + 1.3°C.[10]

The Milankovitch cycles have, these last ten millennia, been conducive to progressively cooler summers and warmer winters throughout the northern hemisphere. At 75°N, the former trend will have been two or three times as steep as the latter, whereas from 55°N southwards the rates have been very similar.[11] By the year 1000, however, this 'astronomical' effect was being overridden by factors affecting warming in the shorter term. One was the European and east Asian deforestation considered in Chapter 3. Another was solar fluctuation as defined by the Oort and Wolf sunspot minima, 1025 to 1100 and then 1280 to 1330 respectively. Dust loading of the high atmosphere was a third.

According to the Chinese records cited in Chapter 4, there had been a reduced incidence of meteor showers by the eleventh century. Even so, a major nocturnal event occurred over Europe on 4 April 1095. That at least one substantial meteorite was involved is connoted by a near-contemporary chronicle: 'For the stars in the sky were seen throughout the whole world to fall towards the Earth, crowded together and dense, like hail or snowflakes. A short while later a fiery ball appeared in the heavens; and then after another short period half the sky turned the colour of blood.' Clube and Napier have judged no other such events to be that conspicuous for the next two and a half centuries.[12] This 1095 one contributed quite powerfully to the atmosphere of high drama with which the First Crusade was launched (see pp. 178–9).

Of more consequence, as a rule, however, were the variations within the stratosphere of volcanic dust. The ice core record from the Crête station in Greenland can be summated thus. Dust levels were moderate to 820; rather high, 820 to 854; and moderate until 1257 except for two huge Icelandic eruptions: Eldgjá in 934 or thereabouts and Hekla in 1104.[13]

Oriental archives have here been used to gauge the overall incidence of meteor showers. What has to be admitted, however, is that a similar tabulation for sunspots could give a misleading impression. Oriental records of them are few from AD 600 to 800, then relatively frequent from 800 to 1100, and the more so from 1280 to 1700.[14] However, physical research at the University of Arizona, using variations in the production of cosmogenic isotopes (Carbon-14 from tree rings and Beryllium-10 from Antarctic ice), has confirmed a solar maximum from '1100 to 1250' between the Oort and Wolf sunspot minima.[15] A consequent upward forcing in global average temperature as between 1080 and 1150 is put at 0.6°C.[16]

Inspection of the Arizona data makes it hard to speak of a medieval maximum before 1120, the low turning point in the Oort minimum being *c.* 1060.[17] Lamb did a compilation of six reviews (conducted between 1893 and 1964) of historical sunspot or aurora reports. It indicated a low frequency in the first half of the eleventh century. But the basic 22-year sunspot cycle was not readily traceable.[18]

The conclusion emerges that a warming that, on balance, took place globally was strongly forced by solar fluctuation, the upward tendency to 1250 being strengthened further by deforestation as well as by a low level of vulcanism. Looking at the forcing calculation in the Arizona study while allowing for Milankovitch etc., one may be surprised that the net forcing, as expressed in European temperature rises, was not more. Still, such reckoning is about movement to an equilibrium mean temperature that may not have been attainable within the operative time-frame.

Regional modulations

What cannot be gainsaid is regional variation in climate flux, even within Europe and in areas that impinge on it. An overview of the differences may best work east from Greenland, a territory where the peaking out of medieval warming came early. There is close correspondence between two key sources. The one is the oxygen isotope analyses of the Crête core done under Willi Dansgaard at the Geophysical Isotope Laboratory at Copenhagen.[19] The other is a profile of Icelandic temperatures by Astrid Ogilvie in 1984 built up while at the Climate Research Unit (CRU) of the University of East Anglia.[20]

To *c.* 1170, the Icelandic archival record is very skeletal. Then it quite steadily consolidates. In 1261, sea ice was recorded 'all round' Iceland. From 1280 the weather was more severe overall, though the sequence was erratic.[21]

The progression as observed at Crête can be summated thus. From the late tenth century to the early twelfth, the regional mean temperature fell fairly steadily. Over the next 250 years it fell further less steadily.[22] Within that setting the two renderings here cited concur quite closely about severe cold in the late twelfth century, and very closely about such a spell from 1280 to 1300. Additionally, Ogilvie discerns sporadic severity between 1233 and 1275. If one has any reservation about the concurrences, it has ironically to be that, according to the Copenhagen interpretation, the Icelandic temperature profile for underlying trends should lag a century and more behind that of Greenland.[23] As noted above, however, a secular lag longitudinally need not exclude phase concurrence on time spans of up to a century or so.

One might presume that, within conditions as severe as those bound to obtain around the Greenland settlements, variation of a kelvin degree or two in mean temperature would affect human prospects little. A critical factor in the High Arctic, however, was the distribution of sea ice and currents. Access to salt water around the edges of the pack ice or on nearby ice floes was crucial for fishing, sealing and whaling; and in north Greenland, with little grass for musk-ox, this marine harvest underpinned the Inuit economy. Since 1945, successive compilations have shown more ice present by the thirteenth century.

When the Birnick Inuit first reached these longitudes *c.* AD 900, they spread very much into the High Arctic – e.g. by settling on Ellesmere Island (76 to 84°N). But *c.* 1200, with the weather already that much chillier, they turned southwards more. By 1500 their Ellesmere settlements had finally been abandoned. Well before that, their southerly translation had brought them more into contact with the Norse, this for good and ill.

In the north of Norway and Sweden, the anticyclonic circulation of air identified (especially as a winter phenomenon) in Chapter 5 continued through the Medieval Optimum. Though glacier fluctuations proffer general corroboration, tree-ring growth has here proved to be more exclusively geared to mean temperature trends as well as being as always (see Appendix A) much more reactive and precise on intra-decadal scales than is glacier extent. The July mean isotherm emerges as the strongest determinant of Scots pine growth near Lake Torneträsk in Sweden.[24] On that basis, 21-year running means show a cluster of cold summers around 1140 and, less emphatically, around 1235.[25] These event nodes are within the context of a lowering of regional temperature that continued through the tenth century but which, in the twelfth, became subject to dramatic alternation. Severe cold from 1110 to 1160 was followed by relatively pronounced warmth, 1160 to 1190. What this has meant statistically is that, using either 20- or 50-year units of comparison, both the warmest and the coldest spells in the Torneträsk series across the time span AD 750 to 1860 are located in that twelfth century.[26]

But that erraticism is subsidiary to the more general reality. At the 1993 Durham meeting of Britain's Quaternary Research Association, Keith Briffa of the CRU emphasised that overall the span between 1100 and 1300 was relatively cold in northern Scandinavia. In 1994, a millennial Hughes and Diaz time series backed that judgement.[27] Norman Pounds was perhaps alluding in part to students of the Fenno-Scandinavian scene when in 1973 he spoke of 'several writers' locating the peak of medieval warming as early as 1000 or 1050.[28]

Although the arboreal record derives from the brief summer months, the suggestion above has been that it may still betoken a firmer organisation the year round of the circumpolar high classically to be expected within a 'planetary wind system' (see Chapter 2). The key to its emergence thus will presumably have been a weakening of the wintertime Siberian High, a result of secular warming across temperate latitudes within Eurasia. Tangible support for the idea that such realignment can occur is to be found in several recent studies. A review from 1725 to 1925 shows striking correspondence in coniferous tree-ring growth as between northern Scandinavia and the polar Urals;[29] and the Hughes and Diaz series endorses this, albeit less emphatically, before 1400.[30] Meanwhile, an examination of over 27,000 temperature profiles for 1950 to 1990 from the lower troposphere above the Arctic Ocean revealed no warming trend in spite of a resumed greenhouse effect.[31] A sense that the climate history of the Middle Ages could roughly be repeating itself is strengthened by some strong positive anomalies in mean winter temperatures over Siberia of late and by the reality that a 'cold pool' anticyclone like the Siberian inherently lacks strength in depth.

The medieval Swedes faced the node of cold more directly than did their Norwegian cousins. Correspondingly, the former were even less inclined than the latter to push the frontier of settlement northwards, their inurement in north Russia notwithstanding. In southern Sweden, as we know it today, the rule of King Knut Eriksson (d. 1196) marked a climax in the development of the Lake Malaren environs as the national cornerstone – governmental, ecclesiastical and commercial. A fortress was built close by the fishing village of Stockholm. A bishopric had been established in 1068 in nearby Uppsala, 54 years after the first Swedish one at Skara.[32] By 1196, five sees with defined boundaries had been founded in Sweden together with a sixth at Åbo (Turku) in Finland. Uppsala was an archbishopric as of 1164.[33] Yet at just below the 60-degree parallel, it was still the northernmost see.

Within these confines, agricultural advance continued apace. In south-east Sweden the number of farms is reckoned to have risen from close to 5,000 in 1100 to three or four times that by AD 1300. From 1100, too, this agrarian expansion was 'spilling over onto climate-dependent soils with poor production capabilities'.[34] Concurrently, however, agriculture was made more adaptive by the introduction across southern Scandinavia of the harrow and of sturdier kinds of plough. They underscored the involvement that region already had in three-field rotation.

The impression one gets is that today's January isotherm of – 7°C mean surface air temperature delimits what would have long been the settlement frontier, each side of the Scandinavian mountain spine. For the Norwegians, this delineation extends well beyond the Lofoten Islands along the immediate littoral of the Norwegian Leads, those stretches of often calm water that lie along Norway's Atlantic seaboard between the successive offshore islands and the main coastline.[35] In the more continental ambience of Sweden, this isotherm all but intersects the coast of the Gulf of Bothnia a mere 50 miles north of Uppsala.

More basically, the persistence across north-central Sweden (*c.* 62–65°N) of a very sharp temperature transition will probably have determined the medial lie of the polar front then. That would also be closely congruent with two other very singular tendencies noted in the previous chapter. The one was the moistening of the Jutland bog between 900 and 1200; the other the northward displacement of storm tracks, from the tenth century, in the Volga basin. Looking ahead, a third correlation might be with the heavy damage from landslides and flooding at 61°N near Josteldalsbreen in the early fourteenth century. Jean Grove and Roy Switsur suggested glacial expansion may have played a part in that.[36]

Between Baltic and Mediterranean

By the 'Baltic' is meant in this sub-title 'the Baltic and North Sea'. Likewise, 'the Mediterranean' may include the Black Sea. In other words, what one is setting bounds to is that axial European peninsula extending from out of the Russian plain down to Iberia. One must encompass, too, the British Isles.

A general conclusion, supported by Lamb's collation of English evidence, has been that, throughout axial Europe as thus defined, the climate movement into a 'little climatic optimum' was characterised by noticeably warmer and drier summers as well as, by the twelfth century, milder and wetter winters.[37] Dynamically, that would be consistent with the Azores anticyclone being more influential in summertime and with an open westerly flow in winter as allowed by the Siberian High being in quasi-recession. Warmer conditions over China can also be related to that hypothesis. Exactly when the optimum subtly peaked out temperature-wise may not be too important. All analysts seem to agree it is soon after 1275 that the general run of weather assumes a nastier mien (see Chapters 8 and 9).

None the less, a thermal turning point is looked for as a benchmark in the literature. Le Roy Ladurie has been among those disposed to locate it early on. He has been influenced by signs of a quite vigorous offensive by the Alpine glaciers from, in his judgement, 1150 or maybe 1200 to 1300 or 1350. He has borne in mind, too, isotopic analysis of a well-ringed stalagmite in a cave in the Ardèche, analysis which for some reason showed a fall in the mean ambient temperature of 0.6°C between 950 and 1150.[38] Also he had noted earlier how prone to drought the ninth- to twelfth-century summers appear, notably in France and Germany.[39]

By 1984, Hubert Lamb was persuaded that the 'warm epoch' could be said to extend from 1100 to 1300. At the same time, he cited a peat bog near the English–Scottish border as showing this same period (though particularly the thirteenth century) to be considerably drier than before or after.[40] In general, however, he stressed the drought dimension less than have other analysts, tending to see a rainfall decrease averaging 10 per cent in the summer as offset (at least in simple volumetric terms) by an increase in winter.[41] In 1966, indeed, he wrote of botanical studies 'which already suggest an important increase of total rainfall in northern Europe around 1200–1300',[42] and of a trend towards higher summer rainfall over the Russian plain (induced, one presumes, by convection) extending into western Europe, periodically and on decadal timescales.[43] Yet at this stage in our knowledge, an overview as elaborate as Lamb here formulated is best taken as illustrative of the complexities liable to have developed rather than descriptive of those that assuredly did.

In principle, one could expect that, as and when rainfall increase set in across temperate

European latitudes, it first did so via convective showers well inland. Yet in the Tregaron series in central Wales, bog growth is said to have recovered strongly after three centuries of near standstill, AD 900 to 1200.[44] A view of the then climate of eastern England gleaned from contemporary chroniclers involves a wet phase, interspersed with summer droughts, 1250–72; next a mainly warm and dry spell to 1289; and then nigh on four decades of unparalleled wetness and misery from the poor harvest of 1289 to the good one of 1326.[45] Obversely J.Z. Titow, having explored the archives of the far-flung fiefs of the Winchester diocese, judged the period 1270 to 1312 to have been very dry.[46]

The Alpine anomaly

Undeniably, things are complicated by the advance of the Alpine glaciers in the High Middle Ages. The distinguished American medievalist Robert S. Gottfried aligned closely with Le Roy Ladurie in seeing this as the harbinger of a broader reversion to cooler and wetter weather, a reversion Gottfried reckoned began in 1150 or soon thereafter.[47] One issue to resolve is whether this glacial resurgence related more to increased precipitation (particularly in wintertime) or more to lower temperatures, not least in the summer. Le Roy Ladurie has long been persuaded that temperatures in 'the hot season, the season of ablation' are very generally those which count when secular warming is under way, and does not doubt that this obtained in this instance.[48] A survey of Alpine data on recent glacial fluctuation has suggested that, on average, 58 per cent of any variance is a function of the temperatures in July and August, 16 per cent of it depends on precipitation in June, and another 5 per cent on precipitation from October to May.[49]

Granted, any pronounced contrasts in behaviour between glaciers on different aspects within the Alpine region would indicate that a changing precipitation pattern was the dominant control. Glacial fluctuations globally reveal many such discordances throughout the Quaternary. However, the Cambridge survey alluded to above found a fair measure of consistency in the performance of Alpine glaciers in the High Middle Ages. In particular, there was a tendency for them to advance between 1050 and 1250, much as Le Roy Ladurie inferred. Nor were the advances negligible. Tree-stump dating shows the Aletsch Glacier, a few miles south of the Jungfrau, to have stretched nearly two kilometres beyond its present limit between 1050 and 1150.[50] Likewise, 'very cold' weather from 1050 to 1200 is revealed by isotope ratios measured in peat in the mountainous borderland between the Bohemian plain and Poland, though not by similar measurements near the Baltic coast.[51]

A stark contradiction is thus presented. An extended cold spell, neatly delimited in space and time, occurred right in the middle of Europe right in the middle of a major continental warm phase. Maybe a clue to its resolution lies in the contrast noted in Chapter 2 between a low level of climate erraticism during the Wolf Minimum in sunspot activity (1280 to 1330) as compared with, say, the Spörer Minimum (1410 to 1534). Suppose a relative evenness of the temperature sequence year by year did extend back to 1050, a notion to which the Chinese imperial archives lend some credence (see Chapter 8). Then fewer abnormally hot summers will have been a check on ice melt or ablation, while fewer very cold winters will have been conducive to higher snowfalls. Granted, each argument will have applied the other way round. But it could still be that, in this Alpine context, the net shift will have been towards glacial accumulation. As usual, the positive feedback due to the high albedo of ice will have accentuated any tendency in whichever direction.

Another approach to the problem is to ask whether the dynamics of climate change would have involved any reorientation of the prevailing winds, with particular reference to their perhaps coming more from a northerly quarter. Certainly, those clusters of cold summers over the north of Fenno-Scandinavia *c.* 1140 and again *c.* 1235 were pronounced features – the former especially so. It would therefore be reasonable to surmise that, each time round, the said tendency pulsed southwards quite often. Such pulsation may similarly have occurred during shorter spells of this kind.

The nub again lies in weighing the implications for the Alps. When polar northerlies penetrated that far, advecting air cool even at the surface and with a pronounced lapse of temperature with height, the situation would have been conducive to convective showers accentuated by mountain uplift. On the other hand, the anticyclones these winds would have flowed round would have blocked frontal depressions. Nor can one guestimate the effect the scintillating clarity of boreal air would have on glacial melting and ablation. Nor is it easy intuitively to accept that any of these effects would have made the Alps and their environs a climatic island. The time lags of several decades characteristic of glacier response must also be allowed for. In fact, the thesis that air mass advection contributed appreciably to glacial readvance ought to be tested by realistic computer models. Meantime, one may note that transient warming in Alpine foothills around the upper Po valley could well have been due to a *föhn* effect that would fit this larger picture (see Chapter 9).

The British situation

To reserve judgement is not to deny that a more northerly inclination could have been manifest. So could it down the eastern seaboard of Britain, against a background of secular warming. In the meteorology of the British Isles, a plunge of northerly air behind a cold front has always been a theme.

It seems the more so again today. Thus moving averages show the frequency of westerly winds across most of Britain and Ireland to have been in steady decline between 1948 (or even 1922) and 1985.[52] Another analysis, covering 1947 to 1994, has revealed a tendency (very clear-cut between 1964 and 1974) for the westerlies to decrease in summertime frequency over the south of England in contrast with their prevalence over Scotland.[53] An earlier assessment, looking just at north Scotland between 1967 and 1982, had discerned a high incidence of anticyclonic blocking.[54] These three accounts do not dovetail perfectly. None the less, they tally sufficiently to connote a linkage between a regional anomaly and the more general warming under way, especially since 1965. Something similar may have been operative through the early Middle Ages, the important differences in geophysical dynamics notwithstanding.

Let us here consider the corollary of Lamb's proposal that, in the past, hemispheric cooling has been liable to decrease the amplitude of the Rossby waves observable north of the equator.[55] It is that warming would connote strong meridional ridging in the upper zonal flow over the east Atlantic. This in its turn could have favoured the genesis and lingering of anticyclones to leeward of the ridge. In the evocative text on Britain's weather he first published as a Royal Naval climatologist in 1943, Professor George Kimble of McGill observed anticyclones centred near the North-West Approaches to be particularly frequent in late spring/early summer,[56] the season of most rapid warming. Maybe this annual tendency can be recapitulated by a secular one.

The east Asian situation

Pertinent, too, is whether the eleventh and twelfth centuries reveal any accentuation of the Rossby standing wave that flows north around the Himalayas and the Tibetan plateau to return south obliquely across the east Asian seaboard to trough out along a longitudinal axis lying just east of Japan. The comparative dryness that spread from the Yellow River valley to embrace the Yangtze during this time could have resulted from this. So could an initial coolness before warming resumed after 1200. Recent research has taken into account (a) the northward extent of herbs and citrus trees, and (b) medieval China's reliance on an adjusted lunar calendar. The result has been to identify the thirteenth century as a time of peak warmth: averagely close to a degree kelvin higher in south Henan than has obtained of late.[57] Also relevant to a geophysical interpretation is the ecological resilience Angkor Thom was able to display (see Chapter 5).

For Japan, the signs are disparate and sometimes contradictory. None the less, the countrywide temperature near sea level can be gleaned with some confidence from the archives. In particular, the mean April temperature in Kyoto (national capital from 794 to 1192) is still signalled, century by century at least, by the median date a genus of cherry first blossoms. This indicates for our immediate purposes the following. After exceptionally early seasons for about two centuries, there was a turning towards cooler Aprils during the eleventh and then a transient warmer spell in the thirteenth.[58] Meanwhile, tree-ring variations usually bespeak, within the Japanese archipelago, mean temperatures for the year. For Yaku Jima (an island just south of Kyushu), there is a low turning point in the early fourteenth century, the underlying trend being downward for nearly two centuries beforehand and then upward for more than one.[59]

In modern times, Japan has tended to be sandwiched in wintertime between two strong and contrary circulations, the Siberian High and the North Pacific Low. Fierce 'north-easter' gales (the *hokuto no kyofu* – 'great northern wind' – so dreaded during the 'Little Ice Age' of the seventeenth century) have brought low temperatures, plus wind chill, together with much snow on exposed coasts. However, any recession of the Siberian High will always have been liable to weaken these north-easters and to cause them to draw round less continental air. Herein may lie an explanation for the April warmth transiently experienced at Kyoto in the thirteenth century. Maybe, too, the city was affected by some westerly displacement of the Rossby trough axis, a shift that would have made the Rossby ridging round Tibet that much more acute.

However, an alternative proposal has been that something approaching half the perceived variance of winter temperature is accounted for by an atmospheric cold 'wave' first discernible over the Japan of the twelfth century but which is adjudged then to have migrated westwards, by whatever mechanism, to arrive over western Europe in the seventeenth.[60] At the very least, this concept shows how intricate the climatological interaction between those two regions could prove. Also to reckon with in the case of Japan (more than with China or even the Mediterranean twin basin) is the immaturity of a topography heavily folded in the Tertiary, the most recent of the great eras of mountain building. That situation gives rise to a multitude of sharp local contrasts in aspect and altitude, these often connoting acute variations in climate.

Challenge and response

This circumstance is reflected in how traditional farmhouse designs exhibit a variety in detail that might otherwise be dubbed extraordinary in a country of limited total extent and extremely limited arable space.[61] But there is an underlying theme with distinctive Japanese modalities within a more general pattern Richard Beck has reflected on (see Chapter 2). It concerns coping with the climatic challenge inherent in a locale within temperate latitudes but on the eastward (basically, the leeward) periphery of a large continental mass. The rub is a big temperature contrast between high summer and deep winter, coupled with the fact that much of Japan's rain falls in the summer months, thereby aggravating thermal stress. Compare two sites at between 36 and 40°N: the one Miyako, on the Pacific coast of Honshu, and the other Gibraltar. The range in monthly mean temperature (January to August) in Miyako has lately been 41°F; in Gibraltar it has been 20°F. Then again, 31 per cent of the year's rain at Miyako falls between June and August inclusive, whereas in Gibraltar not two per cent does.[62]

Faced with so marked a thermal range, the early medieval Japanese felt obliged to make a hard choice. They would mitigate either the sticky monsoonal summer or the chilly north Eurasian winter. Like true heirs to the Children of the Wisconsin (see Chapter 1), they resolved to give the former priority, meeting the rigours of winter 'by stoicism and the wearing of additional clothes'.[63] Architecturally this involved recourse to wooden structures mostly designed to be well screened yet well ventilated. Among their characteristic features were floors raised off the ground, walls comprised of sliding panels (*amado*), wide verandas (*engawa*), and steep roofs with broad overhangs.[64] Though dwellings along these lines were first introduced before AD 650, the main thrust in that direction came towards the end of the Heian period (794–1185).[65] The years 850 to 1050 had seen pronounced warmth in the then core of the country (Kyoto and the Kansai Pass to Osaka on which it peripherally stands), partly because it was topographically well sheltered from intrusive polar air. Meanwhile, much of northern Honshu and all of the even more exposed Hokkaido were still under Ainu (i.e. aboriginal) control and therefore not eligible to decide Japanese priorities. Furthermore, the overriding cultural influence of China finally ended when links in that sphere were formally severed in 894. After annexation, even Hokkaido would be adopting *amado*, *engawa*, etc. quite extensively.

The eighth to tenth centuries also saw the evolution in Japan of *shinden-zukuri*: formalised residential structures for the elites in which the outhouses were connected with the main hall by passageways always roofed but without full curtain walls.[66] All in all, one is tempted to conclude that the physical toughness enjoined by an architectural disregard for winter became a signal national trait. Witness the Japanese troops who fought to the death defending island outposts against Kublai Khan's invasion fleets in 1274 and again in 1281, shielding thus from Mongol conquest their own archipelago but maybe, too, other Asian lands and even Europe. Witness, too, a matchless determination to fight to the death that so consistently characterised the armed forces of Imperial Japan until the final days of the Second World War.

China, too, exhibited a fair amount of variety in domestic architecture, including building on pile-supported platforms in the flood plains from the Yangtze southwards. But the underlying emphasis was on the pattern created in the 'old North China cultural hearth'. Its manifestations included the fully enclosed courtyards into which all doors and windows faced, and the ubiquitous use of sun-dried brick for the curtain walls.[67]

But during the eleventh century, China embarked on an agricultural revolution that dramatically improved its general adaptiveness to more monsoonal climes. This was the distribution from Fukien (following an imperial edict of 1011) of rice that had originated in Champa, the temple state in the lower Mekong valley. Introduced initially because droughtiness had caused crop shortfalls on the Yangtze/Hwang Ho plain, Champa rice possessed, in one variety or another, two most positive attributes. The one was a pronounced ability to resist water shortage; the other was early ripening. Though low in crop yield per unit area compared with what varieties long established on the alluvial plains optimally achieved, the Champa rices proffered the extra dimension the grain basket required at a time when (a) the lower Yangtze basin was nearing full capacity, and (b) north China was growing more dependent than ever on rice imports from other parts of the country. Their spread into (and adaptation within) upland areas that were marginal in terms of water or temperature was gradual but decisive.[68]

The fact that this innovation was demand-led relates to the eleventh century being one in which the Chinese economy as a whole went through a market-driven lift-off. For a trenchant depiction, one is indebted to William McNeill. Though the imperial government still kept 'the capitalist spirit . . . firmly under control, the rise of a massive market economy during the 11th century may have sufficed to change the world balance between command and market behaviour in a critically significant way. China swiftly became by far the richest, most skilled and most populous country on Earth.'[69] Meanwhile the coolish dryish interlude further facilitated the advance of the Han Chinese across the Yangtze valley and beyond. However little it realised this, Europe was thereby being outstripped.

Actively debated at present, however, is whether the ultimate consequences were not in the opposite direction. The proposition that this could have been so rests on the fact that, while growing rice responds very positively to much strictly manual attention, this singularly soft grain requires comparatively little energy after harvest to prepare for eating. On both counts it did little to encourage greater recourse to mechanical power, an important precursor of wider industrialisation.[70] Granted, wet paddy cultivation depended on hydraulic control. But even that did not apply to the dry Champa so much relied on in the southern uplands. Besides, it had to be human energy that created the canals and the roads, not to mention forest removals on the tortuous uplands.

A GERMINAL CENTURY

Yet in so far as one should talk in terms of 'centuries', the eleventh comes across in both Europe and east Asia as having a germinal quality that historians ought to pay more attention to.[71] Historical climatologists may be entitled to wax impatient about this, seeing that the said century was veritably the mid-forenoon of medieval warming.

Strategic consolidation

If germination was in the European air, it was so against the background of Christendom becoming more consolidated territorially. This was true for Constantinople initially but more enduringly for Rome. As the Scandinavian proto-states formed up, they turned to Catholic Christianity. In the millennial year 1000, the Icelandic Athling adopted the Christian faith. Shortly before, King Harold Bluetooth (reigned 935 to 985) had decided to do as much on behalf of his Danish people. Olaf II (1015–28) was to do likewise for his Norwegians. Meanwhile, missionaries were active in Sweden and Finland.

Norse mythology extolled, above all else, the martial virtues. In fact, its whole ethos was informed by a philosophic pessimism that found its supreme expression in the legend of Ragnarök, the 'twilight of the Gods': a terminal crisis ushered in by Fimbul – three solid years of ferociously snowy, stormy and sunless winter.[72] Christianity must have come across as a more hopeful creed, intrinsically, as well as one associated closely with an agricultural revolution in southern Scandinavia that itself was quietly helped by climate improvement. Nevertheless, it is salutary to recall that – even in the south of Sweden – it took Christianity three centuries to break conclusively the pagan grip on the populace in the more remote areas.

An episode that, for well over a hundred years, has attracted a special measure of scholarly and popular interest, certainly throughout the English-speaking world, is the Norman Conquest of England between 1066 and 1072. Already the country was a well-structured unitary kingdom with a Church that helped to bind it together and also link it to the Continent. Under the Normans, these attributes were to be underscored, a brutal transition notwithstanding.

The received English version of the immediate background to this crisis has always been that, when Harold Godwinsson made a pledge to William of Normandy (at the latter's court in 1064) to support his claim to the English throne, he was acting under sacred oath but also under deception and duress, having been shipwrecked. Therefore Harold assumed the crown himself within hours of the death of the old king, Edward the Confessor, in January 1066.

Behind William's decision to invade in 1066, however, were deeper reasons. He saw England as somewhere his fractious barons could work off their brutish energy. He saw it, too, serving for his Norman duchy as a strategic hinterland, one suffused with an aura of permanency or even, William likely reflected, legitimacy. He had himself been born out of wedlock, and his own marriage lacked papal endorsement.

Nor will he have been oblivious to England's repute for prosperity. Goscelin, a Flemish visitor at that time, had celebrated near to ecstatically its manifold riches. Nor is it hard to imagine that a great diversity of topography and soils did leave England well placed to experience and benefit from what, given its oceanic aspect, would have been most welcome tendencies towards warmer and drier weather. Indeed, a modicum of prosperity does seem to have been diffusing across much of the land.[73] True, the infrastructure of relative affluence still was visible mainly south-east of a line from the Wash to Southampton Water. But much of the old Danelaw (extending from the lower Thames and Lea valleys to the Scottish border) could boast not merely high population densities rural and urban, but also the 'best trading connections overseas'.[74] After all, Boulogne's trade had declined long since; and, although England and Flanders traded together increasingly, the likelihood is that as late as 1050 each was trading with Scandinavia more. First Frisian and then Danish trading communities had been established in York the previous two or three centuries.[75] Then to judge from the tentative evidence concerning two structural criteria (sheep farming and urbanisation), England in the eleventh century was more thriving than it was to be through, say, most of the fourteenth. Apparently, too, it had a trade surplus in commodities sufficient to allow of the import of a deal of German silver.[76]

What cannot well be demonstrated is that those regional lags in development that undeniably remained brought about the bitter insurgencies waged around the country in the several years following the defeat of the English, with the manic mutilation of their King Harold, on the hill above Hastings. A causal explanation resides instead in the inner insecurity of William himself, but also in how isolated and overstretched his entourage of 10,000

Normans perennially was. That is why waste was repeatedly laid to swathes of countryside punitively or even pre-emptively, a strategy of overkill that drew severe strictures from the papacy despite its having overtly blessed the invasion originally.

Some of the worst mayhem took place within the Danelaw,[77] prosperous enough at the outset but with a propensity to resist central government as a matter of course. In offensive sweeps between 1068 and 1070, William's troops laid waste much of Yorkshire up to the River Tees, as well as the Cheshire Plain and parts of Pennine Lancashire. However, they appear not to have entered more remote and backward regions, perceiving them as non-rebellious.

In principle, the upland valleys and moorlands of the destitute far north stood to gain from climate change, not least as water cycles were moderated. In practice, the ability of the populace to avail itself of the potential benefit was compromised by the security problem posed in the borderlands during the reign as King of Scotland of the bellicose Malcolm Canmore. Throughout that span (1058 to 1093), Northumbria was raided continually. Moreover, Cumbria seems to have been more or less under Scottish control through the 1060s. Then in 1070, Malcolm invaded Northumbria via Cumbria in a campaign that ended in confusion. Two years later, William led a land–sea task force to raid Fife.[78]

One result of all the violence was the effective confirmation that the English–Scottish border ran almost exactly along what we now know to be an ancient geological suture between (to the south) alkaline and permeable Carboniferous limestone and (to the north) considerably older Silurian rock: silica-rich, acidic and impermeable though fractured. But another result was an entrapment in backwardness exemplified by the northern English lands figuring little in the Domesday Book of 1086. Northumberland and Durham, together with Cumberland and Westmorland as then delineated, are omitted altogether from that economic gazetteer. Lancashire receives no coverage except peripherally in the Yorkshire and Cheshire folios.[79] What this exclusion chiefly connotes is the sheer fragility of that north-west region, its utter reliance on support from the Palace of Westminster.

In those areas most savaged by Conquest violence, the attritive legacy might be evident 15 and more years later, not least through the aggravation of any effects of bad weather. It is ominous that the *Anglo-Saxon Chronicles* mention poor harvests, famine and pestilence as widespread in 1078, 1082, 1086 and 1087, even though western Europe as a whole seemed freer from such recurrences across that particular span.[80] In fact, a tree-ring review shows only 1070 and 1081 as droughty across north-west Europe during those two decades, while 1074, 1082 and 1089 come over as having enjoyed good growing seasons.[81] Other things being equal, one would expect England still to have been more robust agriculturally than its continental neighbours. The Norman Conquest had left things unequal.

Nevertheless, the underlying resilience of the English economy, perhaps one should say of the English political economy, expressed itself in due course. Between 1086 and 1190, over a hundred new towns were founded. The spread of these centres intra-regionally was remarkably even; and many of them did survive and flourish,[82] aided no doubt by the secular amelioration of climate. But what one can further ask about is the part the elements had played in shaping the 1066 campaign. Many times during this past millennium the outcome of armed conflict as between England and the Continent has been influenced by the vagaries of the weather in the Narrow Seas that stand between them. Never has this been more portentously the case than with the invasion of Normandy in June 1944.[83] Never has it been more protractedly so than during the invasion threat that culminated on the field of Hastings. So might this protraction have been related causally to secular climate improvement in a way King Harold Godwinsson for one would have found extremely perverse?

By mid-August, a Norman expeditionary force was ready to sail, subject only to the advent of a good southerly breeze. Ready, too, was King Harold, deployed on England's south coast with troops and ships that would have been hard to prevail against. But winds from the north proved almost unremitting, the upshot being that, come early September and harvesting, he was obliged to stand down the fyrd militias that comprised most of his army. Alas, he learned almost immediately that Harold Hardrada, King of Norway, had taken advantage of the northerlies to land an expedition near the approaches to York. Quickly reconstituting a field army, he marched north in a week to annihilate the Norwegian army in a surprise attack on 25 September at Stamford Bridge. He killed on that field his own brother, the brattish Tostig, along with the the savage Hardrada.

Soon afterwards he heard that a sudden break in the northerlies had allowed William to land on the Sussex coast at last. Harold relentlessly marched south once more and confronted the Norman force near Hastings on 14 October. Like many other critical battles, it was fought hard and evenly most of the day but ended in total triumph for the one side. Harold's lack of command experience had left him less adept than Duke William at managing what proved to be very much a set-piece encounter. The Normans eventually made some limited use of an important innovation, the cavalry charge with couched lance. For his part, Harold had made a bad error in presenting exhausted soldiery for battle, no matter what other considerations weighed with him weatherwise or whatever.

In any case, the obstinate persistence of that weather type across the Narrow Seas had stretched virtually to breaking point his strategy for containment on two far-flung fronts. And was it not something over and beyond a stochastic weather anomaly? May it not exemplify that prevalence of blocking anticyclones near the North-West Approaches to Britain provisionally adjudged above to derive from climatic change? Most pertinent is the fact that, in the northern Scandinavia tree-ring series, 1066 experienced the second coldest summer of the century.[84] Together, 1066 and 1067 register a very singular and discrete cold snap, a spine-like anomaly the effects of which would likely have been felt southwards. Therefore, subject to what further research reveals, a climate correlation does seem warranted.

Granted, one medieval source on the Hastings campaign tells of the weather regime in the English Channel that summer being westerly cyclonic, cloudy and rain-bearing. That source is *Carmen de Hastingae Proelio*. Until recently, received wisdom had it written by the spring of 1068 by Guy, Bishop of Amiens. However, an alternative interpretation is that it was composed later, possibly much later, by an unknown continental author. If so, it will have drawn on such sources as William of Poitiers, who (writing *c.* 1071) was obsessed with rhetorical stylisation and also with a yearning to laud William and blacken Harold.[85] It is easy to imagine how a writer disporting himself thus might wish to give his narrative an extra flourish via a few conventional remarks about Channel storms. A later ascription for *Carmen* was trenchantly argued by the late Professor Ralph Davis of Oxford then Birmingham.[86]

The German anomaly

By 1100, a Holy Roman Empire that by now was four-square German-based had extended its rubric over Burgundy plus the northern half of Italy. This gave the emperor of the day a chance to exert direct leverage on the Pope, an option held to be important in that from *c.* 1085 the imperium and the Holy See were continually locked in an investiture contest

Map 6.1 South Britain

about the appointment of senior clerics. The sensitivity the Empire displayed on this score reflected internal weakness, a lack of cohesion that a presence in Italy was to make all the worse throughout the remaining seven or so centuries of its notional existence. Had the German-speaking peoples currently faced a threat from the East comparable to that once presented by the Huns or, more recently, the Magyars, they might have focused on the need to organise more solidly north of the Alps. Instead, eastern Europe was becoming more deeply sedentary, the defining aspect of a convergence towards the West.

St Stephen (reigned 1001–38) was the first Hungarian monarch to be generally accepted. He had effected the conversion of his people to Catholic Christianity, by which time Poland, too, was emerging within the new regional order. Its conversion to Catholicism had begun in 966 under Duke Mieszko I, the founder of the Piast dynasty. His successor, Bolesclaus I (reigned 992–1025), had elevated the ducal title to kingship. Wielkopolska, the heartland of this nationhood, stretched from the middle Vistula to the middle Oder. Poznan was its first capital and (from 968) the site of its first episcopal see. Under Bolesclaus, the pristine national vitality was expressed in what later generations would come to regard as Poland's manifest destiny: fighting to defend or extend insecure borders. Having at that time expanded in all directions, it was to control awhile territories that (on the western side alone) included Pomerania, Silesia, Moravia and Bohemia.

Though a fabled 'land of the thousand lakes', Wielkopolska was less watery than much of the surrounding country. A fall in its mean water table as the climate turned drier therefore allowed full advantage to be taken of soils often richly mixed and, when dry enough, eminently workable. This involved *inter alia* more emphasis on grainstuffs. The verdict of modern research is that, by the High Middle Ages, the Polish climate was more favourable to agriculture than ever before or since. In the Karkonosze Mountains, the tree line was 600 feet higher in the fourteenth century than in the twentieth, and vines, apricots and melons were grown in valleys where they would not have survived of late.[87] Against this improving background there was, from the eleventh century, a drive 'to adapt Western legal norms and systematically combine them with local customary law.'[88]

By 1100 the governance of the German-speaking people had started to evolve from personal/feudal bonding into the more formalised principalities of the later Middle Ages. But that was where political evolution was destined to level out for a long time,[89] partly because things were already more stable to eastward. Even the twin-pronged Mongol offensive into Europe (1240–2) little resembled previous nomadic intrusions. Admittedly its onset was so sudden, ferocious and mysterious as widely to induce a paralysing sense of Apocalypse. But, as things transpired, central Europe was to face this threat for less than two years, not for decades or centuries. Nor was the Holy Roman Empire penetrated more than peripherally.

The Mediterranean arena

In Iberia, the *reconquista* from the Moors was well under way by the mid-eleventh century, Toledo being captured and the lower Tagus reached in 1085. A Christian kingdom of Portugal declared its existence in 1139, just before Lisbon passed firmly into Christian hands. A moot point is whether the differential effects of climate change did anything to encourage the ongoing, if intermittent, Christian advance.

Taking this point to hinge on whether a climatic realignment gave the Christians more strategic assets, the provisional answer should probably be a lukewarm affirmative. Maybe the elaborate Islamic irrigation routines were put at some disadvantage by differential rainfall trends. But any such judgements should be made from a context of the kind afforded in 1963 by Jacques Pirenne. Following his father, Henri, he viewed less than beneficently the overall Muslim impact on the Mediterranean world. What he fulsomely acknowledged, though, was the magnitude of the Moorish agricultural triumph in Iberia. He was adamant that in Portugal, in particular, the *reconquista* was a disaster. After the Christians had consolidated the lands gained into vast new holdings, private and religious, production went into 'rapid decline' as 'great estates were left fallow'.[90]

Yet basic here, as elsewhere, is the truism that, by failing to effect a clear separation between an amorphous religious leadership and structured political sovereignties, Islam has always been liable to compromise the latter. Even before the abolition in 1031 of the caliphate of Córdoba, political divisions weakened Islamic Iberia more than any did Christian. Moreover, emigration was a major theme throughout Al-Andalus (alias Islamic Iberia) by 1100, and will have owed something to a popular loss of interest in martial obligations. Psychological polarisation within a 'hydraulic society' had induced the populace to leave war as far as was possible to a governing elite. Witness the occasional employment of Christian troops.

In the cooler, damper and stormier climes of the Christian north, war efforts were backed by a broader resolve that also extended to a willingness to learn much from Muslim military science.[91] Yet not a few historians would hear Hugh Kennedy's comment that 'it remains a central and intriguing question as to why the self-confident and dominant Muslim political society of the year 1000 should have divided, shrunk and eventually, half a millennium later, disappeared from Iberian soil completely.'[92] Research on this whole Iberian era has burgeoned the last couple of decades and may, in due course, provide fuller answers. Perhaps this will lead to a more thorough understanding of the military operations. Perhaps, additionally or alternatively, it will be assisted by historical climatology. Any such assistance may take the form of focused analyses of regional water cycles within Iberia, a territory where variations in evaporation, run-off and seepage are more than averagely important. Such enquiry may show how natural causes aggravated such disasters as the Portuguese transition. It may also show how climate change outside Iberia bore on the *reconquista*.

At all events, a strategic roll-back had begun across the Mediterranean by the turn of the millennium. In 961 Crete was regained by the Byzantines. In 972 the Saracen (i.e. Muslim Arab) raiders were ousted from their forward base at La Garde Freinet on the Provençal coast. Their forays around the Riviera and the Gulf of Genoa thenceforth diminished sharply. A particular gain for Christendom was that the routeways around and through the western Alps could be more safely accessed. Even in Roman times, quite the most celebrated of the passes in use had been the Great St Bernard at 8,100 feet. So it remained, its famous hospice being founded by St Bernard of Menthon. Further east, the reservations the Romans had entertained on strategic grounds about opening up too many passes were now less relevant.[93] However, the climatic constraint was very comparable to a thousand years previously, the Alpine glacier readvance from *c.* 1050 offsetting awhile the continental warming trend. The Brenner Pass at 4,500 feet stayed open almost routinely but was rather too far to eastward, seeing how as late as 1100 towns like Hamburg and Vienna were still barely in the rear of the eastern limits of German peasant settlement.

More significant for a burgeoning trade between West and East via Italy were the passes of the central Alps. Here, the parallels with Roman times are close. The Julier and Septimer passes (at 7,500 and 7,600 feet respectively) were open very regularly in both eras though, in the eleventh century at least, the latter was too often snowbound. Obversely, the St Gotthard (at near to 10,500 feet but on the direct route from the upper Rhine at

Basle to the upper Po near Pavia) was not yet in use. A critical bottleneck along its course was the precipitate gorge, so often swept by strong winds or snow, on the River Reuss near Andermatt. The arch that was to span it in the thirteenth century was a sublime engineering achievement, aided though it will by then have been by climatic easement.[94] The spanning was subsequent to the transient surge noted above of the nearby Aletsch Glacier.

Urban growth gathered pace in the north and centre of Italy in the course of the eleventh century. It had been during the ninth that the region resumed a lead in this regard within Catholic Europe. The population of the little fishing village of Amalfi zoomed to 70,000, double what some have said Rome itself fell to in the depths of the post-imperial recession *c.* AD 600.[95] Amalfi had achieved this primacy through trading anew with the Moors and Arabs. But it was not to last long. By the eleventh century, the front-runners were Milan, Genoa, Pisa and – above all – Venice. In its exceptional case, a near-to-deltaic lagoon proffered defensibility. Elsewhere, steep slopes (expressive of the geologic immaturity of Tertiary folding) afforded screening from overland sorties as well as deep fairways in inshore waters.

A measure of natural protection made it easier for the emergent Italian cities to bargain flexibly with the Empire, either individually or together. This flexibility was usually directed towards securing a high degree of functional autonomy while still swearing 'fealty to the emperor'. Milan was an exception that proved the rule. Economically it was a pacemaker, its urban boom being well under way by the year 1000. But it did stand exposed to military attack. In 1162 it was sacked by an emperor acting with military support from several nearby cities. Twelve years later, however, the Lombard League (as the association of northern Italian cities was then called) inflicted at Legnano near Milan a significant defeat on imperial forces. By then, too, the League had assumed responsibility for the reconstruction of Milan.[96]

For that city, the obverse side of military exposure was commercial nodality and access on all sides to a farming hinterland. Elsewhere, too, agricultural progress was a backdrop to urban growth. In other words, it is inadequate to say of the Italian coastal cities that their farmland was so circumscribed topographically as to oblige them just to look seawards for prosperity. The choices were never that stark. Having reviewed urban–rural relations in the region, Gino Luzzatto found irresistible the conclusion 'that land and the income from farming and forests, pasture and hunting, remained the principal support of part, and possibly a large part, of the urban population.'[97] Research on the agrarian side of early medieval life has not yet progressed enough for a synoptic assessment, in relation to ecological trends or whatever.[98] It is clear, however, that by 1000 much investment was going into 'impressive hydraulic works'.[99] Italy may also have been a pacemaker in Europe's great surge of forest clearance, AD 1050 to 1250.[100]

Not surprisingly, in the light of so much enterprise, the indications are of agrarian advance moving ahead of climate improvement. Take the compilation Lamb did for Italy of years either with significant flooding or else generally wet from 350 BC to AD 1300. These average 1.5 per half century between AD 900 and 1100, an incidence equivalent to the mean for the last centuries of the Roman Empire. After 1100 the number rose quite steadily to nine by the late thirteenth century.[101] Extreme rain/hail events will always have been unwelcome. As a rule, however, the frequency of wet years should be a goodish measure of secular rainfall tendencies; and higher rainfall totals would have been of benefit in most of Italy most of the time. Shallow soils, rapid run-off, permeable rock and warm sunshine will have made them so. Relevant here is the recent study by Walter Dragoni of the University of Perugia that focuses on lake variations. It discerns a secular transition to higher rainfall, putting its median onset at *c*. AD 1175 in north-central Italy.[102]

A temperature profile (derived largely from tree rings) for the middle to upper Po valley and the nearby Alpine foothills unfolds erratically, especially before 1190. But the essence is that a warming thrust through the late eleventh century is not well sustained. Forty-seven years in the twelfth century are identified as anomalously cold or very cold and but 12 as warm. In the thirteenth the figures are 46 in each direction.[103] All that connotes unwelcome instability in the upland farms, hill pastures and woodland. At lower altitudes, cooler, moister conditions will have been preferable to ones too hot and parched.

But the upper Po basin may not be too representative against a background of renewed Alpine glaciation. Overall, the archival indications are that Italy, together with the *langue d'oc* area of southern France, had experienced an agricultural crisis of underproduction that deepened through the tenth century but then gave way to pronounced recovery. One analysis calculates known transfers of land each quarter of a century, the premise being that a high turnover is customarily associated with 'rampant famine' and a consequent urge to improve the efficiency of tenures, not least through territorial consolidation. On that reading, a dramatic recovery from slump is evidenced by a fall in transfers by a half during the first 50 years of the eleventh century. A contemporary Lombardy source depicted the year 1018 as marking the end of two decades of continual hunger.[104] Soon famine was less prevalent throughout.

Once more one has the two streams of evidence: the geophysical and the human historical. Most of the data on each score trend in the same direction, with agrarian recovery moving significantly ahead of rises in rainfall. On balance, Italy was not to prove the exception to weather improvement that *a priori* assumptions about the shift of climate zones polewards could have led one to expect.

In 1082 a preferential trading status throughout Byzantium was conceded to Venice. The thousands of Venetian traders already in Constantinople exploited this, making themselves pivotal to the entire eastern basin. No matter that western Europe still found it hard to match an interest in the exotic wares of the East with an ability to meet the prices charged in well-cornered markets. Its own softwood was not easy to transport. Its metals were less than abundant. Slav slaves were marginal in terms of geographical origins but also as regards licit trading. Not even the Venetian lack of scruple could lightly brush aside theological objections to Christian bondage.

Psychology and culture

While Catholic Europe was thereby setting its limits and consolidating within them, it was also evolving in outlook. It was now more footloose, literally as well as metaphorically. The band of pilgrims was veritably a peripatetic institution, with the Holy Land itself the destination more and more. Even allowing for a thinner coverage of the earlier centuries, the surviving archives bespeak an explosive growth in this activity as resources became more available and travel a shade less stressful. It was one way the mental expansiveness clearly discernible from around 1070 found expression. As of 1959, six long-distance pilgrimages were on record for the eighth century; 12 for the ninth; 16 for the tenth; and 117 for the eleventh. Many of the pilgrim bands comprised hundreds of individuals, while one, from south Germany in 1065, exceeded 11,000.[105]

Significant as lending added impetus to the *reconquista* was the trail to the presumed tomb of St James the Apostle at Compostela in Galicia. This cult had begun locally during the ninth century but was to spread well beyond Spain after the turn of the millennium.[106] From which point one must also be more alert to the millenarian inclination that (in Judaeo-Christian and, indeed, Islamic cultures) has often found expression, religious or political, in times of stress. An enveloping vision is articulated by a great leader lately arrived on Earth or imminently anticipated. He tells of the drawing nigh of history's last great struggle, a deep gorge of apocalyptic crisis that must and will be traversed to attain the celestial city on the hill – a thousand years of peace. The 'New Earth' suffix appended to Ragnarök as the Norse poets came more under Christian influence is archetypical.

As the tenth century drew towards its close, such prophesying will have waxed stronger throughout western Europe. However, its overt influence waned awhile once the second Christian millennium had dawned. For one thing, millenarianism was now alarming the existing order. Henri Focillon noted how comprehensively the chiliastic declamations are ignored in sources derived from the late tenth century.[107] Also, Norman Cohn has pointed out that successive millenarian outbursts in central Europe in the ensuing several centuries (outbursts liable to turn decidedly vicious, not least towards Jews) drew support from the 'amorphous mass of people who were not simply poor but who could find no assured and recognised place in society at all.'[108] Such a stratum was not that evident in the Europe of 1000. But it became more extensive during the ensuing century as economic structures evolved, particularly in the relatively crowded valleys of the Meuse and the middle to lower Rhine.

Within the intellectual and cultural mainstream, a marked transition in or near the late eleventh century has long been evident. Until then, the mood was overly taut or febrile, too prone to 'emotionality and panic' to address life's deeper themes coherently.[109] An instance from the heavens above often cited is the cataclysmic birth in 1054 of the supernova we know as the Crab Nebula. Its advent is never remarked on in the writings from Christian Europe that survive from then, visible though this event must have been for weeks on end, by day as well as night. It is recorded in China and Japan and, more allusively, by the Muslims. Already over twenty depictions have been identified in American rock art, in locations from Texas to northern California.[110] Had attitudes in this celestial realm been more positivist, somebody somewhere in Europe would have recorded the event, maybe as a 'cometary' phenomenon. Being understood (as per Aristotle[111]) to exist below the altitude of the Moon, comets might have been mentioned without breaking a taboo against acknowledging smudges on the hallowed undersurface of the firmament. But in similar circumstances well over a century later, not even that remedy was adopted (see Chapter 9).

In wider respects, however, the first fruits are already apparent of what G.G. Coulton, a distinguished Cambridge medievalist, endorsed as 'a very real revival, comparable to that later revival which we call the Renaissance.'[112] A resurgence of deforestation and resumed growth in population were among its primal manifestations. Romanesque architecture (drawing on both Roman and Byzantine themes and techniques) was among its more expressive, especially after 1070. Important, too, was the founding of the Cistercian monastic order in 1098.

Over and beyond all of which was something more diffusive, something to do with the edification of what for most would remain, come what may, a short and hard life of penury and constriction (see Chapter 8). Lord Clark, the art historian, wrote metaphorically about there having been, in the second half of the eleventh century, a Great Thaw that 'seems to have affected the whole world but its strongest and most dramatic effect was in Western Europe . . . . In every branch of life – action, philosophy, organisation and technology – there was an extraordinary outpouring of energy, an intensification of existence.'[113] This cultural overview could relate *prima facie* to a structural interpretation essayed in 1993 by the two world systems theorists cited earlier (p. 87). They inferred a growth phase began more or less throughout Afro-Eurasia early in the eleventh century and persisted until late in the thirteenth.[114] Yet on their own admission, these authors did not address ecological fluctuations properly. Their presumption that any climate variations must have been entirely exogenous in origin confirms that all too well.[115]

Material penury

In terms of economic output *per capita*, the Europe of the eleventh century cannot have been so very far ahead of those 'prehistoric' societies (Old Stone to Early Iron Age) the anthropologists and archaeologists were so long disposed to concentrate on. A contemporary doyen of the Annales school has calculated that energy usage through medieval times might have averaged 12,500 big calories *per capita per diem*, a mere five times the calorific value of the food an adult might typically consume even then. Furthermore, the availability of every energy source will have been subject to climate vagaries. Still more of a constraint on energy mobilisation, however, were the prevailing levels of technocratic culture, capital accumulation and institutional organisation.

Closely related to the inadequate energy supply were the shortages of metals. Over several thousand years, that very special genre of materials had continually been made more available and, by the same token, cheaper in real terms. Yet through the early Middle Ages even iron was chronically in what we today would regard as expensively short supply. By 1100, however, improved smelting techniques (forced draughts; use of water power) were easing that situation somewhat. Witness the widespread introduction of iron ploughshares.[116]

Often in short supply, too, were the precious metals used for coinage and ornamentation. Between 979 and 1016, an otherwise booming England opted for currency devaluation six times, largely to ensure a supply of silver sufficient to cover the Danegeld bribes the Vikings demanded to leave the country in peace.[117] But an incidental effect does seem to have been to stimulate exports, and hence the whole economy. As a more general rule, the impact of constraints in money supply was then akin to common experience with that other ambient factor, climate change: that is to say, their effect was not decisive except where a critical situation had been engendered by other factors. Nevertheless, the final collapse of the Abbasid silver trade after 1050 (in the context of an ecological downturn in the Near East and the weakening of Kiev) was a matter of great concern. Responding, German miners in the Harz Mountains led the revolution of sinking quite deep mines (with ventilation and drainage) in hard rock.[118] Climate had little direct impact on such operations except through elevation of the water table. In practice, mine flooding was not to be too much in evidence until the fourteenth century (see Chapter 9).

Inevitably, the resource balance largely hinged on what was happening demographically. After an apparent slowing down in western Europe during the early tenth century,[119] population growth recovered in the eleventh. A collation by B.H. Slicher van Bath, covering Europe as a whole, suggests a rise then of 14 per cent (i.e. from 42 to 48 million). That is well short of the 38 per cent (i.e. from 50 to 69 million) guestimated for 1150 to 1250. Even so, the impression of a general lift-off complements the archival findings about less frequent food shortages.

Through 1040, however, western Europe was still recurrently famine-prone. Take the cannibalism recounted by Raoul Glaber, a monk of Cluny, shortly before 1050. Though he was inclined to overstate, his observations on this score are in the main corroborated by other chroniclers. Nevertheless, his averration that, after the millennial anniversary of Christ's death (presumptively in 1033), a new era of bounteous harvests began for Europe,[120] was too previous. Around that very time, in fact, the incidence of famine increased awhile. Poor harvests between 1032 and 1036 led to dearth across Europe. In France human flesh was on sale in 1032 and 1033, then again in 1036. After that, though, things did ease, by and large. Between 1100 and 1250, no major food shortages are recorded in either the Low Countries or Germany.[121] Peace or war apart, the avoidance or otherwise of famine was a function of the usual variables of secular climate trends, climate erraticism, demographic trends, advances in agriculture, and investment in bulk transportation.

One very visible sign of progress was how much farmers continued to push outwards and upwards the limits of their activities, movement upward being the readiest response to warming. Particularly to be remarked on is how much new settlement took place from the eleventh century on or beyond the forest-clad ridges that so closely confine the Rhine from Basel to Koblenz: the Black Forest, the Odenwald, the Hunsrück, the Taunus . . . . In the Black Forest, 1075 or thereabouts saw the commencement of a co-ordinated settlement drive headed by the dukes of Zähringen and the monasteries they dominated. Apparently, it elevated the margins of managed farmland to a representative altitude of 1,000 metres, several hundred metres higher than several centuries before.[122] Not that all this gain can be ascribed directly to ambient warming. After all, the lapse of air temperature with height is unlikely to have been less than one degree kelvin or Celsius every 150 metres. Therefore even where gradient, aspect and soil structure were satisfactory throughout, a rise in the mean temperature locally of that one degree could in itself have raised the upper limit of cultivation only by such an altitude. Perhaps, on the other hand, the improvement in climate also gave a psychological fillip to bold endeavours. But if so, the core inference should probably still be that the said amelioration pushed the boundaries of farming upwards by generating a bigger regional demand through demographic pressure more than by this inspirational uplift or by improving the mesoclimate of the upland margins.

By similar token, warmer summers would not have had much direct bearing on colonisation eastwards, even had the wider circumstances of the eleventh century more consistently favoured frontier advance. The mean lie of the isotherms in that season is too nearly latitudinal. What might have been an influence, other things being equal, is a rise in winter temperatures. But suppose again this was one degree Celsius secularly, that would only have been tantamount to an eastward shift of the midwinter isotherms by 175 to 250 km. An alternative rendering of this can be that, within the German–Slav borderlands, the number of days a year with a temperature mean above freezing point would therefore have increased by five or ten. Then as now, average rainfall will have been spread quite evenly across the North European Plain in the summer half of the year and also in the winter. Of late, the average January rainfall has been *c.* 35 mm in Paris, Warsaw and Moscow.

How rainfall may have affected medieval colonisation will have depended on hydrological circumstances at local level. The North European Plain had been subject in the Pleistocene to extensive glacial erosion and, still more so, deposition. The legacy, most conspicuously between the Weser and the Vistula, was weak and ill-organised drainage and a highly irregular distribution of fertile soil. That irregularity will have tended to mask any climatic tendencies. It will sometimes have left niches around long-existing German settlements affording scope for arable expansion *in situ*.[123] However, too little is yet known about the *modus operandi* of two key social groups – the lay nobility and the independent peasantry.

The southern Mediterranean

As and when geographers bisect the Mediterranean region, this is usually into its western basin and its eastern. In the public mind, however, the dichotomy most recognised is that between the northern side and the southern. It is also the one most relevant politically, certainly as regards the recovery of Catholic Christendom *vis-à-vis* Islam.

Although the early Christian advances in Iberia may not have owed much to the local Muslim economies being weakened by climate change or other ecological factors, one should still ask whether North Africa from Tangier to Gaza did experience ecological stress and, if so, how Europe was affected. To seek an answer, the geophysical assessment should focus mainly on the Mediterranean and its littoral west of longitude 60°E: in effect, a line through Corfu and Benghazi. It is instructive to treat (as in the next chapter) the sea area to eastward as part of a climatic zone that embraces Persia. Given the hydrological dominance of the mighty Nile, Egypt should likewise be set apart.

According to hallowed principle, a single caliph should be the supreme religious and political head of all Islam. Yet from 780 to 1171 there were always the two or three caliphates. In the year 1000, they were located in Córdoba, Cairo and Baghdad respectively. Contrary to experience within Christendom, the effect of religious splits was to undermine the authority of individual statehoods – most critically the Córdoban. An outward expression of this, by the ninth and tenth centuries, had been Muslim enlistment of infidel troops, either mercenary or slave.

What calls for a generic explanation, however, is the close concurrence across a wide arc of nomadic incursions into areas of established settlement. The tenth century appears, across the southern Mediterranean and Near East, to be a time of 'some disturbance of the settled order'.[124] A review of famine in the Islamic world has spoken of an increased prevalence from *c.* AD 1000 from Spain to Afghanistan, this against a background of rapacious dynasties, Bedouin incursions and the neglect of irrigation works.[125] Climate variation does not figure in this summation. But Andrew Watson has allowed that it could be a reason for the 'precocious abandonment', from as early as the ninth century, of settlements on a desert frontier extending from the Hejaz to south Syria.[126] Again, one should bear in mind the axiom that the closer communities live to desert margins, the more susceptible they will be. What one has also to bear in mind, however, is that the eleventh and twelfth centuties were agreeably cool and moist in Palestine (see Chapter 7).

In the ninth century, members of the radicalised Shi'ite wing of Islam arrived in the eastern Maghreb from the Yemen. They attracted the forceful support of impoverished Berber tribesmen (pastoral and agrarian) living in the uplands, the upshot being that in 909 a new caliphate-cum-dynasty (duly named after Fatima, the daughter of the Prophet and – importantly for Shi'ites – the wife of Ali) had been established in Kairouan. In 912, they founded the fortress city of Al Mahdiyah on the east Tunisian coast, and made it their capital in 921. Very early on, however, some Berbers were in revolt against these Fatimids, ushering in decades of unrest thereby.

In 944, Berber nomads entered the more settled parts of the Maghreb in strength. Their avowed aim was to further a religious revival based on Kharijiism, a creed that had arisen within the compass of Islam a couple of centuries or so before. It was akin to Shi'ite belief, theologically and ascetically. A signal attribute was the emphasis it placed on the 'general will' as revealing Allah's purposes on Earth, an emphasis derived from a tribal tradition of consensus. It thereby commended itself to 'particularist tribal groups within Islam, whereas the appeal of Shi'ism was rather to suppressed majorities.'[127] But the converse was that the

Kharijiist appeal was weaker away from the tribal fastnesses. In any case, those concerned were unable to reduce Al Mahdiyah.

For their part, the Fatimids adopted a strategy of accommodation within the Maghreb coupled with expansion back along the North African coast. In 969 they conquered Egypt and founded Cairo, whence the Kairouan caliphate was transferred four years later. Not that their position there would ever be secure. Economic depression derivative from ecological crisis precluded that. Between 931 and 1070 (as Fekri Hassan sees it) weak Nile floods were exceptionally frequent. The breadth of the river's main channel near to where Cairo would stand was reduced by successive major accretions of the east bank between 942 and 1281.[128] The notion of economic malaise fits in with what is understood of the demography. Estimates cited or formulated by Josiah Russell point to a grim secular decline. In the first century of the Christian era, the population of Egypt was near a peak of *c.* 4.5 million, according to Russell. From 700 to 900, in the distant wake of Justinian's plague, it putatively ranged between 2.2 and 2.6 million. The nadir comes in the tenth and eleventh centuries, with the inferred total hovering just above 1.5 million.

Yet one cannot but feel unease about how far Russell's delimitation of a critical era of low floods (i.e. 1022 to 1121) is offset from Hassan's. In fact, the former depicts the centennial span, 922 to 1021, as experiencing highish levels.[129] William Quinn's tabulation gives stronger backing to Hassan, especially as regards the tenth century. Meanwhile, obscurity still enwraps those Nile accretions. Were they, as Hassan suggests, due to weak scouring during seasons of much diminished flood? Quinn finds 942, for instance, to be a year of rather deficient flooding in the middle of a 21-year phase in which 11 other annual floods are actually as weak or weaker.[130]

At least Hassan and Russell agree that the half century 1022 through 1070 was one of water shortage. Between 1065 and 1073, Egypt sank into anarchy against the background of a succession of bad harvests all the annals mention. Fatimid suzerainty over the Nile valley was little more than a figment most of the time. Since 1051, however, the Fatimids had been transferring to the western Maghreb perhaps 200,000 bellicose Bedouin lately arrived from Arabia. The historians' accounts of their behaviour once there tell of sacking towns, felling trees, filling in wells and generally turning prosperous farmland into arid wilderness. The counter-argument is that these desert warriors forged in due course an Arabist cultural and political unity much more thoroughgoing than what obtained before.

The Saharan background

Geopolitically, the Maghreb was or might have been an invaluable back-up to Al-Andalus. Accordingly, one has to have serious regard for the view that, in the critical tenth and eleventh centuries, that region was made less stable by deficiencies in Nature's water budget. But to test this hypothesis further one needs to find out what one may about the evolution of the adjacent Sahara. Besides, that great desert was directly important in human historical terms as a thoroughfare for salt and gold. The latter remained important in the currency stock of Catholic Europe in spite of the eighth- and ninth-century switch into silver. All else apart, silver remained in short supply. European deposits were very limited, and the Abbasid influx was ending. For these reasons alone, trans-Saharan gold exports from West Africa to the western Mediterranean were important. Jewish merchants usually mediated transfers from Islam to Christendom.

Over and beyond which, Byzantium's 'bezant' coinage was minted from an alloy of nearly pure gold, this for nearly 600 years until the military disasters of the late eleventh century.

Modern historians are disposed to agree with the medieval perception of the bezant as a great catalyst of prosperity as well as an almost mystical token of prestige.[131]

So what of Saharan geophysics? Was this great desert axially displaced polewards? Did it expand or contract? Are there signs of its character being altered by medieval warming? One is tempted to say there must be since it lies in much the same longitude sector as Europe. However, Europe's experience was not consistent. The anomaly of northern Scandinavia has been noted. Still more pertinent, however, is the doubt expressed about whether Mediterranean Europe saw any medieval rise in mean air temperature.[132] So stationary a state is not easy to relate to what we know of dynamic change in rainfall distribution. All the same, secular temperature trends do tend to be more gradual at lower latitudes.

The late Pleistocene (from *c.* 250,000 years BP) is rich in proofs of the Sahara having been extensive in the deeply cold phases yet diminished and fragmented during the markedly warmer 'interstadials'. Take the data now being evaluated from around the most recent glacial peak, *c.* 20,000 BP. Both the Sahara and the Kalahari were much larger than now. Moreover, the medial axis of the former had been displaced close to the 18° parallel of latitude whereas nowadays it lies more or less along the Tropic of Cancer, at 23.5°N. A pronounced equatorward displacement of the Kalahari was also evident.[133]

However, one must look to such direct evidence as there thus far is about Saharan behaviour in the early Middle Ages. It is best to turn first to the southern fringes of the desert, given the great economic importance to Europe then of this Sahelian zone – its western side at least. From AD 700 to 1200, rain-forest pollen was deposited unusually far north within West Africa. But that could have been due to less opposition from contrary winds as the atmospheric circulation was translated southwards. Early in that span, too, Lake Chad began a millennium of irregular shrinkage.[134] Its water inflow comes essentially from high ground well to its south.

It is germane to ascertain the affect on the fortunes of Kanem and Ghana – the first West African statehoods the Arab chroniclers record. Each had emerged by AD 1000 as a strong monarchy. However, Kanem, located around Lake Chad in what today is a steppic grass landscape, was never really urbanised. Conversely, Kumbi Saleh, the capital of Ghana, set 200 miles south-west of Timbuktu within what now is a park landscape (i.e. savannah grass and clumps of trees), achieved an advanced stage of medieval urbanisation reliant on water obtained from deep wells. Describing all this in 1067–8, al-Bakri, a Córdoban geographer, also credited the kingdom of Ghana with an army 200,000 strong. Such a figure could connote a population of not less than 3 million or 30 per square mile, about what the region was supporting when the modern Sahelian drought cycle first struck so visibly *c.* 1960.

A cardinal difference between those two eras lies in the importance of the trade routes the medieval kingdom bestrode. Ancient Ghana assumed nodal importance in a transcontinental trade dominated by alluvial gold from West Africa and salt from the Saharan seas of long ago. Until 1350 or so, some two-thirds of the gold being imported into the European and Arab worlds would come from West Africa. Yet barely a decade after al-Bakri was writing, Ghana was overrun by a confederation of desert tribes that had secured the allegiance of the Berbers of the west Maghreb. This nexus had been consolidated by the Almoravids (as the confederation was called) having adopted Islam.

The Almoravid triumph over Ghana precipitated that kingdom's collapse in all dimensions – agricultural, commercial and therefore urban. With this dénouement came wanton violence and destruction. Yet mindless savagery was not what had been gaining for the Almoravids dynastic control over the west Maghreb and, by extension, Muslim Spain. That the Ghanaian demise was so ugly points to an ecological threshold abruptly being crossed.

Ghana's regimen could have been critically undermined by less rainfall, groundwater depletion or Malthusian overgrazing. The highest probability is a permutation of all three, this being very much a sphere in which weakness in one respect accentuates other stresses. Ghana was to be succeeded by the Mali Islamic empire, this during the twelfth century and under the auspices of Mande-speaking Negro people from the Niger basin. In the late eleventh, the western Mediterranean had passed through a gold shortage, highlighted the more by a regional upsurge in economic vigour. Agriculture thrived on diversity in the Maghreb. Among the new-found strengths of Al-Andalus was silk production for export.[135]

So what of desert encroachment or recession in north-west Africa? Across a quarter of a century, Hubert Lamb insisted that, from the eleventh century to the late fourteenth, the northern limit of the desert was roughly along the twenty-seventh parallel of latitude,[136] and that during that time even the middle Sahara was relatively moist, though not east of the 20° meridian. Yet drawing a line at 27°N implies a southward displacement of climatic zonal limits by up to six degrees of latitude from the present. Moreover, it does not relate to structural boundaries in terms of topography or hydrology. Nor is it evident from the Arab writers that the desert had contracted to any great extent, if at all. Hubert Lamb cited contemporary reports that the Sahara took two months to cross.[137] If that implies a desert not less than 1,200 miles wide, that is actually about a third as much again as its breadth from close by the Atlas Mountains to near the Niger bend through most of the twentieth century. Moreover, cedar-ring analysis from Morocco suggests the late eleventh century was a good deal drier countrywide than virtually any time since.[138]

A highish level of trans-Saharan traffic could as well be explained by the rising demand for bullion and by the stoic zeal of nascent Islam as by any putative trends towards desert shrinkage. Meanwhile, the most dramatic upshot politically – Almoravid achievement of hegemony around the western end of the Mediterranean – owed much to divisiveness within the pre-existing Islamic order in both the Maghreb and Spain. In any case, the new hegemony was never rock solid and was to survive barely a century. It conformed to, perhaps inspired, the dictum of Ibn Khaldūn that nomadic herdsmen recurrently conquer and reorganise agricultural civilisations but are then destined to lose, within three generations, their own identity and sense of purpose.

One should wait upon further research on the Arab archives. So should one in regard to the physiography of the desert fringes. But for now, there is little reason not to reaffirm the view that unrest in the tenth and eleventh centuries, on the North African and Near Eastern fringes of Islam, related to accentuated water shortage. Since this effect was so general and pronounced, the Holy Land excepted, it must have stemmed primarily from natural alternation of the desert as opposed to human maladroitness. That scenario runs flatly counter to the contraction hypothesis. Perhaps more to the point, it cannot easily be reconciled with scenarios of desert shrinkage during warmish Pleistocene interstadials. An added complication is that, while a typical rise in level of atmospheric CO_2 of maybe 50 per cent from glacial maximum to interstadial will have stimulated directly the growth of most types of vegetation, certain savannah grasses will have been among the exceptions. But maybe close analogies cannot usefully be sought seeing how much more limited medieval warming was in both temperature–time profile and global scope.

Mediterranean resilience

Overall, the impression gleaned from several centuries prior to 1100 is of the resilience of Mediterranean economies in the face of what could be critical climate changes, especially as regards the water balance. Witness the boom in Islamic/Christian long-distance trade as the eleventh century drew towards its close, notably as between the western basin and the Near East.[139] One factor in this development may have been the migratory rainbelt discerned by Claudio Vita-Finzi. Another was the way topography presented alternatives. Take viticulture. The extension northwards, in high medieval times, of the bounds of vine cultivation in north-west Europe seems not to have been offset by any general retraction geographically within its Mediterranean heartlands. For one thing, a displacement of one or two hundred metres on a steep mountainside can transpose the grape to a quite different mesoclimate, certainly as regards warmth and sunlight.[140] In other words, the margins of cultivation may shift in the vertical more readily than in the horizontal.

The introduction of several score of new crop plants was another aspect of medieval adaptiveness. Very predominantly it was the Muslims who reached so far beyond the customary Mediterranean triad of grape, wheat and olive. Important in generating this greater choice was the extension of water control for irrigation and to check erosion. It proffered extra resilience up to a point but was prone to entrap an economy in undue water dependency beyond that. To an extent, the Muslims restored what the Romans had left behind. Across North Africa from the Atlantic to the Red Sea, their economic development will rarely, if ever, have matched that of the Roman zenith. In Spain, the Moors were able to pioneer more in most sectors. Witness the several thousand waterwheels in the Quadalquivir valley alone. Before long, building on Arab precedents, the Normans in Sicily so harnessed water to population growth, income generation and culture expression as to be 'the envy and wonder of the world' come the twelfth century.[141] No doubt that southerly island derived added benefit from the storage quality of the hard wheats, and the barley, reaped from its dryish slopes.[142]

Meanwhile, the development or redevelopment of irrigation was under way in the Italian north. Already the network of canals created in the Po valley outstripped anything the Romans had essayed.[143] Maybe it was such virtuosity that led the 1966 *Cambridge Economic History of Europe* to conclude, with specific reference to the Italy of that era, that 'Climatic fluctuations there may have been but their sequence is uncertain. . . . They did not disturb the traditional processes of farming, still less determine developments in medieval rural life. These had their own chronology, independently of physical conditions, and were governed by cycles not of climatic but of economic change.'[144] That dismissive stance was in line with the general thinking of Sir Michael Postan, the editor. Just as inadmissible would be to discount the extent to which an economy can be influenced by changes in climate elsewhere. Italy was the main conduit for the import of luxury goods from the East into a central and north-west Europe itself entered upon a boom that was considerably climate-driven. The transient readvance of Alpine glaciers retarded little this ramifying linkage, the St Gotthard route excepted.

What is not immediately apparent is whether the era leading up to the Medieval Optimum saw any accentuation of a Mediterranean pattern still remarked by geographers, even apropos modern times. It is unevenness in the spread of population.[145] The prevalence of small coastal plains tightly encompassed by high relief is basic. Otherwise the reasons are various and often obscure. Local peculiarities in the water cycle down to sea level may be significant. Important, too, may be abrupt contrasts in the inherent richness of soils, sometimes on account of past volcanic action. So may the irregular progress of epidemics. Likewise the irregular incidence of extreme weather. Armed threats and incursions have also figured.[146]

The fear of armed attack had long been largely a function of the Islam–Christian confrontation. But through the middle of the eleventh century its battle lines seemed to be dissolving, at least in the central Mediterranean. Burgeoning trade was one factor in this and pilgrimage to the Holy Land another. Relevant, too, was the appreciative attitude to Islamic culture, in all its aspects, overtly struck by the Normans arriving in Sicily.

Yet things worked out otherwise. Instead of détente, there was the first of the Crusades to secure the Holy Land. These 'divine campaigns' had two mainsprings, the one within Islam and the other in Catholic Christendom. The former is addressed in the next chapter. As regards the latter, an underlying reality was that feudal bonding was in early crisis, this because of dynamic economic development and the way geopolitical consolidation had left western Europe less exposed to outside threats.

The erosion of feudalism

The Italian peninsula was still focal in certain respects. On it, the feudal nexuses were visibly in decline by the turn of the millennium. For one thing, the physical and political geography had never allowed of a divide between Christians and heathens as stark as that presented in Spain. For another, binding obligations were giving way quite rapidly in Italy to a fair degree of social mobility encouraged by market forces. Social stratification vertically was being complemented by more horizontal interaction. The manor was receding in the face of the urban commune and its guilds.[147] Granted, in central Italy a lingering fear of armed attack had led to the *incastellamento* or *révolution castrale* of the tenth century: a coming together of the population into fortified hilltop villages. Yet although these were usually under the auspices of a local lord, they could not be created and maintained except through new relationships. In the course of the eleventh century a similar pattern emerged in the Italian north.

So was Italy one of those exceptions said somehow to prove a rule? The answer does appear to be negative. A long-standing debate has lately gained a new lease of life. It concerns how much idealised notions of the European feudal norm owe to the retrospective rationalisation of late medieval scholastics. Was the archetypal feudal model ever applied in a pure form? Did anything approximating to it ever obtain across Christian Europe as a whole? Ought emphasis to be placed instead on (a) free peasants and (b) monarchical power? How did things evolve over time?[148] Issues like these help steer us towards an understanding of how climate change acted within a mix of contingent factors to avert or precipitate crisis during the Middle Ages.

In pursuance of incipient feudal decay, it may be instructive now to turn to what may loosely be termed the opposite side of the continent, to Scandinavia. Although the Rus trade with Islam had virtually ceased by AD 1000, the ongoing agricultural revolution in southern Scandinavia still allowed of a big rise in population and prosperity, most visibly in Denmark.

A disposition to organise much of the new cultivation into strips is redolent of manorial feudalism. Thin though the evidence still is, however, it does seem to connote in this case a radically new lifestyle, *bybildning* in Swedish, based on inter-family collaboration at village level. Its ethos was something like this. The priority given in new settlement to individual farms or hamlets betokened the primacy of peasant proprietorship. Yet thanks to primogeniture and all the other variables, this soon gave rise to a divergence between prospering peasants and a burgeoning landless class. None the less, this economic divide was softened socially by a democratic individualism expressed in sombre but authentic mode by the character and profusion of burial mounds and runestones. Here the spread of Christianity smoothed the path of social change, instead of revivifying a pre-existing hierarchy.[149,150]

In Denmark, royal taxation of all private land facilitated heavy defence expenditure, the country being both prosperous and exposed. Among the programmes covered were the Trelleborg circular fortresses, the largest of which exceeded 250 metres across and contained 48 identical wooden halls. Structures like that were designed to shield whole communities. In short, the Danes and Swedes were not so much concerned to evolve out of feudalism as to preclude its emergence. Extending the frontiers of cultivation and settlement enhanced the prerogatives of peasant colonisers.

However, to settle and cultivate northwards any distance would have been an option so tough as to be manageable, if at all, only by a martial aristocracy or warrior holy order. Critical impediments would have been the juxtaposition of thick forest and bleak tundra with everywhere only thin, acidic soils, and, of course, the acute temperature gradients herein deemed characteristic of that era across central Scandinavia. When at last, in the twelfth century, a few villages started to appear in higher latitudes, their denizens were subject to 'collective obligations . . . unequalled anywhere else on the continent.'[151]

Throughout the German lands of the Holy Roman Empire, local feudal lords – either laity or prelates[152] – assumed special prominence. Not least was this so in the so-called mark lands delineated when the Germans began, in the tenth century, to probe the moraine-dominated stretches of northern mixed forest (i.e. deciduous and conifer) between the Elbe and the Oder. The term 'mark' had originated in idyllic nostalgia about rugged village communities in Teutonic tribal days. Early in the Middle Ages it became synonymous with 'marche' – the francophone term for a disputed border zone as in Italy, England and France itself.

Had German colonisation in the eleventh century been directed more strongly eastwards, the effect would probably have been to galvanise anew the feudal nexuses. This is, after all, what happened on such frontiers at other times or places, primarily on account of the imperatives of military protection. With the emphasis on advancing inwards and upwards instead, there was more scope for the emergence of a freer peasantry. Even where ducal involvement continued, it will have been more on a basis of mutual collaboration.

About Poland, one plain fact is that only a third of its area was under cultivation as late as the tenth century. Using the yardstick of a family of six working a two-field rotation, recent research has arrived at a population density of 4.5 per square kilometre overall. This estimate may be compared with three for Kievan Rus, six for Bohemia and Moravia, and ten for Germany.[153] Allowing for population growth, these calculations match fairly closely those for the Slav lands in Norman Pounds' surmise in 1973. He reckoned that, in the late eleventh century, the density of people in Poland and maybe Germany, too, was under half the 10–12 per square kilometre he adjudged then typical of western Europe.[154]

Polish village communities were isolated in a manner redolent of those in emergent Russia. But they were not exposed to so harsh a winter environment. The January temperature mean at the bishop's seat, Poznan, will probably have been, then as now, eight degrees Celsius higher than Novgorod's. Correspondingly, the Polish villagers were not as collectivist and subservient as their counterparts further east, being rather more prepared to resist total domination by the lords, dukes or monarchs and to uphold individual prerogatives. The rub was that self-willed villages set well apart amidst lakes and forests could hardly constitute a matrix for territorial defence. But between 1160 and 1240, the *ad hoc* formulation was largely completed of what became a comprehensive, if somewhat inchoate, body of German law designed to regulate the *modus operandi* of German settlers occupying sites set in the main between Polish villages.[155] At that time, neither people was in the mood either for ethnic cleansing or for assimilation. The Germans were leading the way in the adoption of the watermill and, less conspicuously, of the mouldboard plough.[156]

Across in unruly Flanders, serfdom was never very significant, regardless of land clearance and local reclamation. The fertile country of the lower Scheldt-cum-Leie was a qualified exception. There the population was at its densest and a three-field crop rotation operative.[157] In the Ardennes the deeply chiselled landscape will have resembled that of the central Rhine uplands and will similarly have favoured relatively liberal modes of colonisation.

For Ireland, the situation was complicated by the retention in service, through the early Middle Ages, of the few thousand *crannogs* and tens of thousands of ring forts, the great majority being those built in the fifth and sixth centuries (see Chapter 4). However, that morphological continuity obscures the evolution, through the eleventh century, of a more hierarchical society. This was interwoven with the development of towns by the native Irish (as opposed to Viking sea rovers), coupled with a growth in regional trade. The impression gleaned is of an island people cautiously moving in singular fashion in a high medieval direction. New ring fort construction was being abandoned by 1100 or so.

Ireland's location on the oceanic periphery of Europe would have made climate change more halting than elsewhere. Also, isolation from the economic and social mainstreams must have been retarding its development. It has been averred that Ireland had joined 'a northern trading network during the 9th and 10th centuries'.[158] But its involvement will surely have been tenuous.

A modern view about manorial production is that 'it never encompassed the majority of peasant households' in Europe.[159] Nevertheless, archetypal feudal forms were dominant for several centuries roughly between the Garonne and the upper Meuse: an arc of territory that had been the Carolingian heartland and which, in terms of geophysical dynamics, was well placed to experience early medieval warming at its most vigorous. It would have often lain in the path of long south-westerly fetches of air sustained by a north-easterly ridging of the Azorean anticyclone, assuredly a dominant weather mode especially in summertime. In that core area the said warming may have favoured the early consolidation of manorialism. If it tended to work the other way towards the lower Meuse–Rhine confluence, this will have been partly because of the disparate landscape and partly because of strong population growth from the outset.

The adoption of feudal principles was most categoric in the Duchy of Normandy, the polity that had arisen out of the cession of the lower Seine in 911 to Vikings mainly of Danish origin, this in a desperate attempt to buy them off. By then, too, other principalities (notably, Blois and Aquitaine) were emerging within what we know as France. From 987, the Capetian noble house included the dukes of Francia, a small but nodal territory based on Paris – the former Roman city that the Franks had made their capital *c.* AD 500. Yet it was not until the reign (1108–37) of Louis VI that their struggle for primacy among the French feudatories achieved anything like enduring success.

Contrast this with how much was achieved by the early Norman kings of England. Their drive to tight centralisation was the follow-through of the ruthless pacification that had itself been a follow-through of the Battle of Hastings. However, the Anglo-Saxon institutional precedents did afford strong guidelines.[160] An underlying reality was the insular and compact geography of England, plus the natural nodality of the lower Thames and its estuary.

Within France, meanwhile, improved external security and economic revival afforded scope for the elaboration of enfeoffment linkages, too much rein thereby being given to a 'feudal anarchy' overseen by greedy and oppressive barons. The internal wars the Capetian kings were continually engaged in through the eleventh century reflected that. At the same time, a shift out of pastoralism and into grain-producing arable accelerated. It would be tempting to presume (as was done above in regard to Wielkopolska) that this was simply a response to (a) the promise of goodish fields of corn as the weather turned that bit warmer and drier, and (b) an increased demand for food as the population rose. However, any explanation pertinent to this feudalism in the raw must embrace two other considerations. The one is how exposed small flocks and herds were to knightly brigandage. The other is the added leverage local lords often gained through the control of milling facilities.

The most drastic remedy open to a serf or smallholder was to seek freedom by breaking entirely new ground in a remote forest or swamp. Though a tough and risky option, it might be preferred to working under lordly control to tend and extend manorial strips, maybe (as not infrequently in the Ardennes) reclaiming from scrub or bog land abandoned by earlier generations. Part of the attraction will have been to draw nearer the mainsprings of a woodland paganism still ingrained within the peasantry, a paganism that at its best gave vent to an innocent naturalism (see Chapter 9) and, at its still extant worst, to family planning through infanticide by means of hideous rituals and expedients.[161] As time went on, however, those that desperate for freedom would look more and more towards the towns rather than the wilderness. The Low Countries is where those alternatives were posed at their starkest.

The truce of God

Something we know of only episodically apropos the tenth to twelfth centuries is overt peasant unrest.[162] Whatever class violence came from that quarter was too localised and random (and maybe, at manor level, too commonplace) to find its way into the archives. To be observed more coherently is the development, within France and neighbouring lands, of a Christian mass movement for social peace, a departure that had its origins in the campaign for spiritual renewal that Cluny Abbey (which had been founded, in upper Burgundy, in 910) had launched across the Catholic world. Its first regional council had been held at Charroux in west-central France in 989, but for the first one or two decades it was associated more with inner Provence, still the most Latin and urban province of what had been Gaul. Soon the movement was suffused with a vision of more material equality as a precondition of social peace.

Then, during the first quarter of the eleventh century, the centre of gravity swung towards the Loire to Moselle sector. A climax came in 1034 during those several famine years that gave rise to a trade in human flesh, another barbarity paganism was too ready to provide a rationale for. The Church in mighty Aquitaine led the way in arranging synods and special councils to endorse new codes of behaviour – above all, of knightly and baronial behaviour. As the century moved on, more emphasis was placed on enlisting support in Francia and also in Normandy, various security pacts being signed between burghers and their king or duke. Social peace was thereby to be secured among all Christians as a precursor to a crusade against the non-believers.[163] That interpretation of the 'Truce of God' was sure to be extolled by the Benedictine reformers of the Cluniac order. Witness their focusing on the ninth-century shrine of St James at Compostela in Galicia, an inspiration for the *reconquista* of Moorish Spain. They even created a network of monastic foundations along the trunk routes to there.[164]

But there were wider connotations. The theme of a 'great peace' achieved through the final triumph of good over evil could otherwise be given a millenarian slant. Through the eleventh century, the 'amorphous mass' of potential millenarians characterised by Norman

Cohn swelled conspicuously around the middle Rhine against a background of demographic pressure and structural economic change.

As the last decade of the century dawned, a disposition became prevalent across France and in the Rhine–Meuse–Scheldt region to launch towards Jerusalem sooner rather than later a divine campaign capping those undertaken against the Muslims (a) from Castile since 1072 and (b) by the Normans in Apulia and Sicily from 1016 to 1090. Soon a portent was bright in the heavens, the meteor shower of April 1095, an event extensive and spectacular enough to be much remarked throughout France. The least that might be deduced was that heavenly patience with continued inaction was wearing thin. More substantively, a drought cycle had been gripping the country for several years past; and bucking what had seemed to be the secular trend, famine had returned. Peasants reverted to eating wild roots and herbs

Map 6.2 Gaul/France

as food shortages were aggravated by hoarding and brigandage.[165] Blocking anticyclones, in one lie or another, will have been the cause.

An occasion for overseas action was afforded thus. In 1071, a Byzantine field force of some 80,000 men had been routed by a Seljuk Turk army half its size, in a battle near Manzikert, 45 km north of Lake Van. The former had been inexpertly directed, before and during battle, by Emperor Romanus. But the most basic problem was its being half comprised of mercenaries, most of them non-Seljuk Turks and nearly all poorly motivated.

The upshot in Constantinople was ongoing turmoil. Within a decade, a new emperor, Alexius I, had appealed to Pope Gregory VII for military assistance only to find him preoccupied too exclusively with concerns nearer home. Worse, a Norman couched-lance cavalry charge clinched a stunning victory over the Byzantines at Durazzo in 1081.[166] Then in 1095, observing disunity among the Seljuks, Alexius appealed again to the papacy, now in the person of Urban II. This time the response from the Lateran palace was more positive. A French aristocrat himself, Urban called a council, to be held that November at Clermont in the Auvergne, of the bishops and abbots of France. A select group of knights was invited as well. Urban, no mean orator, gave the keynote address.

No authorised transcript has come down to us. The several accounts we have from contemporaries may all be partial in both senses of the word. None the less, it is clear that the Pope held out the prospect of high adventure and of fiefdoms from participation in war against the Turks. He described the land of France as 'too narrow for its own population; nor does it abound in wealth; and it furnishes scarcely food enough for its cultivators. Hence it is that you murder and devour one another, that you wage war.' Absolution would be granted to those who died in holy battle. Rich and poor alike should go.

Urban continued to pursue the theme throughout France and in Italy, by preaching and discussion, most of the next twelve months.[167] Through that winter, the preparations for departure under one banner or another were feverish. Come the spring of 1096, the French drought was to be broken across much of the country by abnormally wet weather. That summer's harvest was bounteous.

The allusion to land hunger as a core motivation ought to be treated with more scepticism than some historians have evinced. Agreed the population in much of north France and Flanders was then rising fast, its having been well favoured by climate change. Even so, a density still not much above 70 per square kilometre across Cotentin as late as 1328 can be deduced from the royal hearth lists. Meanwhile in Provence, the figure remained below 30 – i.e. about 75 per square mile. Even the second figure is high by medieval European standards. But, if it is accurate, the actual figure for 1095 may have been only half that. Fertile Cotentin may have become awhile a special case. Otherwise and subject to whatever the Pope may actually have said, one should probably read population pressure as essentially a euphemism for the excess belligerency of martial young bloods.

Historians do seem solidly persuaded that one of Urban's genuine purposes, perhaps 'his chief aim', was to unite the Greek and Latin churches 'under the headship of the bishop of Rome',[168] ending a deep split lately much aggravated by uninvited papal legates brusquely presenting a bull of deposition and anathema at the Patriarch's church in Constantinople in July 1054.[169] In accordance with that approach, the Pope was looking towards a military expedition being well organised and accoutred, along feudalistic lines, and assembling in good order at Constantinople. Instead, the first mass departure, from Cologne in April 1096, was of the tens of thousands of hapless *sans culottes* galvanised into a mission impossible mainly by the charismatic fanaticism of Peter the Hermit or, as he was soon to be dubbed by the forthright daughter of Emperor Alexius, 'Peter the Cuckoo'. The chiliastic susceptibility of the Rhine–Meuse–Scheldt people was currently all the greater by virtue of their region being 'precisely' the one that had just endured for ten solid years 'an almost unbroken series of floods, drought and famines'. Their misery had been compounded since 1089 by 'a particularly unpleasant form of plague which would suddenly and without apparent cause strike at town or village bringing an agonising death to the majority of the inhabitants.'[170]

Soon after leaving Cologne, members of Peter the Hermit's crusade were massacring Jews in other Rhenish towns. It would be agreeable to believe that these were atypical excesses, a consequence of those concerned being residually influenced by a mish-mash of perceptions generated long ago in the shadowland between Catholicism and paganism. But the reality is that anti-Jewishness, at times virulent, was repeatedly a theme within the cultural renaissance then beginning. In the next century, it was to be endorsed by such as Abbot Peter the Venerable of Cluny and even, albeit more temperately, Peter Abelard.[171]

The people whom Pope Urban was apparently so concerned to divert to this overseas adventure, the young French knights and men-at-arms short of licit employment, were the creatures of the contradictions of feudalism as accentuated by strategic consolidation as well as by economic progress. Edward Gibbon allowed that the volunteers were looking for a respectable outlet for talent and energy but moved swiftly on to insinuate that their crusading forays were otherwise driven by sheer avarice.[172]

A century ago, the history profession as a whole still tended to highlight avarice as a driving force for the knights and their retainers. Also, there was a disposition to stress – additionally or alternatively – the influence of primogeniture, the tenet that a feudal estate should pass in its entirety to the eldest surviving son. Across northern France, primogeniture was becoming more common in the face of population pressure. Yet it was still far from dominant.[173] Nor does the latest evidence confirm the assumption that those who crusaded particularly emanated from among the younger sons. What does come across is that, for most, the overriding material concern was covering their outlays rather than the prospect of gain.[174] Surely a quest for meaning and purpose was a consuming motive. It so often is in war.

Acceleration through climate change

The essence of eleventh-century experience is that institutional structure and social ethos evolved very readily in those communities that, by virtue of dwelling in or close by axial western Europe, were well placed to benefit weatherwise from what will have become a prevalent pattern: the summertime ridging north-eastwards of the Azorean High. But across the board, the pathways of progress were various. The organisation of a feudal order in England (before and, the more so, after 1066) went hand in hand with the emergence of national kingship. In the Low Countries, the feudal stage was all but by-passed. Across France, and above all in Normandy, feudalism was robustly established early on.

By the eleventh century, French feudalism had moved into deep crisis. The reasons are hard to elucidate fully. Suffice it now to say that, if any case at all is to be made for seeing the Crusades as basically armed emigration in reaction to Malthusian pressure engendered by climate improvement, the location to select is Normandy. The high density of population cited above for Cotentin in 1328 may be contrasted with a tentative estimate for that peninsula in 1450 presented in a 1971 study by Norman Pounds and Charles Roome. This was for a quite modest 10–20 per square kilometre. Making due allowance for (a) the impact of war, famine and plague in the interim and (b) margins of error all round, this does rather suggest population growth had previously been unstable.[175]

Yet to see even the Norman Crusaders as escapees from land hunger remains altogether too simplistic. It is so for reasons already put in more general terms. True the Normans also launched themselves against England as well as against Sicily and beyond. But everywhere they forayed as martial elites only a few thousand strong.

Prospect predicting retrospect?

The Mediterranean twin basin is peculiarly hard to assess in regard to climate variation. Its topography is intricate, a particular aspect being the near absence off many coasts of a continental shelf – sometimes a valuable repository of biological or artefact remains. Also the region more or less straddles a major climate divide between hot desert and a temperate maritime regime. Then again, though the Mediterranean may have been very much a cradle of archaeology the whole emphasis was until recently on the early civilisation to Late Antiquity span. In spite of all this, a lot of progress with medieval historical climatology has at long last been made east of longitude 60°E. Often the record elsewhere is still too uncertain or incomplete.

Assuredly more and more data will be fed in to enable the climate of the twin basins' medieval past to be more definitively interpreted, using air–ocean coupled models. In the meantime, is there merit in looking for analogies not just in glacial history but in contemporary predictions of global warming? The presentation on climate change in the 1995 report of the Intergovernmental Panel said that, from 1990 to 2100, 'warmer temperatures will lead to a more vigorous hydrological cycle: this translates into prospects for more severe droughts and/or floods in some places and less severe droughts or floods in other places' (p. 7). More specifically, that could connote variable impact around the Mediterranean.

What the presenters further said was that, when the models are responding just to greenhouse gases (i.e. without anthropogenic aerosols being fed in) then rainfall totals across southern Europe regularly decrease (p. 43).[176] However, that prediction, which is essentially one about latitudinal displacement, does not relate well to the compilations on medieval Italy by Lamb and Dragoni cited above.

More closely in line was a predictive review published for the United Nations Environment Programme in 1992. One tentative prognosis for the next 30 years for the twin basins was of increased autumn rains on much of the northern littoral and reduced rains on much of the southern.[177] Meanwhile, a collateral prediction for the Po valley, plus the Venetian lagoon, was that a mean air temperature rise of 0.5 to 1.5°C will be associated with pronounced erraticism, this involving spells of heavy rain yet not infrequently, too, hot and dry summers or mild winters.[178] There would also be adjustments in marine salinity.[179]

But what if we do assume that these forecasts are valid enough for our century? How might they relate to the slower but essentially secular trends of the early Middle Ages? One could expect sea temperature and salinity then to have risen quite closely in phase with air temperature gains, because the latter will have been comparatively slow. One could not even be precise about this, however, without sophisticated modelling of the exchange of waters (very salty Mediterranean, and less salty Atlantic) through the Straits of Gibraltar. Apropos the outlook this century, indeed, that aspect calls for more attention given its importance even on the oceanic side of the straits – e.g. in controlling the motion of the North Atlantic deep water.[180]

In the Mediterranean, however, other stages in the water cycle may be exceptionally important, critically subject as they widely are to specific local conditions. Evapotranspiration can vary markedly over time and from place to place. So can percolation. After all, much of the bedrock all round is composed of permeable limestones raised up by Tertiary folding.

The advances made in historical climatology east of 60°E cover a climate zone that extends as far as Persia. Behind this academic commitment are (a) a fervent desire to transcend Gibbonesque prejudice about Byzantium, and (b) a new-found preparedness to carry historical geography in Israel forward from the New Testament, partly in order to lay some very recalcitrant ghosts.

In terms of geophysical dynamics, a zonal unity is apparent in the eleventh and twelfth centuries even though the key trends are not consistently in the same direction. There are major implications for the Crusaders in the Holy Land. But the influence of climate flux on the unfolding of that great *démarche* may be traceable much earlier in their European homelands.

7 The Near East in crisis

Byzantium to Manzikert

No doubt the disaster that befell Byzantine arms on the enclosed plain near Manzikert could be explained in terms of the battle management of a motley army inevitably being too set-piece to cope with the tactical opportunism of Seljuk mounted bowmen. But further back in the chain of causation is the decline of the *limitanei*, the defence posture based on soldier-peasant settlement on the Anatolian plateau.

Organised territorially into what were called *themes*, these men were mainly geared to local defence along guerrilla lines. But they had also comprised the backbone of a field army envisaged as 120,000 strong, including some elite mercenary units, and with corps of logistics and of engineering plus a medical service.[1] In their prime, field force and *themes* were complementary. But in 1071, Emperor Romanus had felt obliged to campaign perilously far to the east because the *themes* system was so visibly breaking down, leaving much of Anatolia exposed to marauders.

Yet in many respects Byzantium had, the previous two centuries, been a successful example of a Mediterranean city-based polity. Come the twelfth, Constantinople would have a population of 800,000 or more as compared with 100,000 in Paris, western Europe's largest city.[2] Between 875 and 1025, the Empire had expanded anew to incorporate (a) the nodal island of Crete, (b) *c.* 100,000 sq. km in the strategic border zone extending from the 'Cilician Gate' (through the mountains behind Adana) to the headwaters of the Tigris and Euphrates, (c) *c.* 250,000 sq. km embracing Bulgaria and Macedonia, and (d) substantial territory in the 'heel and instep' of southern Italy. Economic growth had started to accelerate through the first half of the ninth century, and a cultural renaissance concurrently began. At the time, particular prestige attached to the monopoly Byzantium had long exercised within Christendom in the supply of woven silk, purple cloth and gold embroidery. That monopoly was broken by the Venetians in the chaotic aftermath of Manzikert.[3]

One analysis describes as 'something of a puzzle'[4] this renaissance from the ninth century. This admission invites the surmise that climate alteration may on balance have been a stimulus. Such conjecture may relate to what we understand of demographic shifts. Population growth was to continue strong until the eleventh century but would be, by then, heavily concentrated in the Balkans. Both contemporary narratives and official records of attempts at recolonisation confirm that Anatolia had become more thinly peopled. Relating this to populations inclining downwards in the nearby Muslim lands, one may hypothesise a north-westerly displacement of rainfall patterns in harmony with continental climate trends. Corroboration is afforded by the level of Lake Van falling.

Byzantine society was thus regrouping more around its Hellenic core, around the tap-root of its culture and fine art.[5] In the resultant renaissance, Hellenistic style was blended as never before with religious motifs, this in the aftermath of the final defeat of Iconoclasm in 843. The result was that the tenth and eleventh centuries were the finest period of Byzantine pictorial art as, too, of Byzantine carving. The strong reassertion of Byzantine sea power as against Arab, from the ninth century, may also relate to the demographic refocusing.[6]

Not that the influence of climate can be gauged simply in terms of what would inevitably have been a rather uneven translation of precipitation patterns. Temperature change has also to be considered. One's first thought is that the growing season will have extended as Byzantium's more northerly aspects shared the warming trend under way from Moscow to Lisbon. Yet it may not have gained much. After all, the annual range in mean monthly temperature (i.e. that as between January and July) is very generally as much as 30°C throughout the Anatolian plateau. The logic of this may be that an overall increase of even a degree, say, will only stretch the season by about a week at either end.

More consequential may have been the effect on snowfall and snow lie. Then, as now, midwinter temperatures across much of the plateau will averagely have been close to freezing point. So winters just slightly milder could appreciably reduce the proportion of the annual precipitation (typically 15 inches, and this mostly in winter) falling as snow. That in its turn could mean readier run-off with less diversion to the groundwater reserves. On the other hand, less snow would have allowed flocks and herds to search more freely for winter feed, thereby favouring the more extensive grazing strategy of the rancher/landowner as against the relatively intensive husbandry of the soldier-cum-peasant. Also to be recognised is the likelihood that, for an interval extending from the tenth century to the thirteenth, there was more wintertime cyclonic activity on a median track from Cyprus to the Persian Gulf. Over much of Anatolia, the passage thus of a low-pressure centre is, and would then have been, liable to give 'warm south winds till a cold wave sweeps down in its rear as it passes eastward and brings bitter weather and deep snow to the bleak open steppes; at such times, thousands of sheep may perish.'[7]

Such a weather tendency would have exposed the Anatolian tableland more to the soil erosion consequent on forest denudation the previous thousand years and more. Primary archives tell of huge efforts by Emperor Justinian to limit this through damming and diversion. That it was still a very real problem a good 500 years later seems confirmed by an account from the French contingent on the Second Crusade of a march from Nicaea to Attalia by way of Smyrna (alias Izmir) in the winter of 1147/8. Mention is continually made of storms and swollen soil-laden rivers.[8] Moreover, the probability is that such tempestuous weather rarely worked to the comparative advantage of the soldier-cum-peasant smallholder. No doubt he cosseted his animals in winter in a way the rancher did not. But he was bound to be more precariously placed in relation to any losses. The 'big man' was *ipso facto* more adaptive to the vagaries of the elements.

How intractable the agrarian problem was is underlined by the continued recurrence of dearth. The 'great famine', *megas limos*, of 927/8 obliged many peasants to sell out to big landowners in spite of a law, passed in April 922, designed to buttress anew the peasantry's proprietary position. Till recently, there was a disposition in the literature to see *megas limos* as the *alter ego* of an 'appalling' winter during which, beginning on 25 December, 'the Earth was held in the grip of frosts' for 120 days and the destitute streamed into Constantinople. Now archival research has endorsed the contrary interpretation (first broached by S. Vanderstuyf, a Belgian scholar in 1909) that this weather occurred in 933/4.[9] This latter date coincides with the Eldgjá volcanic eruption in Iceland. This was easily the strongest registration in a Crête acidic ash series extending back all but 1,500 years, and the actual year can be confirmed from the Icelandic sagas.[10] Nor was this the end of an era of privation. As in western Europe, the 1030s saw a marked recurrence. In 1032, a 'major' famine was to break out in and around Cappadocia, a province in east-central Anatolia renowned for its cattle and grapes. Much the same happened in 1037 in Macedonia and in the 'bread basket' that Thrace was by then deemed to be.[11]

Although, until 1150 at least, Constantinople itself 'seemed still fantastically prosperous', this prosperity diffused too unevenly into the rural hinterlands. The cultural renaissance observed in the ninth century gained momentum in the eleventh and twelfth. Yet neither the commentaries on Aristotle nor the numerous treatises on mathematics and science served to stimulate an agrarian revolution. The educational ethos had waxed too indulgent 'of uncreative erudition, of sterile good taste'.[12] An alternative rendition could be to speak of too great a preoccupation with formalism.

Often the big landowners did fare best whether as ranchers in Anatolia or, the more so, as grain farmers in the new lands gained in the Balkans. True, peasant migrants from Anatolia might end up doing well enough in the coastal valleys of Asia Minor, some of which were enriched appreciably – as elsewhere in the medieval Mediterranean – by the deposition at lower levels of soils eroded from higher.[13] Yet even allowing that little, if any, numerical data on Byzantine farm output survive from that era, it is safe to say that farming technique had advanced little since the days of rule from Rome.[14] Granted, there had been a wider introduction (chiefly between AD 350 and 700) of what was to become an archetypal symbol of seigneurial control, the waterwheel.[15] But even this had been largely in its less advanced horizontal mode. Perhaps, however, the general backwardness of the countryside has also to be understood within the topographical setting of much of the Byzantine world. Shortish rivers flowing unstably down steep and confined valleys hardly lent themselves to an Andalusian style of management: grand schemes for the systematic irrigation of a diversity of crops. At least in the flatter and more spacious of the Balkan grainlands, the heavy iron plough was at last coming in.

Otherwise, the class conflict between the big landowners and the peasantry continued with little respite, with the imperial government seeking to preclude the collapse of the latter with the dire consequences it feared this could have for territorial defence. The three or four decades after 928 were studded by legislation in support of the peasantry drafted in ever more categoric terms, only to be flouted ever more brazenly. Then in 963, Nicephoros Phokas, very much the scion of a Macedonian landowning family, gained the imperial throne. He has not been well received by historians, though lately a more sympathetic account by Alain Ducellier has stressed his endeavours to rebuild frontier security, manage the currency proactively and constrain the expansion of the big monasteries.[16] His immediate successor, Basil II (widely adjudged the greatest of that Macedonian line), determinedly used both land laws and tax rules to curb large lay landowners as well. Nevertheless, their onward march resumed after his demise in 1025.

Overall, the years 950 to 1070 'saw the increasingly rapid disintegration of the free rural community.'[17] An imperial document of the tenth century anxiously insisted that 'The great number of peasants is a sign that public needs are being met through payment of taxes and the fulfilment of military duties; both of these would fail were the large rural population to disappear.' Already many accounts spoke of the insatiable greed of the wealthy who 'like gangrene seize on village communities to achieve their ruin.'[18] A damaging twist in the next century was the imperial authorities being obliged to constrain the acquisition of large estates by former senior military too prone to turn their skills and connections to personal advantage.[19] Something else favouring the rural rich (since it led to an extension of tax farming) was a central revenue shortfall that was to become the more acute in the wake of the Manzikert disaster.

The suggestion above was that climatic and hydrological realities, fluctuating over time, were importantly part of the background against which Byzantium's crisis came to a head. But an assessment thereof ought to be made relative to another ambient influence – currency flow. In the eighth century, its officials had been aware enough of how intra-regional trade could be bolstered by a build-up of gold bullion: this largely from the Arab world but also through Iconoclasm as well as from the Caucasus and, via Khazaria, the Urals.[20] Then from the mid-ninth century (that time of two or three cooler decades across so much of the extra-tropical northern hemisphere), a revival of copper minting was to encourage local marketing too.[21]

As regards subsequent experience, the received view has been that, from 950 to 1100, the Byzantine economy sank ever deeper into financial crisis as imperial overstretch caused it to experience the bullion shortage brought about elsewhere in Christendom by the drying up of the Abbasid silver flow.[22] However, Ducellier has made a compelling case for seeing the coinage depreciations (in terms of weight and alloy) then undertaken as a well-judged and, indeed, anticipatory response by Constantinople to a looming constraint on money supply as a consequence not just of bullion shortfall or military strain but of economic development. A shift from subsistence agriculture towards the big commercial farms was one aspect. An Aegean urban boom in metalwork, ceramics and textiles was another.[23] More generally, one can probably say that apposite fiscal management enabled Byzantium to adapt to changes in the geophysical climate more smoothly than its rural backwardness would have led one to expect.

The Seljuk ascension

An appreciation of how the Seljuk Turks emerged as what today would be called 'world players' should be set within the general history of the Turkic people of inner Asia. The steppes they had come to inhabit had been dominated until Late Antiquity by the Huns to the east and the Sarmatians centred around the Don valley to the west, the Alans being one of their major branches. The Hun exodus into axial Europe (see Chapter 2) was to destroy this balance.

Its aftermath was a rather unstructured milieu from which evolved, in the sixth century, a loosely confederal Turkish domain interactive, in peace as well as war, with Tang China. In cultural norms and even physical appearance, the peoples involved were diverse: Khazars, Kirghiz, Oghuz, Pechenegs, Uighurs, Uzbeks. . . . The unifying factor was a language group characterised throughout by exceptional clarity of structure. Even the Magyars owed a considerable debt to Turkishness in vocabulary as well as in social norms.

Early on the said domain divided, in effect, into a north-eastern wing and a south-western one. However, the former, having been pressurised into accepting Chinese suzerainty in the seventh century, remained insecure with successive tribal displacements to the south or west a result. These started with a southward retreat by the Oghuz in the seventh century and climaxed with one by the Kirghiz in the early tenth. A closer consideration of the linkages between such inner Eurasian developments and climatic variation should wait upon consideration (in Chapter 8) of the much-remarked Mongol example. Suffice for now to note that, although their explanations were different, both Gumilëv and Lamb thought this expansion began at pretty much the same time as a reversion to worse weather around the Gobi after a prolonged improvement in this regard.

After the retreat just referred to, the Oghuz relocated in the steppes to the north of the Caspian. The Volga duly became the boundary between them and the Judaic Turkic state of Khazaria, the Oghuz likely accepting an ancillary role that included the contingent provision of military support. Certainly, other Turkish warriors fought alongside Khazarian troops in battles against the Persians in the Caucasus. As for peaceable activity, the archaeological evidence from that era is of the Khazars staying in what has been termed 'symbiosis' with tribes still close to nomadism. That would have been against the background of a climate that remained as yet tolerably salubrious. Correspondingly, the Khazars themselves had waxed numerous and prosperous with vineyards and orchards among the farming assets possessed by every clan. Their conversion to Judaism took place *c.* 740. Awhile in the ninth century, their sway extended from the Caspian delta of the River Ural to the east bank of the Dneister.[24]

Consideration of the influence of climate trends has thus far been more definitive apropos this south-west side of the Turkish realm than for the north-east. Even for the former, however, we in the West still rely heavily on evaluations of data assembled between 1959 and 1963, this largely from fieldwork primarily focused on Khazaria. These evaluations have been relayed to us by the pen of Nikolaj Gumilëv. In the article just cited, he stressed how disastrous for the Khazars was an abrupt rise in the Caspian early in the tenth century caused by a displacement of the storm tracks towards the headwaters of the Volga west of where Moscow would soon stand. This rise, which was of three or four metres, brought the Caspian close to where it was to be in, say, 1960. One consequence was that more of the Volga's deltaic distributaries became navigable by shallow-draft vessels, thus making it that much easier for the Rus to push forward. Still more seriously, this sea-level rise directly denied to the Khazars two-thirds of their core homeland around the delta. What had been their flourishing capital, Itil, was gradually swamped as well. At the same time, however, the deeper hinterland was drying out, again due to storm-track diversion.

Gumilëv adumbrated major movements around that same time by the still nomadic tribes of central south Asia. He discerned a general movement to the west or south, this impelled by droughtiness. The instances he particularly identified were (a) the Pechenegs leaving the shores of the Aral late in the ninth century to settle in the southern Dneiper basin and (b) the Karluk people moving *c.* AD 950 from the Balkhash lakeside to the vicinity of the Pamirs.

One overt case of outright dispossession was not mentioned. The Samoyeds, a tribal community originally from the Ural/Altay sector (and located within that linguistic group), were forced by their Turkish neighbours to migrate well north *c.* AD 1000, this deep into the *taiga* coniferous forest of west Siberia. In a dramatic adaptation, they virtually dispensed with herding in favour of gathering, hunting and fishing. Their experience bears little on the causal sequence here being explored. But it stands as a salutary example of a drought-induced displacement bringing about a reversion back down what is generally taken to be the normal path of economic evolution.[25]

Of the various movements, one bore very directly on the genesis of the Crusades. During the Khazari droughtiness of the tenth century, an Oghuz personality called Seljuk emerged as leader of a tribal element that duly assumed his name. He led them south into Trans-Oxiana, a similarly arid land beyond the River Oxus that had long been a zone of turbulence as between the nomads and comparatively sedentary Persians. He also made them the first of the Oghuz to convert to Islam, this in anticipation of entry into Persia and elsewhere to the moister south.

Their conversion was actually to Sunni Islam. It was notional at first but was to be steeled by the Shi'ite influence dominant in Persia and strong in Mesopotamia. Soon the Seljuks were invited into the Khurasan province of Abbasid Persia in the hope that there they might be overseen better. However, this strategy was turned on its head as their war parties ranged ever more boldly over the Persian plateau, raising their sights from pillaging to domination. By 1044, they were in control of Isfahan; and by the time these Seljuk bands were unified once more under Alp Arslan (a distant relation of Seljuk) in 1063, they were already well ensconced in Baghdad, the seat of the Abbasid caliphate.

By then, too, the Seljuk ranks were swelling as other Turkish tribesmen acceded. A direct challenge to Byzantium in Anatolia was now not just feasible but inevitable. What made it so was, above all, a need on the part of these martial nomads for a new external goal, something more heroically Islamic than managing a dilapidated Mesopotamia. The upshot was the campaign that culminated in Manzikert. In its wake, the Seljuks occupied much of the Anatolian tableland against ineffectual *limitanei* resistance. Within a few decades, this gain had been legitimated as the sultanate of Rum. The capital of this new polity was at Konya, a site set aggressively well forward.

Nomadic reversions in Persia?

However, none of the above explains why Persia and Mesopotamia had proved so susceptible to Seljuk takeover. Nor does it assess how much a consequent consolidation in depth did for the resilience of the Islamic Near East in the face of the Crusaders. Nor, indeed, does it ask how far any causal connections may have been modulated through ecological change, climatic included.

At least one influential interpretation has been dismissive of climate flux. It is that advanced in 1968 by Xavier de Planhol, a specialist on the cultural history of Islam. What this effectively said was that, within Persia, nomadism proved enduringly to possess a dynamic of its own – one not entirely governed by the facts of geography, be these changing or changeless. De Planhol saw many signs in the Persian landscape of 'bedouinisation' in the historical past: in other words, of switches (whether complete or partial) from settled agriculture back into nomadism. From the classical Greek historian, Herodotus (484? to 425 BC), it could be inferred that much more land was then under agriculture in Persia than has been the case even in the twentieth century.

De Planhol was inclined to attribute the big net change effected in the interim largely to the 'massive' nomad invasions (Turkish then Mongol) of the High Middle Ages, episodes he believed involved far more people than ever the Arab takeover had done. He cited linguistic evidence in support of the view that the successive incursions had driven the Baluchis, in particular, from the north into Seistan and the Makran, the northern approaches to the area we know today as Baluchistan. Once there, they changed the farming landscape from, in the main, settled agriculture to nomadic transhumance.

Nevertheless, de Planhol did allow that, from the thirteenth century, the underlying trend has been towards settlement by the erstwhile nomads, this in response to a pressure of rising population to which, of course, any influx contributed. He still insisted, none the less, that right through to modern times, this trend has been punctuated by nomadic reversions, not least Baluchi ones. He pointedly observed how the Zagros Mountains, 'where climate might have been expected to favour cultivation and a settled way of life', came, in fact, to be dominated by the 'great nomadic confederations' – the Qashghai, the Bakhtiari and eventually the Khamseh.[26]

The Bakhtiari are to this day famed the world over for the rigour of their transhumance routines. Their time-honoured lifestyle has been giving way only slowly in the face of the economic imperatives of the world around. Such could have been much more the case in medieval times.

What must be admitted is that the climatic history of Persia in the medieval era is far from easy to elucidate on the basis of hard evidence from the country itself. None the less, a revealing picture can be built up inferentially.

One intriguing piece of a gappy jigsaw is the report Ellsworth Huntington published early this century on what was loosely termed Turkmenistan. His findings primarily related to Seistan, a geologic basin (alluded to above) consisting of a broad plain of Quaternary alluvium enclosed by Tertiary mountains that in one direction stretch deep into Afghanistan. Huntington was then but one or two years away from the formulation of his 'pulse of Asia' thesis. In what may therefore be read as a precursive rendering (albeit one applied just to that part of Persia), he wrote of secular fluctuations in rainfall though also of 'a gradual desiccation of the country from early historical times down to the present.' He quoted Lord George Curzon, Viceroy of India (1898 to 1905), as finding Seistan to contain 'more ruined cities and habitations than are perhaps to be found within a similar space of ground anywhere else in the world.' Curzon was suffused with a deep sense of history. That in its turn was informed by a keen eye for the past as registered on the landscape and in architectural remains.

Huntington himself was persuaded that, from 300 BC through AD 900, the Seistan water cycle still sufficed to sustain a virile urban civilisation. But he also believed that, not so long afterwards, the presumed desiccation passed through a critical threshold. In this interpretation, unlike in the rather more refined 'pulse of Asia' formulation, his core analysis disregarded the reality that precipitation can fluctuate across timescales measured in decades or centuries, not just millennia.

Other problems remain, even on the evidence as Huntington himself here presented it. He tells us the city of Zahidan was founded sometime around AD 1000, and, nodally located as it was within Seistan, flourished until sacked by Tamerlane in 1388. Moreover, the central feature of the said inland drainage system, Lake Seistan, was judged to have enlarged considerably in the early Middle Ages. Nor in so flat a landscape is that inference likely to have been incorrect in substance or too far wrong on timing, even allowing for the limited techniques (in geomorphology and archaeology) at the author's disposal.

What cannot be accepted without qualification is the explanation proffered. He noted how, at some time in or after the tenth century, the Helmand River was deliberately diverted northwards to feed Lake Seistan directly instead of following its natural course southwestwards via the Zirrah, a feature upstream that sometimes has been a lake (maybe merging at times with the Seistan) though at others (e.g. nowadays) merely a broad swamp. He thought the diversion was 'probably' a sufficient reason for the expansion of Lake Seistan.[27] (See Map 4.3, p. 112.)

Being then very committed to the notion of progressive desiccation across two thousand years and more, Ellsworth Huntington had been too reluctant to acknowledge the probability that, through early medieval times, the Seistan basin as a whole was considerably moister than long before as well as ever since. Meanwhile George Curzon erred in more or less the opposite direction. Apparently overlooking the possibility that climate may have varied across the centuries, he looked as viceroy 'to the day when the British would lease part of the Helmand valley, dam the river and recreate in Seistan the garden and granary to the former prosperity of which countless ruined cities bore witness.'[28] By 'former', he most particularly meant prior to the visitations of Genghis Khan and Tamerlane. The background is that Curzon saw as a primary objective in the nineteenth-century 'great game' of Asian geopolitics the exclusion of any rival state from using Persia as somewhere from which to threaten the security of India.[29] Until the diplomatic revolution of 1906–7 he, like the other policy makers in Calcutta and London, saw Russia rather than Germany as the state most keen and able to pose such a threat. He and others further saw the denial to Moscow of Seistan as crucial in thwarting its wider purposes.[30] This consideration will have claimed more attention in the official corridors than historical climatology could possibly have done.

Extended atmospheric science

But for our purposes, too, Seistan has to be seen as part of a wider canvas. It is very unlikely that its local climate will have been that much wetter through the early Middle Ages except as part of a wide regional tendency. After all, the rains that fall nowadays over central Persia and even Afghanistan occur very largely in association with the wintertime depressions that leave the Mediterranean south of the Anatolian plateau and which then track eastwards sometimes as far as the Indus valley. The associated rainfall is liable to be increased by the upland topography.[31]

In the 1968 *Cambridge History* cited above, the then director-general of the Iranian Meteorological Service identified two distinct patterns in a critical relationship between this cyclonic flow and the westerlies so dominant, not least in winter, in the upper troposphere. The one pattern is decidedly mobile, the other much less so. The former occurs when a depression near the surface moves in harmony with a travelling disturbance in those westerlies. The latter does when a deeper and quasi-stationary cold trough forms in that upper air.

A depression slow-moving in association with such troughing may imbibe a lot of extra energy from flood plains in Mesopotamia or else from the Persian Gulf.[32] How critical that factor might have been eastward from the Gulf, within the context of climate change, can be sensed from the atlas of *Global Ocean Surface Temperature (from 1860 through 1980)* compiled in 1990 by the UK Meteorological Office and the Massachusetts Institute of Technology. In the coolest month, February, the mean sea temperature is 17.6°C in the upper Gulf and 22.8°C in the Straits of Hormuz. Across the winter quarter (December–February), the means for those two locales are 19.1°C and 23.6°C respectively.[33] Both are thus in a temperature band in which the curve of saturation vapour pressure (a measure of how much water the ambient air can retain in vaporised – i.e. gaseous – form) climbs ever more steeply. It rises from 12.3 millibars at 10°C to 23.4 millibars at 20° but then to 42.5 millibars at 30°. The extra latent heat of condensation from the bigger volumes of ascending vapour may energise cyclonic systems.

One indication of how sea temperatures in the Gulf could respond to any wider tendencies towards climate warming is afforded by moving averages calculated for the Indian Ocean as a whole for the span 1860 to 1985. These reveal that sea-surface temperatures rose more than did night-time air ones: 0.50°C as against 0.38°C.[34] That aspect apart, however, the energy latent in the waters of the Gulf could still have come to count for more regionally because of a continental reorganisation of the atmospheric circulation. Though it is wintertime that one must ultimately address, a clue as to the possibilities comes from Rajasthan, a large constituent state in the north-west of India with a monsoonal circulation. Its western side is taken up by the Thar, a desert on which hardly any rain falls in the winter half-year and rarely above a few inches in the summer half. The paucity of rain even in summer is due to sheltering by distance and topography and to closeness to the ‘eye’ of the monsoon.

In his last major study, Hubert Lamb cited a graph drawn up by Reid Bryson from research by G. Singh. This registers a sharp rise in Rajasthan rainfall from a tenth-century minor low to a strong twelfth-century peak. An annual total of 33 cm is cited as representative in the former while 44 cm is in the latter.[35] Yet the Nile floods were weakish across much of the eleventh century, which connotes either a slackening or an outright retraction of the monsoon's outer limit. Put those two findings together and the picture created is of the south Asian monsoon becoming more tightly confined on its western side in the face of the extending influence of the Mediterranean. The nub is whether this tendency was manifest, too, in wintertime. Lamb envisaged Europe's climatic sphere of influence advancing eastwards into the Levant in summer as the Azorean ridging strengthened and realigned, this causing relatively cool surface air to flow round its north-western flank to feed into a zone of cyclogenesis in the eastern Mediterranean. In his seminal 1972 study, he had depicted the axis of a summertime upper trough as characteristically lying through Kola and Sicily during the eleventh century. He also predicted a pronounced genesis or rejuvenation of frontal depressions within the eastern basin in winter. *A priori* it does seem to make sense. [36]

Two pertinent studies have been completed in Israel of late. A 1986 one, undertaken at the Ben-Gurion University of the Negev, focused on the Kadesh-Barnea valley oasis in north-east Sinai. It found that a fill deposition began there *c.* AD 1200 and was continual for several centuries. The basic cause appears not to have been anthropogenic but the onset of wetter conditions, an especially moist period being delineated (by a close correspondence of tree rings and Dead Sea levels) as between 1170 and 1320. A broad correlation with the Vita-Finzi hypothesis was perceived. One question raised was the extent to which the registration of extra 'moistness' may really have been due to a higher proportion of the rain falling in heavy downpours,[37] probably from unstable air of polar origin.

Then in 1991 came the first fruits of some exotic fieldwork led by Amos Frumkin of the Israel Cave Research Center. This examined Dead Sea shoreline varves, though also wood fragments and, above all, the widths and heights of caves within the nearby Mount Sedom salt diapir. The gist of its findings was that, from AD 900 to 1300, the climate was somewhat moister than in the centuries before or after.[38] Close parallels with both Italian and Persian experience are evident, no doubt explicable in terms of wintertime depressions tracking from the Gulf of Lyons and reviving *en route* to the Levant and beyond. That interpretation can also be compatible with the perception of pressure being seasonally high over northern Scandinavia.

Synoptic analyses in the early 1950s of recent 'excessive rainfalls' in Israel showed them usually to result from an 'influx of deep, moist and cold polar air along meridional trajectories'. This air 'establishes contact with the warm surface air in a Cyprus Low. With the build-up of the Siberian anticyclone as winter progresses, such a situation becomes less plausible and there is less chance of the formation of a strong jet stream over central Europe and the Mediterranean which would feed sufficient air into such a circulation system.' This, it was inferred, is why the heaviest rains are virtually confined to the early winter (i.e. November/December).[39] In Athens, likewise, the last two months of the calendar year are, to judge from recent decades, the wettest, averagely yielding between them a third of the annual rain. Assuming analogies can usefully be explored between seasonal weather today and secular climate change in the Middle Ages, they predict more vigorous cyclonic activity in the Mediterranean (and especially its eastern basin) being encouraged by a high medieval weakening of the wintertime Siberian High. It is an approach that can probably be reconciled as well with that adopted by Claudio Vita-Finzi. Moreover, a reconciliation of the time profiles of the two Israeli studies just noted is best achieved by assuming that an axis of maximal rainfall was displaced southwards as the 'little climatic optimum' peaked out at hemispheric level.

What is needed to round off the medieval scenario, however, is evidence about temperature. Relying mainly on isotopic analyses of rainwater radicals in lacustrine carbonates and in stalagmites, Arie Issar affirmed in 1995 his view that in the Levant the period AD 1000 to 1200 was rather cold as well as humid relative to the centuries that came before and after: the 'Crusader cold spell'.[40] However, the conclusions drawn by a 1987 NATO-sponsored study had been less definite. Reviewing the Mediterranean region as from AD 1150, it had dubbed the first century therefrom 'intermediate' in terms of temperature. The following (1250 to 1340) proved to be 'warm'.[41] The common cause found with Issar is a switch from cooler to warmer in or near the early thirteenth century.

A Fertile Crescent?

The collation for the Fertile Crescent is congruent, both within itself and with what was said earlier about cold drives on the Anatolian plateau as well as about changing circulation patterns (at low and high levels within the troposphere) across Europe. It therefore reaffirms that, as the Medieval Optimum approached, the Mediterranean did extend its climatic influence further across Mesopotamia and Persia as frontal lows brought more rain at least as far as Seistan. Viewed geophysically, the difference will have been less than dramatic. Even so, a modest increase in rainfall in Khorasan or Seistan, say, could have had a more than proportional influence in human terms. As to what this influence was, it seems initially to have been to defer progress out of tribal nomadism, thereby impeding the emergence of a central statehood able to contain the Seljuks and, in due course, the Mongols.

More fundamentally the steppic and desertic plateau that comprises virtually the whole Persian heartland was not conducive to truly strong central government, however much its broad and flattish horizons may have encouraged the invention of chess – the original imperial war game. So allowing that there may be some validity, contingently at least, in the Wittfogel thesis about the 'hydraulic' foundations of 'oriental despotism', one cannot but observe the absence of the long and wide river valleys and broad alluvial plains, the sort of topography that calls for an overarching management structure.

Wittfogel himself came close to admitting as much in the very brief comments he made about Persia in *Oriental Despotism*. Citing the Arab sources, he acknowledged no fewer than 10,000 people were employed by the water department in Merv, then on the Transoxianic outer fringe of the Persian realm. But with a payroll like that, the department in question was deemed to have an internal security role as well. Karl Wittfogel placed Persia in the third of the four stages he identified on a descending scale from 'compact' to 'loose' central hydraulic control.[42]

Since the 'twin rivers' of Mesopotamia rise in southern Anatolia, one must enquire how the drives of cold air across that plateau in winter translated into precipitation within that catchment area. Despite some tectonic instability, Lake Van again proffers a datable record by dint of the absence of a riverine outlet and because the varve deposits from its alkaline waters alternate crisply between a white carbonate in winter and a darker one in summer. Issar cites a study completed in 1984 by a team led by E.G. Degens. Subject to shorter-term fluctuations that correlate closely with the basic sunspot cycle, the varves show a net fall in lake level of close to 20 metres from the peak *c.* AD 500 to a troughing out *c.* AD 1150. This trend was as steep and prolonged as any the last three and a half thousand years.[43] The only thing is that this troughing seems a century or so late in relation to other findings here noted.

Also to reckon with is silting and salting of the lower reaches of the Tigris and Euphrates, this due to the longevity of the irrigation system but more especially to the arid climate, the low permeability of the compacted valley soils, the lack of natural flushing as effective as that provided by the Blue Nile in spate, and the way irrigation was compromised by earthquakes and political unrest. As early as 1700 BC there had been severe salinity in Mesopotamian canals, while the Tigris, in particular, posed a major silting problem. The population of Mesopotamia fell from 630,000 in 1900 BC to but 270,000 in 1600 BC.[44]

Archetypal in this regard was the Nahrwan, a district centred some 50 km south-east of Baghdad. Around AD 500, the Persians constructed there what is deemed 'their most remarkable project: two canals that carried water from the Tigris to irrigate fields on either bank for a distance of 300 km on either side of the river.' In places 100 metres wide, they 'were on a scale little different from the largest built today.'[45] They and their branch network brought water to former desert. Salt was then kept at bay by regulating irrigation and by planting weeds to lower the water table, the concept being that water in the ground has more time to turn saline than that which is recycled more readily.

What two American researchers found, however, was that by the seventh century AD the irrigation of the lower Nahrwan depended on feeder canals originating well upstream. By the twelfth, silting had raised field levels a metre in general, thus impeding water distribution. By 1150, indeed, most of the district had been abandoned since only 'a trickle of water' was left to 'supply a few dying towns'.[46] The debilitated regime had failed to deploy the thousands of labourers continually needed to stop the system clogging. A further factor was tectonics. Between 1094 and 1204, Iraq and Syria experienced the appalling climax of an era of earthquakes. Some historians would stress, too, the *coup de grâce* coming in the form of one of the trunk canals being breached during military operations. Whatever the exact sequence, over 10,000 square kilometres of farmland was regained by the desert.

As usual in such situations, cause and effect worked both ways. Ecological problems accentuated social and political crises, but also vice versa. From 1056 to 1179 there were repeated famines and epidemics in Mesopotamia and nearby Arab countries. In Iraq, 1118 and 1194 are recorded as being both earthquake and famine years, there probably being a causal link. A whole succession of ecological misfortunes helps explain why the assumption of power in Baghdad by the Seljuks, in 1055, never led to a halt in the demographic and managerial decline of this hydraulic civilisation. Already, in fact, populations had fallen drastically, especially in the cities.[47] Undoubtedly this reinforced the Seljuk desire to progress in Anatolia. There at least, the will of Allah might demonstrably prevail.

Islam in crisis

At the time of Harun ar-Rashid, the formal suzerainty of the Abbasid caliphate had stretched from Kairouan to Samarkand. At the time of the First Crusade, it still extended from Jaffa to Lahore. The population of Baghdad itself had remained of the order of 500,000 to 1,000,000 around AD 1000.[48] That made it quite the most sizeable conurbation in the Islamic Near East. By then, however, central control of the caliph's realm was patchy, a disintegrative tendency being driven considerably by religious factionalism.

But that did not mean that what happened in and around so large a metropolis mattered not elsewhere. Take the drastic cutback from the ninth century in the supply of Abbasid silver to Scandinavia. This silver had been coming from mines scattered over the uplands of the Abbasid realm as far afield as Transoxiana. But it was not mere chance that its curtailment was concurrent with a no less precipitate reduction in the number of new settlements on the Tigris–Euphrates flood plain. Part of the same syndrome was the caliphate's already heavy reliance militarily on Turkish tribesmen (arrogant and ambitious soldiers of fortune, very largely heathen and non-Arabic-speaking), reliance above all for the security of the capital itself. A political crisis developed ahead of the nadir of ecological decline.

The first half of the tenth century was 'distinguished in Baghdad by an unending succession of riots, rebellions and military seizures of power.'[49] The eleventh witnessed factional violence within the city in 1002, 1007, 1015–16, 1045, 1051 and 1055, and again in 1072, 1076, 1082 and 1089.[50] This is the background against which the caliphate invited the Seljuk forces into the city in 1055 to prevent its final disintegration. It is therefore difficult to endorse Jacques Pirenne's view that this invitation was itself 'the death blow of Moslem civilisation'.[51] His verdict seems to have stemmed from a notion about the singular ruthlessness of the Seljuks. So absolute a perception is ill borne out by, for instance, the peace with honour offered Emperor Romulus of Byzantium when he was made captive at Manzikert. None the less, vindictive ruthlessness could be all too often exhibited on whatever side in the Near East in that fractious era. Glubb Pasha, from 1939 to 1956 the British commander of the Arab Legion, well contrasted the early medieval mores or absence thereof with the restraint very generally shown during the initial Islamic takeover.[52]

Egypt developed more in line with the general evolution of the Near East than its unique hydrology would lead one to presume. Attention has already been drawn to the difference of opinion as between Josiah Russell and Fekri Hassan over the dating of long secular phases of mainly low Nile waters around the eleventh century. Hassan has lately reiterated his 1981 view that *c.* 1070 a 'major low' episode at last gave way to a 'major high' one. He avers this was followed by another 'major low' from 1181 to 1350. All in all, the whole period, 930 to 1470, is seen as exceptionally unstable.[53] It is a delineation that matches well enough an authoritative listing of conspicuous famines in Egypt: 939, 1066–72, 1201 and 1294–6.[54]

What the Hassan alternation does not well relate to, however, is the account of Egyptian demographic changes proffered by Josiah Russell. Yet here Russell was at least on home territory, in terms of subject area. His research, mainly on tax records, found that Egypt's population decline troughed out at 1.7 million within the span 950 to 1050. Then it recovered to 2.4 million or so in 1200 and perhaps to 4 million by 1348, the eve of the Black Death.[55]

However, Josiah Russell ascribed population growth in the twelfth century largely to the colonisation of Upper Egypt, a move facilitated by the prowess of Saladin (1137?–93) in military but also civil affairs, irrigation development included. Otherwise Russell's explanation was in terms of the simple peasant, *fellahin*, usually growing more grain than he and his family consumed. To resolve this surplus value, procure consumer goods and meet tax demands, the peasantry sold grain, a proportion of which would averagely be exported to Europe much as in Roman times. Should this income fall short, young *fellahin* would defer marriage, thereby arresting population growth.

It is an ingenious theory. What might be difficult is assembling data to confirm it. But between the ninth and eleventh centuries, strong trading nexuses did develop between the West (notably Amalfi, Venice and Genoa) and Egypt.[56] However, from *c.* 875, the Christian West conducted a commercial-cum-naval offensive (albeit without much co-ordination) to regain sea control across the Mediterranean; by the commencement of the Crusades, its leading participants had achieved this.[57] What is unclear is what this *bouleversement* meant for Muslim or, indeed, Byzantine maritime trade viewed in the round.

Map 7.1 East Mediterranean

Yet not being able to account definitively for Egypt's modest demographic recovery can be no reason for denying its reality. Its ultimate manifestation was the way Cairo, eventually and under Saladin, assumed the lead in galvanising the Islamic territories affected into something like a united front against the Crusaders. Through the late eleventh century, the Seljuks east of the Sinai had been repeatedly at war with the Fatimids in Egypt. To the latter, indeed, the Crusaders had initially appeared as potential allies. Meanwhile, many disaffected

Shi'ites under Seljuk rule accepted Fatimid claims, couched with studied vagueness, of descent from Ali and Fatima and therefore of Imam status. To them, the arrival of the Crusaders was 'like famine . . . one of the bad things that presaged the end of the world.' Out of this dénouement would come the fulfilment of their millenarian vision of a thousand years of peace.[58] Saladin fought under Nur ad-Din, the ruler of Damascus, to occupy Egypt. Then with Nur ad-Din's death in 1174, he confirmed himself as Sultan of Egypt and took over Damascus as well.

To do this and to firm up the encompassing of the Crusaders by further operations against fellow Muslims, he needed a sizeable and well-provided expeditionary force. The creation and maintenance of that force put the Egyptian economy under considerable incremental strain. But the fact that it coped was expressive of an underlying dynamic.[59]

Yet constraining the Crusaders thus would still have been hard, had not the lands to eastward become better consolidated, economically and politically. It was noted above how a factious Abbasid Baghdad had exercised ever less authority over all the local satraps. But at least by early in the twelfth century, under Seljuk leadership, power had been devolved more systematically to several regional centres, notably Damascus and Konya. Maybe, too, that devolution was sustained by some recovery in winter rainfall across the Fertile Crescent.

If one is to speak here of an Islamic crisis, one should interpret the word 'crisis' in a sense closer to its classical origins than has been usual of late. To the Ancient Greeks, *krisis* was not *ipso facto* disastrous. It was a time of decision, a time when things could go very wrong but might go very right. In modern catastrophe theory, the 'catastrophes' are not always catastrophic.

The divine campaigns

The term 'crusade' can be discerned in several tongues by the end of the eleventh century. But it took the Third Crusade, a hundred years later, to project it into popular usage throughout western Christendom. Employed that ubiquitously, it very generally referred to those armed expeditions to the Near East directed towards gaining or holding Jerusalem.[60]

There were, none the less, several other locales for 'divine campaigns' that waxed and waned within broadly similar time-frames. In 1059, the then Pope endorsed the Norman invasion of Muslim-held Sicily just as his successor was shortly to endorse that of England; and the hope that an island so nodal within the Mediterranean might eventually become a papal state was cherished in Rome for the next 80 years. In Spain, the Muslim realm was to be reduced virtually to Granada by the battle of Navas de Tolosa in 1212. Various crusades in the Baltic included the three Swedish against Finland: in 1154–5 and 1249, and then from 1293. From 1208 to 1229, there was the ferocious crusade against the Albigensian heretics in south-east France. None the less, those to or close by the Holy Land stand apart with regard to how they were generated and sustained.

The ragamuffin 'People's Crusade' that Peter the Hermit led out of Cologne in the spring of 1096 was predestined to disaster so ineluctably that there is little point in tracking its progress in relation to the vagaries of weather or climate or anything else. Most of its members had disappeared, in one way or another, before ever it got to Asia Minor. There the remainder soon took heavy casualties in desperately one-sided fighting against the Turks, Peter the Hermit disengaging himself adroitly from the worst of the fray. Some remnants from this forlorn legion eventually came together in Syria and Palestine as an ill-accoutred coterie styling themselves the Tafurs – i.e. vagabonds. In battle they were truly savage and in triumph literally atrocious.[61] Peter the Hermit continued to act adroitly.

The 4,000 or so cavalry and the 25,000 or so infantrymen who made up the First Crusade proper likewise suffered heavy losses as, through the summer of 1097, they forced their way across a harsh Anatolian landscape, in places the more impoverished in the aftermath of Manzikert. Next came a nine-month siege of Antioch which, though finally successful in June 1098, had exacted a further grim toll, mainly through malnutrition and disease. Poor preparation and ill co-ordinated leadership had compounded the appalling strain on the rank and file.[62]

Even so, the Crusaders resumed their march in November and were to storm Jerusalem in July 1099; then, with the Tafurs well to the fore, they proceeded to massacre most of its Muslim and Jewish inhabitants (see Chapter 1). Yet just how precarious the situation of the Christians remained militarily was to be highlighted in the summer of 1101 when the Turks used Fabian tactics (i.e. the luring defensive) to wear down Christian reinforcements in the persons of 50,000 armed pilgrims as they negotiated a blazingly hot and dry Anatolian plateau. Few made it as far as Syria.

The political response to insecurity was to set up an informal commonwealth of Christian-led Levantine statelets headed by a Latin Kingdom of Jerusalem. The weakness of this 'Outremer' enclave was demographic. It rarely sought to convert the indigenous inhabitants. It was only mildly successful in attracting immigrants; and both the birth and the infant survival rates among its Christian inhabitants stayed ominously low.[63] The result was that the Christian population of Outremer never exceeded 150,000–200,000, perhaps a tenth of the population within the defined borders and a very low percentage of all those in that strategic region.

Meanwhile, the Muslims began to grope their way towards a greater regional unity. Their first keynote success was the capture of the Outremer city-state of Edessa in 1144. Inspired by Abbot Bernard of Clairvaux (otherwise famed as a guiding light of the early Cistercians and as a promoter of peace within Christendom, the Jews included), a Franco-German Second Crusade was duly set in train. Its fate was sealed when, during the autumn of 1147, the German contingent was decimated on the steppes of Anatolia.

The Third Crusade was a response to the overwhelming success of Saladin on the battlefield of Hattin in July 1187. Having pinned down 20,000 Christian soldiers on this pair of waterless, sun-smitten Galilean hills, his Muslim troops set fire to the scrub. Virtually the entire Christian army was killed or captured. Come October, Acre, Ascalon, Beirut, Jaffa and Jerusalem were in Muslim hands.[64] Jerusalem was not to be regained until 1917.

Yet this Third Crusade had initially been led by an impressive monarchical triad. It comprised the Holy Roman Emperor, the flamboyant Frederick Barbarossa; the astute and determined Philip Augustus of France; and Richard I of England, little proven as a peacetime ruler but superb as an up-front battle commander. However, Frederick died in a bathing accident. Next, Philip and Richard quarrelled, the former returning home. So Richard was left to face Saladin. Hattin notwithstanding, the latter had had an uneven record as a campaign leader. But he was adept at disarming his opponent psychologically through chivalrous conduct, something towards which he was on the whole disposed.[65] He persuaded Richard to settle for a treaty merely giving Christian pilgrims access to Jerusalem. The initiative thereby passed decisively to Islam.

In 1198, the call to a Fourth Crusade resounded across Europe. Eschewing Anatolia, the Crusaders bargained for transport in Venetian ships initially to Egypt. Unfortunately they thereby became entrained in the grand strategy of Venice, which was to (a) preserve trading links with Egypt, (b) restore its own position in Dalmatia, and (c) seek to establish a more pliant regime in Constantinople. The upshot was that the Crusaders were drawn, more or less by default, to intervene militarily in the Byzantine capital in April 1204.

This ill-thought-through departure descended into several days of boundless looting and burning of what was still the world's most splendid metropolis. The repercussions were disastrous. Though several more Crusades were later staged, the vision had been shattered. Acre, by then the sole Christian stronghold in the Levant, surrendered in 1291.

As one traces the influence of climate fluctuation on these extraordinary events, the most evocative impression is of the parched hostility of the Anatolian landscape in summer, an image consistent with what else we understand of its environmental history – including the slow recovery from the Manzikert campaign. But to turn away from Anatolia as an access route had to be to turn more towards the sea. Utilisation of the Mediterranean itself for peace or war in classical and medieval times is now intensively a subject of underwater archaeology.[66] Again one has to caution against a tendency, in even the most definitive studies, to assume that, because the climate of the eastern Mediterranean basin seems to have been broadly similar in modern times to what it was in Roman, it will have been similar throughout.[67] If the climate analysis herein is correct, blustery northerly winds will have whipped up choppy seas in the winter half of the year, during the Crusader cold period more than now. That will further have inhibited seafaring between November and March inclusive.

Most remarkable is the absence of a sustained Muslim attempt to challenge the Crusaders' sea control, particularly in the sixty-plus years between the Venetian destruction of an Egyptian naval task force in 1123 and Saladin's campaign against Jerusalem. One consideration may have been a paucity of good anchorages on the geologically less folded North African coast; another the domination of the eastern basin even in summertime by northerly winds, the Etesians famed in Antiquity. With early medieval ridging of the Azorean High, these quasi-'trade winds' may then have been still more invasive. They might give squadrons deploying from the north a crucial initial advantage.

Of greater importance, however, will have been the seasonal weather on land. Starvation was the biggest threat the soldiers of the First Crusade faced while laying siege to Antioch, 1097–8. Ships with relief supplies of food arrived as late as mid-November and then as early as February. Crucial, none the less, were the foraging parties across radii of up to 50 miles. Yet for all their endeavours, many Crusaders, knights as well as lower ranks, did die of hunger; and their echelon of horses, having declined from perhaps 4,250 to about 750 during the transit of Anatolia, diminished during the siege to something like 150.[68]

Here as so often later, environmental exposure was aggravated by insufficient preparation and lack of unified control. Maybe it was more specifically, too, by what Marc Bloch depicted as 'the surprising folly, so often repeated in the Middle Ages, of choosing the summer season as the time for taking to these scorching regions.'[69] Looking for advantage in relation to harvest time need not have been so overriding a consideration. All in all, it is not hard to imagine that, had the winter rains been somewhat less liberal than one infers they were, the thirst and famine the Crusaders endured would have been absolutely unbearable. The First Crusade could never then have been dubbed an 'almost miraculous success' by Sir Steven Runciman, at the same time as he was averring that, seen 'in the perspective of history, the whole Crusading movement was a vast fiasco.'[70] Undoubtedly, however, the Crusaders also gained at first from the divisiveness of the local Muslim polities as well as from the wider tensions (made manifest so often, in one guise or another, throughout history) between the Nile and Mesopotamia (see Figure 7.1). Perhaps Islam was initially

Figure 7.1 Krak des Chevaliers, Crusader fortress, Syria
Source: courtesy of AKG Photo, London/Tarek Camoisson

inhibited, too, by what a renowned Mameluke historian not so long after recorded as renewed famine and plague in the Nile valley in 1096–7 and then 1099–1100.[71]

As usual the argument can be pursued beyond the realm of military campaigning. Did the coolish and rainy clime the Crusaders found in the Levant favour better crops? Can the more relaxed mien such a circumstance might induce explain why, at local level in rural and urban Palestine, Christians and Muslim labourers fairly soon grudgingly struck a 'live and let live' accommodation mediated by Christian military might and ruthlessness but still better than ethnic cleansing or forcible conversion?[72] And did this ensure the comparative success, over quite a few decades, of the Outremer?

It would be tempting to respond with a simple affirmative. What has to be admitted, however, is that more work needs to be done on relevant aspects of the historical geography of the Holy Land. A century ago, George Adam Smith produced what still rates as a classic on this subject. But writing from a Free Church of Scotland perspective, he concentrated heavily on Old Testament times in a study structured, in any case, along geographical as opposed to historical lines.[73] Maybe that set a pattern. Evidently, however, palaeoclimatologists in Israel have lately been paying more attention to the medieval world. The mainstream of Israeli historical geography has similarly been extending.[74] A theme particularly worth exploring is the alacrity with which the Outremer Christians exhibited the same penchant as the Muslims for castle building or renovation. That penchant King Herod, too, had evinced in a similar climatic phase (see Chapter 3).[75] Not that the Outremers began to compare with that tortured personality as regards civic construction.[76]

The thorough study by Andrew Watson of early Islamic agriculture has underscored the notion of a very general retreat of its outer territorial limits through the eleventh century. Its onset would usually follow hard upon forceful incursion, a disruptive *démarche* liable to lead to less intensive farming. Otherwise, institutional changes within Islam are reckoned to have had a negative effect. Two regularly mentioned were larger-scale applications of the *waqf* principle of institutional endowments; and the widespread adoption of the *iqta'*, the 'farming out' (often to army officers) of tax collection and other prerogatives.[77] If one is also looking for a climate explanation, finding one that well relates to what has been said above about the Levant and Fertile Crescent may not be easy. But sometimes less rain falls in peripheral locales because more has fallen on less marginal ones. Besides which, some warming from *c.* 1100 may have critically increased evapotranspiration at the margins.

The legacy

The ramifications of the Crusades on the long history of the Near East have been profoundly adverse. For they polarised the eastern Mediterranean as between Muslim and Christian in a manner that can only be described as gratuitous negation. As Runciman put it, 'In the middle of the 11th century, the tranquillity of the east Mediterranean world seemed assured for many years to come. Its two great powers, Fatimid Egypt and Byzantium, were on good terms with each other. Neither was aggressive and both wished to keep in check the Moslem states further to the East.'[78]

Yet instead of more progress towards cultural pluralism, political multilateralism and general détente, one was left with deep and lasting polarisation. To quote perhaps the best-known American political economist of our time:

> No shadow is so long as that of the Crusades. It remained in the memory of Islam that men had come from afar, with religious purpose and sanction but also to take up the land and engage in secular pursuits. The fear persisted that one day they would come back. It was inevitable that any who did return would be viewed with the utmost hostility, and especially so if they claimed anything that seemed remotely like religious sanction. Thus it did not matter too much whether those returning were Christians or Jews. The shadow of the Crusades is still over Israel.[79]

But it was to Byzantium that the most immediate and dreadful damage was done, this to the commercial advantage of Venice but with a grave weakening (cultural and geopolitical) of Europe as a whole. No doubt Byzantium

> was already in a well-advanced state of internal disintegration and fragmentation by 1203/4, but that state need not have had, and indeed did not have, anything to do with economic decline as such – although it has to be admitted that the constant disruption involved can have done little to improve the short-term economic position.[80]

At any rate, that situation does not compare with the dispersion and, in most cases, destruction of a huge mass of literary and artistic treasures. Nor with the decades of governmental chaos ushered in by the sacking of 1204: 'The conquests of the Ottoman were made possible by the Crusaders' crime.'[81]

The origins of the Crusades were governed considerably by climatic flux in the Khazarian steppes, western Europe, Byzantium and the Near East. In particular, the progress of the Seljuks towards the fateful showdown in Anatolia was facilitated by the way pre-existing central authority was weakened by an improving hydrological situation in Persia and a deteriorating one in Mesopotamia. Likewise, the Crusaders' initial progress was also climate-modulated to quite an extent. During the ascendancy of Saladin, on the other hand, the balance of climate advantage was tilting rather towards Islam, even though the Holy Land stayed tolerably moist. Rainfall in Seistan may have drawn close to a secular high. Iraq was apparently spared acute ecological crises from 1180 to 1193 inclusive. No low Nile floods are registered in the Quinn compilation between 1160 and 1199 inclusive.[82] But it would be hard to show that the ugly culmination of 1204 owed anything to climate variation. Rather, its perpetrators had shown an utter disregard for (or, just possibly, sheer ignorance of) the Nilotic crisis from 1200. That September, Egypt experienced (against the background of an El Niño strong enough to cause exceptional flooding in Peru) what probably still stands as the lowest flood peak since regular records began. In 1201 came severe famine. Then and in 1202 peaks were apparently lowish again.

8 How savage a culmination?

HOW CRUEL A SEA?

The most contentious assertion about Europe's weather as the climatic optimum drew nigh has been that the first half of the thirteenth century witnessed extreme storminess around the North Sea basin. If this really is demonstrable, then the economic and social consequences will have to be weighed. But a further question will be whether such weather was but a passing phase or whether it marked a secular transition to cooler, damper and maybe more erratic conditions.

Neither interpretation is persuasive *a priori*. A 'passing phase' does not totally convince in the absence of an identified cause. Yet none of the standard possibilities (e.g. solar cycle, high tides, vulcanism, meteoritic impact) well presents itself to this end. Meanwhile, the idea that early thirteenth-century storminess signalled a sharp transition of a more fundamental and lasting kind is not congruent with the secular profile of temperature change. This suggests the passage to less clement conditions was not that abrupt or that early.

Beaten by storms?

As to whether the early thirteenth century really was that storm-beaten around the North Sea or beyond, C.E.P. Brooks was adamant it was. He did a compilation of coastal storms and floods around Britain and Belgium, a total being presented for each half century. His reckoning for Anglo-Belgian storms and floods rose unsteadily from seven in 1001–50 to peak at 27 in 1201–50, and then, implausibly, fell to 11 in 1301–50. A profile for Europe as a whole rose and fell more smoothly from 21 in 1001–50 to a peak of 28 in 1201–50, then down to 15 by 1401–50.[1]

What Brooks duly did, however, was point out how records 'increase in frequency as they approach the present day . . . simply because the volume of literature becomes greater.'[2] Only since 1970 or thereabouts have medieval writings referring to the weather systematically been subject to evaluation on this and other counts. Before that natural scientists, in particular, were too little aware of inaccuracy and replication in that domain.[3] In regard to ingress by the sea, Hubert Lamb is among those who may have been precipitate. He visualised a North Sea basin visited upon by spells of storminess every several centuries, AD 500 witnessing one putative climax[4] and 1200 to 1250 the next. The latter span he perceived as studded by inundations from the sea as lethal as any lately occasioned by tropical cyclones in the congested delta lands of the Brahmaputra. He wrote of 100,000 estimated drowned in 1099 in a sector embracing the Thames estuary and Holland. As many, he averred, were reckoned to have died in north-west Germany early in 1164 and again in Friesland in 1200.

No fewer than '306,000' were said to have perished in North Holland in 1212, while the 100,000 benchmark was passed again, in Holland and around the Heligoland Bight, in 1218.

About a score more such events (some allegedly causing tens of thousands more deaths) were presented by Lamb for the thirteenth century. The most challenging reports were of storms in 1287 starting with one on New Year's Day: an event decisive, he concluded, in transforming the Zuider Zee (the 'South Sea') from a swampy lagoon into a bay of the North Sea. But quite singular, morphologically speaking, is the assertion endorsed by Lamb that a storm in 1300 reduced the long axis of the island of Heligoland by over half, down to the 25 km it measures today. Heligoland was and is a sandstone plateau standing a good 60 metres above sea level. Not that easy to truncate. Besides, the said assertion jars with one in the same tabulation that 'much of Heligoland' was lost in 1216.[5]

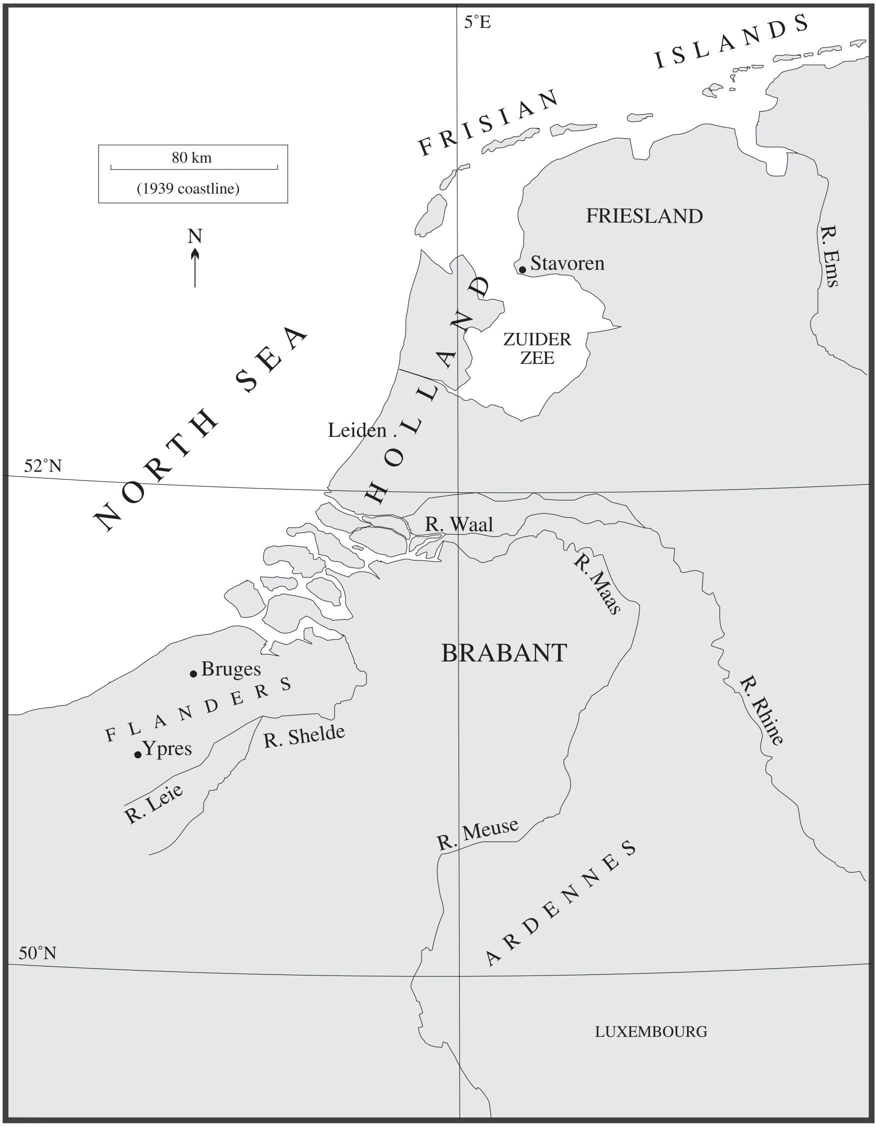
In 1995, Hubert Lamb revised his last major work, a charming and evocative autobiography excepted.[6] It adheres strictly to his 1977 interpretation. As elsewhere, he reproduced as a histogram what originally he had tabulated as the incidence per century of 'severe sea floods' on the North Sea and English Channel coasts. The former he recorded as nil in the tenth century; seven in the eleventh; three in the twelfth; 13 in the thirteenth; and then four in the fourteenth and again in the fifteenth.[7] Yet such events in the Channel he listed as but five across that whole span, a contrast that can hardly be explained in terms of the differential dynamics of the atmosphere.

With Lamb, as with Brooks and Huntington, a lack of provenance too often weakens the historical rendering. Here it does especially as regards death tolls. The land most at risk of inundation will have been that which, screened by embankments, lay below mean sea level to start with. In the Netherlands today about two-fifths of the total area (which is 16,000 square miles) is below MSL. But through the Middle Ages, a good deal less territory will have been in that situation. Nor will all of it ever have been flooded at any one time. Nor was by any means all put to agricultural use. Much was left as peat bog, valued locally as a fuel source plus game and fish reserve. Rarely, it therefore seems, would more than several hundred square miles of enclosed arable or meadow be flooded.

What that could have meant in terms of the flood risk to humans may be indicated by H.E. Hallam's study of population density in the fenland of medieval England. He inferred that, inclusive of the few smallish towns, there were 200 people for every square mile of enclosed farmland in the mid-thirteenth century.[8] It is a conclusion that relates well enough to a demographic analysis of the Brabant fiscal census of 1437. This inferred that a little over 400,000 town and country dwellers resided on the 4,300 square miles of that Netherlands Duchy: a density close to 100 per square mile averaged over a territory which, being mainly well inland, will have been extensively farmed for a long time.[9] So one may assume that, on reclaimed wetland, densities would rarely exceed 200 per square mile. What must be borne in mind, too, is that dwelling places would regularly have been on the higher and firmer ground. All of which strongly suggests that the loss of human life in major flood events could never have reached many tens of thousands.

It is unlikely, too, that major storms will have broken one side of the North Sea but not the other. It is therefore appropriate to test the Lamb sequence against a weather chronology for 'the British islands' published by the UK Meteorological Office in 1937. Compiled by C.E. Britton, its multi-line entries draw on contemporary accounts by individuals or monastic institutions. The first quarter of the thirteenth century is the span of most interest and contention.[10]

There is nothing in Britton to complement at all closely Lamb's reference to disaster in



Map 8.1 The Low Countries

Friesland in the year 1200. All that can be gleaned from the former is a quote (p. 77) from the Annals of Loch Ge in Ireland that speaks of that year as without parallel for cold and food shortage. But both 1205 and 1210 appear in the Britton sequence (pp. 79–81) as experiencing late winters seen by contemporaries as exceptionally prolonged and severe. Light is shed on this by the Briffa series on tree growth during the north Scandinavian summer. Inspection thereof seems to me to reveal 1190 to 1210 to be a distinctly chilly interval, albeit less so than those which Keith Briffa and his colleagues expressly identify in this regard.[11]

The inference that might once again be drawn is that recurrent plunges of sub-polar air will have been determining the North Sea's weather in significant measure. Britton further records (pp. 76–81) much of England as ravaged by high winds in January 1207, and severe flooding (be it riverine or littoral) between then and 1209.

Even so, there is not a word in his compilation to match Lamb's entry about an 'estimated 306,000' fatalities in 1212. Nor is there much to support the latter's citing of 1212–15 as reportedly a time of 'Extraordinarily many very severe North Sea storm floods.'[12] About the only entry even vaguely supportive, in fact, was some near-contemporary rapportage by Matthew Paris and Roger of Wendover (pp. 82–3) of a great Channel storm of 26 September 1215. Of that, Lamb makes no mention.

The assertion by Hubert Lamb that 20,000 died as Bremen was inundated in 1216 may or may not relate to entries in Britton about tempests that May and September. Finally, nothing in Britton lends credence to an averration by Lamb[13] that a further 'estimated 36,000' Frieslanders perished in a storm on 16 January 1219. Conversely, entries in Britton depict the year 1222 as one of summer drought though also recurrent storms. To that depiction, Lamb offers nothing.

Hardly at all does Britton's chronology encourage a belief in death tolls for particular occurrences being reckoned in their hundreds, let alone their tens of thousands. An exception may be the inrush of the sea around Wisbech in the English Fens in November 1236 (p. 70), an episode that is recorded in Lamb.

Another study along very similar lines was that compiled by J.H. Brazell for the Meteorological Office. Published in 1968, it reviews the weather history of London. Granted, it draws to quite an extent on the same sources as Britton. None the less, certain comparisons can usefully be drawn. A freeze-up of the Thames early in 1205 recorded by Britton is confirmed by Brazell as being of the river at London. Likewise, a savagely destructive north-easter gale (not, by the way, noted by Lamb) is confirmed to have occurred on St Luke's Day (i.e. 18 October) in either 1220 or 1221. Then again, the Fens flood of November 1236 had its counterpart in the Thames estuary as the recession of a very high tide was impeded by a strong wind off the sea. Winter thunder was very prevalent in 1193, 1232 and 1233.[14]

Little thus far said warrants our taking at anything like face value the Lamb histogram of storm frequency, to say nothing of the casualties attributed. However, seeing that the Low Countries are the very focus of this debate, it is germane now to weigh in the balance the views of some of the galaxy of historical scholars that this region has brought forth in our time. Henri Pirenne wrote not of population losses but of demographic expansion, its most visible manifestation between 1100 and 1350 being urban growth to a level then unparalleled elsewhere in Europe.[15] But the doyen of Dutch agrarian history, Slicher van Bath, was to cite as apposite a work on the English climate by Josiah Russell. The latter adjudged England to have witnessed three 'serious' floods (by implication, surges of the North Sea) between 1000 and 1150; 16 from 1150 to 1300; and five from 1300 to 1450. He further concluded that the number of years either with 'very rainy periods' or else with 'very dry' ones were respectively 3.6 and 1.7 times greater between 1150 and 1300 than in those equivalent spans of time immediately before and after.[16] That implied an interlude of pronounced erraticism.

However, a tree-ring analysis 15 years later by the British historical climatologist D.J. Schove yielded a more even spread. The sum of those two opposite tendencies, as he registered them, was 10 in the tenth century; 23 in the eleventh; 28 in the twelfth; 25 in the thirteenth; and 19 in the fourteenth. Though maybe of more consequence was the variation discerned, century by century, in the ratio of dry growing seasons over wet ones. Schove rendered this as 2.33 and 1.37 in the tenth and fourteenth centuries, respectively, with a troughing out at 0.65 in the twelfth.[17] The accent on wet seasons through the medial axis might be read as connoting, too, more in the way of stormy summers.

M.K. Elisabeth Gottschalk undertook, between 1971 and 1977, a systematic survey of Netherlands floods (both coastal storm and riverine) grouped in half centuries from AD 800 to 1700. The incidence of storm floods she found to average just one every 50 years between 800 and 1150. Then, in the exposed northern Netherlands, there were nine 'moderate to severe' such occurrences in the second half of the twelfth century or during the early thirteenth; and six during the late thirteenth. Thenceforward the events increased in number and intensity. In the peak century, the sixteenth, there were to be five 'very severe' instances and tens of 'less severe'. Her findings were incorporated into a 1981 quasi-millennial review by C.J.E. Schuurmans of the Royal Netherlands Meteorological Institute, avowedly a disciple of Hubert Lamb.[18] They were also endorsed by W.T. Bell and Astrid Ogilvie as an exemplar of objective rigour.[19] After 1250, they do not correspond at all to the Lamb profile.

Similarly, the more general narrative accounts of the Low Countries' economic and social history regularly refer not to great tempests or cataclysmic death tolls but simply to recurrent inundations. Moreover, their frequency and/or intensity tends to increase throughout the Middle Ages. A British authority on Flanders, David Nicholas, has stressed that intermittent sea flooding between 1014 and 1042 was 'less catastrophic' because less extensive than what the next couple of centuries were to witness.[20] He nowhere suggests that the notion of 'catastrophe' embraced in this context huge loss of human life. Earlier, J.A. Van Houtte, proffering a widely cast Dutch perspective, had intimated that, in general, a rising sea level associated (so he oddly presumed) with increasing rainfall was making the coastal plains progressively more susceptible to transgression by a cruel North Sea. These trends he saw as under way since Roman times and wreaking their maximum havoc in 1287 and then from 1322.[21] Neither author lends credence to the Brooks/Lamb notion of an early thirteenth-century peaking. Nor, of course, does the *primus inter pares,* Pirenne.[22]

However, as from that year of storms, 1287, and averaged over the next several decades, there was more than usual in the way of rough seas. Increased erraticism in that part of the Briffa tree-ring sequence favours such an interpretation.[23] So does the special attention accorded 1287 itself throughout the sources. Thus Britton cited several medieval accounts in respect of the New Year tempest and of another east coast inundation that he dates as on 17 December.[24] Likewise, the relevant volume of the *Cambridge Agrarian History of England and Wales* (edited by H.E. Hallam) looks across the North Sea to 50,000 reportedly drowned three nights before [*sic*] in the 120 km sector between Stavoren and Ems. What does seem confirmed is that the land then affected was left untouched for some years.[25] In marsh manors along the Kent coast, much effort went into the urgent improvement of sea defences in the aftermath of the storms.[26]

Not that an account of this irregular progression would be at all complete without mention of Philip Alexandre's exhaustive compilation of the contemporary narrative sources. Yet scanning (for the period 1200 to 1350) his data on continental western Europe, one encounters no references to Low Countries storms (on the coast or inland) in the thirteenth century and but two in the fourteenth; and this in spite of the said region receiving due coverage in more general terms.

What one does find, on the other hand, is a raft of accounts surviving from the 1280s of storms somewhere between Frisia and Tuscany, more than from all the previous half century. Yet until 1310, the overall volume of surviving archives continued to rise but slowly. In Alexandre's judgement, it is under 10 per cent more for the 1280s than for the 1190s.

Moreover, just one other decade to 1350 (namely, the 1310s) comes at all close to the 1280s in respect of storm records.[27] By then, however, the total archival database has expanded a further 50 per cent.[28] The prominence thus of one particular decade, the 1280s, could herald a new climate regime. Arguably, the notion of so acute a transition is in line with (a) what we know in general of how the atmosphere behaves and (b) modern catastrophe theory.

Sea levels

Next to consider is how far the explanation of any marine transgressions lies in the shifting land–sea balance along and within the shorelines in question. The shifts will have been brought about by alterations in the level of the sea relative to the pre-existing shoreline or else by reclamation or erosion. Regarding relative sea level, a cardinal distinction can be drawn between the northern North Sea basin and the southern. North of a line from Cumbria to Jutland, the Earth's crust has continued to lift up slowly these last two millennia, as a follow-through of the post-glacial 'isostatic' adjustment. South of it, subsidence has been dominant, the rate of crustal descent (averaged over time and place) being a centimetre a decade the last 5,000 years.[29] Around much of the Thames estuary, however, the net submergence since early Roman times has been some five metres. Not that this descent has been constant. From *c.* AD 500 to 1250 there was actually emergence, and then 250 years of very rapid submergence.[30] In the Netherlands, tracking the progression is made that much easier from the early fourteenth century by the survival of fairly accurate coastal maps.[31]

What in this historical context cannot be discounted entirely is eustatic change – alterations in the world sea level due to fluctuations in the global ice mass on land. The ready contraction or expansion of marine pack ice affects the argument only via albedo changes (see Chapter 2). This is because, applying Archimedes' principle, the volume of the water that floating ice displaces is equal to the volume that ice assumes on melting.

The present debate about greenhouse warming affords some guidance on this score. A scenario presented in 1996 by the Intergovernmental Panel on Climate Change depicts the mean air temperature worldwide as having risen 0.75°C over the past century and being expected to rise a further 2.0°C between 1990 and 2100. Yet mean sea level is predicted to rise only 40 cm between these two dates, using middle value parameters for ice melt.[32] Visual graphical inspection of the graphs suggests that, were the mean air temperature rise to be limited to 0.5° over this span, the collateral MSL rise would be unlikely to exceed ten centimetres. The early medieval rise in air temperature was probably rather less than that, averaged worldwide.

On the other hand, in a regime of more gradual but prolonged warming than we currently experience, the mean sea temperature would more closely keep pace with that of surface air. The thermal inertia of sea water and ice would count for less. However, this is not one of the more predictable aspects of extended atmospheric science. The Laboratory of Tree Ring Research at the University of Arizona has produced a long (more than 5,000 years) series of growth rings of bristlecone pines in White Mountains, California, a series likely to be secularly representative of the hemispheric trend in summer warmth. It indicates a warming from *c.* 500 BC and continuing to *c.* AD 275, the mean rise in air temperature being discernible though below 0.25°C.[33] It is a trend paralleled by a global rise in sea level adjudged under way by 600 BC but not to have peaked until *c.* AD 350, a lag due to some thermal inertia. This analysis was conducted at the Instituto di Geofisica, Bologna. Using archaeological evidence from Italy (especially fishponds and wharves), it found that – from 600 BC to AD 100 – the net rise per century was 18 cm.[34] However, a definitive Dutch study has discerned a rise of but 20 cm between AD 1000 and 1500 in mean high water in the Rhine–Meuse delta, and has attributed this largely to 'tectonic' (i.e. isostatic) sinking.[35]

Reclamation

All in all, it does appear that isostasy did not affect the high medieval experience very much and that eustasy did less. Quite the most salient influence on the land–sea balance was human reclamation of low-lying land. To lapse briefly into anthropomorphic metaphor, any marine transgressions were Nature's counter-offensives. Exposure to them will have been made worse by a failure to anticipate the deflation of peat surfaces due to drainage and decomposition. Researching the reclamation of the English Fens in the seventeenth century (a very systematic process undertaken with Dutch assistance), Harold Darby saw no sign of engineers allowing for this factor.[36] Things were probably no better several centuries earlier. Rises in natural sea level or, indeed, in the incidence of high winds onshore, will have aggravated matters (see Figure 8.1). Yet if such adverse tendencies had any tangible effect on policy, it was probably to encourage reclamation rather than constrain it.[37]

Wetland reclamation with systematic embanking began in the Low Countries in the eleventh century:[38] the target zone initially and – to quite an extent – throughout being the peat bogs behind the coastal dunes and marine deposits. Then from 1150, there were significant 'reclamations' along the coast itself – these initially to graze sheep but, as the new lands turned less saline, for arable. An acceleration of this wetland conquest had been in response to population pressure, its strength confirmed by the fact that, by the time reclamation phased out awhile in the late thirteenth century, the extra farmland collaterally gained from heath and forest was 'much more' than that won from bog and tidewater.[39] But the latter had none the less been considerable.

One side-effect was the clogging of waterways with silt. To an extent, this was due to the slack natural drainage, a circumstance inherent in the regional geomorphology. What much increased accumulation, however, was the way the pre-existing ecosystem was savaged. An indication of how the silt volumes grew is afforded by the port of Bruges. This problem was acute there by the late thirteenth century; and by the early sixteenth the maritime trade of Bruges and its outport was virtually to disappear, as hydrological crisis interacted with civic conservatism.[40]

With erosion came surface deflation as peat bog 'cushions' were consolidated through drainage to form a clayey arable. Peat can thrive just above the water table by keeping soggy through capillary attraction. Should the table lower appreciably that balance will break down, leading to decomposition through oxidation. To cause a clay sod ten centimetres thick to form from peat that has been 80 per cent water by volume, it may be enough to draw the table down half a metre. With peat that has been 90 per cent water, a draw down of only a metre may suffice. In other words, the central surface of a bog undergoing reclamation might therefore sink one or two metres. Studies of the medieval Low Countries have tended of late to accent this mechanism rather than presumptively stormier weather when explaining a greater incidence of flooding, not least sea floods.[41] Correspondingly, the loss of human life, even in the worst inundations, is reckoned in thousands, not in scores or hundreds of thousands. The St Elizabeth's Day flood of November 1421 is now judged to have killed 10,000, not the 100,000 talked of in early accounts.[42] A recent study of storm surges in the sixteenth century across approximately 140 square miles of the north Flanders littoral shows only one-eighth inundation even during the huge storm of 1570.[43]

Figure 8.1 Floods in Holland, 1861
Source: courtesy of Mary Evans Picture Library

The revisory approach draws further succour from a Winter Severity Index prepared by the Royal Netherlands Meteorological Institute (KNMI) for a contribution to a EU programme for 'Reconstitution of Past Climates'. This shows the thirteenth century to have been very consistently moderate in this regard. In the course of the fourteenth, there was a secular trend towards more erraticism though less severity overall; and in the fifteenth century both those tendencies were further accentuated.[44]

Hydrological comparisons can usefully be made with the opposite side of the North Sea. Take three parishes on the margins of the English Fens, several miles north-west of Cambridge. Though evidence about the lie of the water table is 'often fragmentary, indirect and inconclusive', there are clear signs of flooding being extensive and prolonged in the early fourteenth century. Abrupt relocations of settlement were necessitated in the Oakington and Cottenham sector, before 1315, by the reversion to lake or marsh of some two square miles of land draining into Oakington Brook. Though its effects were to last for centuries, this event was apparently sudden.[45] It could have been brought about through the upstream impounding of fresh water during a sea storm that reportedly savaged the English east coast in February 1307.

To assess this likelihood, the hydrology must be viewed in the round. As regards precipitation, the first quarter of the calendar year has historically been the driest around the southern North Sea. A survey of the rainfall records at Greenwich from 1815 to 1927 showed that quarter to include the wettest month in only five years. The last quarter was the most rainswept. Thus it included the wettest month in 50 of those years.[46] Yet it is February, averagely the driest month of all, that has customarily been known as 'fill dyke'. The reason is that the water table starts high because of heavy autumnal rains and low winter evaporation. An additional factor in, let us assume, 1307 could have been the deflation through drainage of a spongy bog. This could have given the watery intrusion a quasi-permanence. Even by 1405, it seems, the recession of the waters had only been partial.[47] Reclamation was now less of an economic imperative, especially since the Black Death.

Across the English Fens as a whole, the medieval boom in the construction of banks and ditches, principally to convert marsh to arable, was from 1150 to 1300.[48] Nor were the connotations simply ecological and economic. Four times in the two centuries from the Norman Conquest of 1066, rebels against overweening royal authority had long resisted siege in the Isle of Ely. From then on, however, such defiance could not be sustained because reclamation had deprived Ely of its quasi-insular identity. Reversion to marsh or open water was not very viable as a tactical expedient.

The English evidence is consistent, as far as it goes, with the conclusion that the proliferation of what the Dutch call 'polders' (lands gained from bog or sea) was the dominant factor in any increased exposure to marine storms through much of the thirteenth century. What also is confirmed, however, is the caveat that for several decades through the turn of the fourteenth (1287 to 1330), an increased frequency of severe gales did contribute: this as part of a radical shift in climate reflected in higher average rainfall and general erraticism, most notably as expressed in the 'Dantean anomaly'(see Chapter 9). Collation from the coast of Sussex (on the English Channel, southwards from London) indicates one 'great flood' in 1275 and then another (which virtually destroyed the Cinque Port of Old Winchelsea) in that *annus horribilis*, 1287. Major floods were then recurrent to 1340, after which came a more anticyclonic interlude to 1367. Serious floods were to return late in the fourteenth century and, the more catastrophically, the first three decades of the fifteenth.[49]

Otherwise the high incidence of storm records on the Low Countries littoral as compared with what has emanated from the English and French coasts clinches the conclusion that the underlying cause through 1250 had been anthropogenic, a propensity to reclaim then evinced most strongly by the Netherlanders. A sheer need for extra arable was clearly the primary driving force. But it is not hard to imagine new social forces in the urbanising Low Countries waging something of a *Kulturkampf* against the wetlands lifestyle with its bloody-minded denizens and, far worse, miasmal ecology. For some centuries yet, medical people would aver that disease spread overwhelmingly through contact with noxious humours and putrefactory miasmas in the ambient atmosphere. Marshland figured as a major source thereof, a baleful blemish on the treasured medieval summer.[50]

The land of the gods

The belief that the cause of storm damage simply lay in tempests of abnormal ferocity and frequency may have drawn some encouragement, justifiably or otherwise, from a Japanese national legend dating from late in the thirteenth century. This says that the Shinto gods revered at Ise Shrine on the southern coast of Honshu conjured up the two storms that shattered the Mongol invasion fleets in 1274 and 1281, and thereby, it is averred, changed the course of history. Traditionally the term *kamikaze* ('the wind of God') simply applied to a balmy westerly that often wafts across the beautiful Ise peninsula. In modern times, the term has been extended to those two events and thence, of course, to the Second World War suicide pilots.

First, one must ask how exceptional each storm was. Notwithstanding its profile, there is no good reason to see the first (in November 1274) as anything other than a strong winter gale, presumptively from the north. The storm of 15 August 1281 is another matter. It was a terrific typhoon that reduced much of a combined Mongol fleet veritably to matchwood. As to whether it should be regarded as merely a stochastic weather event or as part of a climate tendency, one can observe that it did occur well ahead of what today would be seen as the height of Japan's typhoon season. The six most severe typhoons between 1945 and 1960 (ranked in terms of human fatalities) all occurred between 15 and 26 September.[51] So it is possible that here, as around the North Sea, 1280 or thereabouts marked the onset of a more stormy interlude. Nor was it just that the second *kamikaze* was the mightier geophysically. It was also of more strategic consequence.

The 1274 invasion fleet had comprised 40,000 seamen and soldiers, many of them impressed Koreans and Chinese. On the 19 November, its troops came ashore in Hakata Bay and engaged the Kyushu *samurai*. The latter fell back but in good order and looking to heavy reinforcement. Under the circumstances, the Mongol force commander decided not to risk his army's staying ashore overnight and had it re-embark. As his ships reached open water, the storm struck. Korean archives tell of 13,000 men being lost during this brief campaign, many through drowning. But that spurred Kublai Khan to seek revenge. In 1275, he established to this end an 'Office for the Chastisement of Japan'. The conquest of south China in 1279 cleared his yardarm for this purpose.[52]

In 1281, the Mongols again made Hakata their focal point of entry. By then, however, virtually all the bay's shoreline had been tightly walled in. Starting the last ten days in June, an eastern fleet that had sailed from Korea with over 40,000 men (mostly Korean) tried to establish a viable beach-head but were frustrated by the topography, the wall, Japan's resolute infantry, and its enterprising light naval forces. After six weeks, the invaders pulled back to the offshore island of Takashima. On 12 August they were joined in Japanese waters by a southern route army from China that may have comprised as many as 100,000 soldiers and 60,000 sailors.[53] But before the two fleets with their 4,000 ships could together launch a fresh offensive against Hakata Bay, the *kamikaze* supervened. Many vessels were caught in open water near the entrance to Imari Bay. More than half of those that had embarked were lost.

The key to a geophysical explanation of this exceptionally early and ferocious typhoon likely lies in sea temperatures across the north-west Pacific. As the current debate about global warming has proceeded, something of a consensus seems to have emerged to the effect that a sea-surface temperature of 27°C constitutes a threshold above which one is much more liable to see the generation of tropical revolving storms – the features long known in the Chinese seas as 'typhoons' (partly from *tai fung*, 'great wind').

Through the mid-twentieth century, typhoons curving northwards towards Japan have originated very predominantly in the near oblong of ocean bounded by the parallels of 5° and 20°N and the meridians of 118° and 160°E. Moreover, virtually all that sea area had average August surface temperatures between 28 and 29°C. Even around the coast of Kyushu, indeed, those temperatures were in the 27–28° range.[54] The inference can be that seas even slightly warmer, if such they were, in that month in high medieval times could well have encouraged the emergence of more and stronger typhoons and their survival with vigour as far as Kyushu. A secular rise in sea temperature could have been a general consequence of the 'little climatic optimum'. Quite possibly, too, the weak El Niños apparently characteristic of the last half of the thirteenth century will have favoured warmer surface waters across the area of typhoon genesis here identified.

At all events, the *kamikaze* typhoon did not settle matters entirely. Kublai Khan continued to exercise himself about the subjugation of Japan until his death in 1294 but was never again free enough from internal problems to act. As for the Japanese, they remained on contingent alert the next 20 years. Although the country was then gaining economically from a progression to more intensive agriculture, the strain was considerable. It is considered to have contributed to the waning of the Kamakura shogunate (1192–1333).[55] But more conclusively than anybody else, the Japanese had shattered the Mongols' myth of invincibility. An unwitting Europe was among the beneficiaries.

THE MONGOL HORDE

The expansion of the Mongols out of inner Eurasia (1211–81) surely ranks as the most awesome episode in the whole of military history, the nuclear death blows to Imperial Japan not excepted. Yet no such expansion might ever have taken place but for the birth *c.* 1167 of Temujin, he who in 1205 assumed the title Genghis Khan in order to promote himself as the new-found leader of 'all who dwell in tents of felt' – i.e. the fractious tribesmen of the Gobi region. But to recognise the towering importance of this individual is not to exclude climate change as a major ambient influence.

In 1211, Genghis Khan launched an offensive against the Song Empire in China, capturing a well-fortified Peking (now Beijing) in 1215. Next, campaigns in south-west Asia led to the fall of various cities, among them Bokhara in 1219 and Merv in 1221. According to the medieval chroniclers, 700,000 were massacred on the latter occasion, another wild exaggeration but all the more expressive for that of the paralysing fear the Mongols so widely induced. Two years later, a Slav coalition force of 80,000 under the Prince of Kiev was defeated.

Operations against China resumed in 1226, and were to be little interrupted by the death of Genghis the following year. North China finally fell in 1235 but the surviving Song realm in south China was to not follow suit until 1279. What is not at all easy is divining how far this eventual consummation may have been ordained by shifts in relative climatic advantage. One might have assumed that the northern Song and its Mongol legatees would in turn have been the worse afflicted by an aridity trend (see p. 69). Yet the opposite seems to have been the case. A 1926 compilation down to provincial level by Dr Co-Ching Chu, sometime president of the National Southeastern University in Nanking, shows recorded drought rising more markedly in the southern Song area, 1127–1279, in spite of the availability of drought-resistant Champa rice.[56]

Nor has this been contradicted by the indirect indicators. In the twelfth century, the Song dynasty had been able to build new fortifications well north of the Great Wall. In the thirteenth there seems to have been little or no renovation or reconstruction in that sphere,[57] following the Mongol accession. Meanwhile, south China is said to have been decidedly famine-prone by the end of the thirteenth.[58] Granted, that will have been in the aftermath of the progressive encroachment by Kublai Khan on that fragile hydraulic civilisation. Yet his takeover may not have involved great dislocation. No large-scale epidemics are recorded for anywhere in China between 1276 and 1307.[59]

A priori, one may presume that China would have shared the European experience of increased climate erraticism from *c.* 1275. But only apropos the old cultural and political heartland of north-east China may the surviving archival coverage be even enough over time to allow of tolerably definitive comparisons. Take then the records of droughts plus floods from the provinces identified by Co-Ching Chu as Chihli, Shantung, Shansi and Henan. Using his century-by-century tabulation one finds a rise from the quite high level of 71 in the thirteenth to 108 in the fourteenth, and then recession to 36 in the fifteenth.[60] This is compatible with the notion of heightened erraticism from 1275 through 1350.

The Mongol struggle to subdue China was long drawn out, initial success notwithstanding. In its aftermath, Kublai Khan, the able grandson of Genghis, apparently heeded a simple piece of advice from Ch'u-ts'ai, a Chinese adviser to his regime. This was that 'The Empire was won on horseback but it won't be governed on horseback.' Though asserting a notional suzerainty throughout the new-found Mongol domain, Kublai made himself more particularly the first Emperor (1260–94) of the Yuan dynasty in China-cum-Mongolia. His endeavours to foster Chinese art and literature evoked some response. A fine tradition of mature painting was upheld. Vernacular drama and fiction enjoyed a pristine boom. Kublai renovated the pre-existing imperial infrastructure (roads, canals, granaries . . .). He transformed Khanbalik (the name he gave Beijing) into a truly imperial capital. He fostered foreign trade and diplomacy. In short, he turned diametrically away from the 'man on horseback' mode.

Arguably, his so endeavouring was the most profound of all the Mongol adaptations. It was certainly singular in Mongol terms. From 1236, the genocidal devastation that had usually marked their advent had been visited upon Russia and elsewhere in Christendom. Among the Russian towns and cities sacked during the winter of 1237–8 by Sabutai, the evil genius in overall command of the Mongol forces, were Riazan, Moscow and Vladimir. A resumption of offensive action in 1240 culminated in a merciless sacking of Kiev and left the Mongols poised to cross the Vistula. Early April 1241 saw them win one signal victory in Silesia and another in Hungary.

Received historical wisdom has it that the death that December of Ogedai Khan (the son of, and successor to, Genghis) diverted the Mongols from a Catholic Europe distracted by a savage Pope-versus-Empire conflict and therefore all the more exposed to Mongol conquest. But cause and effect may have been less simple. A very innovative research paper by Andrea Kiss of the Central European University in Budapest draws on a wide range of contemporary Hungarian and Dalmatian sources to demonstrate that, while the winter of 1241–2 may not have been very anomalous across Catholic Europe as a whole, the entire month of January 1242 was extraordinarily cold in Hungary – enough to freeze the Danube solid in a week or two under normal circumstances. At that time the Mongols were poised to move west in force across the river and will have seen the prospect of its freezing really solid as a major bonus. However, this outcome was delayed a good fortnight by the Hungarians repeatedly breaking the ice. Instead of a solid passage the Mongols faced the worst of alternatives, cascades of ice floes. A firm freeze-over came only towards the end of the month. Just a few days later, a thaw began.[61]

Given the efficiency of the Mongol pony express, the army in Danubia will have heard of the demise of Ogedai within a fortnight. That it persevered at first with its strategic aim shows its leaders did not see the succession as calling for immediate resolution any more than Ogedai's accession had. With more of January to play with, they might have projected a large force into north-east Italy, an area pivotal to the Pope-versus-Empire contest and maybe only a week away in terms of the mobility of a Mongol host. Finally, in the spring of 1242, the Mongol troops turned homewards, leaving terrible famine behind them. The Hungarian ice-breakers may well have saved Catholic Europe from violent disintegration. Maybe Venice was saved from destruction.

The course events took in the Near East was curiously similar. A major campaign launched in 1253 effectively wiped out the Persian wing of the Assassins, a heretic fraternity of Ismaili Muslims who for two centuries had terrorised the Islamic mainstream from their base area, the Elburz Mountains. True, the sect remained entrenched in Syria. None the less, the crushing of its Persian wing was applauded in Abbasid Baghdad. Then in 1260 that city (still, to outward appearances, the most resplendent in all Islam) was comprehensively sacked by the Mongols. After which, they turned their predatory attention to Egypt. But in 1259 the fourth Khan, Möngke, had died. So faced with a looming struggle for the succession, many of the Mongol troops turned nearer home. Those remaining were to be defeated by a much larger Mameluke army at Ain Jalut near Nazareth in September 1260. From that time, too, transcontinental Mongol unity began to weaken.

Not that Ain Jalut ended Mongol expansion. As noted above, Kublai Khan never gave up on conquering Japan. Furthermore, he sought (from 1277) to utilise his position as the Song legatee to gain at least the nominal allegiance of the several 'temple states' of south-east Asia. In 1293 an expedition to Java seized its capital though was soon obliged to withdraw. A Mongol regime was established in Sumatra, briefly. Between 1294 and 1297, the kings of Siam, Cambodia and Burma formally acknowledged Mongol suzerainty.

No doubt Kublai hoped that advances in east Asia (and, above all, a conquest of Japan) might galvanise anew the Mongol sense of unity, under Khanbalik leadership. But that prospect was receding. On any definition of 'natural limits' consistent with the means of internal control available to them, the Mongols' domain was already overextended, even allowing that rainfall moderation associated with an accentuation of the Rossby standing wave enveloping the Himalayan/Tibetan highlands had perhaps made south-east Asia more accessible to them. Besides which, many orgies of blood-letting had by then assuaged to an extent the bitter envy evinced towards settled (and especially urbanised) societies by Mongolian tribesmen (see Chapter 10).

Near boundless skies

The mainspring of envy had, of course, been their having been condemned to a tented existence in the Gobi: a flattish windswept area of poor steppe and near desert mainly lying 800 to 1,000 metres above sea level with mean monthly temperatures ranging from perhaps 20°C in July to –16°C in January. S.R. Turnbull has written of this wild land as subject to winter 'nine months of the year'.[62] If by 'winter' is meant a time when frost recurs more or less every 24-hour day, he is at one with the 1963 magisterial review of east Asian historical geography by Albert Kolb, then Professor of Geography at Hamburg. This has the isopleth of but 100 frost-free days a year effectively bisect Mongolia.[63] The ferocious low-level dust storms are another major dimension.

What might further be argued, however, is that this flat and very bare landscape, boundless beneath some of the least cloud-laden skies in the world, will have been conducive to a cardinal theme then emergent in such organised religious thought as the Mongols were given to. This theme was that 'Eternal Heaven' gave its blessing very clearly, albeit impersonally, to the notion of universal kingship. It will have helped young Temujin draw the warring tribes about him to form a confraternity solid enough for external adventurism; then, as Genghis Khan, to set in motion processes whereby his followers accommodated as conquerors religions as deep-rooted and elaborated as Christianity, Islam, Zoroastrianism and Buddhism, always so long as those concerned dutifully applied their scholarly and technical skills to the support of Mongol suzerainty.[64] The problem with somewhere like Baghdad was that, as the seat of a caliphate, it was an alternative political focus.

In a drawing together of the tribes lay the key to military proficiency. The British prophet of modern mechanised warfare, Basil Liddell Hart, wrote that a Mongol army was 'a machine which worked like clockwork, and this very mobility made it irresistible to troops far more strongly armed and numerous.' As always, he may have been too disposed to isolate 'mobility' as an attribute. As he himself well observed, after all, the Mongols were also amply provided with firepower, principally in the form of equestrian archery. But, more fundamentally, he did stress how much their strategic and tactical dexterity depended on a sense of oneness.[65]

As to how far the outcome of the early campaigns was influenced by the climates of the lands then under attack, too much has perhaps been made of a special Mongolian hardiness that enabled men and horses to thrive in the most inclement weather. Take one facet oft remarked: the extensive use of Russia's frozen rivers as axes of deep penetration during the winter campaign of 1237–8. First of all, none of the Russian chronicles quoted in I.E. Buchinskiy's descriptive chronology of the climate of the Russian plain during the Middle Ages records that particular season as notably severe. Second, wintertime was the season customarily preferred for long-distance travel by the Russians themselves. In 1436–51 Barbaro, a Venetian diplomat and traveller, wrote of a Muscovite predilection for sledge travel along the smooth frozen roads. In the summer, 'few would dare to make a long journey because of the deep mud and the swarms of midges which are raised in the great forests.'[66]

Climate modulation

However, the main burden of our interest is not the influence of climate viewed as a stable phenomenon. It is instead the variation of the key parameters across decades and centuries. Drawing heavily on his own fieldwork, Ellsworth Huntington inferred that, at any rate across a broad swathe of central Asian territory extending from Seistan through Sinkiang, the tendency through the Middle Ages was towards lower temperatures and more abundant rainfall.[67] But Hubert Lamb was to proffer an interpretation at once more tentative and more intricate. He presumed the underlying reality to be a build-up of population in central Asia in 'times when the pastures were in better than usual shape'. None the less, he was inclined to explain the suddenness of the Mongol outburst in terms of its being triggered by unwelcome plunges of polar air due to secular cooling in high latitudes.[68]

As the debate about just what was happening to the regional climate in this case has ramified, it has sometimes come too close to an inverse determinism, claiming we know how the climate was trending because we have observed the human response. What ultimately invalidates such a claim is continuing uncertainty about what may, in any case, be slender and contingent linkages between cause and effect. G.F. Hudson, an Oxford historian of the Far East, argued that worsening aridity could actually have favoured the Mongolian nomads as against those around them struggling to grow crops. This is because the zone of quality grassland the latter partly cultivated would give way before the decidedly marginal grazing acceptable to the former.

The simple model he presented was of three concentric zones progressively extending outwards. The outermost is forest, presumably the coniferous *taiga* of Siberia, the southern limits of which quite closely encompass the northern edge of the Gobi.[69] A key consideration is that a well-established forest will resist, maybe indefinitely, displacement through changes in the climatic ambience. In consequence, the intermediate zone of quality grassland will be tightly squeezed. All will therefore hinge on whether the agriculturists could readily create new forest clearings. Were the answer affirmative, they might retain the upper hand. One reason for anticipating the opposite outcome has to be that *taiga* soils are liable to be too acidic for cereal grasses to flourish.[70]

Contrariwise, Nikolaj Gumilëv rejected any idea that the initial expansion under Genghis Khan was essentially a drought-induced 'natural migration' of a people. To him it was a military adventure initially underwritten by 'an abundance of livestock and people'. The level of the Caspian Sea had generally been low for centuries past. But from 1300, said Gumilëv, it rose markedly.[71] Lamb was more disposed to see it rising, on balance, through the thirteenth.[72] Huntington had been vague on this score but did proffer the useful opinion that any shifts in the course of the River Oxus will have affected the Caspian no more than marginally.[73]

According to the Gumilëv thesis alluded to earlier, a higher shoreline would have connoted drier conditions around the Caspian itself and wetter ones in the upper Volga basin. In the study here cited, he extended the former zone from the Caspian littoral to the Tien Shan mountains and by implication the Gobi. Yet it is surely wrong *ipso facto* to extrapolate as far as that, not least because the longitude of the Tien Shan (80°E) is something of a climate divide. Likewise, it does seem that Gareth Jenkins erred in seeking neat correlations between (a) climate trends as far afield as Switzerland and Alaska, and (b) turning points therein and the onset of the Mongol expansion. The said tendencies do not match well the Genghis Khan era. Nor do they one another. Thus Greenland was colder from 1180 to 1210 whereas northern Scandinavia enjoyed relative warmth from 1160 to 1190. Here again, longitudinal separation was dynamically important.

The nub of the argument about climate and the Mongol take-off has to be when change occurred around the Gobi and in what directions. A good proxy may be temperature trends in north China. In fact, Jenkins did perceive a north China minimum in the early thirteenth century that would be quite the lowest in the last five millennia, three degrees below a peak in *c*. AD 800 and nearly 2.5°C below the present-day mean.[74] It has been suggested, partly in the light of British upland experience, that a reduction in mean annual air temperature in Mongolia of two degrees centigrade might cause a decrease of no less than 40 days in the grass-growing season.[75] Given a mean monthly temperature range (July to January) as wide as 45° in the central Gobi, 20 days may have been nearer the truth.

The notion that the early thirteenth century did turn colder across much of central and northern China, and also its continental borderlands, is lent credence by other contributions. Three analysts arrive at such a conclusion with specific reference to the Tibetan plateau. A fourth source does, too, for Liaoning province between Inner Mongolia and the Yellow Sea.[76,77] A fifth does for east Henan, a provincial area between the Yangtze and the Hwang-Ho on the western margin of their combined flood plain.

This last analysis discerns as well a tendency to more floods and droughts.[78] A further study, again by Jin-Qi Fang, of lacustrine tendencies across China shows a sharp secular reversion after 1250 from droughtiness to moistness.[79] This corroborates earlier studies well enough. One by Justin Schove showed 'raininess' passing through a minimum in north China in the thirteenth century.[80] The study conducted in the National Southeastern University in the 1920s had calculated the drought-to-flood ratio for all China to have been 1.04 in the twelfth century, 1.80 in the thirteenth, and 1.06 in the fourteenth. The accuracy suggested by that rendering will be falsely high but its general import can still be valid.[81] Furthermore, it is consistent with more intrusion by dry northerly air. Clinching the argument, a decadal ice core analysis from the Nan Shan locale (38°N, 96°E) shows colder than average conditions continually from 1150 to 1300.[82]

In this instance, it seems licit to relate what must therefore have been a greater prevalence of cool, dry winds from a northerly quarter to an accentuation of the Rossby standing wave that envelops the Himalayan–Tibetan topography – this within the context of a Eurasian tendency towards warming. Another possible causal linkage is with the atmospheric 'cold wave' that, it has been surmised (see Chapter 5), migrated from Japan to western Europe between the twelfth and seventeenth centuries. Assuming steady progress, it would cross Mongolia through the thirteenth. To which one might add that a short but felicitous study draws together the principles of animal ecology and what we may divine of the Gobi situation then. It concludes that the catalyst for confederal togetherness and then territorial expansion may well have been a sudden deterioration in the weather regionally after a run of good years during which a highly reactive nomadic population reached the climax of a long phase of demographic increase.[83] This deterioration must basically have been a shift in the prevailing wind towards a more northerly vector. The Malthusian inference drawn is obliquely supported by an endeavour (somewhat sanguine, no doubt) to track the percentage change in the population of Asia century by century: plus 10 in the ninth century and again in the tenth; 25 in the eleventh; about 8 in the twelfth; and then minus 8 in the thirteenth.[84]

The ensemble thus created appears pretty much in harmony with what Lamb proposed. For reasons probably connected with the Rossby standing wave passing through an amplitude peak, in the first half of the thirteenth century Mongolia was in a decadal phase of droughtiness and coolness between two eras of relative warmth and moisture. The preceding spell will have favoured the region's sharing in the population growth then very prevalent across Eurasia. And on the desertic fringes, in particular, this will have been of horses as well as people. Then the cold and aridity will have induced a Malthusian crisis that could be addressed militarily by dint of the extra manpower and horsepower. Eventually renewed warmth and precipitation will have helped sustain this response. The weather throughout may have been less windy in late winter than modern travellers have reported, the Siberian High being weakish.

All the same, a number of strands remain to be untangled. One is how far the Mongolian ecology may have been compromised directly by human action, not least as regards the water cycle. Owen Lattimore drew a formal distinction between (a) a 'neo-classical' view that the successive waves of nomadic migration were caused by exogenous changes in ecology and especially climate, and (b) a 'semi-classical' view that overcultivation or even a switch from hunting to grazing can itself bring about desertification and, indeed, associated climate change. But having done so, Lattimore went on to stress how interactive in practice the relationship between these two kinds of causation was. This interaction was modulated by, but also encouraged, a great diversity in cultural evolution, even as between the nomadic tribes of inner Asia. He cited variations in tent design as expressive of this, the wooden-framed Mongolian *ger* probably being derivative from an ancestral forest habitat.[85] May one remark that one's own perception had been very similar overall when, 30-plus years ago, one encountered great variegation in domestic architecture as between different traditional villages in the southern approaches to the Sahel, this on a parkland landscape that outwardly appeared serenely uniform.

Otherwise a basic difficulty is that indications as to what the hydrological situation will have been in the Mongolia into which Temujin was born are, thus far for sure, slender and indirect. Writing in 1225, the Arab geographer Yacut recorded that, four years earlier, Mongol forces besieging the city of Urgenj (the ancient Khiva) had deliberately diverted the Oxus from the Aral Sea to the Caspian,[86] a further commentary on how finely the regional hydrology was balanced as well as on the ruthless aplomb of the Mongols. From China come further indications that are indirect but perhaps instructive. Joseph Needham cited the Shantung-based Confucian philosopher Mencius (*c.* 371–*c.* 288 BC) as deploring the destruction of forests, no doubt as part of the sage's wider concern with anarchic disorder. Mencius warned, more specifically, that too intensive browsing by cattle and goats precluded regeneration. But Needham discerned no general recognition until the sixteenth century of the danger overgrazing posed.[87] Take, too, the Ordos plateau, a feature covered with gravel, sand or loess that effects a wide deviation of the upper Hwang Ho and which has been subject to progressive desertification the last 2,000 years. It does seem that human malpractice has been considerably to blame.[88] It would be optimistic to assume that the nomads of Inner Mongolia treated their ecological resource base any better, particularly against a background of climate deterioration.

Consonant with that view are the legends coming down to us about the turbulent milieu of Temujin's childhood and youth towards the end of the twelfth century. Allegedly, his own father was poisoned by rivals. As regards Mongol history at that level and during that time, however, evidential material is flimsy. Only two written sources might be seen as at all primary. The one is a chapter in an encyclopedia by Rashid-ad-Din, a prime minister in the Ilkanate in Persia who died in 1318. More prominent is the other, a *Secret History of the Mongols* written in China early in the Ming dynasty (1368–1644). But the late Arthur Waley, the distinguished British orientalist who translated much of a Chinese abridgement, adjudged it all but useless.[89]

The Mongol impact

If one is persuaded, none the less, that a climate reversion hard upon prolonged improvement helped set Mongol adventurism in motion, then the transcontinental orgy of blood-letting that ensued *ipso facto* owed something to this onset of dryish cold. Across much of Eurasia, the long-term consequences were great. Yet initially the Genghis Khan regime was not so unique a phenomenon, compared with previous 'tents of felt' dominions.[90] Take the Liao Empire of the Khitan people that held sway (947–1125) over Mongolia, Manchuria and north-east China. In this case, too, the regime was underpinned militarily by 'fire and movement' based on tactical formations that were multiples of ten, as well as on the iron stirrup, light body armour, ferocious archery, and several mounts per trooper.[91] The need for remounts has been related to the tendency for horses range-bred on the Gobi fringes to be hardy but small.[92]

East Asia had long witnessed alternation between northern barbarian nomads and the Han Chinese. When the former were strong, the *yang* of Chinese expansion would give way to the *yin* of 'barbarian' invasion'. All or part of the Chinese Empire might come under the sway of the barbarians but always they would then adopt imperial institutions. The Hsiung-nu were considered in Chapter 2. A later example was the northern Wei, a Turkic dynasty that held sway in north China from 439 to 535. A key to rainfall fluctuation as a determinant is this. In the twentieth century, the gradient in mean annual rainfall between, say, 400 and 100 mm is a good deal steeper in south-east Mongolia than in the lower Volga to Aral region, to make the comparison that most readily invites itself. That contrast is likely to have obtained historically. It was bound to make that borderland region all the more susceptible to even a small shift in the rainfall pattern.

Still, the domain it is natural to take first of all, Japan, is one the Mongols interacted with little except in the realm of amphibious warfare. But the subsequent burden of continual preparation against renewed Mongol aggression was borne by a Kamakura shogunate already enfeebled by declining motivation, a decline that celebration of the *kamikaze* triumphs was unable to arrest. In 1333, the Kamakura military finally fell, and by 1338 had been replaced by the Ashikaga shogunate based on the old capital of Kyoto. Not that this could truly revivify the concept of *bakafu*, 'government from the tents' – i.e., in effect, from the military cantonments. Though the Ashikaga staggered on to 1573, it never did get a grip on internal strife.

The geopolitical situation the Mongols faced in China had been cast a century before. By 1125, the Liao Empire had been shattered by Chin (alias Jurchen) tribal rebels from the Manchurian grasslands, acting in cahoots with a Song dynasty based on Kaifeng and holding sway from the Great Wall to Hainan. A year later, however, the Chin had destroyed the northern Song. But they could not then prevail among the rivers and canals of the central flood plain. So a Southern Song Empire had consolidated around Hangchow. Through most of the thirteenth century, something approaching two-thirds of China's population of maybe 110 million lived under the Southern Song,[93] underpinned by Champa rice cultivation. They progressed in virtually every aspect of life: literacy, the imperial bureaucracy, the art of war, internal and external commerce, visual art, philosophy. . . . They did eventually succumb to the Mongols, as discussed above. In the interim, Hangchow paid the latter tribute most years but was never a mere puppet regime.

After he had finally overcome the Southern Song in 1279, Kublai Khan established the Yuan dynasty in Beijing (Khanbalik). Despite distortion by Marco Polo (see p. 222), a pattern emerges which, while not inchoate, is studded with ambiguities. Though in the ultimate, Yuan rule was that of a Mongol warrior clique, it was concerned to acquire a kind of legitimacy. Much was preserved of the old political culture as well as culture in the wider sense. The naval power deployed as far afield as Japan and Java was a legacy from the

Southern Song. Confucianism got strong official backing. So, too, did Lamaist Buddhism and Taoism. Certain alien religions were indulged as well.

The evolving ethos is not easy to elucidate, but the signs from China are that not just demographic growth but economic development in general slowed down during the thirteenth century. So did the imperial authorities come to see a market economy as too much of a good thing – e.g. widening the rich versus poor gap? Or was slowdown more a result of an ecological deterioration, more especially in the south? How far did the ensuing years of warfare accentuate its effects?

In central Asia, the longer-term results of Mongol depredations were uneven. Though Samarkand had been sacked by Genghis, it was made the capital of a far-flung Turkic–Mongol empire by Tamerlane (*c.* 1336–1405). Reputedly, it then reached its zenith as grand mosques were built and splendid gardens laid out. Conversely, Merv, another ancient seat of learning and government, did not recover from its spoilation for centuries, its halting progress being set back yet again by a sacking by its rivals in Bukhara in 1790. During the Russo-Turkish war of 1877/8, the British waxed apprehensive about how close the Kremlin was getting to annexing Merv, an event that finally occurred in 1884. In Calcutta, the fear then was that this would precurse an advance down the Khyber Pass as per Tamerlane and others. But as the then Foreign Secretary, Lord Robert Salisbury quipped, 'Mervousness does not stand the test of large-scale maps.' In other words, a close reconnoitre would readily reveal the region still to be weak infrastructurally.

The Mongol legacy could have been a reason, even across that span of time. For exaggerated though chronicle accounts may have been, there is no doubt the medieval state of Khorezm (extending from Samarkand to the Caspian astride the old Silk Road) had suffered terribly at the hands of Genghis because (a) dependence on irrigation made it susceptible, (b) it was the first urbanised and Islamic state the Mongols encountered and (c) their emissaries had been executed by its Shah. So one might say that, notwithstanding Tamerlane and Samarkand, the Khorezm region was left in no fit state to benefit, in terms of economic 'take-off', from higher precipitation as the Little Ice Age drew closer.

The evidence from the nearby Caucasus does indicate glacial advances from the thirteenth century to the nineteenth that were recurrent enough to point to conditions turning wetter over time as well as cooler; and, this last century at least, precipitation trends in the Caucasus seem to have matched quite closely those in the Pamirs, a watershed critical for Khorezm.[94] Then, to apply again the Gumilëv thesis about Caspian sea levels, one finds that the axis of highish rainfall lay once again across north-west Russia *c.* 1740 to 1820 – i.e. after the nadir of the Little Ice Age.[95]

Had the Islamic polity of Khorezm, set at what can be deemed the fulcral point of Asia, been left alone, poised to develop its full cultural potential against a background of climatic improvement, the history of the modern world could have been very different. Quite possibly, it would have been sweeter.

The impact of the Mongols on Kievan Russia likewise went deep. It is best gauged against the background of the century or two prior to their advent. In the 960s, the Kievan regime had delivered the *coup de grâce* to Khazaria. Then, under the ruthless but shrewd Yaroslav the Wise (reigned 1019–54), the former was to reach its zenith. None the less, Yaroslav made Novgorod (by then a city of perhaps 15,000) his capital. Accordingly, the centre of gravity shifted north or north-eastwards except that much power and influence slid into the localised hands of fractious though interrelated princes. In 1169, Kiev was pillaged by an army from Suzdal.

The gravitational shift found expression in the distribution of a large number of newly identified townships.[96] So did it in the clearance for arable of much mixed woodland or even coniferous forest, this often in conjunction with the adoption of feudal bonding. The shallow and acidic soils would never match the deep black earths of the Ukraine for cereal growing. But there was much scope for gathering, hunting and fishing.

A suggestion has been that the switch to Novgorod owed something to a desire on the part of the Varangians of Kiev to consolidate their ties with Scandinavia.[97] What surely counted for more, however, was a wish to avoid nomadic pressures. Meanwhile, the positive side of such climate change in the more wooded zone will have been (a) some general and genial warming, and (b) a northward withdrawal of the southern limits of an area of surplus annual moisture that otherwise will have extended well south of Moscow.[98] This will have allowed of less reliance on slash-and-burn agriculture, except perhaps for root crops, in what then may slowly have become a rather less acidic zone of transition to the northern forest.

Unfortunately, the chronicles do not bring us very close to a definitive assessment of Russian ecological trends in the High Middle Ages. One aspect of the flimsiness of this database is the fact that no original manuscripts earlier than the fourteenth century have yet been found.[99] But considered altogether, the texts do show how prone the several million Russians still were to famine, be it caused by (a) searing drought (with forest and urban fires as widespread concomitants) or (b) flooding as heavy rain and snow interacted with weak natural drainage. Nevertheless, the historians seem satisfied that the Russia of the early thirteenth century had been poised to make progress. Then, in some basic respects, the Mongol incursions put it back a century. Metallurgy was a case in point, a specific reason being the Mongol practice of impressing into their own service wholesale other peoples' craftsmen and technicians. As regards total population, the decline 'can hardly have been less than ten per cent' from 1237 to 1240.[100]

Yet by 1400 the population of east Russia is estimated to have reached 10 million, a third more than two centuries earlier. This growth was related to an accelerated exodus northwards, in the thirteenth century, by people anxious to be less exposed to pillage. It seems unlikely this acceleration drew added encouragement from climate change. Famines, sometimes leading to cannibalism, occur too often in those higher latitudes. What the Russian chronicles especially record from 1225 to 1300, so far as the weather is concerned, is a high incidence of disastrous floods.[101] This is worthy of remark in itself. A recent survey at the Russian Academy of Science for the north and central Russian plain finds drought to receive more archival mention than all other weather extremes put together across the wider span, 970 to 1380.[102] It bears out earlier work. An interpretation is proffered in the next chapter.

Across Russia as elsewhere, the influence of the Mongol/Tartars worked, in due course, in favour of long-distance trade. But as regards political culture, it was not a question of progress being aided or retarded; it was instead of the Mongols effecting a drastic alteration of course. George Vernadsky, writing as Professor of Russian History at Yale, stressed the emergence, by the sixteenth century, of the Tsardom of Moscow as a nodal polity that embraced 'an entirely new concept of society and its relation to the state. All classes of the nation . . . except the slaves were bound to the service of the state.'[103] Comparison was drawn with what had been the much freer polity of Kiev.

In according the Mongols a significance not just in arresting Russian development (an effect most historians had been paying heed to[104]) but in altering so morbidly its very character, Vernadsky was following in the steps of that celebrated Russophobe, Karl Marx: 'in the terrible and abject school of Mongolian slavery . . . Muscovy was nursed and grew up. It gathered strength only by becoming a virtuoso in the craft of serfdom.' This famous passage of his was cited with particular approval by Tibor Szamuely, the Hungarian dissident and one-time inmate of Stalin's *gulags* who later worked in exile as a political philosopher at the University of Reading.[105] The very fact that Mongol suzerainty over Russia could only be indirect made it the more enduring and its legacy more profound.[106] That judgement inverts the usual interpretation of how climate and landscape constraints affect historical development.

Also avid in pursuit of this theme was Karl Wittfogel, at one time a doyen of the Frankfurt School of Left-radical Marxist revisionists. He focused explicitly on the 'Tartars': a term too often loosely used but properly referring to nomads who, in the wake of Genghis, took over much of the southern steppeland here alluded to. Their political culture was Mongol but their language and religion Turkish. Wittfogel saw Moscow as ascendant in reaction against them yet also in emulation of the despotic centralism they themselves felt they had learned, in the first instance, from China.[107] Clearly, Moscow itself was well placed to assume this morbid primacy given its interposition between the headwaters of rivers respectively destined for the Caspian, the Black Sea, the Baltic and the White Sea. Its existence is first recorded in the chronicles in 1147.

In the Near East, the Mongols inflicted on a once splendid 'Arab civilisation a blow from which it has never fully recovered', to quote one of the more distinguished and empathetic of its historians. When at last they were defeated at Ain Jalut, it was by the Mameluke military caste under Turkish leadership. The eventual upshot was the establishment of a dreary Ottoman Empire across the Arab world. So for 'nearly 500 years' this world stagnated. 'No creative worker or writer or thinker appeared among the Arabs, and they were not awakened from the slumber until the Western nations appeared in the East.'[108] But of the three main foci of urbanised Arab culture in the region – Baghdad, Damascus and Cairo – only the first two were ever to be reached and duly sacked by the Mongols, in 1258 and 1260 respectively. Added to which, Cairo would prove able to emancipate itself from the Ottoman Turks sooner. This difference in background may still bear on events.

But there is another 'might have been' to consider. Could the Mongols and the Latin Christians conceivably have forged a durable alliance against Islam? If so, that would have been a geopolitical and philosophic revolution such as to redirect the history of the world, a remarkable end-product of the original Mongol expansion.

For nearly a century from 1248, such a *démarche* was recurrently mooted.[109] The first, and arguably the last, real opportunity arose in the wake of Ain Jalut. Everything hinged initially on what was still left, post-Saladin, of the Christian polities in the Levant. Did they stand any chance of rebuilding their position strategically, given that they were small urbanist elites extensively exercising sway over a Muslim peasantry? And could they then have been confident of preserving internal stability?

What hope for such stability as there might have been would have rested on the good productivity the Muslim peasants' agriculture registered during this interregnum. This will have owed nothing to any Frankish strategy for improved farms.[110] On the other hand, the climatic tendencies may have been conducive. Thus it is likely that the strength of the water cycle was maintained well enough while the Levant emerged from the nadir, *c.* 1100, of the 'Crusader cold spell'. That much is suggested by a very steady water level in the Dead Sea until the thirteenth century, and maybe too by a now rising one in Lake Van.[111] All the same, a proactive Outremer role within an alliance would have depended on sizeable troop reinforcements from western Europe, something then little in prospect.[112]

After that, other ostensible possibilities episodically opened up as both Mongol expansionism and Crusader adventurism became ever more pragmatic. But the downside to pragmatism was each side becoming more disparate with diversifying interests and aims. In the event, the one geopolitical *volte-face* achieved in that area involved not the Christian West and the Mongols but Byzantium and Islam. Around 1300, liaison between Constantinople and the key Muslim powers regionally obliged the Mongol Khans of Persia to convert to Islam, thereby coming into line with the great majority of their subjects.[113]

Our understanding of the Mongol emergence has always been stultified by too little hard fact, not to mention the paralysing terror initially aroused and long remembered. For his part, Gibbon is at his most callow when he opines that the religious philosophy of Genghis Khan himself 'best deserves our wonder and applause' because he 'anticipated the lessons of philosophy and established by his laws a system of pure theism and perfect toleration.'[114] The vaunted goal of 'universal empire' had itself been enough to preclude tolerance being anywhere near 'perfect' because, especially in those early years, that would have been altogether too fissiparous.

None the less, the measure of Eurasian unification achieved did create certain opportunities. Advantage was most visibly taken in China. The Southern Song had abandoned all trading contacts with inner Eurasia in order to develop strong trading links with south-east Asia and the Indian subcontinent. Initially, at least, the Yuan dynasty considerably restored this maritime dimension but meshed it into a trade revival with central Asia.[115]

Responding, Western merchants sought new links with the East. One Genoese initiative was the establishment of a trading post at Kaffa in the Crimea *c.* 1266. Meanwhile, Dominican and Franciscan friars had started to proselytise in the Mongol realms. But the scale of neither the religious nor the lay activity should be overplayed. The 'first definite papal interest in China' was expressed in 1289 with the dispatch of six Franciscan missionaries.[116] Likewise, any notion of strong non-clerical networking is vitiated by burgeoning suspicions that Marco Polo (*c.* 1254–*c.* 1324) never went to China at all.[117,118] Nor should that revaluation surprise us. To make such an overland journey, whether alone or as part of a Mongol caravan, would have been an awesome prospect for any European not suffused with religious zeal.

The mobility that history has seen as the supreme hallmark of the Mongols had other connotations too. It was conducive to the spread of epidemic disease, not least through the way Mongol caravans from Kaffa or wherever tended to interweave over a breadth of terrain far greater than had been the norm on the Silk Road. This disposition, perhaps somewhat encouraged to 1275 by climate change, will have brought those concerned more into contact with the wild rodents of the steppes. It was probably then that the latter became prime transmitters of bubonic plague and other diseases.[119]

Another aspect to consider is how far the strategic mobility of the Mongol host was a less than free option, being rather a proclivity imposed by a constant need for pastures new. The typical size of a Mongol army is these days thought to have been 30,000 men with their several mounts apiece.[120] Normally several armies were in being. Even ignoring any trains of people and animals in support, that implies quite heavy pasturing demands. This point was made in Chapter 3 in relation to the Huns and whether they were as reliant on mounted troops as we know the Mongols were. The criticality of Mongol pasture demands have also been considered in relation to the Near East crisis of 1260[121] and, indeed, the Danubia winter campaign of 1242.[122] The inference can be drawn that there might often have been little choice between strategic withdrawal and continual advance, leaving to rearward newly subject communities cowed by destruction and death. The dilemma was as stark as the choice customarily faced by steppe chieftains dissenting from their khan: that between leading their own warriors away or staying to fight to the death.[123]

Though more encompassing, this scenario is redolent of the theory that, once Germany had started to mobilise its army in 1914, it was *ipso facto* committed to invade Belgium in a matter of days or face hopeless rail congestion.[124] To judge better whether an equine equivalent would have applied anywhere the Mongols reached, it would be needful to amass more field data on the then water cycle and apply to it hydrological modelling. As regards the influence on this whole saga of fluctuations in the water cycle or in other climatic parameters, one may provisionally conclude that the Mongols' sanguinary adventure drew initial encouragement from a relatively warm, moist and maybe calm trend in their homeland, giving way quite suddenly to a cooler, drier regime. Also in China and Japan their progress or lack thereof was modulated to an extent by climate trends. In axial Europe any such linkage is obscure. Nor are there any indications, from Quinn at least, that their big surges into the Near East coincided closely with monsoonal anomalies.[125] Nor is there any record of short-term climate adversity behind the inter-boyar warfare that so weakened Russia (and especially its old south) just ahead of the main Mongol invasion. Between 1235 and 1240, Kiev changed hands seven times.[126]

9 Through the optimum

Subject to variations regionally, European temperatures were turning downwards by 1275 and rainfall rising by 1300. So how far did this climatic climacteric aggravate social tensions, maybe turning critical strains that might otherwise have been accommodated? To take a different tack, how far were the thirteenth and fourteenth centuries strengthened against ecological adversity by the cumulative progress made the previous 500 years?

The concept of the 'frontier' is relevant. Archibald Lewis distinguished between the 'external' geopolitical frontier of western Europe and the 'internal' frontier of clearance around many a local community. He saw each of them, plus some more metaphorical frontiers (e.g. cathedral building), as closing between 1250 and 1350, along with an onset of cooling.[1] Both kinds of territorial frontier afforded inducements for innovation.[2] My native Chiltern Hills (dry, thin-soiled chalk downland) were a region of 'fairly advanced' agrarian practice in the High Middle Ages.[3]

The external frontiers were curtailed well ahead of any climate turnaround. In 1187 Saladin took Jerusalem. In 1240–1 a Mongol *blitzkreig* reached the Oder. In Iberia the Christians gained the Algarve, Andalusia, Murcia and Valencia, 1212 to 1275, but then Muslim Granada stood firm till 1492. In 1261 the Greeks regained Constantinople, under Latin control since 1204. Seven years later the Crusader principality of Antioch fell to the Turks. All in all, some weakening of Catholic Europe's martial resolve pre-1275 would be hard to gainsay. So did this herald a more general crisis?

Action and reaction

Half a century ago, Charles Haskins introduced the notion of a twelfth-century Renaissance. If there was one, it effectively began with the new spirit abroad from 1070. Come 1204, Europe had universities at Paris, Montpellier, Bologna, Salerno and Oxford. Paris was pre-eminent in vigour, scale and diversity.[4] France as a whole was a pacemaker with its philosophers and vernacular poets and, above all, its Gothic architecture.[5] A hallmark of the era was the translation into Latin from Greek or Arabic of many texts from Classical Antiquity. Toledo became an important translation centre after falling to the *reconquista* in 1085. A signal beneficiary, as it were, of the literary revival was Aristotle. Thus two Latin versions of *Meteorologica* were completed. A pre-1163 one, *Vetus Versio*, had had three of the four books translated from Arabic and the fourth from Greek. The other, the *Nova*, dated 1260, was entirely from the Greek.[6] Literacy became the hallmark of a restless new elite.[7]

Yet there were fateful flaws in this 'renaissance' or, as some have much preferred,[8] 'revival'. The polymathic Frederick II (1194–1250), Holy Roman Emperor and King of Sicily, personified a contradiction. His Arabist–Byzantine–Catholic–agnostic court of all the talents at

Palermo matched any fount of self-conscious humanism in that greater Mediterranean Renaissance so imprinted on our consciousness by Michelet and Burckhardt. Yet with a badly abused harem guarded by eunuchs, and with his executive ruthlessness, endless machinations and boundless conceit, this self-styled *stupor mundi* ('wonder of the world') elevated himself to as barren an isolation as that achieved by any *virtuoso* prince of the sixteenth century (see Chapter 10).[9]

Weaknesses are evident, too, in the 'reformational' aspects of this whole experience. Since monasticism had become considerably lax, several new orders were launched. Under St Bernard of Clairvaux (1090?–1153), the Cistercians (founded in 1098) applied their puritan ethos to proliferating abbeys, mainly across upland areas made somewhat more accessible by climate improvement. By the year 1200, there were 530 of these monk-cum-lay communities, sheep farming being their principal bent. In 1210, the mystically ecological St Francis of Assisi – saluted by the atheist philosopher Bertrand Russell as 'one of the most lovable men known to history'[10] – founded the Franciscan friars as they became known. Unfortunately, both of these movements soon came up against a conflict between (a) a yearning for the simple lifestyles of the early Christian fathers and (b) the obligations and temptations presented by the material resources their *modus vivendi* generated.

For 30 years, Henry of Lausanne, a literate intellectual-cum-militant heretic, preached throughout south-western France – making it a land where, according to St Bernard in 1145, 'Churches are without people; and people without priests.' By then, in fact, Languedoc was the heartland of the Albigensians: a core element in the Catharis, a New Testament revivalist movement of Persian derivation. Their theology was and is obscure. But their pacifistic idealism widely caught on across Catholic Europe during the twelfth century. However, Pope Innocent III (elected 1198–1216) sought to affirm (a) the authority of the papacy over monarchies and (b) that of the Church over heretics. He authorised the Fourth Crusade, 1204, and the crusade against the Albigensians from 1208 – the latter being successful, in the course of two decades, by dint of its utter savagery.

This heralded a conservative reaction, philosophic as well as governmental. As Haskins put it, 'By 1200 the medieval renaissance is well advanced, by 1250 its work is largely done.'[11] To put it another way, a crisis of cultural identity had broken, this well ahead of the climatic turning points. One could conjecture that Languedoc had been getting too dry because of zonal displacement, but the evidence from nearby Italy ill supports this. Nor was Languedoc otherwise under Malthusian pressure in the thirteenth century. The coastal strip was quite densely peopled but well developed in all respects. The interior was lightly populated.[12]

War with Islam

Iberia, being more within the ambit of the Azorean High, may have been getting droughtier. Infrastructurally, however, its Muslim realm – Al-Andalus – started the thirteenth century much richer than the Christian kingdoms. Córdoba may have had nearly a million inhabitants ahead of its fall in 1236, and Seville over 300,000 before it fell in 1248. Moorish Granada was close to half a million in 1492. Compare those estimates with 22,000 for the key northern mart, Lübeck post-1350.[13] Little sign in all this of the singular vulnerability of 'hydraulic civilisation' to worsening aridity or violent conflict or both. The progress made by Christian armies up to 1275 was ultimately secured by two twists in the fortunes of war. The one was the Muslims' failure to exploit their victory at Alarcos in 1195; the other their ultimately catastrophic defeat at the close-run battle of Las Navas de Tolosa in 1212.[14] If climate adaptation enters the equation, it does so via the development by the conquering Christian nobility of fine merino wool produced on the basis of long-range transhumance over the *meseta*, the central plateau area.

Initially this departure could well have been a response to conditions of greater drought on the *meseta*. By 1350, villages were being abandoned as arable margins receded under various influences, including weather that was cooler and perhaps markedly more erratic.[15] All the same, the transhumance concept just outlined owed something to Moorish precedents, and from 1154 there is evidence of the immediate forebears of the merino sheep being imported from North Africa though, according to Robert Lopez, true merinos were not shipped over until *c.* 1350.[16,17] In 1273, Castilian sheepmasters formed the Mesta, an association to supervise transhumance.

The adoption of this economic pattern on this strategic frontier involved the creation, in newly reconquered areas, of *latifundia*, large estates that were to be expressive of a deep social cleavage the next seven centuries.[18] Southern *latifundia* of up to 5,000 square kilometres apiece gave the aristocrats of the fourteenth century a peculiarly strong grip on Castilian politics, a grip they exploited to the utmost. The rearing of sheep from *c.* 1280 (one to two million by 1300) took precedence over an arable/viticultural sector now widely moribund through water shortage and, in any case, too vulnerable to hostile action. The requisite space had been created by heavy ethnic cleansing of the Muslims, especially after their rural revolt in 1263.[19]

In 1204, Egypt was fulcral to the strategic balance in the eastern Mediterranean. Specifically, it was the declared target for the Fourth Crusade. The Holy Land itself was now less than appealing. The Muslim victory at Hattin in July 1187 had confined the Crusader presence in the Levant to a coastal strip between Antioch and Acre. All else apart, the incendiary annihilation of their entire field force had left the Christians without enough troops to garrison properly any castles bar Tyre.

Fieldwork has confirmed that the Levantine moistness phase was at last ending by the thirteenth century. The key evidence comes from palaeohydrology in the northern Negev,[20] and from the Dead Sea.[21] Moreover, a pronounced trend from AD 1200 to 1500, whereby isotopes in the Sea of Galilee but also in Lake Van averagely become heavier, indicates a warming perhaps more extensive regionally than the eleventh-century 'Crusader cold spell' had been. At the same time, the level of the Dead Sea fell.[22] That will eventually have worked to the disadvantage of Islam and/or Byzantium. When the Fourth Crusade was being mooted, however, it could have constrained the Latin West, given (a) its need to create Outremer lodgements spacious enough to be stable, should the Holy Land be the ultimate objective, and (b) its core reliance on heavy cavalry with its weighty armour and stolid horses. In the course of the twelfth century, in fact, Western armies had become even more armour-clad (see Figure 9.1).[23] Moreover, the strain will have been compounded by how the Mediterranean harvest routine tempted all sides to take to the field in high summer.

Obversely, Egypt was overtaken by famine. But its dimensions are uncertain. In 1987, Josiah Russell allowed it but 2.4 million people in 1200, albeit on a secular curve firmly upward.[24] In 1969, T.H. Hollingsworth had read its total as falling from 16 million to 10 million through that turn of century.[25] Nor do analysts concur about whether, as modelling by Reid Bryson has suggested, there had been, from 1000 to 1300, a very consistent trend towards less adequate Nile floods.[26] Near the crunch time, however, good agreement emerges. The year 1200 saw that uniquely feeble annual flood. The next two may also have been weakish. Cannibalism reportedly broke out; and 1201 saw a severe epidemic. Since the

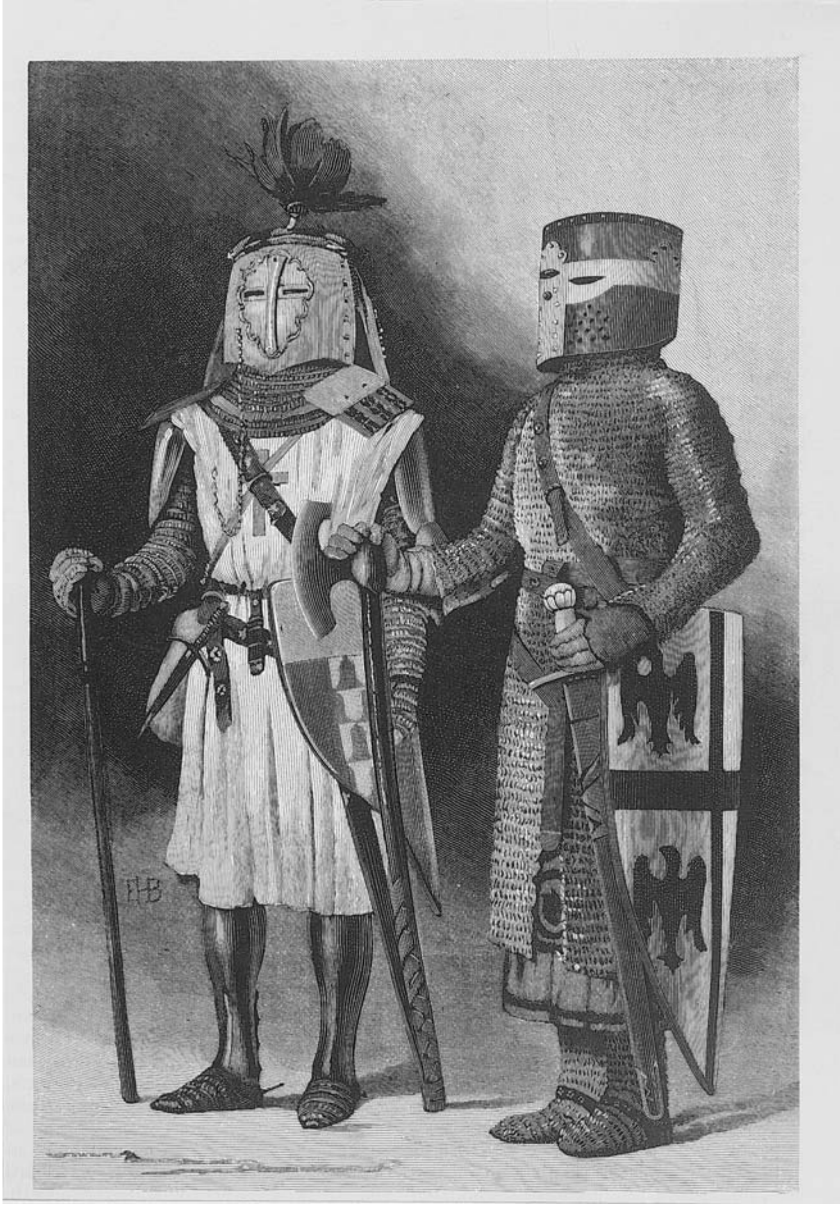


Figure 9.1 Military armour, 1190–1312: (*left*) armour of 1295–1312, from the seal of Hugh of Chatillon (broigne; steel winglets at shoulders; steel plates at tibia and upper arm; helmet with visor screwed on, surmounted by garlands and lambrequin); (*right*) armour of 1190, from the seal of the Count of Montmorenci (chain hauberk and hose; great steel helmet and battle-axe)

Source: courtesy of Mary Evans Picture Library

death of Saladin in 1193, the regime will have been more susceptible to natural calamities. As sultan of Egypt he had proved a positive civic ruler, not a mere warrior.

In 1219, hard upon another lowish flood,[27] the Fifth Crusade seized the main Egyptian port of Damietta but withdrew in 1221 having failed to capture Cairo. The Fourth Crusade might have achieved no less, had not the Venetians used their leverage as conveyors to get it re-routed via Constantinople. A defining meeting may have been that in December 1201 at the Swabian court of the Holy Roman Emperor between Boniface of Montserrat (lately appointed as generalissimo of the expeditionary forces) and Alexios the Younger, the son of Isaac II – the Byzantine emperor deposed and then blinded in 1195.[28]

Having reached the Bosporus in June 1203, after sacking Zara, the Crusaders got involved in the vicious internal politics of the million or so-strong Byzantine metropolis.[29] Their sacking of that splendid place ten months later 'put the massacres of Antioch and Jerusalem in the shade'.[30] Ambivalence towards the eastern fellow Christians did not ease the savagery; quite the contrary. The Venetians and next the Franks were the prime beneficiaries. Since the sack of Zara, a peaceable Adriatic Catholic community, the whole expedition had been excommunicated.

The effect on an already dwindling stock of Crusader idealism was disastrous. But something every bit as repugnant was to follow. In 1212, tens of thousands of children (mainly from Italy, France and the Rhine valley) more or less spontaneously converged on the ports of Marseilles and Brindisi, seeing themselves as soldiers of Christ destined to gain Jerusalem for good. Those who embarked consistently ended up as slaves of Islam. The reaction of St Francis to this Children's Crusade is not recorded.[31] This probably bespeaks the horrified embarrassment of the older generation at how utterly ineffectual they had proved, faced with this criminal situation. The only redeeming feature was that the young Frederick II caught and executed the two main shipowners, a response that will have helped him posthumously to become a millenarian cult figure in spite of all the contradictions he manifested so conspicuously later in life.

Though more regular Crusades intermittently continued, the dynamic had been lost. Catholic Europe no longer had the will to sublimate its internal tensions by bold initiatives on the external frontier. Henceforward, those tensions would have to be addressed directly.

Scientific discourse

It was implied above that by 1250 a Catholic European crisis of identity had been accommodated, not that it had been resolved. The key political issues of relations between popes and princes, people and princes, and people and popes had been aired strongly but inconclusively. Nor was it clear how far new learning might promote conflict resolution through reason and enlightenment or, indeed, contribute to raising living standards against a background of population increase and ecological constraints.

All the same, the renaissance/reformation of the twelfth century had given European culture more sensibility. Women partially emerged from the shades of distrust and apprehension.[32] More tangibly and assuredly, the European university was founded as an institutional genre that would in due course approach more closely than any other the ideal of independent enquiry in every realm of knowledge. Two new orders of friars, the Dominicans (founded 1216) and the Franciscans, were especially instrumental in getting universities going. Among the Franciscan schoolmen of the 1200 to 1350 era at Oxford were three of considerable import for the development of natural science: Roger Bacon, Robert Grosseteste and William of Ockham.

A point at issue in the rich literature about science in the High Middle Ages is how far and, indeed, why it was stultified by insufficient factual observation. In the monastic and cathedral schools that controlled higher education in 1070, the liberal arts were divided into the trivium (grammar, rhetoric and logic) and the quadrivium (arithmetic, geometry and astronomy, together with music viewed as the study of acoustic proportion). Roman law was revived at Bologna, and by 1200 medicine and theology had been added there. Yet even then the emphasis was to be on 'thought experiments' rather than data collection.

This inclination was, for a while, reinforced by the surge of translations. Mathematics (Euclidian, Islamic, Sanskrit . . .) was a lead factor. By 1350, Europe would have 'garnered the mathematics of all Eurasia and was seizing leadership'.[33] Not least there was the mathematics the Arabs applied to astronomy and astrology. Algebra, alkali, almanac, Betelguese, root, sine and zero were among the Arabic science words adopted.[34] The twelfth century saw, too, a revival of astrology, a pagan superstition the Church was unable to smother.

Still, much hinged on Aristotle – especially as interpreted by Averroës (Ibn Rushd) (1126–98) and St Thomas Aquinas (*c.* 1225–74). Averroës was from Córdoba and can be adjudged the last great philosopher of Moorish Spain. Aquinas, a Dominican of Naples and Paris, so deployed his peerless knowledge of the texts of Aristotle (translated, in the main, between 1120 and 1220) as to ensure that the intellectual pitch of the mainstream Catholic hierarchy was Aristotelian rather than Platonist throughout this Renaissance foreglow.

Aristotle is, in the final analysis, more of a towering presence than Plato. But integrating his classical ratiocination into the scholasticism of the High Middle Ages was, for that very reason, difficult. Modern scholars reject a medieval disposition to attribute to him a cosmic teleology, a sense of everything moving towards an ultimate purpose. Moreover, Averroëists in Paris and elsewhere insisted that what he inferred about immortality was that collective intellectual awareness could survive but that the individual soul could not, an inference hard to square with mainstream Christian revelation. The 'double truth' dilemma thus posed came to a head in Paris in 1270. Seven years later, Parisian theologians formally challenged another of Aristotle's tenets: that, since the geocentric cosmos was created economically and therefore symmetrically, physical life could never exist on other heavenly bodies. Such debates led to a more clear-cut separation, in the fourteenth century, between theology and philosophy.

Atmospheric science is a good yardstick of the progress of medieval science. It is so because it resided, in effect, on the periphery of the seven liberal arts. This sphere is among those in which Aristotle showed himself to be strong on observation. About *Meteorologica*, Joseph Needham said, in his own magisterial study, there was no Chinese counterpart 'similar in scope'.[35] What is more, the reasoning contained therein is systematic and can be highly definitive. Take the account of dew and hoar-frost formation on a clear and still night: 'Some of the vapour that is formed by day does not rise high because the ratio of the fire that is raising it to the water that is being raised is small. When this cools and descends at night it is called dew and hoar-frost.'[36] As a succinct exposition, that remains hard to beat.

One might surmise that Aristotle's observations were so sound as to discourage anyone else from addressing similar fields of knowledge. But as far as extended atmospheric science was concerned, little progress had been made in Europe since Late Antiquity – i.e. a long time before this revival of Aristotle. On such topics as the theory of clouds or of rain there was to be little or none until well after 1400.[37,38] Nor was there to be, until the fifteenth century, any further discussion of the kind conducted extensively up to the time of St Augustine as to whether Noah's Ark should be taken as straight fact or rather as an allegory about baptism and renewal.[39] True, in 1090 or thereabouts, a French monk, Walcher of

Malverne, calmly described an eclipse of the Moon.[40] In 1128 John of Worcester painted, very formally, a pair of sunspots (see Figure 9.2). But the next tolerably conspicuous supernova, 3C58, which burst in 1181, has no surviving records in Christendom or, indeed, Islam – only in east Asia.[41] The earliest known weather diary in Europe was the one Walter Merle, Fellow of Merton College, kept daily at Oxford or in Lincolnshire, 1337–43.[42]

Nevertheless, the twelfth century did see weather study genuinely advance. Adelard of Bath and Bishop Robert Grosseteste decisively endorsed the Pythagorean/Aristotelian view, a subject of some uncertainty in Late Antiquity, that the Earth was spherical.[43] That endorsement helped an understanding of climatic zoning. The earliest known example in the West of a map of global climate zones is in a work of 1110 by Petrus Alfonsus, a converted Spanish Jew. He derived it from Arab sources.[44]

At the same time, seminal contributions were made to extended atmospheric science, some covering (in a world laced with prophesyings) the art of prediction. For instance, Grosseteste worked on a theory of light.[45] Also he and William of Conches each correctly deduced that the air is colder aloft because it is thinner, generally more transparent, and less exposed to re-radiated heat from the surface. Among the many formulations William attempted was one for the circulation of the atmosphere and oceans. Others (e.g. Adelard) addressed the mystery of where the waters to sustain the Noahic flood had originated. And so on.

Basic to climate study was geographical description and speculation, including about antipodal land(s) that might be inhabited.[46] But in that day and age, Catholic Christendom had a less clear idea about the Indian Ocean, say, than we have of the cosmos ten billion light years away. Arguably, our equivalent of their narrow horizons is an inability to view synoptically the microscopic world of biology.

Then, as now, the reaction to incomprehension was not entirely rational. Be dogmatic to mask uncertainty. Fail to distinguish what you do know from what you do not. In the particularly intriguing case of the Indian Ocean, there was likewise a communication gap between Arab scholars residing in that area and their Mediterranean counterparts. There may well have been, too, between those Arab scholars and Arab seafarers. Meanwhile, according to a psychological interpretation from an Annales perspective, the reaction in Christian Europe was to have that supposedly enclosed sea serve as 'a mental horizon, the exotic fantasy of the medieval West, the place where its dreams freed themselves from repression'.[47]

Maybe. But the inability of the new *literati* of the West to get a handle on far-flung geography is no adverse commentary on their commitment to reason and learning for more tangible ends. Not least did men like William of Ockham, William of Conches and, most zealously, Adelard of Bath extol science as the path to a full understanding of the divine purpose behind the natural order. Likewise Roger Bacon anticipated quite remarkably through his inquisitiveness the precept of his namesake Francis (1561–1626) that knowledge is power. To both men, knowledge meant, first and foremost, numerical science.

There is little direct evidence regarding everyday knowledge about weather and climate. The folklore encapsulated in oral adages went almost entirely unrecorded, save those from the Gospels. In England, the compilation thereof nearest in time is *The Shepherd of Banbury's Rules* that 'John Claridge, Shepherd' first published in 1670. Its prognostic indicators are often well founded. Among classical authorities, Pliny the Elder is mentioned once and the *Book of Weather Signs* by Theophrastus (co-founder with Aristotle of a philosophy school) twice. Meanwhile, such contemporary scientists as Hooke and Newton are referred to by Claridge a number of times in what reads very much like an endeavour to elevate and

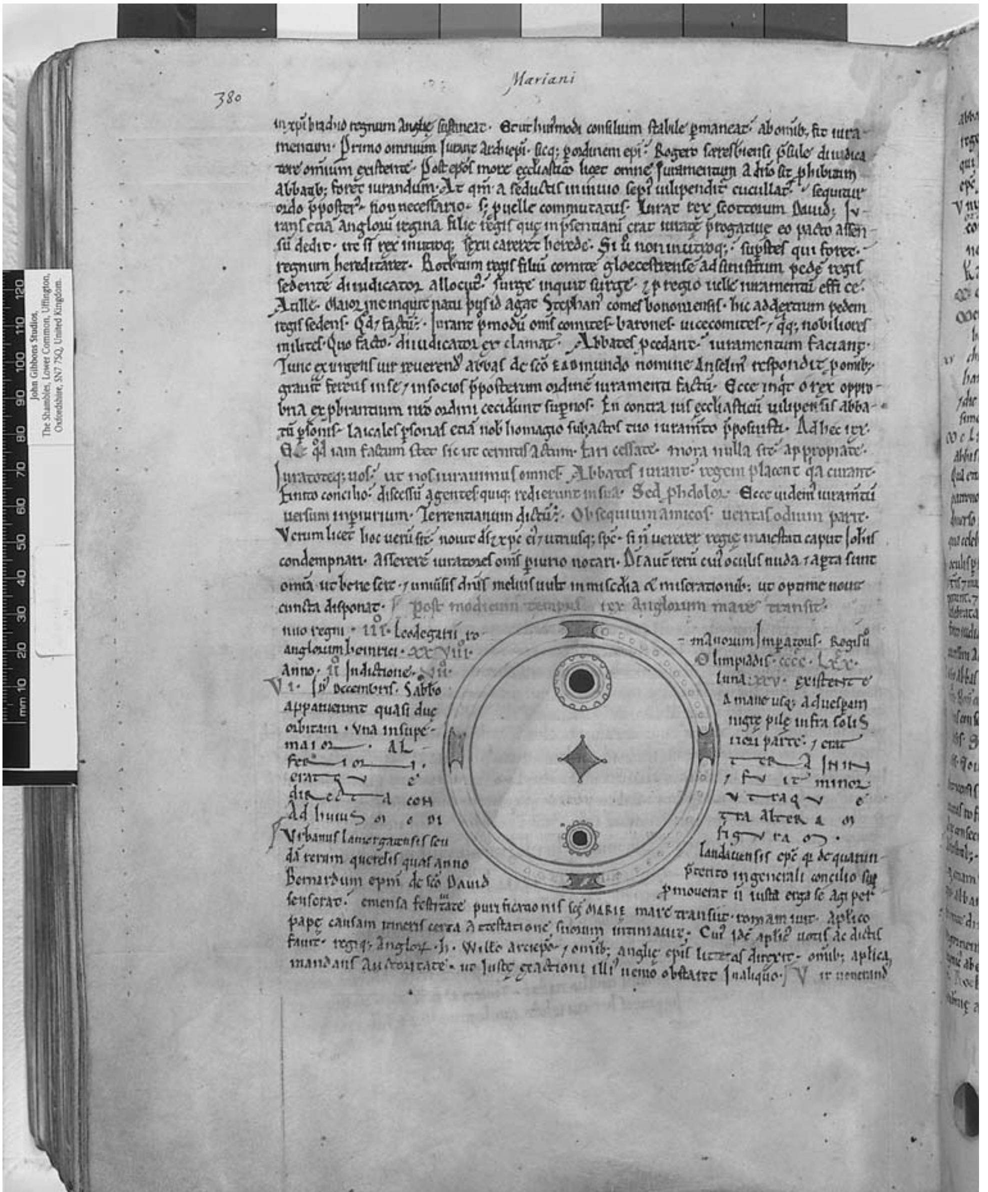


Figure 9.2 Sunspots seen in the reign of Henry I, inserted 1128 by John of Worcester into the chronicle begun by Florence of Worcester (d. 1118). Parchment, English School (twelfth century), Corpus Christi College, Oxford, UK (ccc Ms 157, p. 380)

Source: by permission of the President and Fellows of Corpus Christi College, Oxford. Courtesy of Bridgman Art Library edify a moribund tradition.[48] However, the lore of several centuries earlier had probably been less rich and, indeed, less rational. Witness the persistence through to the sixteenth century of a popular belief in the weather being tampered with by human individuals: these, as in northern Europe from the eleventh century, usually being women. Mostly they were allegedly malevolent 'storm-makers'. Sometimes they were truly specious storm preventers.[49]

A culture of calculation

A reflective student of medieval affairs observed in 1947 how the more inclusive sensibility of the twelfth century *literati* was matched by the evolution of floral decorative motifs in ecclesiastic architecture. Between 1140 and 1230 it progressed from abstract formalism to the point where 'many species are clearly recognisable'.[50] Yet this parallelism does not prove much overt interaction between craftsmen and natural scientists outside of the cathedral schools and the monasteries. Received wisdom among social historians is that there was to be little until the centennial span 1675–1775, when advances in precision construction much assisted each side.[51] As regards the High Middle Ages, the graceful mechanics of Gothic architecture, say, were worked out largely by illiterate people little in contact with the Roger Bacons of the day, if only because the latter were so few. Yet the said mechanics can be absolutely trusted, some eight centuries later.

Agriculture was another economic activity that did not owe a lot directly to the schoolmen, except perhaps in north Italy. Moreover, the culture gap in this sector was to widen in the fourteenth and fifteenth centuries in that 'No vernacular textbook on farming was written in western Europe.' The lack of interest in contemporary or, indeed, classical writers on the subject was too comprehensive.[52] Accordingly, aspirant authors will usually have been too little in contact with their target audiences to glean much wisdom reciprocally. However, a significant thirteenth-century exception had been the English author Walter of Henley, and 32 copies of his main treatise are still extant. He discussed various farming problems in tough cost–benefit terms.[53] *Inter alia*, he well understood that a combination of dung and earth could make good compost, perhaps to spread on fallow after its first ploughing. But neither his nor any other English book on husbandry in that era addressed the question of how densely to sow seed for grain, a matter about which local practices might vary severalfold for reasons not always apparent. Silence falls, too, about the ability of leguminous plants to give soil extra nourishment. Yet across the country the acreage under peas or beans had long been appreciable.[54]

Compare, too, the progress the Romans made with selective cattle breeding. According to an analysis by the late Professor Bökönyi of Budapest, they increased the average height of a cow at its shoulders from 112 cm in Iron Age times to 124 cm. In the High Middle Ages, it was 112 cm again in former Roman Europe and but 98 cm in Russia. In other words, there had apparently been retrogression.[55]

Even at its most sanguine, the medieval world was considerably pessimistic about and defensive towards the future. Reviving the Classics was, in part, a manifestation of that. A defensiveness towards either transmitting or imbibing new information expressed itself at every level from manor to metropolis. Most seigneurs in most districts felt little need or obligation through a mainly buoyant thirteenth century to invest in farming more than minimally or to deploy existing farm assets more efficiently.[56,57,58] Granted, the expanding towns and cities assumed more salience in the diffusion of new knowledge and attitudes. Even so, their famous craft guilds were not called 'mysteries' for nothing.

Yet in spite of what has been read as a very circumscribed medieval sense of progress over time,[59] what may be termed a culture of calculation insistently emerged. The fascination with esoteric mathematics evinced by some of the twelfth-century *literati* may not have communicated itself much beyond them.[60] The technological encyclopedia which Al-Jazari, a Mesopotamian craftsman, compiled in 1205 had no counterpart in Christendom.[61] Nevertheless, a disposition to think more arithmetically was there diffusing in many directions. A key aspect of this was a gradual shift towards the more consistent registration of the daily passage of time. Before 1150, this was rendered more or less exclusively apropos natural time and as indicated by church bells. By 1350, mechanical clocks were operating, however problematically, in various cities from Lombardy to Flanders allowing of recourse to a 24-hour day, the format the Babylonians had long ago devised. A growth in monetary accounting and transaction was, by the thirteenth century, a salient part of this acculturation.[62] Witness Genoa's *genois* and the Florentine florin, each a gold coin struck in 1252. Yet throughout one must allow for gradual proliferation. The Arabs' abacus calculator spread across western Europe in the eleventh century. Not until the fourteenth was this geographic coverage matched by 'virtual ubiquity' in depth.[63]

A signal respect in which the culture of calculation expressed itself was the belated adoption around the Catholic Mediterranean of crops the Arabs had introduced. Since the eleventh century, sorghum had reportedly been a major crop in Galicia. But only in the thirteenth did sour oranges, lemons, limes and hard wheat become familiar in Christian Spain and Italy, sugar-cane return awhile to Sicily, and spinach begin to spread.[64] At first sight, this acceptance of Arab biodiversity is not easy to reconcile with the spread of *latifundia* in Iberia via ethnic cleansing. Nor is it with the putatively liberal Sicily of Frederick II (ruled 1197–1250) virtually completing the clearing out of its Muslims in a succession of bloody ethnic conflicts, 1161 to 1263. Likewise, this anti-Arab violence is hard to relate in its turn to the European hunger for Arabist high culture or, indeed, to sundry pacts between Muslim and Christian princes during the *reconquista*. As regards the Christian abandonment of Moorish irrigation works, that may have been modulated by how a zonal climatic shift led differentially to droughtier conditions. It is noticeable that, in the wake of the *reconquista*, irrigation networks were abandoned around Murcia and Cartagena but preserved around cooler, moister Valencia. Nor should we forget how sensitive is the hydrology of much of the *meseta* to slight changes in precipitation or temperature. Perhaps the withdrawal from arable agriculture to make way for sheep was not always, after all, the gratuitous spoilation it seems in retrospect.

Exhausted soil?

An alternative to climate change as a lead explanation for a high medieval agrarian crisis could be soil exhaustion consequent not on deficient or excessive rainfall but simply on poor husbandry. Early last century this notion gained favour, albeit on little hard evidence.[65] Later on, Sir Michael Postan pitched his considerable authority against discounting the possibility that not enough was done to keep cultivable land fertile, especially on the holdings of dependent peasants 'weighed down with dues and having but limited grazing facilities.'[66]

The debate thus engendered has focused, maybe unduly, on the nutrient balance rather than soil structures. Within that framework it has focused rather too exclusively on nitrogen supply. Nitrogen enters the soil naturally from the atmosphere through (a) rainfall, (b) being fixed by free-living bacteria, and (c) fixing by symbiotic bacteria in the roots of leguminous plants. It also enters, over decadal timescales, from the decay of dead life within the ecosystem and the application of green or, more particularly, animal manure. What the Postan/Malthusian school of thought essentially now says is that, by the High Middle Ages, an impatient concern of farmers to keep up arable production caused too little emphasis to be placed on the pasture needed to fertilise it. Hence a steady decline in productivity.[67] Unfortunately, discussion too long amounted to contending parties talking past one another. Take a 1978 contribution. The three statements made led to an entirely open-ended result about, for example, fourteenth-century legume use.[68]

Nutrient flow charts for individual medieval manors ought to be essayed. Something akin has lately been attempted for Cuxham, a manor in Oxfordshire a couple of miles below the Chiltern chalk escarpment spring line. Since Cuxham manor was a fief of Merton College during the span chosen (1320–40), its record keeping was elaborate. The inconclusive conclusion of this research is that the inputs and outputs of nitrogen were too complex and voluminous for a net balance even to be guestimated. There was probably a sufficiency of potassium but a slow decline in the amount of phosphorus 'available' in the soil. It is acknowledged that the balances for sulphur, calcium and magnesium might usefully have been assessed as well. No other elements are expected to have posed a problem, judging from twentieth-century British experience.[69]

Pending much more fieldwork, only this can be said. There is little sign that many thirteenth-century farmers made the use of manure, legumes or marl (a clay–lime mix) a quantified science even to the extent the Romans had.[70] Yet given the variegation of Europe's natural landscape, many localities will have been prone to nutrient deficiencies. Farm output will therefore have been the more susceptible to climate adversity, especially on land newly tamed.

Sacred groves

Among the world community of twentieth-century medievalists, perhaps the most creatively transdisciplinary has been Lynn White, the one-time Professor of History at the University of California cited above. A free-ranging essay White published in *Science* in 1967 sees the High Middle Ages as a time when Latin Christianity was visibly 'the most anthropocentric' of religions, averring that Nature exists only to serve mankind. St Francis, the most celebrated dissentient voice, was marginalised soon after his death.[71]

Not that the White thesis is entirely compelling. If its assertion 'the Greek saint contemplates; the Western saint acts' identified a genuine contrast, how did Byzantium come to create so enriched a culture centred on a metropolis, that ultimate expression of proactiveness? In any case, Europe was not as yet the supreme manifestation of technocratic dominance over Nature. Pride of place emphatically belonged to China still – Buddhist, Confucian, Taoist China.[72]

Ever since the early Church, on the other hand, the divide between Christian and pagan had been at its starkest over whether primeval forest should be seen as full of satanic menace or as harbouring sacred groves, not to mention the milk and meat celebrated so exotically in Germanic culinary mythology.[73] The pioneer anthropologist, Sir James Frazer (1854–1941), concluded that, in ancient German religion, 'the veneration for sacred groves' was foremost, oak trees (along with thunder) being especially revered.[74] To the Church, such localism undermined not just the papacy *per se* but also the holistic integration of faith and reason sought by the scholastic theologians led by Aquinas. Sometimes, not least in the Celtic realm, the Church accommodated to paganism, one modality being to link a sacred grove with a particular saint or the Virgin. Whenever Christianity waxed strong, however, the inclination was to confront pagan practice head-on. One instance was the ruling by the 1215 Lateran Council that trial by ordeal (e.g. making a defendant negotiate hot cinders blindfold) had no theological justification. However, paganism could prove tenacious. Witness the human sacrifices at Uppsala in the 1070s, some 250 years after Christianity was first introduced into Sweden. More benignly, can paganism take the credit for an exceptional Scandinavian propensity to cherish the forests as protective and supportive?[75]

More generally, did a paganish concern never to eliminate the forest too comprehensively tangibly influence the advance of the frontiers, internal and external? This possibility was aired above apropos the Anglo-Saxon invasion of Britain. Later on, German colonisation eastwards looks *a priori* like something of a test case. Impelled by demographic pressure that resurged 1200 to 1250, the frontier zone moved from roughly the Elbe to the Oder. During the next half century it gained as much again but then slowed right down, save for the Teutonic knights along the Baltic.

Not all scholars would concede that the Germans, however defined, really had inherited a sylvan culture. They would point out that colonisation on the North European Plain tended to produce 'champion' landscapes: stretches of treeless arable that would later constitute the Junker estates. Only in the Celtic lands did one regularly encounter 'bocage' – small fields with boundary banks set amidst many woods or copses.[76] On the other hand, in Germany the demographic pressure to extend eastwards was not too compelling. So one can talk about new arable ground being broken where the post-glacial geology was suitable for roots or grainstuffs (e.g. the Silesian loess and certain boulder clays) rather than for, say, acid-loving conifers. However, several times more arable may be needed to feed a human community as and when animals are an intermediate link in the food chain. At which point a predilection for red meat becomes an argument for destroying more of the woodland, not less.

But the big restraining influence was, in any case, the political reaction from the East. In the course of the twelfth century, the Elbe–Oder belt was divided into duchies and marches affiliated to the Holy Roman Empire. The same applied, albeit more loosely, to Bohemia and Moravia. Beyond the Oder, the Baltic littoral excepted, was a newly consolidating Polish kingdom. Poland and Bohemia each accepted many German immigrants in the thirteenth century, in colony villages and in urban *faubourgs*. This was part and parcel of a two-way cultural exchange within the Catholic–Romanesque–Gothic context, an exchange that steadily became richer and more even.[77] Witness the foundation of the University of Prague in 1348 and the Jagiellonian University of Kraków in 1364, two campuses destined to gain high international repute.

In some measure, too, this dialectic was modulated by climate change. An analysis from the Polish Academy of Sciences has stressed that, given the delicate hydrological balance across the North European Plain, a secular rise in rainfall during the thirteenth century caused not a few valley bottom settlements to be abandoned.[78] What can still be surmised, none the less, is that the further east one looks, the more advantageous extra rain on balance was.

At all events, Catholicism felt constrained each side of this ethnic divide, but also elsewhere, to incorporate pre-Christian customs and beliefs concerning 'man and nature or man and man'.[79] Maybe this is why, in parts of northern and central France, the forests actually expanded in the early Middle Ages. Sometimes the Frankish kings actively protected sacred sites or hunting preserves against sod-breaking zeal, though, from the eleventh century, the rural abbeys tipped the overall balance more towards clearance.[80]

Much of southern Europe (and above all, the Italian peninsula) has an immature geomorphology vulnerable to Mediterranean downpours, a vulnerability accentuated by Man's ecological interference from Neolithic times.[81] What one wonders is how much the early/medieval perspective was shaped by the Roman legacy. That the Romans were exercised perennially about water control is clear. But did they not stress ploughing and terracing more than woodland when protecting hillsides from erosion? And did not timber or charcoal shortage sometimes impel them in this direction? It used to be felt that the Romans were given to what the similarly placed Japanese have customarily called *ranbatsu*, the reckless felling of trees. Then perusal of wartime aerial photographs post-1945 encouraged a softening of this judgement.[82] Probably removal was patchy, with much of Mediterranean Europe remaining forest-clad into the High Middle Ages. But in Corsica, for instance, pine was naturally displacing beech by 1200 as the weather there turned cooler and damper.[83] Yet it remains hard to believe that the Romans addressed forest conservation with quite the concern they otherwise expressed for good husbandry.

Obversely their attitudes to the deep, dank forests of *mittel Europa* bespoke a collective withdrawal syndrome. Extensive clearances of virgin woodland did take place – e.g. on the Burgundy limestones – to plant the vine. Yet relative to what we presently know of ecology and climate trends, these efforts hardly match the creation of the 'bread baskets' of 'Africa' and Egypt (see Chapter 3), zonal climate shifts notwithstanding. At its second-century peak of warmth, much of Roman Europe was not quite a degree Celsius warmer than now.[84]

Military discomfiture came into play. In AD 9, the Romans had had the two legions destroyed in the Teutoberg Forest in Germany, and another later disappeared without trace in Scotland. From Pliny the Elder in AD 77, Roman writers came to envisage much of the latter country being blanketed by a forest of Caledon.[85] Had Severus persevered with the conquest of Scotland, his strategy would have been heavily amphibious.

However, the most critical interaction between humankind and the natural forest was the one of which medieval people were blissfully unaware. In Chapter 3, the suggestion was made apropos of Late Antiquity that while felling was going strong it would have increased atmospheric carbon dioxide, but that a century or so after clearance had more or less ceased this trend would reverse. Recently, ice core data on the High Middle Ages has borne this precept out, albeit subtly. The volume of CO_2 in the atmosphere rose from 278 parts per million in AD 1000 to 285 in 1225, but then fell to 277 by 1325.[86]

Malthus revisited

The intricate and often incommensurable inputs of culture and ecology work against a primitive Malthusian model of the pressure of population on territorial space eventually crossing a defined limit of tolerance, as per a rodent community confined in a cage. Certainly the thirteenth century witnessed a sharp increase in the numbers of *extranei* or *vagrantes*, landless paupers trekking in search of work.[87] But at the same time new opportunities were being created by increased social mobility. Throughout, medieval Europe 'was very much a world in formation'.[88]

What seems well confirmed, however, is that, in Europe as in Asia, the population had been rising for two or three centuries prior to the thirteenth. That of France may have risen from 5 million in 850 to 13 million in 1300.[89] There is a measure of agreement that the population of England rose from 2 million at the time of the Domesday survey (1086) to *c*. 6.5 million in 1300.[90] For western Europe as a whole, Jacques Le Goff has quoted impartially both J.C. Russell and M.K. Bennett. The former saw the total climbing from 22.6 million in 950 to 54.4 million in 1348; the latter from 42 million in 1000 to 73 million in 1300.[91] Reworking Russell's figures for England, Hollingsworth concluded that population growth was at its fastest percentagewise as early as 1143–75.[92]

With the continent-wide expansion, the demographic weighting towards the Mediterranean, so evident as of the Roman heyday, effectively disappeared. In its place, France emerges as a central zone of high population density as well as in regard to qualitative aspects of the high medieval experience.[93] Meanwhile, the sustained increase overall will have entailed improved levels of general health – less of the blindness and the many other diseases borne of squalor and malnutrition. Russell further inferred that the survival of more babies especially applied to the clinically weaker sex – i.e. the males.[94]

Yet around the turn of the fourteenth century there is a fairly sudden levelling off or maybe slight reversal of European demographic growth. In 1950, Postan adjudged the population of England, and very likely the near continent, to have peaked 1300 to 1320, 30 to 50 years ahead of the Black Death.[95] In 1985, Russell surmised that population control was practised to effect in Europe by 1280: mainly by deferment of marriage, though also by infanticide *inter alia* – chiefly of females.[96] In Sicily, demographic decline was probably behind an increase in farm desertions from 1280 and especially from 1320, this in spite of a diminution of military threats.[97] But there is some tentative evidence that the island had passed through a secular rainfall peak as early as 1150.[98]

Axial Europe booms

However much or little it owed to the cultural/intellectual revolution adumbrated above, one can sense, in the 1180s or thereabouts, a sea-change whereby 'urban vitality' came to prevail throughout, not just in northern Italy. Indeed, Georges Duby's view has been that this change was still 'more noticeable' on the north-east frontier of Catholic Christendom,[99] near the continental base of that axial European peninsula extending out of Russia to Brest.

One priority in Bohemia and Poland was to relax the martial feudal stance a little. Another was to improve the ratio of grain yield to seed corn. In thirteenth-century Poland, the norm was still a mere 2:1.[100] Improvement involved, first and foremost, a general introduction of the heavy plough with its big share and a mould board to turn the furrow. This was another aspect of the cultural transfer that was not so much delimiting the West's frontier sectorally as dissolving it. Ironically, when this plough is first evident to us, in the sixth century, it is so among the Slavs. In the twelfth, axial Europe as a whole was imbued with 'a passion for the mechanisation of industry' unprecedented in its experience.[101] Often when an idea was adopted from the East, it was modified in the process. Conceived of in Persia with a vertical axle, the windmill was given a more efficient horizontal one by the Europeans.[102]

Two equestrian innovations diffused from the western borderlands of Siberia: a region not so far from the first confirmed travel on horseback, this east of the River Dneiper, *c.* 6000 BP.[103] A 'modern' harness arrived in Latin Europe in the eighth century; and from the time of the Bayeux tapestry (*c.* 1100) is depicted increasingly. Likewise, nailed iron horseshoes were well known across Europe by then.[104] Horses were slow to replace oxen before the plough, but they were making substantial inroads in Europe's haulage sector by 1100.[105]

It has therefore been said that the horse can stand alongside climate improvement as a factor critically enhancing medieval agriculture.[106] Threshing by millpower also made a big difference. Then again, the customary growing of crops in allocated strips within an open field rotation (mainly three fields per village north of the Alps; two to the south) spread the risk of harvest failure – a circumstance which, in itself, should have encouraged the peasantry to be bold with innovation. However, the poverty-trapped and paternalistic manorial setting was not in other aspects conducive. Something one does at last find by the fourteenth century, however, is a burgeoning sense of the restorative power for soil of legumes. On the Bishop of Winchester's estates (spread across seven counties in the south of England) the acreage of legumes proportional to that under grain soared from 0.97 per cent in 1300 to 8.26 in 1345.[107]

Ever since the pioneering work of Thorold Rogers in the nineteenth century, much attention has been paid to the movement of agricultural prices in England since the High Middle Ages.[108] Yet tracing the sequences remains difficult. The records pre-1200 are too sparse to set the scene well. Still, there are indications of a Malthusian tendency episodically developing as the thirteenth century progressed. On half-century averaging, English wheat yields per acre rose maybe 10 to 12 per cent from 1275 to 1325,[109] a rate something like that for population increase. On seven-year moving averages, the prices of all the major grains multiplied 2.2 to 2.4 times during the thirteenth.[110] That wheat failed to move ahead of the poorer grains confirms that, until the early fifteenth century in fact, there was no general tendency for it to contribute more of the bread corn than before.[111] This rigidity was encouraged by cooler, damper weather and reflected how near to famine a late medieval peasant could often be. This is further borne out by marked reductions in individual land-holdings during the thirteenth century.[112] On the other hand, tabulations from a Norfolk manor do show the proportion of a harvest worker's food budget spent on bread falling from 45–50 per cent to 35–40 through the first half of the fourteenth.[113] His diet was becoming rather more exotic.

All in all, one cannot simply say English medieval agriculture was trapped in a *Lebensraum* gridlock. That could hardly have been the case while grain yields per unit area were still five to ten times lower than in modern times. Nor can pressure on land be described as absolute as long as the internal frontiers existed. Wetland reclamation apart, their early medieval advance can here, too, be well expressed in terms of altitude gains. One source speaks of the tree line across the northern half of Europe characteristically being 80 metres higher in 1300 than it is today, and of the limits to cultivation as typically 60 metres higher.[114] Another perceives 'at least 100 metres in altitude' gained for cultivation in southern England compared with pre-800.[115] These reckonings for the cultivated limits are effectively equivalent, and do represent received wisdom. For when a median lapse of temperature with height is applied to those altitude figures, the results are compatible enough with the notion that around 1300 the mean temperature across axial Europe was about a degree Celsius higher than it was in 800 or than it has lately been.

Granted, the advances are rather more conservative than those proposed elsewhere for south Poland and for the middle Rhine. But it may well be these districts further from the sea were the more responsive to climate forcing. One recognises in these instances, too, that any altitude gain will not have been just a function of change in the local ecology. It will also have been governed by the economic parameters. Nor can ecological ambience be defined simply in terms of the annual mean for air temperature. Many other aspects, atmospheric and landscape, will have figured. Through the drying eleventh century, English husbandmen choosing arable sites had eschewed sandy soils in favour of more retentive clays, notably the clay-with-flints often left through differential erosion (over geologic time-frames) along the tops of chalk or limestone escarpments.[116] Wetter conditions would be liable to invert those priorities. Soon, however, a strong disposition developed to turn marginal land (especially upland) into sheep pasture. Spain has been cited. In Italy, too, the regulation of sheep transhumance was a major theme by the twelfth century. But from

1050 through 1300 England was quite the biggest wool exporter, not least to the merchants in Flanders and Florence then so dominant in the Continent's cloth trade.

The upland ranch was a setting far removed in spirit from the strip-farmed manor. Correspondingly, Eileen Power, a pioneer historian of medieval England's wool trade, averred that, in the twelfth and thirteenth centuries, those parts of England 'marked by exceptional freedom' were largely those characterised by sheep farms.[117] But two caveats must be entered. The one is that, in Yorkshire at least, the footloose social elements well mobilised by the Cistercian abbeys from 1128 were somewhat a legacy of William the Conqueror's punitive repression. The other is that in England, perhaps more than elsewhere, the Cistercians themselves sometimes resettled coercively the pre-existing peasantry.[118] All the same, sheep farming was part of a process whereby, against the background of climatic amelioration, the north of England had by 1300 drawn closer economically to the south.[119]

This rise of a quite detached pasture sector must have constrained the upward movement of arable locally. Judging how much, however, is complicated by the distribution of the new pastures not being just a function of climate and landscape. Thus much of East Anglia was eminently suited to growing wheat. Yet by 1300 market access had created a singularly 'intensive livestock economy' in this English region.[120] Two general inferences can be drawn. The one is that the direct effect at this time of climate change on agrarian margins was a sight less than lapse rates in air temperature might lead us to expect. The other is that we need from the archaeologists more local information on this score.

As already noted, the geography of viticulture was visibly under market influence. Nevertheless outer limits were set quite categorically by climate. Allowing for the needs of particular vintages and also for soil and topography, the climate requirements for wine grapes can be outlined thus: a longish ripening season with plenty of sunshine and daily mean temperatures exceeding 10°C (50°F), as a rule by a good margin; little or no frost once flowering has begun and no severe frost otherwise; not much moisture while the grapes ripen; and minimal wind. Following on from a mid-nineteenth-century French study, American researchers compiled a heat summation table in 1944 that, in California at least, has proved helpful. If the cumulative degree-days above a 50°F baseline are rather less than 2,500, that will be good for light dry table wines. For full-bodied wines, either dry or sweet, 3,000 to 3,500 is desirable. And so on.[121] It is important to remember that, although the imbibing of wine is very obviously the main aspiration behind viticulture, the unfermented grape has great appeal also. However, this only partially explains why vineyards fared so well under Mediterranean Islam.[122]

In the Rhine valley, viticulture had by no means been knocked out by barbarian invasion. On the contrary, it had been extending beyond its Roman limits since the seventh century. For one thing, Christian missionaries had taken the noble art across the Rhine, once an imperial boundary. By the twelfth, Cistercian and Carthusian monks were laying down vineyards in upland hollows. To the laity also, viticulture appealed in an era of population growth. It was some eight times as labour-intensive as ordinary arable.[123]

That the area under the vine in south west Germany was not to peak out until 1500 shows that various factors were operative. But climate trends modulated the ultimate limits. They explain why the vineyard area in the northerly Main valley could then be four times the twentieth-century norm.[124] They also explain why Alsace could turn so heavily to the production of fortified wine, a departure that probably required 4,000 degree-days on the de Candolle scale just cited.

In England, one sees no sign of wine production in Roman times. Nor is there hard proof of much until the practice was promoted by the Norman invaders. Though the Venerable

Bede wrote that 'wines are cultivated' in England and Ireland, up in Northumbria he was ill-placed to be sure. Likewise, too much has been made of a biblical allusion by King Alfred in the preface to his laws.[125] A royal charter of 955 did grant a vineyard to the monks of Glastonbury Abbey, but maybe just to provide fermented grapes for the Eucharist. But in the Domesday survey, 12 monastic vineyards and 26 lay ones are recorded.[126]

Once established, English wine production made real headway. The monk William of Malmesbury (*c.* 1096–1143) was a prolific recorder of early and contemporary English history. He fulsomely praised the Gloucestershire vintages. Those of Worcester were similarly renowned. In Yorkshire, vineyards were established as far north as the 54th parallel of latitude.

However, the position of the English wine producers was to be compromised by geopolitics well before the weather turned against them in the fourteenth century. Shortly before becoming king in 1154, Henry II (d. 1189) had married the redoubtable Eleanor of Aquitaine. Her fiefs included Gascony. This stimulated the export of Gascon wine to England via the Gironde estuary, supplementing the export of quality French vintages via the mouth of the Seine in English-held Normandy. By 1300, about 25 million gallons of wine left the Gironde annually, near to a quarter bound for England.[127]

A weakness of the south-west of France as a producer region today is the occasional wet summer. In the more Azorean regime of the High Middle Ages, that was probably less true; and, in any case, it will have applied more to the vineyards in England. An accelerating decline in English wine production can be traced from the late twelfth century. To the natural advantages the Gascons enjoyed can be added the privileges accorded their traders by the English crown. The background was that Gascony was continually under military threat from the French, particularly after they gained Normandy in 1204. One might divine the English motives as the preservation of a continental presence as an outlet for feudal martial energy. Otherwise prospering Gascony must be seen as a rather fractious and burdensome outlier of the English realm.[128] At all events, a quite violent popular reaction against the Gascons in England was to lead to their privileges being circumscribed in 1327 and hence to their English trade collapsing. But already English wine production had been ruined by their inroads and by terrible weather of late. An estimated 1,300 English commercial vineyards would before long be grubbed out.[129]

Wine figured even more than wool or salt in the upsurge of long-range commerce across axial Europe from the eleventh century.[130] Thus by 1250, Kraców was regularly receiving Rhenish wines via the Baltic as well as malmseys (see Chapter 1) via the Black Sea.[131] Soon cured fish was to loom large also. By 1200, inshore herring fisheries focusing on the Kattegat were being operated by Danes financed by the German ports. The catch was selling as far afield as Russia and Portugal.[132] By the thirteenth century, too, dried cod was being exported from Caithness and Orkney.[133] These Norwegian earldoms reverted to Scottish rule in 1202 and 1231 respectively as Viking lines of descent expired. Contrariwise fishery development up the Norwegian coast was to facilitate the Norwegian crown's long delayed extension of its authority to the North Cape and beyond.[134] Svalbard was discovered in 1194.

Until 1319, Norway and Sweden were separate. Under Haakon IV (king, 1217–63), Norway attained its medieval zenith, his splendid court at Bergen being especially strong in the patronage of Old Norse culture. As the bounds of fishing extended *pro tem*, so did those of agriculture. Hubert Lamb quoted a Scandinavian palaeoecologist as concluding that *c.* AD 800 to 1000 the tree line and arable limits rose 100 to 200 metres in the central valleys of Norway only to revert as decisively after 1300.[135] A levelling out of the advance as early as the turn of the millennium could be consistent with the organisation in wintertime of a north Scandinavian high-pressure circulation. Fishing and whaling may have pushed northwards longer, being geared more to the slowly rising sea temperatures of the North Atlantic Drift.

As important at continental level as the fish boom was that in mining, given that even iron was still much too scarce. Granted, the more ambitious attainments of the Romans (e.g. shafts to 200 metres at Cartagena) had been lost sight of. But from a low point *c.* 800 there was a slow mining revival, this being concentrated on the Alps by the eleventh to twelfth centuries. Yet to judge from Grove and Switsur (see Chapter 5), it will have coincided closely with the high medieval advance of the Alpine glaciers. But two informed comments bear on this paradox. Le Roy Ladurie remarks how few authenticated contemporary texts mention this glacial episode at all, a state of affairs that surely connotes low societal impact.[136] Obversely, John U. Nef (a pioneer historian of how technology interacts with social progress) wrote of valuable ores being exposed in the Alps at that time by the 'rushing torrents' consequent on seasonal snow-melt.[137]

Mining activity overall expanded markedly in the thirteenth century, partly through geographic spread. But in the early decades of the fourteenth, this progress ground almost to a halt. Nef attributed this to a changing economic climate, but more particularly to flooding as shaft mining came into use (for silver-bearing ores at least) from *c.* 1275. Northwards from the Alps, however, conditions were turning wetter than they had usually been in the Mediterranean mines of Antiquity. Yet the drainage now applied was improvised and haphazard, much inferior to Roman waterwheels and cochlea watershoots in, for example, Wales. Therefore, it would be hard not to endorse a conclusion reached in 1951 by Dr Steensburg of the National Museum in Copenhagen. In essence, this was that the crisis was too sudden, universal and ongoing not to be in part explained by the switch to a rainier climate. About the Gaslar mines in Germany it was stated in 1360 that water levels had been rising for half a century, all attempts at correction having been in vain. In Freiburg, unsuccessful attempts were made in 1365 and 1379 to install hoisting for water removal. In Bohemia, similar problems had arisen at Iglau in 1315, while the Dutchbrod mines had been abandoned as early as 1321.[138]

Though they may abstractly typecast the medieval 'ruling classes' as 'hostile to technology' or society as a whole as having been interested not in 'what moved but what was still',[139] the historians of the period extol how the watermill was adopted on a scale Classical Antiquity never contemplated. In Roman Britain few were installed. Yet even in Domesday England there would be 6,000. By 1300 watermills, together with windmills, exceeded 12,000. However, the number was declining by 1350.[140] Just what this progression meant, relative to English population and income growth, will have depended on the energy throughputs of the mills; that will have been a function of technical gains as well as of the sites selected. The cumulative flow of air or water will have been the key measure of site adequacy.

The monopolistic position of manorial watermills was liable to challenge by a peasantry resolved, maybe in the face of violent seigneurial intrusion, to retain their own handmills. Seeing how localised that particular class conflict would usually be, the indications thereof become surprisingly strong. Besides, the lords and abbots, too, had to reckon with frost, drought, flood and war – the more so in the fourteenth century. Accordingly, there 'was not a single fortress in the Middle Ages that did not have its handmills.'[141]

After their introduction from the East *c.* 1175, windmills proliferated rapidly in part because they were necessarily the means of draining polders reclaimed from marsh or sea.

Meanwhile, watermills were put to a variety of uses apart from corn milling. These included pulping rags for paper, beating hides in the tannery, and hammering iron.

As so often, urbanisation is a goodish indicator of economic development: meaning the ongoing raising of living standards in part through more specialisation and trade. What recent research has done, certainly in the case of England, is accent the rate of medieval urban growth between the eleventh and thirteenth centuries inclusive but especially between 1180 and 1290. Thus the population estimates for the larger towns have tended to rise sharply. In 1976, London was authoritatively credited with 35,000 inhabitants in 1400;[142] that probably meant 50,000 in 1300, pre-Black Death. Now the figure of 80,000 is rendered for 1300 with comparable authority. At the same time, looking outside the formalised network of boroughs and markets has led to a big increase in the number of settlements credited with urban characteristics.[143] One reckoning is that, by the early fourteenth century, there were no fewer than 700. No matter that many would have had but a few hundred inhabitants. The total number of town dwellers will probably have been a million in 1300, five times the 1086 Domesday assessment.[144]

To encompass the small places may be incidentally to emphasise the big role barter had long played in transactions, but of that there is more direct evidence. The coinage in circulation is estimated to have increased 30 to 40 times over the span 1086 to 1300, but prices only four times.[145] Allowing for population increase and rising living standards, it is still quite impossible to square this paradox unless one assumes that, over the said time-frame, the proportion of all transactions conducted with currency expanded from a very minor fraction to a major one. To assume a collateral increase in the velocity of currency circulation, as well one might, is to emphasise the point further.

Nodal location within the matrices of trade could be crucial to a city or region. A striking example was how the cities of north Italy (and, above all, Venice) benefited from the Crusades. Bringing out his *magnum opus* in the same year (and for the same publisher) as Gibbon did his, the great free-market economist of the Scottish Enlightenment, Adam Smith, had reached such a conclusion. He averred that, although the Crusades 'must necessarily have retarded the progress of the greater part of Europe', they 'were certainly favourable to that of some Italian cities.'[146]

Granted, one may still ask whether differential climate change may have been in play early on as well. In this dimension, the Mediterranean is highly idiosyncratic. Current GCM projections of trends in winter precipitation show much sharper contrasts across short distances than any other part of Europe does.[147] Therefore one should not be too surprised at the indications of north-central Italy turning significantly wetter (and cooler) secularly, *c.* AD 1175.[148] If these indications are confirmed and are matched on the Lombardy plain, they could allow of agriculture's being an economic pacemaker in that region. Such confirmation and generalisation may be in prospect in that Hubert Lamb reckoned the number of major floods/wet years recorded per half century in Italy as a whole rose continually from nil in the late tenth century to nine in the late thirteenth.[149]

That there was economic synergy between town and country in the Italian north is suggested by the widespread commutation of feudal obligations from the tenth century. So is it, alas perhaps, by the extensive felling of woodland from that time, this partly on account of timber shortage. So is it, too, by the commercial and industrial progress of the ports and, hard behind, of Florence, Milan and Pavia. The population of Florence doubled to 90,000 in the half century to 1331.[150]

All tenth-century Italy had known depression and famine periodically. But by the late twelfth the Italian rural north contrasted sharply with the peninsular south. There a once buoyant agricultural sector had lapsed into secular decline with disorder a concomitant, this probably a consequence of worsening aridity as climatic zones shifted.[151] Over the past two centuries, land values had been rising very steadily across Tuscany and Lombardy, and reclamation had got well under way. Investment was taking place in water control to check winter flooding and in irrigation to ease summer drought.[152] The Cistercians had a trunk canal working near Milan in 1138, but the main period of development in this regard was 1300 to 1450.[153] It is possible to observe the evolution then 'of a new agricultural landscape of irrigated grass and arable fields which was destined to become, before 1500, the admiration of Europe.'[154] Initially more Alpine snows in winter will have better irrigated the Po valley in summer. Conversely, three great aqueducts originally built to supply Imperial Rome were allowed to slide into disrepair and disuse from the twelfth century, despite lavish renovation *c.* AD 775 to 825.[155] Rome was too far south to remain an economic hub under changing conditions. Even further was Amalfi.

Hard to explain climatically is how, rather suddenly in the late eleventh century, Flanders emerges as the economic pacemaker of north-west Europe. Most of its soil was poor and much of it dank. Also the fact that Flanders was, even by the lights of the time, 'an extraordinarily violent region' internally would normally be read as an adverse commentary on its prospects.[156] Nevertheless, one may proffer at least a tentative explanation of this lift-off. The territory was plumb in line to benefit from the ridging of the Azorean High that had made much of western Europe warmer and drier. Even by late Carolingian times, the population density had been exceptionally high in some areas, and, since the turn of the millennium, had risen further.[157] Some of the small towns thence created were defensible yet accessible in deeply estuarine locations. By 1100, emigrant 'Men of Flanders' were conspicuous as land reclaimers, mercenaries and, of course, Crusaders. The severe sea floods of 1014 and 1042, well authenticated, had given a big impetus to marine reclamation at home. The *modus operandi* of that commitment largely dissolved such feudal bonds as still existed.

Sheep grazing was the best use to put the salt marshes to and also, initially at least, the polders created from them.[158] The local supply of fuller's earth for dyeing was good. A pool of surplus labour was to hand. An export trade in cloth was under way by the early thirteenth century, and already had a quality fraction.[159] Suffice to add that Lamb perceived a sharp rise in the proportion of dry to wet summers (near 50°N and 5°E) as between the first and second halves of the twelfth century.[160] If that did occur, hydrological easement will have helped economic emergence.

A crisis builds

The year 1300 was very successfully promoted by Pope Boniface VIII as a jubilee to anticipate the second coming of Jesus. This papal success was in spite of, yet also because of, a rising tide of social radicalism. There may be many explanations for this, medical ones included. One hypothesis current is that low medieval intakes of sugar (perhaps made all the lower if honey became scarcer and fruit less sweet as the weather turned less warm and sunny) induced collective anger, irritability and fatigue.[161] Second is that weather changes such as those here being considered may stimulate fungi associated with cereal grain; and their most general adverse effect on human consumers will be to lower disease resistance.[162] Particularly prevalent in parts of fourteenth-century Europe was the poisoning brought on by the ergot fungus.

Another stark reality is that the intellectual revival took a long time to sap the ardour with which the feudalistic aristocracy strove to remain ascendant. More and more they sought to commute feudal labour obligations to monetary rents, pressing for advantageous terms. In twelfth-century north Italy, they made the most of the land price inflation.[163] In England as late as the thirteenth century, there was actually a general reversion, labour dues perhaps doubling to cope with enlarged 'demesnes' – i.e. manorial home farms.[164] Against this obduracy, active peasant resistance built up only slowly and, so far as the materials of history are concerned, almost in obscurity. Nevertheless, it is clear that, even during the tenth to twelfth centuries, the firing of seigneurial halls spasmodically recurred anywhere and everywhere between Saxony and Brittany.[165]

One turning point was the bloody and sadistic crusade against the Albigensians, ending with the Treaty of Paris of 1229. The backlash impelling it came mainly from northern France, a region subject, like neighbouring Flanders, to a population explosion and likewise affected by the millenarian propensity endemic around the Meuse/lower Rhine since the First Crusade. Chiliastic manifestations – e.g. spontaneous departure to the Holy Land or reciprocal flagellations – were still most liable to erupt in the aftermath of epidemic or famine, an underlying hope initially being that God would select an ascetic redeemer to rise up within the Church.[166] But as Europe moved into the second half of the thirteenth century, the millenarian emphasis shifted towards social radicalism,[167] the ethos now being more akin to that of the ultra-Left anarcho-syndicalism of pre-1939 Andalusia let us say. Folk music and pagan ceremonies likewise captured a new rural mood.[168] And for several months in 1251 much of France endured the first wanderings of the *pastoureaux*, an angry though inchoate anti-feudal movement that had arisen among the shepherds and farmworkers of the French north. Soon a succession of local revolts occurred in the still turbulent Low Countries – e.g. in 1255, 1267, 1275 and 1280.

Nearly all the expressions of protest thus far referred to were ahead of the climate climax, 1275 to 1300. What this underlines is that the moderate but sustained economic boom was already giving rise to a great number of more particular problems of adjustment that existing institutions and accepted philosophies were ill adapted to coping with. Yet it was an age that did seek to resolve specific issues and thereby modulate general change. This applied to frontier colonisation and to the layout of new towns. It applied, vexatiously, to the division of income from ore mining.[169] It applied to constraining monetary inflation by pegging certain 'just' prices. It applied less formally to the Church's working out a *modus vivendi* with commercial laity (most notably in Italy) about when the interest rates on loans became 'usurious', a peculiarly sensitive aspect of the 'just price' question.[170]

Yet as intimated above, the problem of managing transition proved least acute where it had once seemed least tractable: in the commutation of labour dues. One consideration was that the feudal barons were no longer able to flex their military might to the extent they had in the eleventh century, everywhere from Catalonia[171] through France to Norman England. During the twelfth, the Lombard cities proved remarkably successful in curbing by their own military means the largely feudalistic forces of the Holy Roman Empire.[172] All that stopped them building an independent Lombardy state out of that was the endless rivalry between one city and the next. The Lombard League they first formed in 1167 staggered on fractiously until 1237 without ever formally renouncing the fealty its members ultimately owed to the Empire.[173] So much, once again, for the centralising proclivities the Wittfogel school would attach to hydraulic civilisations.

None the less, one does see here emerging, at city-state level, a territorial nationalism that would ultimately pose a fundamental challenge not only to the Empire but also to the papacy. Already the authority of the latter had receded a long way from when, in January 1077, the Holy Roman Emperor himself, Henry IV, had braved the Alps to travel to the village of Canossa in the Apennines, there to wait three days barefoot in the snow to plead penitently with Gregory VII to lift the excommunication and formal deposition lately put on him. Had his plea failed, Henry could well have fallen, such was the ability of the papacy at that moment in time to mobilise the German princes against him. The immediate bone of contention had been choosing the next Bishop of Milan.

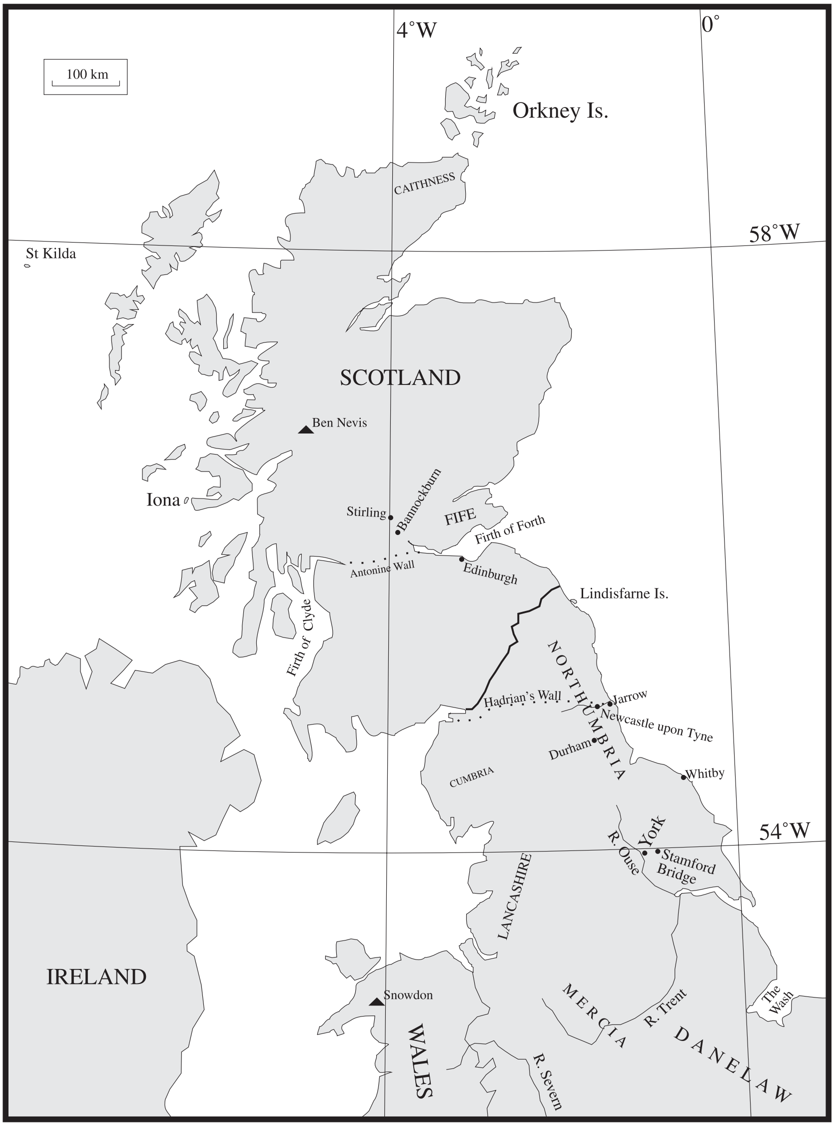
The Canossa episode would have been improbable much after 1100. Nor was papal ascendancy unassailable even before then. From 1077, fortunes alternated savagely in the struggle between Gregory and Henry. Also by then, pilgrims (and soon Crusaders as well) were bringing back from Asia Minor more of a dualist view of Creation itself, one that allowed of the autonomy of evil and thereby undermined the precept of an omnipotent Church. To which must be added the moral failure of the Crusades themselves: 'High ideals were besmirched by cruelty and greed, enterprise and endurance by a blind and narrow self-righteousness; and the Holy War itself was nothing more than a long act of intolerance in the name of God.'[174]

Duly, the moral authority of the papacy itself waned. This, together with its lack of military force, outweighed an ongoing organisational trend towards the more centralised control of a Church still getting richer. Moreover, a tendency for it to slide under the control of the emergent French nationhood was confirmed in 1309 when the new Pope, Clement V of Aquitaine, transferred the papal seat from 'distant, decayed and turbulent' Rome to Avignon. This supposedly temporary sojourn of the Holy See lasted 68 years, with Avignon emerging as 'a ceremonious and brilliant court, the most distinguished in Europe'.[175] It was followed by a Great Schism, forty years during which there were two or even three claimants to be Pope.

From 1305 to 1378, all Popes were French. Their dependence on the Paris government was underlined in 1314 when King Philip IV obliged Clement V finally to disband the Knights Templar, a former Crusading order now hated as prime money handlers. But this presumption on Philip's part was a fateful move against the papacy but also the Empire. A cult of the kingdom of France was abroad by 1300,[176] a cult infused by a justified pride in the University of Paris as the cosmopolitan 'real centre' of Catholic intellectualism.[177]

Something often said of nationhoods is that they need a territorial core. For France and England that was afforded by the Paris and London basins respectively. In other medieval instances, the cores were maritime areas. The prototype was the North Sea empire of King Canute (1014–35). Other examples include Denmark and the Baltic straits, especially 1202–26; Aragon and also Venice *c.* 1350; and Byzantium and the Aegean, especially with the contraction in Anatolia after Manzikert.[178] This inclination was part and parcel of a general orientation towards the sea,[179] for sound logistical reasons and perhaps in the light of what may have been a widely cast tendency (*pace* Brooks and Lamb) to reduced storminess through 1200.

Another comment made about statehoods is that they are forged in the crucible of war. Yet although the thirteenth century (best read here as 1180 to 1280) is very much a seed-bed of the nation-state, axial Europe was then remarkably free of what we today would call international violence, this in spite of deepening tensions in society at large. After the French victory over Imperial-led forces at Bouvines (1214), the larger polities avoided major wars. Not until 1297, at Stirling Bridge, did William Wallace strike the first blow against the idea that the English monarchy enjoyed formal suzerainty over Scotland, thus serving lethal notice that the Scottish national identity was firming up.[180] Thenceforward the struggle between Scotland and England exemplified the transition from a febrile yet peaceable thirteenth century to a much more tortured fourteenth.



Map 9.1 North Britain

On the English side of the border, the colonisation of wasteland abruptly peaked out *c.* 1300. In Cumbria, cultivation had by then reached altitudes not matched again till the Napoleonic Wars.[181] East of the Pennines and Cheviots, the evolution had been very similar. From Yorkshire into Scotland, the highest economic zone was pastoral – cattle, sheep, pigs and goats. Nevertheless, aerial photography has abundantly revealed twelfth- and thirteenth-century ploughings in locations and at heights that make it 'impossible to doubt that the climate was more favourable for cultivation than today.' Population density in the uplands was often greater than now.[182]

In the fourteenth century, the outcome of the latest pitched battle would determine how free the Scots felt to raid across the border. In 1298 the English gained the day at Falkirk, but in 1314 were to be worsted terribly at Bannockburn. In 1346 at Neville's Cross, outside Durham, it was the Scots who were routed. So between those last two dates there will have been many Scottish incursions. It had been a time, too, of general agricultural recession. But patchy though the evidence still is, it does suggest that the aggravation of recession by war tended to be less severe in the raided areas than once assumed.[183] A corollary might be that climate variation affected farming more directly than was supposed.

What was not to be shaken was the English state. England was too well to the fore in the internal development of state power. Thus during the reign of Richard the Lionheart (1189–99), the state machine proved able to function well with the king himself absent abroad almost the whole time. During that century, a very professional Royal Exchequer had been created; and in the Runnymede confrontation with King John in 1215 the barons themselves would be endorsing, more or less, the principle of the royal oversight of justice. By 1300, the monarchy was legislating and taxing ever more widely. Export taxes were being applied, haphazardly, to wool and other commodities to (a) gain revenue, (b) encourage the indigenous cloth trade, and (c) preserve military security. Officials and judges were also active at shire level.

Some continental polities established representative assemblies of barons and/or burghers earlier in the thirteenth century than did England. Nearly every European government had both a chancery and a treasury in place by 1300. Oddly though, there was as consistently a lack of professional institutions in the spheres of foreign intelligence, foreign policy and defence planning. Nor were specialised agencies for socio-economic management established except in quasi-hydraulic north Italy. And otherwise, behind the classicisms, the city-states there varied widely as regards their political cultures. From 1300, however, a trend towards despotism was strong among them as was one towards endemic unrest among their less skilled workers.[184]

All in all, one can readily hear the verdict delivered in a Princeton study that 'Europeans had created their state system only in the nick of time' in terms of coping with the long drawn-out crisis well under way by 1275, somewhat ahead of climate decline.[185] Land shortage in an absolute sense can be discounted. But those upland margins made accessible to farming by climate improvement had largely been taken up. Therefore a tendency for land prices and rentals to rise faster than inflation in much of western Europe was a major reason why real wage levels in, for instance, England fell by maybe a third in the second half of the thirteenth century.[186] What can further be presumed is that on the new frontiers of economic development, metaphorical as well as territorial, there was a diversity of 'growing pains' that the new statehoods were ill adapted to cope with institutionally, and in view of their lack of human and material resources and of operational experience.

An instructive example is smoke pollution in London. The supply of firewood faggots and charcoal from the woodlands of the dozen or so counties around could have well sustained the capital through the year 1300. However, the transportation thereof was often difficult. Besides, quality coal afforded the best means of raising the high temperatures sought to make good lime for masonry. So by the early thirteenth century 'sea coal' was being imported down the coast from Newcastle upon Tyne. From 1285 an official standing commission monitored the smoke effect; and in 1306 a ban on sea coal was proclaimed, culprits being liable to 'grievous ransoms'. However, this ban operated unevenly while the emphasis shifted in the decades ahead towards making ready to regulate particular activities, site location, working hours or chimney stack heights.[187]

Also to weigh in the balance as best one may is the effect China may have had, via the hemispheric trading network, on economic tendencies in Europe. The Mongol conquest was disruptive not just in that all such episodes must be but on account, too, of the swift application of a strategy of curtailing maritime trade (via the Arabs) between Hangchow and the West so as to consolidate links across the Mongol imperium. But the latter was now decidedly fissiparous, a situation aggravated by the migration of a million Mongolian people to China and their acculturation there. [188]

That external trade adjusted to these convulsive changes is confirmed, however, in sundry byways of Chinese art history. In particular, the application (in the early fourteenth century) of 'Mohammedan blue' cobalt underglaze was a milestone in the evolution of Chinese porcelain.[189] Even apart from disease transmission, however, questions remain. To what extent was the trade deficit China developed in the thirteenth century contained by (a) the export of silver, this perhaps easing Europe's liquidity crisis, or (b) the curtailment of foreign imports? Was the resumption of overland links much impeded by the fractiousness within the Mongol realm? What, indeed, might that have owed to climate trends on the steppes? To what extent was the China trade being displaced by that burgeoning with south-east Asia?[190] And did climate change in the latter (see Chapter 5) figure in that displacement?

It is tempting to look for a decisive connection between the travails of mighty China and the crisis breaking in Europe. After all, 1280 or thereabouts was a watershed in both locales, marking in China's case the completion of the Mongol takeover. But the intercontinental trade in question revolved around oriental luxuries. Even allowing in due course for bullion inflows, it cannot have been as basic for Europe as its indigenous farms and fisheries. Correspondingly, the changes of climate that demonstrably affected Europeans were those within their own bounds.

A crisis deepens

Humankind was unwittingly affecting the medieval climate and hydrology in various ways. The reduction in atmospheric CO_2 as a second derivative of deforestation has been mentioned. Wetland reclamation will have diminished the efflux of methane, though paddy field creation in the East will have worked contrariwise. The clearance of land for arable will have led not only to albedo enhancement but also (as archival sources confirm) to faster and less regular rainfall run-off.

Unstable stream flows with silting can compromise river fish. Navigation may then be problematic as well. Erosion and deposition may also increase to a damaging extent.[191] This last factor accentuated flooding in thirteenth-century Poland, even though forest clearance was not to peak there until the sixteenth.[192]

Increasingly from 1000 through 1300, the western Europeans compensated for the strains on the natural riverine habitat by creating fish ponds. By 1350, eastern Europe was following suit. Meanwhile the east and south-east of the Continent tended to proffer a wider range of fish species by dint of having experienced less oppressively the last big glaciation. And as the 'little climatic optimum' drew near, there was a trend throughout towards warmth-loving species. Overall, pond and river fishing seems to have been more important in this era than was sea fishing.[193] The latter though, may have been more responsive to climate change because (a) it had less experience of temperature fluctuation otherwise and (b) it was much better placed to react through migration.

Climate downturn

To assess the impact for any given region of the climate downturn from *c.* 1275 that trend must first be viewed hemispherically. Acidity measurements from core ice from Crête in central Greenland reveal a volcanic eruption at an unknown location in 1257/8 which generated four times as much acidity as did Krakatoa in 1883. That event excepted, a sharp contrast can be drawn between very low levels of vulcanism, 1110 to 1265, and the highish incidence from then to 1500. Moreover, this second phase is characterised by clusterings on decadal timescales – notably, for our immediate purposes, 1285 to 1300, 1310 to 1317, and 1340 through 1350.[194]

Obviously, vulcanism can affect *inter alia* the spread of pack ice. But so, too, can other factors, among them internal oceanic convolutions. Christian Pfister *et al.* believe that how the colder winters were distributed in the fourteenth century does suggest that North Atlantic deep water could have been a forcing agent.[195] That argument lends added interest to the spread of sea ice as an indicator, but also as a determinant, of wider change. Unfortunately the evidence for the critical Icelandic sector is piecemeal for the period 1250 to 1350, even when supplemented by data about Iceland itself. The general inference drawn by Astrid Ogilvie is as follows. The last two decades of the thirteenth century were severe in the winter half of most years but the first couple of the fourteenth were tolerably mild, 1313 excepted. Then 1320, 1321 and 1323 had severe weather with sea ice. After that, only 1331 and 1333 were as severe. In short, the accent was still on erraticism more than on a downward secular trend. Not until 1350 does the weather turn more consistently severe.[196]

Addressing next the influences from outside the Earth, one operates against the background of the Milankovitch long-term temperature decline. Of less certain relevance is the tidal theory the Swedish oceanographer, Otto Pettersson, first proposed in 1913. As related rather agnostically by his compatriot Gustaf Utterström in the course of a pathfinding article published in 1955, its gist is as follows. At high northern latitudes, a uniquely strong tide is generated every 1,800 years by a juxtaposition at winter solstice of Earth, Sun and Moon. Such an event was due in AD 1433; and every nine years or so each side of that climacteric, the said situation will be approximated to, though progressively less closely. These conjunctions may disrupt Arctic pack ice, thus releasing extra drift ice into the East Greenland and Labrador currents.[197] This surmise might help explain more severe Icelandic weather towards the end of the fourteenth century and thereby reinforce the impression of no downward trend in its first half. As Lamb argued, however, the tidal invigoration thus of the North Atlantic Drift was very possibly of more consequence, allowing of the transport northwards and eastwards of added warmth and salinity.[198]

Variation in the intensity of the Sun's radiation may have a more certain bearing. Quite the best delimitation of the Medieval Solar Maximum is that proffered by the Beryllium-10 cosmogenic isotope in the compacted snows of the South Pole. It registers a fall from a peak presence of 460,000 atoms per gram in AD 1075 to a low of 310,000 in 1130. Then in 1250 it starts to rise again, reaching a new peak of 520,000 in 1450. *En route*, it accommodates the Wolf Sunspot Minimum (1280–1330).[199] High ^{10}Be values connote low solar activity, therefore more cosmic ray penetration. Fluctuation in the Carbon-14 level is similarly used as an indicator.

A striking attribute of Europe's weather in its late medieval mode was erraticism. Otto Pettersson said as much in 1912;[200] others, Huntington included,[201] have done so since. A similar reaction was commonplace among contemporaries. The mounting perils of the natural world (though, above all, of the forest) were a major theme, both descriptively and metaphorically, in religious expositions.[202] But in assessing the erraticism, one must allow for our access to contemporary information roughly doubling for the first half of the fourteenth century.[203] Germane, too, is the ancient belief (still alive and well in the High Middle Ages) that unsettled weather betokened the monarch's being ill at ease with his people and therefore with God. But due allowances made, one can accept as a first approximation the sequence for eastern England, consensually depicted by its chroniclers: a warm and dry regime from 1272 to 1289; then one of unprecedented wetness and misery to 1326; and then more tolerable weather to 1350.[204]

Winter cold was especially dreaded. In 1205, the Thames at London had frozen thickly for many weeks. So was it too in 1269/70 and 1281/2. The year of the great eruption 1257/8 was most exceptionally wet across England.[205] From 1272 to 1294, vineyards around the Rhine endured a series of damaging frosts.[206] Then, on mainland Europe, no winter was mild, by twentieth-century standards, between 1305 and 1328. In two seasons, 1305/6 and 1322/3, the duration and intensity of the cold could match the worst these last 300 years (i.e. 1788/9 and 1962/3). In two more, most open water was ice-covered for weeks on end. After that (and especially post-1340), things improved a while.[207]

Throughout the area mainly covered by the Russian Chronicles (i.e. from Poland through to Novgorod), erraticism was endemic in the thirteenth and fourteenth centuries. In Poland, terrible summer rains or floods were recorded 1219, 1253, 1269, 1310 and 1315, while in 1279, 1281 and 1282 the accent was simply on famine. Further east, the chroniclers speak of droughts more. Grimly described is the Novgorod famine of 1215/16 with people eating pine bark. From western Russia in 1282 and Poland in 1315 come allegations that parents ate their children.[208]

Taken together with a steep secular rise in the Caspian's level after 1200, the accounts of more Polish rain and of erraticism further east leave the impression that an energetic polar front medially extended along the Baltic into north-west Russia much of the year. Not that this would exclude rises in mean annual temperature in northern Scandinavia in the course of the thirteenth century. In fact, a 21-year moving average of the Torneträsk tree-ring series in north Sweden anomalously shows strong oscillation between 1050 and 1300 but then little radical change until the bitter cold of the 1550 to 1750 era.[209]

During the early fourteenth century, sheep were not yet poised to replace arable at all extensively on upland margins or wherever. In England, at least, that contrasts with the period after 1350 about which a pioneer of this subject area remarked how 'many sheep enclosures passed by unnoticed as long as the Black Death could be invoked.'[210] In fact, the emphasis pre-1350 was less on what the Germans called *Wüstungen* – the wholesale abandonment of villages – and more on the piecemeal relinquishing of fractions of open fields. As much is clear from the implementation of Nonarum Inquisitiones, a parliamentary war grant to Edward III in 1342 of a ninth of the value of the corn, wool and lamb produced in the realm. Even so, a measured comparison with 1291 tithe records shows a significant acreage to have gone out of cultivation thus in the intervening years, most visibly in north Yorkshire, Shropshire, the vale of Oxford, the Chilterns and Sussex. A good proportion of these withdrawals apparently occurred in the first quarter of the fourteenth century.[211]

On Dartmoor, retrenchment was quite comprehensive. Rising to 620 metres, it rates as the grandest of the granitic bosses that form the flattish high moorlands of south-west England. In the Bronze Age (2000 to 500 BC) it had been worked up to 455 m, but a retreat to 300 m ensued with the cool and wet 'sub-Atlantic phase'. From AD 800 there was reoccupation to 395 m and by 1250 the moorland supported small communities as prosperous as those in the surrounding lowlands. But between then and 1400, over a hundred farmsteads and hamlets were given up, including all the 60 above 300 m.[212] Similarly in the Paris basin, the Brie district was settled latish, *c.* 1150 to 1225. Even so, quite a proportion of the *villeneuves* then created were being abandoned by 1335.[213]

The Dantean anomaly

Henceforward, historical climatologists are likely to pay more attention to the bad weather crisis of 1314–22 in northern Europe, the subject of keynote statements by Lucas in 1930 and Kershaw in 1973 yet otherwise long ignored in favour of the Black Death. The 1996 Princeton study by Chester Jordan does much to restore the balance. This abnormal weather spell I here presume to entitle the Dantean anomaly, Dante Alighieri of Florence having died in 1321.

An aspect of the neglect of this episode hitherto is that those who collate climate data have not usually abstracted mean values applying just to those years. They do not neatly cover a recognised decade. But in 1967, Hermann Flohn highlighted 1310–50 as a time of erratic extremes. Overall it was very wet, not least in the Baltic, and sensibly cold the year round. Likewise, there were interludes of heat and drought.[214] Incomplete though the overlap is timewise, that reckoning looks compatible enough with the Hallam and Pfister assessments above. Nor is the eight- or nine-year interval here identified as anomalously bad impossible to reconcile with a compilation of seasonal moving averages (for France, the Low Countries, west Germany and north Italy) by Pierre Alexandre. This shows that the proportion of wet summers was lower overall 1300–50 than in the second half of the fourteenth century and similar, indeed, to the thirteenth.[215]

Having said that, the isotopic evidence from the Crête core shows a low-temperature turning point *c.* 1300 that is by no means as acute as ones in 1170 and 1370.[216] Nor is the concurrence with the Wolf Sunspot Minimum at all precise. Nor was the cluster of volcanic eruptions, 1310 to 1317, at all exceptional.[217] Nor does the secular trend upwards in the level of the Caspian appear to have altered materially in those years. However, one germane singularity is a decade of strongish tree-ring growth, 1313–22, at Torneträsk,[218] a circumstance that suggests a high frequency of relatively warm, moist southerlies and south-easterlies. Another judgement is that half of all the erosion in Germany the last 1,500 years occurred in the second and fourth decades of the fourteenth century. Arable slopes then averagely receded by 25 cm. The gullies cut into ridge-and-furrow tillage often forced its abandonment. The vigour of the fluvial processes was unsurpassed in that region any time in the Holocene.[219]

The Russian lands lie outside the ambit of this particular crisis. Buchinsky uncovered no major problems around this time apart from extensive droughts in 1309, 1325 and 1332.[220] Another Soviet compilation made an undocumented reference to famine in east Russia, 1314–16. But if its origins were climatic, they could hardly have linked directly to the west European pattern. Meanwhile Ireland may have been located eccentrically in that, although oak tree rings there indicate summer growth 10 to 22 per cent below normal in much of the 1320s, they average 6 per cent above in what are otherwise regarded as the critical years, 1315–18.[221] The local oaks did not find the rains excessive.

As to what the dynamic pattern was, the scenario envisaged by Hubert Lamb for the very wet summer of 1315, and hence for other such summertimes in that decade, looks persuasive.[222] It reads like his visionary insightfulness at its best and may be rendered thus. A high ridging axially down the Greenland plateau displaced southwards a polar front that therefore averagely lay from Newfoundland to the Po valley. This front extended little into the Mediterranean, a reading consistent with the near absence of records of active weather from there for these years. Occluding depressions often slowed up over west-central Europe, thus sustaining quasi-continuously a wide cyclonic circulation of moist and unstable air, polar in origin. This scenario gels well with Utterström's insight that, the deluges notwithstanding, 'the climate can be presumed to have been continental during the grievous years of 1309–1323.'[223] In the wintertimes, of course, the north Scandinavian high pressure will have been a dominant influence. The Siberian High will have been less influential than in most of the twentieth century.

There is a rider to add which just might be important *vis-à-vis* Lombardy. A tree-ring serial interpretation for 45°N, 10°E (in the middle Po valley) shows the weather in the 1310s to have been on the mild side.[224] If so, this will likely have been due to a *föhn* effect on prevailing west to north-westerly winds. An airstream ascending the Alps gains latent heat of condensation as clouds form within it, but these clouds then precipitate rain or snow. Therefore, less latent heat is lost through evaporation on the descent. The weather that side thereby turns drier and sunnier as well as warmer. On the face of it, that interpretation looks persuasive though it is important to remember that north of the Alps, too, tree-ring growth could be strong during that decade. A lot will have depended on exact location and on what the criticality was: temperature, sunlight, rainfall, wind, a combination of these, etc. The Swedish province of Varmland is another European location liable to benefit strongly from *föhn* warming.

When archival and other materials are taken year by year, the identity of the Dantean anomaly is firmly apparent. Across much of north-west Europe, an unduly wet summer in 1314 was followed in 1315 by one of continual torrents. Hay, wine and grain harvests were savaged. The weather obliged the French to abandon a punitive invasion of Flanders, apparently the wettest area of all.[225] Rumours of cannibalism against kidnapped children ran wild in England that winter. Come the spring, the country was gripped by famine with many deaths from enteric infection.[226] To cap everything, a comet was visible through the winter nights of 1315–16.

In terms of sustained downpours, 1316 was no better than the previous year. In 1317, a gross excess of rain was less ubiquitous. But that winter proved the harshest of all: four or five months of numbing cold. From April 1318, things improved generally but could be as bad as ever locally. Similarly, the years 1319–22 saw the weather revert often enough for them to be counted part of the catastrophe. A poor harvest in 1321/2 was followed by long spells of winter cold with much snow lie and with stretches of the North Sea freezing. A truly savage *pastoureaux* resurgence took place in France in 1320/1. Monks, priests and *les seigneurs* apart, its especial targets were Jews and lepers. Soon this millenarian excess was excommunicated and then put down.[227]

The pattern for the worst years is accorded some numerical confirmation by the account rolls of the Bishop of Winchester's far-flung estates in the south-eastern quadrant of England. Calculations of gross annual yields of grain per unit weight of seed (as derived from those manors with adequate data) are as follows. The average for 1209 to 1350 is 3.83, but for 1301–10 it is 4.02. For 1312 and 1313 taken together the figure is 4.48. Then the rating falls from 4.14 in 1314 to 2.47 in 1315 and to 2.11 in 1316. It is 3.33 and 5.07 in 1317 and 1318 respectively.[228]

The end of the Dantean anomaly can broadly be reckoned from 1322. For a while afterwards, however, certain places (e.g. Aachen) endured abnormally wet spells, sometimes interspersed with lengthy droughts.[229] In south-east England, floods and livestock epidemics again did grave damage in 1325 and 1326. But overall, the English experience was that the poorer, thinly populated regions were the more prone to a 'sharp but protracted downturn' in their fortunes.[230] The same will have applied elsewhere.

Estimates from southern England of an incremental mortality of 10 to 15 per cent of the population could well apply to the continental zone affected as well.[231] What should also be pondered is long-term damage to public health through undernourishment of the young from the womb onwards. Chester Jordan is surely right to see scope for an investigation as to whether this left the relevant age group more susceptible to the Black Death.[232] More immediately, there is bound to have been a big fall in the actual birth rate; but this will probably have been corrected (or overcorrected) in a very few years. Unfortunately, examination of the demographic dimension, too, is still constrained by our coming so late to a due recognition of 1314–22 as a singular time.

If any pre-modern rural population dropped by 15 per cent, one would expect the arable margins to have receded for that reason alone. A distinction might also be drawn between colonising initiatives well taken in response to previous weather trends and those ill judged from their inception. Thus the exhaustion of pre-existing arable often perceived in the thirteenth century (and sometimes still ascribed to fertility decline 'in the course of the Middle Ages'[233]) will normally have resulted from too intensive a usage in just the previous decade or two as demand rose and farmers waxed too sanguine.[234] If that could apply to established arable, it could have on new ground as well – sometimes more so. Always, too, sheer luck will have played a part, including with the weather. The Dantean anomaly appears to have been largely a matter of convective rain – i.e. heavy showers. Certain terrains will have been, then as now, especially prone to these rather chaotic events. Windward mountain valleys are an obvious case in point.

In this situation, the balance between the cultivated arable and the uncultivated (i.e. not sown) grassland mainly above it will often have been upset by outbreaks of animal and plant disease or, particularly in the case of planted crops, of failures to mature – e.g. grains or grapes not setting. Ergotism will have been more rife than ever. In the famine years, 1314–17, murrains became more endemic among sheep in Britain. Heavier rain in the summer half-year left these animals susceptible to liver fluke. Wintry springs compromised their lambing. Likewise serious murrain, probably rinderpest, afflicted British ruminants from 1317 to 1321.[235] Granted, across north-west Europe the previous two centuries, horses had replaced oxen extensively for inland transport and on peasant holdings.[236] But oxen were still valued as draught animals, not least on demesnes.

Wherever bad weather affected wine output, small family producers were more precariously placed than the monasteries, say. A commodity for long-distance trade even more in demand was salt. Evaporation pans by the sea worked less well in cool, damp and cloudy conditions. The brine wells of Lorraine and elsewhere were a more costly alternative. Accordingly, salt prices more than doubled during the 1310s. The cost in real terms of all commodities was forced up further by the effect of precipitation extremes on inland transport. Downpours made roads and rivers hard to negotiate. But droughts were liable to uncover river braiding plus man-strewn wreckage.[237]

Interpreting the 1314–22 crisis in terms of coherent patterns spatially is difficult and likely to remain so. Coherence and definition in the time dimension are already easier to achieve. Grain yields per unit of seed have already been cited, constituting as they do a core criterion by which medieval Europe often did an order of magnitude worse than the hydraulic agriculture of the ancient East and two orders (i.e. a hundredfold) worse than the best modern practice. The Bishop of Winchester's rolls plus other records also confirm a big contraction in tillage across England and elsewhere as mortality rose, while seed corn and manure ran short.[238] Fields in Thuringia, for instance, were left untilled for perhaps seven years on end.

The years 1315–17 afforded a classic instance of what the nineteenth century came to know as 'Giffen's Paradox': Sir Robert Giffen's observation that the pricier a staple food is, the more of it poor people will try to buy. On the Winchester estates in 1317, wheat prices were double their 1305–12 norm.[239] Having said that, the situation was further complicated by the approaching culmination of the 'price revolution' of 1180 to 1350. Money supply had increased as bullion production and imports did, coins were debased in terms of bullion content, and banks extended credit. The velocity of monetary circulation may have risen too, though that hypothesis is both debatable and untestable. The crux of the problem was the authorities' lack of the experience, theory and data needed to pursue clear monetary strategies consistently, particularly as bullion inflows levelled out. The surviving barter trade was an added complication. Besides, governments and banks had, as so recurrently since, agendas of their own. The former wanted a revenue flow, not least to be ready for war. The latter wanted good profits and assured stability, objectives the emergent international banks of north Italy were traumatically failing to achieve. In 1298, Siena's greatest bank, the Gran Tavola, had failed. Between 1302 and 1312, five Florentine ones had. A sixth was to follow in 1326.

Nevertheless, Tuscany and Lombardy survived these collapses and the 1314 to 1322 climate crisis rather well, aided no doubt by the investment in water control the previous couple of centuries. A more prevalent *föhn* effect will also have been helpful, certainly on higher ground to leeward (see p. 164). It was during this time, in fact, that Florence led the region to a position of primacy over Flanders in the long-distance trade in luxury cloth. Granted, the output of cloth pieces within Florence itself actually fell by a quarter between 1309 and 1339 but this related to the quality trend and to industrial devolution within Tuscany.[240] A strong take-up of England's quality wools bespoke a certain verve because the murrains its flocks endured from 1314 were in part upsurges of a sheep scab endemic from 1275. Since then, too, the weights of healthy English fleeces had been declining.[241] But the Florentines still preferred English wool at its best to Spanish merino or quasi-merino.

Admittedly north Italy experienced, early in the fourteenth century, the abrupt slowdown in net new investment and population growth general in western Europe then.[242] Even so, it avoided strife as severe as that which smote Flanders, internally and externally. Food riots were savagely suppressed in Florence itself during the north Italian famine of 1328–9. But that hardly compares with how in 1328 French troops (a) cut to pieces an improvised army of Flemish weavers and peasants seeking to win the new millennium by armed struggle and (b) went on to wreak 'a terrible vengeance' on Ypres and Bruges, the cities most implicated.[243] Furthermore, it is from the chroniclers of the southern Low Countries that one hears most this fell decade or two about 'no lack of death', people 'grazing like cattle', and 'beggars without number'.[244] Excess urbanisation and a very overloaded hydrology will have been prime causes.

Fighting for sovereignty

Yet in their way the city-states of north Italy were fully embroiled in the fractious European quest for sovereign territorial polities that could be secure, internally and externally. As in the Alps and Germany, the basic issue still was relations with the Holy Roman imperium. But in Italy and also the Alps, the pressure towards *de facto* local sovereignty was that much more single-minded. In the Alps, indeed, the opening of the St Gotthard pass to regular through traffic *c.* 1230 led to head-on conflict between the Habsburgs and native free peasants. In 1291, three mountain valleys formed an alliance which went on to defeat the imperial forces at Morgarten in 1315. Herein lie the roots of the Swiss Confederation.

But the biggest wars and rumours of wars were those arising out of whether England should embrace all the British Isles and/or whether it should retain territory in France. In 1284, Wales had fallen to Edward I (reigned 1272–1307) but his failure to subdue Scotland led on to the disaster at Bannockburn at the very time the Dantean anomaly was making itself felt. This conjunction left the inept and personally insecure Edward II (reigned 1307–27) at the mercy of ruthless barons. That and the ongoing war needs induced him to send his men galloping through the countryside to tax heavily in kind all and sundry. The contemporary evidence (mainly collated, it seems, by friars and poor clergy) is of a deep and bitter brooding over the untimely impositions. In Lent 1315, a royal ordinance sought to stabilise the prices of livestock and victuals, though not to constrain corn prices.[245] That would have been impossible.

The plain fact was that monarchs still found it easier, up to a point at least, to extract dues from the downtrodden than to constrain the better off. They also found it easier to spend on the prospects for war than for social purposes. The ill consequences bore heavily on France. In 1328, the year the French crown passed to Philip VI, that monarchy directly controlled roughly half the territory between what were already vaguely perceived as *les limites naturelles*, the Rhine and the Pyrenees. But neither limit was secured. Defeat in battle by the Flemings at Courtrai in 1302 had underlined the lesson taught at nearby Bouvines almost a century before. France could never conquer Flanders at a stroke. Since when the English, using largely economic means for largely economic ends, had sought to prise Flanders and France further apart. Meanwhile, a French seizure of Gascony in 1294 had been reversed in 1303. Then through the climate crisis, 1314–25, this conflict between these two incipient nationhoods had smouldered on unresolved.

In the more salubrious years of the 1330s, their mutual antagonism was massively recharged. In 1337, Edward III of England (reigned 1327–77) flatly accused Philip VI of backing the Scots, an accusation that triggered the 'Hundred Years War'. Le Roy Ladurie has stressed how much that dragging out of misery was worsened by the soldiery carelessly spreading disease and destroying rural capital.[246] The trouble was the pattern of conflict. The French failed to expel the English in a decisive battle. They were to lose the three big encounters (Crécy, 1346; Poitiers, 1356; and Agincourt, 1415), in each case because the English responded better to wet conditions on the day. Between times campaigning was *chevauchée* – endless skirmishes and punitive raids.

The contrast between the propensity of the new monarchies to wage war and their inadequacy in other respects was bound to engender discontent that was by no means confined to the poorest. Violent reaction in the 1314–30 period included the deposition of Louis X of France in 1316 and the searing assassination of Edward II in 1327. The expulsion of King Birka from Sweden in 1319 was not connected directly. But the bitter and, indeed, violent struggle involving Pope John XXII at Avignon (1316–34) and Louis IV of Bavaria, a struggle over whether the latter's election as Holy Roman Emperor should be confirmed, did have linkage. Each could be challenged to explain their conspicuous aggrandisement in an age of penury.

A crisis within a crisis

The climate perturbation of 1314 to 1322 (or, if one prefers, 1326) was a western European phenomenon. It was not part of abnormal erraticism globally. Had such a departure for that length of time been global, a strong El Niño might have figured in it. In fact, it does not. Let us again use the Indian monsoon as a proxy via the nilometer readings at Cairo. Only 1313 plus two other years within or near the definable span (namely, 1321 and 1326) show a flood deficiency. All three instances are at the minimal end of the deviation scale, the confidence in each assessment being moderate.[247] Firm indications of several really weak monsoons grouped closely would have connoted El Niño vigour. Apparently, too, the likelihood of that correlation being discernible would have been the greater during a secular inclination towards weak monsoons expressed in low Nile floods;[248] and Hassan if not Quinn is persuaded that the years in question were within an era of generally low floods at Cairo.[249] All in all, the Dantean anomaly does not exemplify what little we currently discern of what may in any case be a subordinate teleconnection between El Niño and climate fluctuations in Europe (see Chapter 2).

So if the anomaly is not demonstrably part of a globally synchronous aberration, it is best seen as an extreme expression within western Europe of the overall deterioration that had set in climate-wise late in the thirteenth century. Simply on the basis of 'roundabouts and swings', therefore, one ought not to be surprised if the regional climate turned out better in the decades to follow. In fact, it did. But that does not negate the proposition that the fourteenth century as a whole lay within a process of climatic decline that was proceeding essentially worldwide into the Little Ice Age, and which, so far as axial Europe is concerned, began *c.* 1275 with the increased storminess and precipitation. One can *a priori* feel confidence in the Little Ice Age being worldwide because the identifiable influences are nearly all planetary in their direct impact. This is true of the astronomical cycles, solar radiation, vulcanism and the carbon cycle. No matter that it will not apply as readily to any interventions by oceanic deep water. Suffice to add that a perception that much of the world (India, the Far East, the Pacific islands, Central America, Greenland . . .) shared Europe's general experience of a climate-driven downturn through the fourteenth century is well established. Early on Huntington gave vent to the idea.[250] Lately its acceptance in the Brandeis analysis of secular currency and price waves shows how far it has already spread beyond the ranks of climatology.[251]

Moreover, this downturn from 1275 or thereabouts undoubtedly played a part in the economic turndown or levelling out of Europe in the late thirteenth century. As suggested above, however, this is manifested first and foremost in managerial confusion at the highest level, confusion most visibly about currency but extending to other matters. That the crisis was not absolutely Malthusian is well confirmed by a résumé of estimated trends in French land prices (in grams of silver per hectare) as between 1201–50 and 1301–50. In the Moselle basin, there was a modest net rise from 734 to 928, but in Royal France a fall from 806 to 745.[252] Such findings point towards the conclusion that Europe might, in principle, have come through this economic recession more smoothly than it did. Here 'in principle' perhaps means except for the Dantean anomaly.

Even as things did transpire, there is much in Joseph Strayer's depiction of the 'promise of the 14th century':[253] a promise forever epitomised by Dante with his literary virtuosity, deistic sense of the unity of all things, appreciation of philosophical issues, awareness of political principles, and, not least, regard for science. At a time when Islamic, Indian and Chinese science were at long last faltering, European science was gradually advancing, especially on the applied side. The blast furnace, artillery barrel, spindle wheel and mechanical clock all exemplified this. Meanwhile, the distinction newly being drawn between philosophy and theology favoured freer expression all round.

Independent colleges of higher education were founded abundantly across Europe, above

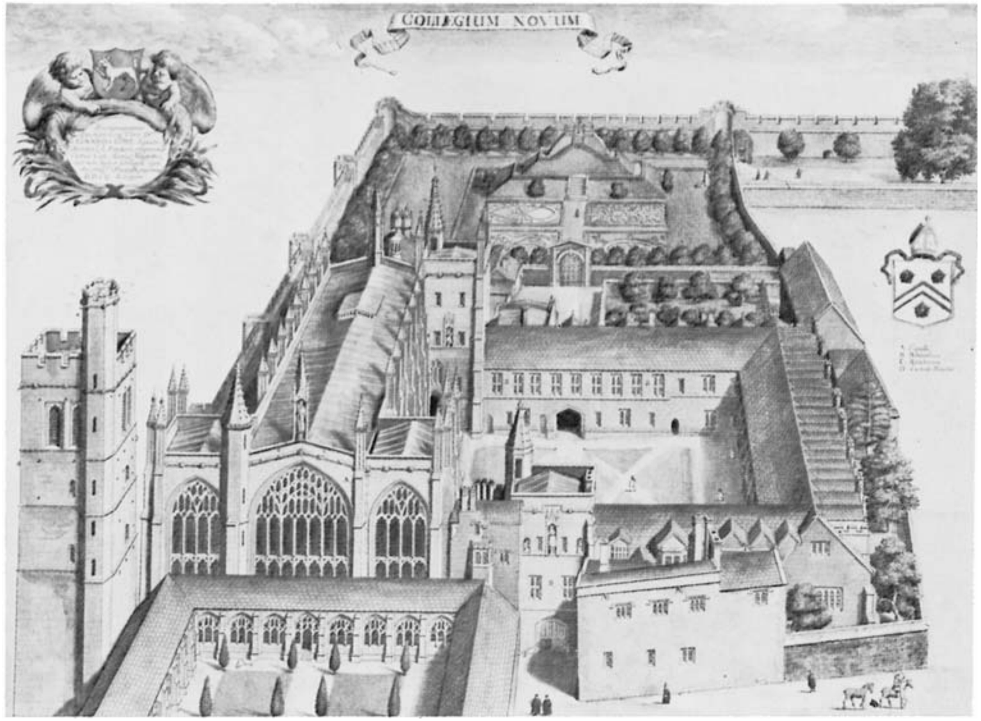


Figure 9.3 New College, Oxford, founded 1379. David Loggam's engraving of 1675 from 'Oxima Mustrata'

Source: by permission of the Warden and Fellows, New College, Oxford all in war-torn France. In a seminal study of the 'forward movement' of the fourteenth century, 25 new colleges are listed for the thirteenth of which 20 were in France; 87 are listed for the fourteenth, 54 of them in France (see Figure 9.3).[254] To an extent, this was a consolidation of an attitudinal shift towards a less Church-oriented society in the western Europe of the thirteenth century.[255] One aim was to provide personnel for the emergent sovereign statehoods: to sit on representative councils (advisory, legislative or executive) and to staff professional bureaucracies. Yet it also involved a major advance for academic freedom. A striking claim made for the fourteenth century is that 'no power – king, pope, bishop, ecclesiastical or lay authority – ever attempted to press its own candidates for college fellowships.'[256] What the possibilities may have been on the diplomatic front for similarly benign progress was the subject of illuminative comment by Sir Maurice Powicke in his 1952 contribution to the *Oxford History of England*. The illumination resides in his not then being exercised by ecological imbalances, monetary confusion or other ambient causes. His concern was simply with the day-to-day political process.

A conciliatory visionary, Gregory X, had been Pope from 1271 to 1276. At the outset, he resolved to (a) pursue ecclesiastical reform, (b) respond positively to overtures from Constantinople for the reunification of the Catholic and Orthodox churches, (c) build a *modus vivendi* in Germany over the election and role of the Emperor, and (d) honour an inherited commitment to launch a crusade. The Crusade proposal repeatedly fell on ears profoundly deaf, an outcome Gregory may not have regretted. Progress made with stabilising the situation within the Empire was undercut by a prior Angevin French takeover of Sicily, this partly in pursuance of the late-medieval illusion that the island remained a 'source of enormous wealth'[257] and partly on account of the leverage its location proffered for geopolitical adventurism. The reunification of the Latin and Eastern Orthodox Churches was formally proclaimed at the Ecumenical Council at Lyons in 1274 but was to come to nothing because of rank-and-file opposition on both sides. Ecclesiastical reform would soon be subsumed by the question of the survival of the papacy itself.

Powicke attributed these poor results to the loss, after the death in 1270 of Louis IX of France (St Louis from 1297), of 'the restraints which had seemed to give a moral sanction to the new order in western politics.'[258] That Louis had been a monarch of high standing is undeniable, vitiated somewhat though he was by Sicily and by undue religious fervour. But another way to look at Pope Gregory's endeavours could be to say the response they elicited would have sufficed to build a new moral order, had Europe moved through the first quarter of the fourteenth century more smoothly than the Dantean anomaly allowed.

Outer Europe

A review of the situation in areas peripheral to the anomaly lends some support to this view. Starting with Iceland, one may note a research review that found the period 1270–1390 among the worst in its history for 'bad year' frequency.[259] No doubt this is a reason why the union with Norway in 1261 worked out in practice to be far less liberal (in terms of political and judicial devolution) than had been envisaged, and why it failed to yield the prosperity looked for.[260] But the fact that the Black Death did not arrive in Iceland until just after 1400 reminds one that, in human historical terms, the country was outside the European mainstream. The heavy dependence on very low-intensity sheep grazing also betokens this.

Analyses of settlement patterns in the late Middle Ages in Scandinavia other than Iceland seem not to take account of the N–S climate divergence identifiable via the Briffa tree-ring series and so on. Nevertheless, two accounts show in their respective ways how involuted the relationship between climate and settlement may be in those latitudes. The one sees the proportion of independent farmers in Denmark as about half in 1250 but then falling steeply, driven partly by a quest for physical protection via hierarchical grouping at a time of internal tension.[261] The other argues, albeit very theoretically, that in Norway the cultivated area had to expand from 800 through 1350 because of, not in spite of, a secular climate deterioration – probably cooling. More land was acquired to make ends meet.[262] One is not obliged to attach too much weight to either argument to take the point about complex causation. Nor did a secular deterioration of climate onset in Fenno-Scandinavia especially early or dramatically. There is 'no convincing evidence' of a general expansion of Scandinavian glaciers before the seventeenth century.[263] Acute Baltic freeze-ups in 1303 and 1306/7 are best seen as singularities.

Against a still tolerable background weather-wise, the Hansa, an association of towns engaged in northern long-distance trade, flourished considerably. It stemmed from a treaty of mutual protection between Lübeck and Hamburg in 1241. At its peak *c.* 1375, the Hansa had 100 or so member towns, about a score of which modelled their constitution and legal systems directly on Lübeck's. It had facilities as far afield as London, Novgorod and Venice.

Of the towns with Hansa connections, only London, Antwerp, Cologne and, of course, Venice had populations above 40,000 in 1300. Nevertheless, the flow of trade in fish, timber, wool cloth, beer, salt, metals, grain, etc. was now considerable, thus completing (via links to the Black Sea, across the Alps and into the Rhône valley) the European trading network. From *c.* 1225, Hansa seaborne traffic was largely in their new cog freighters, vessels 'completely superior' to all other such ships in size, navigability and cargo protection.[264] Winter freeze-ups excepted, the configuration of the Baltic well matched the capabilities of the cogges and their crews. From *c.* 1300, they exercised a monopoly over Flemish cloth exports into that region.

Individually, the Hansa towns paid formal allegiance to local princes. But by the fourteenth century, their collective strength was great. It derived from their esprit; their literacy-driven management; their ability to corner markets; their role as moneylenders and pawnbrokers, not least to rulers; and geopolitical adroitness. They assumed the title Hanseatic League in 1367. Their supreme triumph was to come in 1370 when, aided by Sweden, they obliged Denmark to sign the concessionary Peace of Stralsund.[265] A decline then set in as the local emergent statehoods waxed more assertive, and as a quarter of a century of very active piracy suddenly erupted.[266] About then, too, the herring shoals largely left a cooling Baltic.

The vigour of this maritime boom to 1370 appears the more striking in view of the customary backwardness of the Slav side of the sea. On the other hand, by 1300 those 'cold plains of Eastern Europe' had embarked on a path of economic development that some claim 'nearly overtook' the West[267] in the course of the next 150 years. The dialectic with the immigrant German farmers had encouraged feudal commutation. So, above all in Bohemia, had mining, even though the crisis over mine drainage exacerbated ethnic tensions, leading eventually to expulsions of German technicians and merchants.[268] Meanwhile, increased rainfall will have helped stimulate crop growth in the more continental districts. Also, the Teutonic Knights were consolidating their gains after 1310, not making inroads anew. Yet according to the imprecise but tangible criterion of estimated urbanisation, eastern Europe was hardly more advanced in 1500 than 1300. In the interim, Poland and Hungary had been urbanising faster than anywhere else in the region. But still neither country had even one urban dweller per square kilometre of total area. Flanders had over twenty.[269]

In Russia, no real improvement begins until 1400 or thereabouts; and even then neither process nor timing had much to do with either ambient climate change or economic readiness. Everything hinged instead on the Russian struggle to get out from under the Mongol yoke. The Mongol incursion of 1237–9 had wrecked much of the urban infrastructure and led to the deportation of thousands of artisans. Subsequently, Mongol overlordship was underpinned by punitive strikes.[270] The increase in droughts and floods recorded in the fourteenth century would be consonant with experience elsewhere.[271] But one cannot be sure how closely archival trends reflect reality. Schove's tree-ring analysis for Novgorod revealed 15 abnormally cold and wet seasons in the thirteenth century but only 10 in the fourteenth.[272]

Further uncertainty was introduced by a 1980 endeavour to apply 'spatial dynamics' to the Russian famine record. This debatable methodology identified particular zones in what we know as Russia as being especially famine-prone in particular historical eras. William A. Dando put in this category, for AD 971 to 1550, everywhere north of a line curving from Memel through Moscow to where the 62°N parallel of latitude intercepts the Urals. He found drought to be responsible for a quarter of the 32 identified famines that occurred there within that span. Yet he realised this ran counter to the received wisdom that warmth not moisture is the chief limiting factor on grain development in what we know as north Russia.[273] Maybe what is entered in the chronicles as 'drought' includes the effect deep freeze-ups have on the intake of water by autumn-sown rye or spring-sown barley. The matter merits further consideration. The boundary curve just delineated could well relate to the anticyclonic anomaly presumptively centred near North Cape.

Its obdurate endeavours notwithstanding, there is no doubt that, strategically speaking, Byzantium was well past the point of no return by 1300. Bulgaria and, the more so, Serbia had arisen as independent Balkan powers. The surrender in 1326 of Bursa to the Ottoman Turks (the post-Mongol successors to the Seljuks) curtailed the Byzantine presence in Asia Minor. Now the vast extent of Constantinople itself, always a potential weakness, was an absurdity. It was the more so because the ramifying central administration seen by most historians (*pace* Gibbon) as once a singular source of strength had now all but collapsed.[274]

In 1341, a chain reaction of urban uprisings affected almost every other city the Byzantines still held. Then in 1342 the peasants rose up in Thrace, a province once fertile but so wracked by war as to have assumed 'the aspect of a real desert'.[275] Quite likely, however, the genesis of this revolt also owed something to a drought that embraced Anatolia as well. After all, in 1342–3 there was again serious famine in Mesopotamia,[276] probably because the Anatolian headwaters of the Tigris and Euphrates had been flowing weakly. Bintliff endorsed the view that a secular phase of relatively moist average conditions in Anatolia which had begun *c*. AD 750 had finally ended *c*. 1300.[277] Perhaps that was part of the background to the fall of Bursa.

When the odd-ball Michael Palaeologus, Emperor of Byzantium (1259–82), had proposed reunion of the Catholic and Orthodox obediencies, his main motive had been to preclude Angevin forays against him from Sicily.[278] He epitomised thus the cramping isolation of his diminished realm. None the less, one can imagine how, within the context of general détente, Constantinople could have helped lead Europe towards philosophic pluralism, hopefully avoiding thereby the stark bisection we call the Reformation.

Sceptics will be sure to say that something similar had ostensibly been tried, as between Christians and Muslims, in Norman Sicily. But now Sicily was hardly a model to emulate. Instead, it was a study in ethnic cleansing. A core reason was economic stress associated with the stagnation or decline of the population overall.[279] That, as suggested above, climate change was contributing to this is borne out by Sardinia and Crete likewise being stressed, Sardinia being the better comparison in that Crete was the more prone to get distracted by war.[280] The said change in climate may have been the Vita-Finzi progression or else a broader zonal displacement as medieval warming neared its zenith.

Aware of the situation within Sicily, Aragon made the island a focal objective in its own evolution as a sea state. This objective it gained in 1302. Then in the decades before the Black Death, the Aragonese (alias Catalans) traded all round the Mediterranean: regularly with Tunis and Egypt, contingently with Constantinople. Not that their pragmatism was markedly liberal. They resorted to naval force as it suited them. As with the period 950 to 1050, however, one can imagine how trading links across the Christian–Muslim divide might have led on to a dissolution of religious battle lines. This second time around, the prospect would have been enhanced by the knowledge transfer from Muslims to Catholics, not a lot then about husbandry but much about philosophy. The Jews had proved able to act as intermediaries in commerce but also, as per Toledo and Salerno, with intellectual pursuits. It is germane to recall how much the Old Testament is a bridge between Judaeo-Christianity and Islam.

Yet once again, it all was not to be. Looking back, one does not see the intervention of a papacy strong enough to be liberal and widely inclusive, a papacy made the stronger by the supportive moderation of emergent nation-states. Arguably, the translation to Avignon in 1309 did not completely rule that out. But the prospect was destroyed when that move was so quickly followed by the traumatic Dantean anomaly.

Heavens hung with black

But to judge from an assessment *vis-à-vis* south-east England, the agrarian sector had by the 1340s emerged from that experience in not too bad a shape.[281] Nor was the spirit of rebellion much abroad in Europe's countryside or town.[282] Nor was atavistic irrationality. Even so, the outbreak of the Hundred Years War was a reminder how big questions had been neglected.

Onto that Europe the Black Death exploded in 1347, shattering a freedom from pandemics the continent had enjoyed for half a millennium or thereabouts. It proved the first and most furious of several outbreaks of plague (largely bubonic) by the end of the century.[283] In the judgement of Professor McNeill, the relevant bacillus, *Pasturella pestis*, had erupted in or soon after 1331 either from its old natural focus in Yunnan–Burma or else from a new one on the Manchurian–Mongolian steppes. From either quarter the ambient weather was not going to restrain very long its Eurasian spread towards Europe and around China. If, as is probable, the nodal Mongolian region had turned a little moister and warmer once more, that will have favoured the rodents and therefore the germs.

In 1347, the contagion reached a Tartar army besieging the port of Kaffa in the Crimea. The Tartars catapulted some of the infected corpses over the battlements. The upshot was that the bacillus travelled on by sea to Genoa. The lucid French chronicler Jean Froissart (*c.* 1337–1410?) wrote that 'a third of the world died' in this first wave. For his world, the Near East included, that estimate may have been appreciably on the low side, to judge (*pace* Josiah Russell) from the English evidence.[284] Contemporaries put the epidemic down to atmospheric miasma and disruption, as modulated by astrologic factors.[285] Certainly within Europe the weather proffered little impediment to plague propagation.

Within two or three decades of the onset of the Black Death, an acceleration was apparent throughout much of Europe (with Russia the most obvious exception) in the decline of feudal obligations in favour of a cash-nexus economy in which rewards were calculated to reflect supply and demand, especially for labour. Yet that did not mean the transition could always be smooth and peaceful. More immediately, the Black Death was read by many from the Pope downwards as a manifestation of God's wrath against mankind, maybe as directed via a planetary conjunction. The response of very many people was to try to keep things moving along as if nothing untoward had happened. But there were also lapses into savage superstition. In the years 1348–9, thousands from Poland to the Low Countries joined a viciously masochistical flagellant's millenarian movement that initially was indulged by Avignon and actively supported by quite a few parish clergy. From 1348 to 1351, there were violent attacks on minorities presumed to have wilfully spread the malady – lepers, pilgrims, Moors . . . . In particular, some 200 Jewish communities are believed to have perished.[286]

It is important to appreciate that the extremists were but articulating attitudes many others shared. Society was lapsing into deep confusion and profound pessimism – a state of mind that threatened anarchy. As the great Leiden historian Johann Huizinga put it in a famously insightful 1924 overview: 'The passionate and violent soul of the age, always vacillating between tearful piety and frigid cruelty, between respect and insolence, between despondency and wantonness, could not dispense with the severest rules and the strictest formalism.' Huizinga saw this need as being met most spontaneously by elaboration of the aesthetics of rites of passage.[287] Over time, however, it was sublimated most successfully by the emergent nationalisms. A growing emphasis within the new learning on the vernacular and the local was part of this response.

Alas, the new nationhoods were still geared best to military conflict. In part, this was a matter of scarce resources. However costly an occasional war was, it was not as impossibly so as universal education or social security would have been. Certain of the ancillaries governments did sometimes get involved with (e.g. export controls, city planning, transport improvements) could have military connotations. Another cardinal reality was that wars were relatively easy to control from the centre. A century before the development of printing presses, it was far easier to transmit orders across a battlefield than to dispatch them throughout a kingdom. Accordingly, one attempt made to blend the old and new was via the quest for pride of place in the fight against Islam. Unfortunately, the fourteenth century was inauspicious. The Turks crossed into Europe in 1354, establishing a colony at Gallipoli. In 1389, Serbia's regional might was shattered at the Battle of Kosovo Polje. Then in 1396, a multinational Christian army (including the flower of French chivalry) was routed at Nicopolis: 'Hung be the Heavens with Black.'

Progress through crisis?

So what might have happened had the Black Death not visited Europe when it did? A distinguished Oxford medievalist, Barbara Harvey, has lately argued that 'left to its own devices' the early fourteenth-century economy would not have made those needful adjustments the visitations of the plague induced. Progress depended, in her view, on a big fall in population, one 'far beyond the decline which we glimpse in the first half of the century.'[288]

This belief in the constructive possibilities of crisis has surfaced among historians in many contexts. It has in regard to the Mycenaean 'Dark Age' in Ancient Greece (see Chapter 1). The contention has been that almost all 'the fundamental ingredients' of a 'Mediterranean way of life' were put in place during the adjustment phase. These are said to have included humanistic sculpture, wine and the Dionysiac cult, the olive and about a dozen other themes, some more distinctively 'Mediterranean' than others.[289] But the fact remains (*pace* Braudel) that a Mediterranean community is still far off, three millennia later.

Undoubtedly, times of upheaval can generate remarkable transformations. But some of us would caution that, viewed in the round, these are liable to be seriously flawed. The evolutionary change extolled by Whiggish historians like Fisher and Trevelyan is more likely to produce lasting and positive gains, this in spite of the contradictions Whig progressivism can too often exhibit.

Europe could certainly have done without the Dantean anomaly. It would probably have been better off without the Black Death. The decline in the work ethic that Ms Harvey sees as coming through so strongly post-1350[290] may have been in train in any case, the *alter ego* of the culture of calculation. In more benign circumstances, an elemental desire for free time might have broadened the cultural/educational revolution, thus ensuring that the Renaissance foreglow made much more balanced progress.

Part 3

Une longue durée

10 Water, warmth and emergent Europe

In media coverage of the 'greenhouse effect' worldwide, the disposition is to dwell on the rises anticipated in air temperature at sea level, together with the accelerating rise in MSL typically seen as their chief concomitant. What too easily gets forgotten is that projections of temperature change, prognostic or historical, are markers for a multifaceted adjustment within the atmosphere, and the most important result will usually be altered rainfall patterns. Until now, most of the commentary about the water shortages looming in, for instance, the Middle East has ignored climate change as a further complication.[1]

Among students of past climate, on the other hand, rainfall variation has been identified as a key issue throughout this last century. Early on, the focus was on the steppic bounds of inner Eurasia, where Russian and other European geographers sought to combine scientific exploration with interdisciplinary interpretation. In 1904, Prince Peter Kropotkin, a gracious Russian aristocrat renowned as an explorer of Siberia though, still more, as a philosopher of non-violent anarchism, averred that 'over the whole of . . . Europe and Asia . . . we find traces of a desiccation which . . . has been going on all the time since the end of the great glaciation.' It was, he insisted, 'quite certain' that the disintegration through drought of settled civilisations in Turkestan and Mongolia set in motion the *Völkerwanderung* that helped collapse the Roman Empire.[2] In China, received wisdom reportedly still is that the country has been getting drier for 2,000 years at least.[3]

However, at the Royal Geographical Society in London in 1914, J.W. Gregory argued that the evidence, though complex, pointed firmly to the conclusion that 'in historic times there has been no worldwide change of climate'.[4] But in 1907, Ellsworth Huntington had applied his zest for fieldwork and his flair for the overarching concept to crafting *The Pulse of Asia*. That book was to ensure that a debate remained intense for half a century and more, not least in the two continental heartland states – American and Soviet. But as this debate proceeded, the 'pulse of Asia' dimension receded. The dominant theme became instead how far observed water shortages worldwide were due to war, deforestation, overgrazing or other malpractice, as opposed to climate change pure and simple.[5,6] That has been the thrust ever since.[7] As more account is taken of secular climate variations, past and future, the water cycle is liable to remain a prime concern. It will therefore be necessary always to be mindful of (a) how unsteady rainfall trends, in particular, can be and (b) how inexact a science hydrology often is.

The end of the Pax Romana

The final decline of Rome remains among the most challenging of the episodes here addressed. Two ambient themes loom large. In the fourth century, the Romans turned from silver towards gold for their main money base, gaining the latter with some brilliant mining enterprise. How far, if at all, did that bullion conversion delay imperial decline? And how far was the pressure the Huns exerted from *c.* 370–2 on other tribes and the Roman legions generated by their concern to escape from a downturn in rainfall and maybe temperature? Before and immediately after Adrianople, they were collaborating militarily with the Goths. They may well have, too, on that fateful day in 378. Lesser forays were followed in 395 by a twin Hunnish lunge, across a frozen Danube, through Thrace towards Dalmatia and through the Caucasian passes into Syria. Not till 398 was the Roman situation restored in the East.

In 408, the Huns raided the Eastern Empire again. In the interim, late in 405, 'they seem to have undertaken a tremendous drive through central Europe towards the West from their recently conquered homes in the northern Balkans.' Panic ensued. It did so notably on 31 December 406, when Vandals, Sueves and Alani fled into Gaul across a frozen Rhine. In 422, Thrace was pillaged yet again. Ten to thirteen years later (with the young Attila rising to power), a huge tribute was exacted from Constantinople.[8] In between times, some dialogue and collaboration developed with Rome.

What makes this pattern of belligerence of especial interest is its close similarity to a 12- to 14-year drought cycle that emerges, raggedly but insistently, from a graph of rainfall in the European USSR from 1890 to 1970. After that it breaks down, maybe because of 'greenhouse' warming.[9] Not that one would be entitled, in any case, simply to transpose the said study (conducted at the Main Geophysical Observatory in St Petersburg) across 1,500 years. Cycles too readily alter or vanish. Besides, once the Huns were established in the Balkans as well as European Russia, ecological trends in the latter may have shaped their behaviour less. Then again, the onslaught on Thrace in 422 could be read simply as an opportunistic response to the Eastern Empire's then being at war with Persia.

The part climate change within the imperial realm itself played in Rome's decline and fall needs to be evaluated in relation to other factors at work internally. To A.H.M. Jones, the 'most depressing feature of the later empire' was 'the apparent absence of public spirit' and an overwhelming 'desire to rise in the social scale and to get rich quick'. Yet as he himself well demonstrated, the Empire never had engendered very proactive loyalties: 'Rome was eternal, and the Emperor was a god, who needed no assistance from his worshippers' – a superb rationale for 'passive inertia'.[10] Therefore a 'backs to the wall' rallying as things got worse hardly materialised outside of the army. What little there was found expression at city level rather than imperial.

More fundamentally, the Empire collapsed in the West because wealth and well-being were concentrated overmuch in or near the cities of the Mediterranean basin, especially its eastern side. Jones noted the low incidence elsewhere of truly monumental ruins.[11] Northern Gaul and Britain, not to mention Danubia, were less able to resource their own security. Yet without those territories, the Mediterranean heartland lacked the defensibility in depth needed to withstand the strategic mobility the tribes were capable of.

How far climate change accentuated this imbalance is open to argument. It might have done so through a broad displacement of the climate zones southwards through what we may loosely term 'the fifth century' (best read as AD 375 to 475). However, the strong prevalence in wintertime, to 450 at least, of drives of cold, dry air from Siberia may not have compromised middle Europe agriculturally. After all, cold and dry winters may be beneficial to autumn wheat. On the other hand, wheat could thrive more in a Mediterranean likely becoming moister. It is to be remarked that, at least through the fourth century (270 to 375), Aquitaine exported much food to northern Gaul.

Historians are these days persuaded that the barbarian ingressions were by no means as barbaric as once supposed. Hence the surmise in Chapter 4 that (a) the climate low point was not so low as to keep those involved interminably at loggerheads, and (b) the climate recovery (as from the late eighth century) redounded to the benefit of the Anglo-Franco-German part of Europe. Latin civilisation survived most tangibly around the western Mediterranean. Not least did it do so pre-Islam in Iberia, a territory that, as the Hispanic provinces of Rome, had witnessed some enterprising irrigation schemes and which had (along with Illyria) provided most of the Empire's silver bullion. But the Holy Roman Empire, quite the most explicit legatee of the Pax Romana, was to evolve more to northwards, in a region able to benefit from the unsteady but insistent recovery to warmer and drier conditions. No doubt that location could offer then, as in the twentieth century, more reliability for crops in general. A survey of 1927 to 1933 showed the interannual variation of yield as averaging but 7 per cent between London and Berlin as against over 16 in Portugal and much of the Balkans.[12] Twelve and more centuries ago, the contrast will have been starker still because agriculture as a whole was much more backward.

However, pursuit of climatic cause and agrarian effect is vitiated by the difficulty of visualising just what was happening at local level as tribesmen and Roman citizens progressed through co-existence to melding. Especially uncertain is how far cities decayed. One rendering has had the population of Rome itself fall to perhaps 30,000 by AD 600.[13] None the less, archaeology has now revealed substantial reconstruction (*c.* 775 to 825) of the city's Aurelianic walls as well as three great aqueducts.[14]

More generally, however, Professor Christopher Wickham of Birmingham University does see urban decay at the heart of a process of fragmentation extending well into the eighth century.[15] The proto-states that duly emerged were visibly weak, not least those that had set their bounds wide. Witness how the Visigoth kingdom in Spain collapsed before the Muslim Berber invasion of 711; and how the Merovingian precursors of Charlemagne failed to impose their authority on their Frankish kingdom (558–751) in the face of bellicose factions and of their uppity Carolingian mayors of palace. The later Merovingians (639 to 751) came to be known as *les rois fainéants*, 'the idle kings'. If they were that, it will have been because nobody much cared.

There and elsewhere, the diminished domains of the aristocrats were dispersed over wide areas and maybe across state frontiers. But this could be a source of strength when it came to building factional coalitions. Meanwhile, peasant allod-holders (i.e. owner-occupiers) had waxed more numerous, and would remain quite the biggest class of peasantry through the year 1000, not least in southern Catholic Europe.[16]

On a Whiggish view of progress as building inexorably from one precedent to the next, one might expect a recovery in human affairs to be observable rather ahead of the climate troughing out. In some respects it was. Uplifted by the structural reforms of St Gregory the Great (Pope, 590–604), as well as by Irish missionary zeal, Christianity revived across western Europe through the seventh century. It could therefore lend its authority to the blending of Roman and tribal law where political suzerainties were too weak to enforce compliance unaided. In the eighth, the disparate Christian mini-kingdoms holding out in northern Iberia all adhered to a Lex Visigothorum code first adopted *c.* 654.

Usually, too, economic revival came ahead of the climatic upturn except, it seems, in those parts of the Mediterranean where the downturn after the fourth century had been most acute.[17] The growth of North Sea trade from the sixth century was noted in Chapter 4. A more exotic but tremulous indicator was the import into north-west Europe of Mediterranean tableware and wine. Discernible by late in the fifth century, this trade was in crisis by the early seventh as its Alpine routeways were curtailed, quite possibly by less clement weather. More recourse was therefore had to the Rhône valley.[18] Overall, long-distance trade only revived at all strongly after the economic slowdown of the mid-eighth century. The coolish mid-ninth century proved to be very much a time of 'systemic change', a maturation of statehoods being part and parcel of this.[19]

Comparisons to eastward

The barbarian world of inner Eurasia was, through the early Christian era, ringed by imperial structures. Apart from Rome, Constantinople and China, there was the Sassanid dynasty in Persia; and, between the second and seventh centuries, the Kushan and Gupta dynasties in north India – the former a legatee of tribal incursion down the Khyber Pass. It looks like a quintessential arc of containment.

What has finally been discarded is the interpretation of the barbarian pressures in terms of a simple model of demographic pulsations induced by a regular cycle of drought manifest on a continental scale. In the 1924 revision of his 'pulse of Asia' thesis, Huntington himself conceded that 'changes of opposite types' may, after all, take place concurrently 'on opposite sides of a continent in the same latitude'.[20] Allowing this gels with the notion of a climate divide down the longitude of the Tien Shan range. The fourth century was extremely droughty in north China and its borderlands but not, in the main, in central Europe. Medieval warming may have set in across the former as early as the sixth century. At all events, this warming was associated in north China with a welcome trend, from *c.* 700, to more moisture. That was at variance with European experience. So is herb and citrus evidence from the Yangtze that the eighth-century peak of warmth was there almost as pronounced as that of the thirteenth.[21]

Nor was it likely, in any case, that an aridity crisis emanating deep within inner Eurasia would give rise to concurrent nomadic attacks on two or more widely separated empires. In 1939, a study was completed at Berkeley of barbarian attacks on the Roman Empire between 58 BC and AD 107. Thirty-one times, Roman forces were at war in the Near East. At least 28 of these occasions were soon followed by barbarian attacks in the lower Danube valley and 26 likewise in the Rhine valley. Only nine times, however, were barbarian thrusts in Danubia known to follow hard upon battles involving Chinese troops near the Tien Shan.[22]

But the less than surprising tenuity of this intra-continental linkage does not exclude the exploration of other parallels between the Roman Empire and the Han. Both passed their zenith near the turn of the third century (AD 200), having emerged over similar time-frames. Each had evolved a bureaucratic regime that presided over an infrastructure of cities, fortified walls, paved roads and water management. The big contrast was that the oval geography of the Chinese realm meant that threats, whether from without or within, were easier to contain. For one thing, ovalness encouraged cultural cohesion. For another, it facilitated defence in depth.

However, this last point is subject to qualification. The north of China was, even in the Han through to the Tang eras (206 BC to AD 907), exposed to attack by horsemen from the desert fringes. The fearful admiration thus aroused is encapsulated exquisitely in the brilliant bronze from the Eastern Han (AD 25 to 220), 'The Flying Horse of Kansu'. Sporadic attempts were made from that time on to capture and breed the fleet steeds the 'Chinese barbarian' intruders possessed.[23] As noted in Chapter 4, the extension of the Tang Empire north-westwards in the seventh and eighth centuries, along what became the 'Kansu corridor', was motivated in part by a desire to gain access to what we know as the Ukrainian

Map 10.1 China proper

steppes, the region where the horse had first been tamed.[24] But medieval China never proved able to respond in kind to the mounted threat; not to the speed of central Asian cavalry or the staying power of Mongolian. The supreme remedy it did invoke was expansion southwards into and beyond the monsoonal Yangtze basin, terrain ill-suited to cavalry evolutions. Otherwise, it sought to assimilate any dynasty intruding horsemen might establish. Meanwhile Japan enjoyed insularity but far less breadth and depth. Remarkably, Egami Namio (long a Professor of Asian History at Tokyo University) stimulated a complex, intense and ongoing debate among Japanese historians by developing from 1948 the idea that Japan had first been unified politically (early in the first millennium AD) by horsed warriors from Korea.[25]

At all events, east Asia knew the menace of light horse to an extent Rome never did. Since well before the Christian era dawned in the Mediterranean, China repeatedly faced threats of extinction from the north, threats it had either to parry or absorb. Early in the fourth century, the Yellow River region did come close to collapse. Yet by the seventh, a reunited China was resurging at every level from the geopolitical to the scientific and philosophic. What is also to be remarked on is the energy of the regimes then emerging under its influence in Korea, Japan and Tibet, and the quality of the renaissance all experienced.

Of the three departures, Tibet's was the most transitory. Yet in its case, the interlude in question was no less seminal. Expressing what we now see as a characteristically east Asian value, it exploited increased contact with the outside world to mould eclectically a peculiarly national culture. Infusions of Buddhism in both its Indian and east Asian variants merged with Tibetan magic and demonology to give rise to Lamaism.[26] The unifying ruler, Song-tsen-gam-po (reigned 620–49) introduced paper and ink from China, writing from India, and spelling from within Tibet.[27]

The abrupt collapse of Greater Tibet in the late ninth century invites two explanations. The one is that territorial expansion from 650 (and especially the interdiction of the Kansu corridor, 763–843) brought the Tibetans into collision with China. The other is more directly climatic. It has come to be accepted among climatologists that the Tibetan plateau is 'a significant factor in determining the climate the present solar input maintains' globally.[28] In particular, the strength of the anticyclone that develops over the plateau in summer helps modulate the monsoon and much else[29] (see also Chapter 2). But the obverse side of this is that the seasonal weather on the plateau itself is very sensitive to forcing factors. The release of heat as vapour condenses into shower cloud is one. Another is snow lie. A third sometimes might be intrusions of atmospheric dust. This sensitivity owes much to air pressure over the plateau being half what it is at sea level. Meanwhile, fluctuations in wind chill affect societal survival throughout Tibet. All in all, the eighth-century preliminary peaking of early medieval warming could have been a critical transition.

The genesis of Islam

The notion that short-term variability in rainfall is more pronounced on the arid fringes of a regime bears on how far the emergence of Islam was induced by drought. The fact that Medina and Mecca lie within a topographical rain shadow connotes greater variability in precipitation than applies around the headwaters of the Blue Nile. Therefore, to turn to Nile flood records as proxies for rainfall fluctuations in that part of the Hejaz is to receive a subdued account of the latter even when the correlation is satisfactory in other respects.

With that in mind, one examines the 1992 historical review of Nile floods by William Quinn, the extent of any notable deficiency being expressed on the scale he defined from 0 to 5. It records for the half century 622–71 five 'weak' events, their mean acuteness being 2.8. The corresponding figures for 672–721 are 14 and 2.9. Moreover, the one event registered with high confidence in the former spread is the moderately weak inundation of 662. In the latter span, nine are. Nor do the three events between 633 and 671 correlate at all convincingly with any recognised milestones in the territorial advance of Islam. On the other hand, the deficiency of 4 inferred (with a fair measure of confidence) for 629 fits well the literary evidence (noted in Chapter 1) for Mecca being severely drought-stricken at just the time Muhammad was laying siege to it.[30]

Arguing longer term, Hubert Lamb concluded that most parts of the northern hemisphere in latitudes below 35° were quite consistently warm throughout the first Christian millennium. This he saw as consonant with Kenya's Lake Rudolf very regularly staying high through the span AD 300 to 1100.[31] That would correlate with the mean global lie of the Inter-Tropical Convergence Zone shifting well southwards, and with the associated rains therefore having 'a restricted seasonal migration' within a wide sector of longitude.[32] One consequence could often be a weaker monsoonal flow over north India and Arabia as well as (see Chapter 4) south-east Asia.

Granted, more fieldwork is needed, particularly perhaps on lakes and water courses in Iran that are monsoonally upwind of the Hejaz. At present, however, the impediments to this look greater than in the days of Curzon and Huntington. For the time being, there are no such materials with which to test further the received view that not merely did Muhammad's struggles in the 620s to secure Medina and Mecca (and especially, of course, his blockade of Mecca) culminate during a quite exceptional drought locally. In addition, the faith's expansion across Arabia and beyond, after the prophet's death in 632, is said to have been against the background of a secular worsening of aridity across the Hejaz. Nor can that deeply rooted understanding just be set aside. The Umayyads, the first caliph dynasty, moved from Medina to moister Damascus during the schism of 661. That tells us something.

Le Roy Ladurie's paradox

A more general challenge has come from Emmanuel Le Roy Ladurie. He has discerned a disposition to want things both ways over folk migrations:

> The Teutons of the first millennium before Christ are supposed to have left their countries of origin because of the cold. The Scandinavians of the period before AD 1000 are supposed to have done the same thing for exactly the opposite reason – the mildness of the climate, stimulating agriculture and thus also population growth, is said to have led to the departure of surplus male warriors.[33]

Though the 'Teutons' may more usually be seen as reacting against drought, the basic point still needs to be addressed.

In some cases, the circle may be squared by proposing that expansion may often begin as and when climate improvement has given way to recession. Alternatively, one might think it possible to distinguish between those migrations, born of dire stress, that have involved the wholesale displacement of a people; and those, rooted in enrichment, in which a growing population expands out of what may still remain its heartland. Either way, one should also weigh other motivational factors, not least cultural ones.

The Mongols stand out as a clannish people induced to go for world empire in part by a warmer and moister tendency lately tempered by a cooler drier reversion. Like the Vikings, they never forsook their homeland. But then neither did the drought-stricken Islamic Arabs. Enough of the local Sherarat tribe stayed on to transmit the relevant folklore. Medina and Mecca may have stagnated in the ensuing decades but were never to vanish. The *haj* reminds us of that.

In outline, the Arab mode of expansion resembled the Mongol. Both peoples became elites that, once things had quietened down, would rule with a light touch a diversity of peoples whose talents they mobilised to underpin their own suzerainty. Yet in substance their styles contrasted diametrically. The Mongols deployed mounted troops in far greater numbers. They could turn genocidal in conquest in very short order. Except in China, they bloodily evinced an anti-urban bias that seems morbidly to anticipate the Tai Ping rebellion in the China of the mid-nineteenth century or Pol Pot in the Cambodia of our time. Contrast that with the realm the Arabs loosely created in the Mediterranean and Near East where, despite a legacy of city decay in Late Antiquity, 'Urban development forged ahead . . . with large cities prospering not only in the Levant and Mesopotamia . . . but also in the de-urbanized West where Fez, Kairouan, Córdoba and Palermo rose to prominence.'[34] So might one not unreasonably have presumed it was the Mongols who had been crazed by drought and the Arabs who had been stimulated by refreshing rains?

Maybe the Mongols did entrap themselves logistically by relying on equestrian mobility so much more heavily over long distances than had other nomadic peoples from the Eurasian heartland (see Chapter 7). Maybe, too, their ruthlessness was partly a response to encroachments alien agriculturists had made on their ancestral grazing lands as these became that much moister and as Malthusian pressure built up. Suppose the population of Asia as a whole did grow 50 per cent between 900 and 1200.[35] That could have led to extensive squatting on the ancestral grazing ranges of the Mongols. Nowadays rough grassland converted to arable may then support ten times as many people.[36] In that steppic milieu in those days, this ratio will have been a deal smaller. But one's sense that the Hudson hypothesis outlined in Chapter 8 may have been operating in reverse has been strengthened by a multiple pollen count in a south Manchurian bog, this under the auspices of the National Climate Center in Beijing. It finds that the summers were relatively moist between AD 1100 and 1340. What is not lent support is the notion of a dry, cold interlude in the first half of the thirteenth century.[37] But so transient and Rossby-related a modulation may not have extended to Manchuria.

At all events, the ultimate explanation for the pristine savagery of the Mongols may lie in a realm other than ecological crisis and military response. It may reside instead in a shallow belief system. At first sight, the Mongolian notion of a Providence overseeing a universal empire may not appear very distant from the Muslim vision of Allah: the one true God, not totally impersonal but decidedly austere and remote as he presides till the end of time over the terrestrial and cosmic orders. In reality, however, Allah 'the merciful, the compassionate' transcends a Providence that merely offered a licence for brigandage and a rationale for strategic opportunism. The latter was closer in quality to the Destiny that was to sustain Adolf Hitler throughout, though even more maniacally after the bomb plot against him in July 1944.

Besides, the cultural renaissance the Quraysh tribe had led in the Hejaz from the third century AD (with an artistic Arabic script from the fourth) was to have no counterpart in Mongolia even a millennium later. According to what we understand to be tradition, Genghis Khan did ordain in 1206 that all in positions of high authority should learn to read and write the script of the Uighur, a semi-nomadic tribal people based on the T'u-lu-fan depression in Sinkiang. Yet only during the period 1272 to 1310 was a Mongolian script to evolve.[38] At the level of popular religion, shamanism was not superseded by Lamaist Buddhism until the sixteenth century. In short, the Mongols were ill equipped (*pace* Gibbon) to usher in a universal empire truly based on Enlightenment virtues. There are explicit signs to that effect. Their heartland lay close to the path whereby the knowledge of how to make paper (achieved at the Chinese court *c.* AD 100) had spread within half a century to Dunhuang on the Silk Road, there poised to spread West in spite of mandarin embargoes.[39] Yet the Mongols and their kin were never interested. As the truest desertic nomads of them all, they had locked into a rejection mode: the denial of such civilising skills and the multicultural awareness they encouraged. As Alexander Pushkin put it, 'The Tatars had nothing in common with the Moors. When they conquered Russia, they gave her neither algebra nor Aristotle.'

Something we are not obliged to do, with respect to Le Roy Ladurie, is determine for all time whether tribal peoples go to war because they are racked by ecological disaster or because they are fortified by comparative plenitude. Either driving force may be operative in what may appear to be broadly similar circumstances. So may an alternation of the two. That much can be seen from the behaviour of more structured statehoods. In modern times, nation-states have resorted to offensive action because, relative to their adversaries, they have felt themselves to be getting either weaker all the time or else stronger. Each motive is revealed, too, in the era here under review. The Romans invaded Britain to consolidate their increasing strength. But Arthur conducted the sweep that culminated in Mons Badonicus in order to check remorseless English expansion. The Normans invaded England to consolidate their burgeoning strength. But Emperor Romulus launched the foray that culminated in Manzikert to try to curb the looming might of the Seljuks. Edward Gibbon said it all when speculating (see Chapter 3) as to what lay behind the exodus the Goths apparently embarked on early in the *Völkerwanderung* from southern Sweden. One possible reason was a recent victory. Another was a recent defeat.

A maritime aspect of the response of early Islam to the natural environment concerns what the Nile flood records confirm was an overall tendency towards weakish monsoons between 622 and 999. A consequence could have been to ease the progress of Arab navigators from, say, Muscat to Canton. As things have lately been, the 'bursting' (generally in June) of the monsoon alters 'the whole face of the weather. The wind blows strongly from the south-west, very strongly over the sea; thick masses of cloud cover the sky and the air is saturated with vapour.' Mean wind speed is twice that of the dry north-east monsoon of winter.[40] That averagely means 30 to 35 km per hour over the Arabian Sea, say. In each main season and across most of the route, it is essentially a cross-wind.

Weather that was usually less stressful might well have been important to the link to Canton. After all, passage there from Muscat could take 120 days. The return might have been little quicker. Allowing that, in Bombay for instance, the rains usually last about 135 days, the margin of time left inside a year to cover becalmings or repairs or other diversions could have been slender. Often, in fact, 18 months was allowed for the round trip (see Figure 10.1).[41]

But if one does conclude that a slackened monsoon could have favoured the Arabs in the Indian Ocean, what were the implications for the Arabs in the Mediterranean? We are probably talking about two well-separated maritime communities. We are certainly talking about two very different maritime cultures. Both sides of the isthmus of Suez, Arab sailing ships used fore-and-aft 'lateen' sails as opposed to the square rigs still preferred by the Europeans, the former mode being better for tacking against a headwind though not for exploiting a following one. Yet Arab hull planks were fastened by fibre stitches east of Suez throughout the Middle Ages, though with iron nails in the Mediterranean.[42] So maybe commercial success east of Suez did not translate to the Mediterranean as readily as one might have assumed. Nevertheless, hundreds of foundries in Sri Lanka, sited to be fanned by summer monsoonal winds, would have supplied their excellent weapons-grade steel as far as the famed sword-smithies of Toledo.

The Viking decision to migrate by boat in every direction bar north ultimately derived more from climatic improvement in their south Scandinavian heartland than from any other variable. In this case, however, the accent weatherwise really was on warmth. In so far as the

Figure 10.1 Bombay harbour, fishing boats in the monsoon, 1814

Source: courtesy of Mary Evans Picture Library

water cycle was involved, it was because water was in its liquid form, fluid and assimilable, for rather longer in a warmer year. Nordic expansion encouraged feudal consolidation within western Europe as did that by the Arabs and (from *c.* 890 to 955) the Magyars. Soon, too, the Vikings were transhipping from the Arab East the silver that, in the ninth century at least, may have done as much as the warmer weather directly to promote economic development.

Not least to be remarked is how adaptive the Vikings were to the diverse situations they found themselves in. One can cite the Icelanders, the Danelaw colonists, the Rus, the Finnmark settlers and the Normans in Sicily. Their adaptations varied markedly but all were moulded by a democratic individualism. The Normans in Normandy cannot be dubbed democratic. But they were regional pacemakers in several respects: Romanesque architecture, ecclesiastic and military; feudal governance; battle tactics; commercial enterprise . . . .

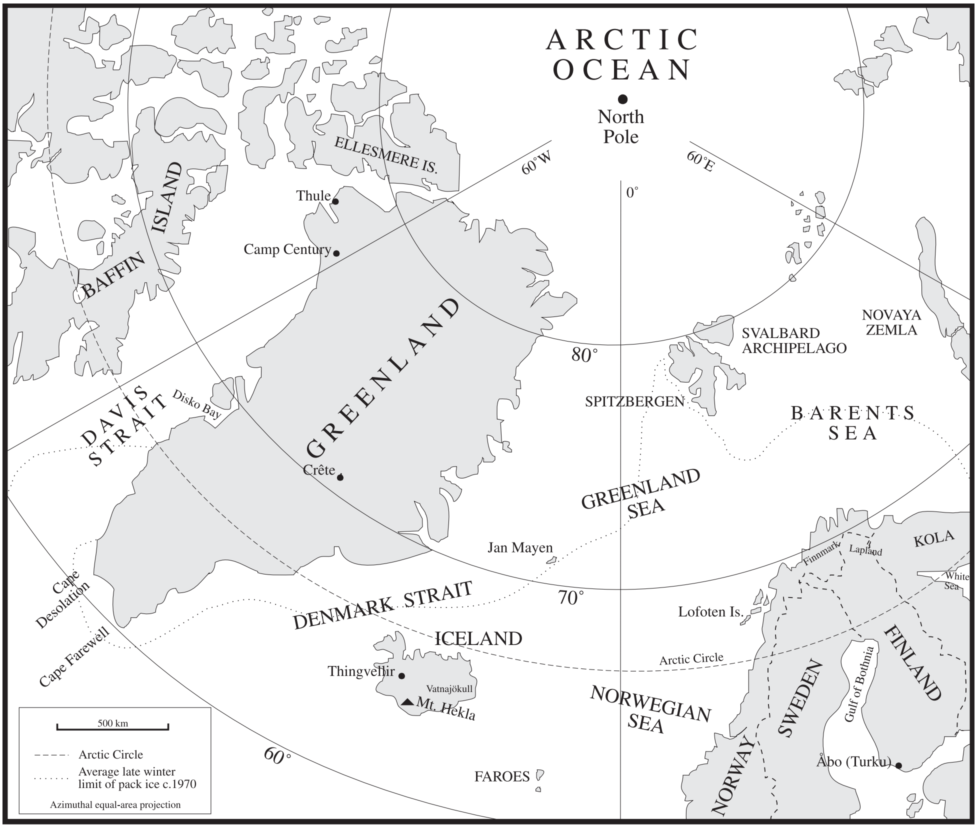
The death of Viking Greenland

The Viking presence Erik the Red established in Greenland in 985/6 has acquired, rightly or wrongly, a less robust image. Given the longitudinal differences in temperature change, Erik and his confreres arrived at the height of medieval warming. But although their descendants and successors held on for all but half a millennium in a worsening clime, they tend now to be depicted as an archetypal illustration of how even a resourceful people may cease to act resourcefully should the environment prove just too daunting. If valid, this interpretation is sobering. To test it, we should follow the grim progression through 1350 and to its misty end.

That ecological management may have been vitiated at the outset by undue individualism is suggested by the record being pieced together for Greenland's parent colony, Iceland. Two-thirds of its landscape was under vegetation before the Viking advent; and, indeed, a good quarter of the total area was stunted birch forest. In the ninth and tenth centuries, however, much was lost to iron production, agricultural clearance, domestic heating, building, accidental fire. . . .[43]

In Greenland, pasture productivity was to decrease by some 75 per cent over time,[44] so marked a decline no doubt due in part to a propensity to overgraze as the ambient situation deteriorated. Erosion increased because of more snow and rain, higher winds and weakened vegetation.[45] So quite early on, the emphasis switched to sealing and fishing. Yet in this respect as in others, there was little disposition to learn from the Inuit with whom these Norse were often in contact as from the twelfth century. No Norse skin-covered boats (as per the Inuit kayaks and umiaks) have yet been found, invaluable though these could have been inshore. Nor have any harpoons or barbed spears for use through ice holes. Instead, the Norse problematically relied on communal boat drives to enmesh the seals at the fjord heads.[46]

For some time, expeditions went regularly in summer to Disko Bay (800 km north of the western settlement) to gain walrus and polar bear products vital to a balance of trade with Scandinavia, a trade itself vital for iron goods and much else materially but also for psychological security. However, incursions that far into a glacial 'back country' were always susceptible to weather and climate. Hermann Flohn has noted indications that a thinnish layer of ice across the north of Ellesmere Island at 82°N dates from *c.* 1350.[47] A measure of the sensitivity of fisheries to temperature trends is afforded by the strong advance of the cod up the west Greenland coast during gradual warming early this last century. By 1917, its limit was 61°N; in 1931, it was 72°.[48]



Map 10.2 The northern world

Nor was the link with continental Scandinavia ever very firm. Early on, the open sea was often less perilous than the currents and ice floes near the Greenland coast. But by 1250, more prevalent ice was obliging skippers to steer southwards.[49] Then in 1261 the Greenlanders, and shortly after the Icelanders, accepted Norwegian sovereignty, hoping this would consolidate trade links. But by 1294, the year a strict monopoly of dependency trade was granted to Bergen, not more than one voyage annually was being made to Greenland. Yet Bergen's majestic harbour might have upwards of 200 ships in at a time.

A collapse in the European demand for Greenland tusks and hides was making things worse. Then, come 1349, Bergen suffered terribly in the Black Death. In the early fifteenth century, the weather in and around Greenland seems to have got drier but much colder.[50] The last passage from there to Europe of which a record survives was in 1408.

A strategy instinctually adopted throughout by the Thule Eskimo (alias the Inuit) was dispersion. As they pushed south in the fourteenth century to mitigate the effects of climate deterioration, their winter houses spread 'all along the oceanic outer-fjord zone of south-west Greenland', albeit in clusters.[51] But subject to social modelling now underway, one must ask what scope for dispersion there was for Norse enclaves that may never have exceeded 5,000 people in the eastern settlement and 1,500 in the western.

Nor would it have just been a matter of economic scale. Physical security would have been a critical problem. Early this last century, received wisdom had it that eventually the Norse were annihilated by the Inuit. But in his 1943 study, Vilhjalmur Stefansson underlined Fridtjof Nansen's closely argued case against this. Specifics apart, all the evidence of much Norse–Inuit miscegenation at some time or other counts against the likelihood of general annihilation at any time. Nor need we take polar dwellers to be warlike regardless.[52] Salutary here is Second World War experience. The Germans put weather stations in Greenland. The Allies sent raiding parties against them. But the brave and resourceful men on each side felt constrained from coming to mortal grips apparently because, in that setting, human conflict seemed trivial.[53]

All the same, it would be naive to assume that the Norse had never to deter the Inuit or, indeed, vice versa. Nor should one forget that, near the end of the affair, attacks could come from elsewhere. By the late fifteenth century, western Europeans were probably fishing the Grand Banks (see Chapter 11). In a remarkable essay published in 1776, an Icelandic missionary to Greenland, Eigil Thórhallesen, surmised that the English among them may have had at least one violent clash with the Greenlanders.[54]

Nor would more dispersion necessarily have been a sure precaution against epidemics. It might have afforded too little opportunity to build immunity through exposure. So what of the 1349–50 Black Death? Should it ever be shown to have reached Greenland, 'we need enquire no further about the steepness of the outposts' decline in the 15th century.'[55] But the odds are it did not. No ship came from Bergen to Iceland in 1350, so probably none to Greenland either. There would, in any case, be the collateral question of what impact plague might have had on the Inuit.

Religion may have played but a limited part in the early life of the Norse settlements. None the less, Tom McGovern shows how the profile of the Church rose, once the first bishop had arrived in 1125. Between then and 1300 especially, some elegant churches were built; and it would appear that, by the latter date, the Church owned two-thirds of the best grazing land. McGovern sees this as part and parcel of a Greenlander tendency to lock themselves into a preset pattern, 'elaborating their churches rather than their hunting skills'.[56]

The deterioration in climate was a tortuous process. In the fourteenth century, extreme inter-decadal fluctuations in temperature were experienced. About then, too, precipitation increased in the inner fjords. That applied in both summer and winter and must be seen as negative. In 1492, the worldly Pope Alexander VI expressed concern at how spreading sea ice was precluding contact with the colonies. Alas, they will have caved in some years previously. Yet with Norse Greenland, as with the Roman Empire as portrayed by Gibbon, the surprising thing is not that it declined and fell. It is that it 'subsisted so long'.

Germs and Jerusalem

Disease certainly bore on a mightier overseas endeavour: the Crusades to the Holy Land. Malaria comes first to mind. It much discomfited the First Crusade as it proceeded down the Levant towards Jerusalem through the bitterly wet autumn of 1098. It was a primary reason why on the Third Crusade, during the Palestine winter rains of 1191–2, 'sickness and want weakened many to such a degree that they could scarcely bear up.'[57] No doubt, too, malaria's propensity to debilitate rather than kill outright helps explain the poor health of the Outremer communities.

Less easy to be sure about is climate change (the 'Crusader' cold and moist spell identified by Issar) compounding the malarial threat. In a seminal article on historical climatology published in the *American Historical Review* in 1913, Ellsworth Huntington drew on US Army experience gained while digging the seaway across Panama. The gist was that the host mosquitoes bred most happily in temporary lakelets generated by overflowing streams.[58] This could suggest that wetness did accentuate the malarial threat to the Christian expeditions. Yet things may not have been that simple. The tough time the World Health Organisation has lately had trying to gain a conclusive victory over this disease shows how impoverished our understanding of its criticalities still is. The impact of climate change has been proving especially hard to elucidate.[59]

In any case, the Crusaders will not have found malaria as shocking a novelty as their Roman predecessors found plague and, indeed, malaria to be in the Near East early on. One can never be sure about local mutants of germs or carriers. Nevertheless, a clear difference from the Roman ordeal was some strain of the disease having long been endemic across Mediterranean Europe and even as far north as the English Fens.

What this point relates to is work done, most notably by William McNeill, on differential susceptibility to epidemial infections. One conclusion is that, from Late Antiquity through medieval times, the peoples indigenous to the Near East usually suffered less mortality from such episodes than did those of either east Asia or Catholic Europe. This was despite the absence, across much of the Near East then as now, of winters severe enough to decimate certain species of germ or host.

Two reasons are adduced. The more apparent is that their intermediate position regularly exposed the Near Easterners to diseases from both directions, inducing each time round immune responses of some enduring value. The more subtle is that settled civilisation, based on agriculture and some urbanisation and involving large territorial groupings, evolved in the Near East well before it did in east Asia or Europe. It had therefore had deeper historical experience of gaining immunity through interaction.[60]

Demonstrably, the Near East did have a head start in the neolithic revolution in production and lifestyle. Rice growing may have begun in south-east Asia as early as 6000 BC, while barley would soon after be grown in the deep valleys of south-east Tibet by immigrants from the Karakoram.[61] But in south-east Turkey, einkorn and emmer (early kinds of wheat) had been cultivated since 7500 BC, their domestication being achieved as the climate turned moister (though apparently less so than today).[62] Now DNA analysis (led by the Agricultural University of Norway and the Max Planck Breeding Institute in Cologne) has traced the sowing of einkorn back to a single innovation near the Karacadag Mountains in Turkey.[63] The human population of the Near East retained some advantage in terms of relative immunity to infection for a good six millennia, especially in the Nile valley and Mesopotamia. Come the Black Death, however, the region's resistance was unexceptional. Egypt's death rate was high at the outset, 1347–9; and it experienced further visitations through the fifteenth century. In this connection, William McNeill has drawn attention to her having in 1250 come under the direct rule of the Mamelukes, the Turkish warrior caste of slave extraction. He has felt their ties with central Asia via the Black Sea must have been conducive to disease transmission.[64] That in turn related to his conviction that the bacillus was widely hosted among rodents in inner Eurasia.[65] But it related more specifically to the Mameluke need for a steady influx of new recruits, preferably from the Turkish home areas in central Asia. This was because, according to a strict interpretation of Mameluke tradition, nobody could be accepted into the caste who had not been thoroughly trained throughout childhood as a slave soldier. Never mind that manumission usually followed at the age of 18.

With respect, that may not be the right approach. Perhaps the point of departure should be recognition that the Mameluke oligarchies were comprised of 'uncultured, rude, rapacious, tyrannical and treacherous former slaves who were only superficially islamicized and never urbanised.' And yet under their alien racially isolated rule, Egypt became the unchallenged leader of the Arab world. It did so politically, economically and culturally. Islamic art and literature were strongly encouraged. Above all, hydraulic infrastructure was developed.[66] This transformation was encouraged by the average Nile flood being considerably stronger in the second half of the thirteenth century than in the first.[67] That enabled a rough-hewn regime to preside over sophisticated progress.

The Mamelukes are customarily delineated as two successive dynasties. The Bahrites were mainly of Turkic–Mongolian extraction. The Burjites, who succeeded them from 1382 to 1517, hailed from the upper Kuban valley in Circassia, the western Caucasus. The four decades prior to that succession repeatedly witnessed savage street battles in Cairo itself between rival factions, familial or whatever. This discord reflected the waxing and waning, over several generations, of the Mameluke identity. It owed nothing to ecological anomalies. The Nile floods, 1341 to 1382, were medianly close to the long-term mean.

A big shift in Mameluke recruitment, in the midst of all this mayhem, from the Don–Volga sector to Circassia probably owed much, according to Ivan Hrbek, to plague in the former.[68] But the latter may not have been plague-free. The regional onset of cooler and damper conditions may have (a) favoured the germ carriers and (b) compromised food production in the upper Kuban valley.

In any case, the plague descended on Egypt through Alexandria in 1347 as part of its ramifying advance around the Mediterranean and far beyond. Recruitment in Circassia began well before then but accelerated after. An ambitious land reclamation drive undertaken in the first part of the century went to rack and ruin.

More account ought to be taken of the variable incidence of the Black Death around the whole region.[69] Meantime one may best assume that the exposure of the Egyptians owed little to Mameluke links with inner Eurasia. Credence is lent to that conclusion by the Chinese records showing no general outbreak until 1353–4. Yet China was under Mongol rule (see p. 291).

Not that one should be concerned just with human ills. Livestock and crops must also be considered. Little hard data exists. But a statistical analysis of English grain prices, 1450–1812, reaches a germane conclusion. A price cycle of 5–6 years periodicity is discernible; and so is one of 13–16 years. But the former does not correlate as significantly as the latter with recognised runs of weather – in particular, a perceived tendency for low temperatures to engender high prices. Scott *et al.* propose the short cycle may reflect instead endogenous alternations as between common cereal diseases (e.g. mildew and rust) and their involuntary hosts.[70] If so, those should also have been manifest in medieval times.

Other ambient factors

Human migrations and transportation incidentally assisted the spread of many infections. But Humanity has also much facilitated the wider distribution of useful plants and animals. This has counted for much in Europe, a continent left low on biodiversity by how, during the Pleistocene Ice Age, the latitudinal alignment of the Alps and of the Mediterranean had impeded both the escape of species from glacial advances and their following up of glacial retreats. Take natural deciduous forest. One reckoning has been that it nowadays sustains 729 tree species in east Asia, 253 in eastern North America, and but 124 in Europe.[71]

As regards harvestable plants, quite the boldest correction of Europe's impoverishment was to be that undertaken by the Arab harbingers of Islam. Crops that spread from lower latitudes more or less throughout the Islamic Mediterranean included rice, sorghum, hard wheat, cane sugar, cotton, watermelons, eggplants, spinach, artichokes, lemons, limes and bananas. Also transmitted were new variants of established crops plus many trees or small plants used for fodder or else in spices, medicines, cosmetics or perfumes. Multiple cropping was widely introduced. The decay of irrigation works was reversed, not forthwith but soon. Irrigation then became more extensive as well as intensive. Soil science progressed. Land management practice provided incentives on the whole.[72] But populations rose accordingly, not least in the countryside. So again one observes a contradiction in the development process. A revolution that had initially made the Islamic Mediterranean more robust in the face of rainfall fluctuation eventually rendered it more susceptible, at least to the more secular alterations in rainfall patterns.

In the sphere of inanimate invention, the late Middle Ages/early Renaissance saw critical transfers to Europe from China. Most modern scholars are satisfied that gunpowder and printing were pretty clear-cut examples.[73] In its essentials, the mariners' boxed compass was, too.

From Carolingian times onwards, bullion shortage perennially threatened to be an ambient constraint on economic development within Catholic Europe. The Viking supply of Abbasid silver had finally waned by 1100. Nor was quality European ore much available until the discovery in 1170 of the Freiburg deposits in Saxony. Nor was the outflow of silver then commencing from China as yet going much beyond central Asia. During the eleventh century and, more especially, the twelfth, there was a partial reversion to gold to sustain a money base expanding in part to finance the Crusades. Not least was it needed to trade with a Byzantium that (a) had a more developed cash flow and (b) relied fundamentally on coinage made with a high gold content that, until Manzikert, had not been debased for 700 years.[74]

But of gold, too, Europe's indigenous output was limited. West African exports were therefore important. True, many of the caravans went to or through a Mameluke Egypt basically hostile to the crusading West. But others delivered gold to the Maghreb, which often circulated around and beyond the western basin, usually after Jewish merchants had acted as intermediaries. However, Robert Fossier regards a bimetallic circulation as stable in western Europe at most from 1240 to 1290, the gold input being compromised thereafter by tensions within the Mali Empire as well as further diversions by the Mamelukes. Yet already, between 1180 and 1230, added strain had been placed on the current stock by inflation.[75]

Worth pondering, is how far a scarcity of bullion for coins brought about the economic crisis of the early fourteenth century. The rains hampered silver mining in Germany. The inflow of Chinese silver may already have passed its peak.[76] As regards gold supplies, Mali had known instability in the thirteenth but its decline did not really set in until the Sigilmassa trading mart was destroyed by the Tuaregs (warlike nomads and caravan managers) in 1362. In any case, governments could debase in order to ease a shortage of coin internally. As early as 985 to 1009, the English state had managed (against a background of healthy trade balances) a progressive decline in the silver content of coins from 93 to 85.4 per cent. Fiduciary confidence had to be maintained. But through the mid-thirteenth century, to take again the English case, this was made easier by the evolution of sophisticated mints.[77] By then, too, merchants from Lombardy and Tuscany were assuming an embryonic banking role, particularly to extend credit for transcontinental actions. In other words, the money supply was being extended by mercantile fiat.

In 1343, this first phase ended as the Italians entered upon a succession of major banking collapses. Earlier in the century, aberrations in the geophysical climate (above all, the Dantean anomaly) had been more fundamental to European recession than were those in the fiscal. David Fischer of Brandeis sees this time as the culmination of the first of four price revolutions as from the twelfth century: 'four very long waves of rising prices, punctuated by long periods of comparative price-equilibrium.' But both this climax and the one he next identifies (in the seventeenth century), he perceives as worldwide and therefore likely to have been caused by shifts in the physical climate zones. Some of the travails the former engendered have been noted as regards Europe and the Mediterranean, China and West Africa. Those of India may be added. Also, Fischer draws attention to two regions detached from Eurasian prices and plagues. Out of the chaos Toltec Mexico had descended into, the Aztecs had been defining a new power base before the Spanish arrived. In the Pacific, centuries of Polynesian advance were being foreclosed. These instances are boldly cast, maybe overly so. At all events, Fischer identifies 1333 in China, 1334 in India, 1362 in West Africa and *c.* 1345 in Mexico as key downward turning points.[78] All come well after the Dantean anomaly.

Mediterranean nodality

Every ambient factor, the geophysical included, influenced the growth of long-distance trade. This truism underlines how the Crusades enabled the fleets of the Latin Mediterranean to gain control of the eastern basin, thus facilitating trade with the Orient via either the Black Sea or other routes. What made this sea control the more efficacious, from 1275 onwards, was a relaxing of the taboos against (a) venturing out of sight of land and (b) winter voyaging.[79] Relaxation owed much to the impact the mariners' compass was by then making across the Mediterranean and, indeed, the Bay of Biscay.[80] Yet not until after 1300 is a general advance discernible in ship construction even within Latin Christendom.[81] Therefore, landfalls were regularly made in Cyprus (under French baronial control from 1192 to 1375) and especially Crete, seized by the Venetians in 1204.[82]

A lot depends, too, on how much the weather may have improved since the early Crusader cold phase. An inkling of what it could have been like at sea then may obliquely be proffered by the ode the Roman lyric poet, Horace, dedicated to his friend Virgil when the latter was bound for Greece. Horace rhapsodised about the mariner 'who first committed his frail bark to the angry sea, and who feared not the furious south-west wind battling with the blasts of the north.'[83] Those lines were penned *c.* 24 BC, at which time the eastern Mediterranean was moving towards the cold 'first century' identified in Chapter 3, a span very comparable climatically with the early Crusader one. Even allowing for some poetic licence, this imagery reminds us how readily ships well out could be in peril. Yet so could those close to rocky or shelving shores.

However, the eastern Mediterranean appears more under anticyclonic influence through 1300. Varves on the Dead Sea shoreline bespeak drier weather. Meanwhile isotopic ratios in Lake Van and the Sea of Galilee show it was warmer, too.[84] Granted, any inference of calmer seas would run contrary to the received overview of the fourteenth century as a time of increased erraticism. But concurrent shifts in regime can never be identical everywhere.

One tendency always to look out for, indeed, is alternation as between the Levant and the Black Sea. Thus in the first Christian century, the Levant has been relatively cool but the Black Sea basin relatively warm[85], the southward displacement of depression tracks no doubt being a common cause. The fourteenth-century varves around the Volga delta suggest the main storm tracks were well towards the north-west of Russia.[86] Reportedly, however, Caucasian glaciers tended to recover from their weak medieval state between the thirteenth and fifteenth centuries.[87] There was, too, some tendency for Lake Van to rise.[88] So maybe Black Sea weather was less settled, with marine transits that much more perilous.

Given the reliance Genoa had placed on Black Sea trading, such a climate shift would have aided the ascendancy Venice gained over it through the mid-fourteenth century. But that surmise ought to be tested against Italian marine records and also against the extension into the later Middle Ages of the considerable research now in train on the climate of eastern Europe through the Renaissance era. Meantime, one can essay provisional judgements, at least on other explanations for the decline in Black Sea trade discernible by 1350. Among them is the weakening of the Mongol domain as a framework within which intercontinental commerce could flourish. The final collapse in 1368 of the Mongol Yuan dynasty in China will have contributed, though a shift of emphasis was already under way from Chinese silk and towards Moluccan spices, a shift driven primarily by the evolution of European consumer preference but perhaps owing something to the South China Sea becoming less settled weatherwise. Also to reckon with is the breakdown of Ilkhan Mongol rule in Persia. From 1335 control passed largely into the hands of local satraps, some of whom (notably in Tabriz) were fiercely anti-merchant. All the same, the final Ilkhan demise did not come until Tamerlane's invasion in 1381.

Tamerlane, like Genghis Khan before him, was pleased to foster trade throughout the territories he had occupied, once the initial orgies of despoliation were done with. He would have encouraged renewed use of the Silk Road route through Merv and Hamadan to the Levant.[89] On the other hand, his ferocious incursions into the Khanate of the Golden Horde (and especially his sacking, in 1395, of Sarai, its capital on the Volga) inhibited any revival of the trade route the Mongols there had blazed to the Crimea. William McNeill perceives demographic recovery as very slow across the steppelands west of the Don. He attributes this to fatalistic resignation initially engendered by the endemic persistence of plague,[90] though a cooling climate could be adduced as well. Edward Gibbon suggested that 'Timour' was at his 'most destructive' when making 'rather inroads than conquests'.[91] That verdict ill accords with the wholesale slaughter perpetrated early on at Merv and Bukhara. Yet in the round there may be something in it. At all events, the Tamerlane saga is subsequent to the twinned shifts in advantage, the decline of Black Sea trade and of Genoa relative to Venice. After all, it was also in 1381 that Venice and Genoa signed their Peace of Turin, an accord that effectively recognised the primacy of the former.

Accepting that the trade with the Far East was compromised by political change in the mid-fourteenth century, one can still ask whether the Genoese might not have found new commercial opportunities around the Black Sea. In a 1966 study, Professor Malowist of the University of Warsaw used eastern Europe as a yardstick against which to evaluate West Africa's economic progress or the absence thereof. He stressed how, by the thirteenth century, craftsmanship flourished in the villages and small towns of the former. He saw this as catalytic for the national economies in question. Politically the ultimate thrust was towards peasant emancipation, a short-term trend towards estate serfdom notwithstanding. The threat from German encroachment was adduced to help explain why this lift-off occurred in eastern Europe but not West Africa. So was the challenge presented by a more limited resource base. The said lift-off[92] was interwoven with 'a remarkable upsurge of government and civilisation' that took place in east and east-central Europe between 1330 and 1380: Bohemia, Hungary and Lithuania constituting its strongest political manifestations.[93]

This evolution ran contrary to the climate trend, if it is assumed to be similar in south-east

Europe to over west and central. Studies from later on (e.g. Romania during the second half of the Maunder Minimum in sunspots – 1675 to 1715[94]) have lent this assumption support. However, a more direct piece of evidence (from the Institute of Geography at the Polish Academy of Sciences) is equivocal. Focusing on flood clusters in the Vistula basin, it finds the period 1200 to 1400 or thereabouts to have been rather dry, contrary to much experience further west.[95] Thus the Dantean anomaly little affected the Vistula.

Through the fourteenth century, Genoa, and also Venice, continued to be involved in the Black Sea despite mounting activity by Turkish corsairs against the Aegean approach routes. Byzantium, too, remained active. Records for 1360–1 from the Genoese *entrepôt* of Chilia near the Danube delta show 30 per cent of the ships then engaged in its Constantinople grain trade to have been Byzantine.[96]

Entering the fifteenth century, one finds the climate (in western Europe at least) deteriorating again. Yet now the Genoese enclave of Kaffa in the Crimea, with its cosmopolitan population approaching 100,000, did emerge as the commercial hub of south-east Europe.[97] Most likely it was a matter of Catholic Europe bucking the trend with newer less weather-prone ships, the carracks and great galleys it possessed in numbers by then. Pending further research, it seems improbable that either the Byzantines or the Muslims were anything like on terms in this regard.[98] But whatever part such adaptation to climate change may then have played in this Catholic involvement, it all but ceased with the Turkish capture of Constantinople in 1453. By 1486–90, less than 10 per cent of the ships in Kaffa were Italian.[99]

As has long been recognised, the Turkish ascendancy did more than merely terminate Byzantium. It presented the whole Mediterranean zone from Portugal to the Black Sea with a considerable challenge. But to this the zone proved resilient at various levels. Maybe this resilience owed something to weather enhancement, with the climatic belts generally edging equatorwards again. Hubert Lamb deplored a singular paucity still of sifted evidence about the climate of southern Europe. But he was disposed to believe that the Mediterranean littoral was by then becoming wetter.[100] An earlier study, focused on Castile and Murcia, highlighted weather erraticism but also how subtle a task it was elucidating the cultural and political responses.[101] That admonition would not be a bad introduction to an evaluation of the Spanish Renaissance.

Central to any evaluation might be the Genoese weaver-turned-mariner, Christopher Columbus (1451–1506). In August 1492 he sailed westwards from a Europe more sure of where its bounds were set than maybe ever before or (especially as regards the exclusion of Russia) ever since.[102] This collective identity had been forged by trial and error since Late Antiquity, this in the context of a natural diversity often accentuated by the modulations of climate change.

11 Pointers to a future

THE EUROCENTRIC WORLD, 1492–1942

The four expeditions Columbus led to the Caribbean between 1492 and 1504 were part of an evolutionary maritime expansion by western Europe. It appears likely that, by the 1480s, Bristol fishermen were fishing the Grand Banks, Newfoundland, because their cod grounds in high latitudes were already affected by falling sea temperatures.[1] More centrally germane were the endeavours of the Portuguese. In 1415, the capture of Ceuta had given them a foothold on the Maghreb. Valorously in the van of the assault had been a young Prince Henry. As 'Henry the Navigator' (1394–1460), he was to mastermind Portuguese expeditions that acquired Madeira, the Cape Verde Islands and the Azores, and probed almost as far into the equatorial 'torrid zone' as Sierra Leone.

Isabella of Castile had dispatched Columbus in 1492 to celebrate how the fall of Granada that year had completed the *reconquista*. As regards more general motives, both Columbus and Henry were stirred by Renaissance 'new learning'. But the overriding concern was the extension of Christian dominion while forging a secure sea route to the spices of the East. Tropical woods and slaves figured too. Columbus's first voyage led to Pope Alexander VI issuing a Papal Bull in 1493 that formally divided the extra-European world along a line of longitude 100 leagues west of the Cape Verde Islands. Everywhere to westward was to be Portuguese and everywhere to eastward Spanish.

One can say the Papal Bull bespoke some recognition across Europe that momentous events were in train on the high seas. But one can as well say that it was so precipitate and arbitrary as to expose that recognition as skin-deep, a trivialising of the said events. Once Magellan's surviving ship had completed a round-the-world trip in 1522, huge import attached to Europe's position at the pole of the 'land hemisphere', the half of the globe's surface that encompasses a high proportion of its land area.

Its explosive break-out contrasts almost eerily with the course Imperial China had taken in this regard less than a century earlier. In the autumn of 1405, Admiral Zheng led out of the Yangtze a fleet of 300 ships with no fewer than 28,000 sailors, soldiers, traders, doctors, etc. on board. He thus began a saga whereby, for three decades and more, a succession of such expeditions betokened the benign dominance of Imperial China around the Indian Ocean basin.

Yet in the 1440s, this strategic commitment was abruptly discontinued. It is clear that a need to focus once again on the exposed northern border was a consideration, a need generated as so often before by climatic adversity (most likely winter chill and summer drought) causing famine among the barbarian tribes and sometimes the Han Chinese of the

Map 11.1 Iberia

Yellow River region. In 1444, the Fanren tribe urgently asked for better land to migrate to but received a few homilies and a little millet instead.[2]

But so pragmatic an explanation cannot account for the categoric manner in which the withdrawal decision was implemented, involving as this did even 'the destruction of many of the records of the fleet and its ship's designs.'[3] The original aim had been to stage a military, political and commercial 'reconnaissance in force'. Once that had been essayed exhaustively, concern about the cultural pollution therefrom of China itself appeared to loom large among the mandarins. One must assume, too, some resentment of Zheng's virtuosity. He was, after all, a Muslim eunuch.

Enter the superpowers

In the spring of 1917, all the indications were that Russia and the United States were finally onto the world stage to major effect. A revolution by moderate reformists had just toppled the Czar; and the United States declared war on Germany. By 1920, however, the Bolshevists in Moscow and the Republicans in Washington had committed their respective countries to more than fifteen years of near detachment from European and global affairs.

Instead, it was in 1942 that each of these superpowers conclusively emerged, at Midway and Stalingrad. Had the Soviet counter-offensive at Stalingrad failed, as had its precursors the previous winter, Hitler could have consolidated a flanking defence from Voronezh or Saratov to Stalingrad then Astrakhan that the Red Army would have been hard pressed to breach, not least because of weak transport infrastructure to its rearward. For him the way would then have been open to the Caucasus and its oilfields, thence towards India, in co-ordination – he would hope – with the Japanese.

That 'Stalingrad' could have been just another Red Army defeat is surely confirmed by the failure of the follow-up offensive towards the Dnieper in February 1943. That Stalingrad itself was, in fact, a crushing victory, 'the greatest ever won in Russian history',[4] was not because Russia was undergoing a fourth exceptionally severe winter in a row. In fact, it was not. But in the average January, the mean temperature on that Volga bend was –10°C; and, once again, the Red Army was better accoutred than the Axis forces for such seasonal conditions. Above all, the Luftwaffe consistently fell far short of its commitment to deliver at least a minimal sufficiency of supplies to the 230,000 Axis troops trapped in the city from 23 November by a Soviet pincer movement. The weather and Soviet opposition thwarted the spirited Luftwaffe aircrews. On the first morning of that pincer envelopment Soviet troops in white camouflage had attacked across snowscapes blanketed in swirling fog. That more or less says it all.

The naval Battle of Midway in June 1942 did not begin to compare with Stalingrad in terms of the scale of commitment and suffering. The death toll on all sides was a very few thousand, not one or two million. But so finely balanced was the outcome of this encounter that, as Walter Lord put it, every participant could say he 'helped turn the tide'.[5] What everything hinged on, above all else, was the location of the opposing carrier forces by the respective reconnaissance flying boats, this as clusters of convective cloud proved more widespread and active than perhaps one might have expected at that time of year, comparatively close to the centre of the North Pacific High. The Americans spotted the Japanese carriers on 5 June, in good time to launch a crippling strike when virtually all those ships' own aircraft were aloft over Midway Island. The previous day the Japanese had seen the United States carrier task force but not clearly enough to identify it for what it was. So they continued to believe their diversionary force had been successful in luring the American carriers away to the Aleutians.

Had it been Japan which won decisively at Midway, it would probably have gone on to seize the Hawaiian archipelago. It would still have been vulnerable to American power (not least to submarines), but more in the longer term. In the interim, Tokyo would have been much more strongly placed to oblige Washington to recognise it as a balancing factor between the Nazi 'new order' and the Americas. So had Hitler also prevailed at Stalingrad, something akin to a '1984' trilateral stand-off might have developed with xenophobic authoritarianism as the order of the day. Nor can we assume that America and its surviving allies would, under those circumstances, have won the race to obtain warheads of mass destruction complete with appropriate means of strategic delivery. The geopolitical consequences of such devices being used could also have been less predictable than they were to be in 1945.

In short, had the Eurocentric world not come to an end in 1942 through Moscow and Washington each achieving strategic ascendancy, the outlook could have been extremely ugly – very likely even worse than if the Second Front had collapsed in 1944. Suffice to reflect on the salient part the weather played in each outcome. Also to recognise how the very fact that neither the 1942 démarche nor the 1492 one coincided with a defined turning point in climate leaves us that bit freer to review the Eurocentric era without determinist preconceptions.

HUNTINGTON OR GIBBON?

Having reviewed climate change in relation to human history through eleven centuries ending in the baleful first half of the fourteenth, one may distinguish between two alternative approaches to cause and effect. The one is to assume, more or less, the mantle of Ellsworth Huntington and treat climate as a prime mover, repeatedly playing a salient role in shaping our historical experience. The other is to locate it more towards the periphery of causation as a factor liable to come critically into play as and when a society or a political regime is delicately poised for other reasons. That is the perception Edward Gibbon came close to when he placed climate aberration not all that prominently among many explanations for Rome's irregular decline and fall.

The impression one gains is that, as from the fourteenth century, the latter interpretation becomes progressively more helpful and the former less so, certainly as far as Europe is concerned. The interplay of air, water and soil exerts less influence on the economic weal. Agriculture becomes more resilient through capital accumulation coupled with innovation. Agriculture as a sector recedes in favour of manufacturing and services. Granted, none of these trends is constant. Nor is any previously unknown. But there does seem to be accentuation across the board from about then. It is a perception consonant with the specific reasons already adduced for regarding the 'calamitous' fourteenth century as one of progress in many spheres.

The key to this and much else has been the harnessing of more and more energy to ever more varied ends. That progression had visibly gathered pace through the High Middle Ages. It has gone on doing so since. One general effect has been to cushion the impact of the vagaries of weather and even of climate. Yet now that thesis is being inverted as human economic activity becomes, far more conspicuously than before, a cause of anomalies in climate and even weather.

Something to ponder first, though, is why energy production took so long to lift off. The megalithic monument at Stonehenge in southern Britain was a triumph of engineering, not to mention its connotations for primitive cosmology. But the energy input was almost entirely manpower. And why did it then take another 4,000 years for combustion engines to appear? Maybe the answer lies in the First and Second Laws of Thermodynamics enunciated by the German scientist Rudolph Clausius in 1850. The First says, in effect, that (subject only to a twentieth-century caveat about nuclear reactions) energy can be neither created nor destroyed, merely redistributed. The Second says that, on balance, this redistribution will always be towards its even spread (locally and, in the final analysis, cosmically) in the 'randomised' form we know as 'heat'. As Clausius himself put it, 'Heat cannot of itself pass from a colder to the hotter body.' This notion is very close to that of 'entropy', enunciated also by Clausius in 1854. These interwoven ideas are fundamental to modern science, not least climatology.

But the immediate point is that the Second Law makes it hard to concentrate energy enough to apply it to mechanical work. Granted, life forms achieve this all the time within themselves. However, the exploitation thus of either fossil organic or inorganic energy sources requires not the grandeur of Stonehenge so much as very exact design and construction. Only thus can energy concentration be achieved, sustained and directed with tolerable efficiency to manifold ends.

Progress was indeed slow for a long time, beautifully designed and crafted though innovations like the watermill were. But from the sixteenth century through the eighteenth, much was to be achieved in terms of refining the components and ancillary equipment that energy-using machines required.[6] The outcome was an energy revolution. An able-bodied man might manage 0.3 megawatt-hours of mechanical work a year.[7] A thirteenth-century European waterwheel run continuously might have yielded 12 megawatt-hours per year: equivalent, on that reckoning, to the workload of 40 people. By 1860, annual world production of inanimate energy was an estimated 1.1 billion megawatt-hours; and a century later, 30 times that. So in 1960, the three billion people worldwide could, in effect, draw on over 2.5 billion such wheels: several thousand times the number actually installed in Europe as late as 1800.[8]

Yet this virtuosity has its limits. Even in 1960, man-made energy was only one part in 5,000 of that reaching our Earth from the Sun. So minuscule a fraction means *inter alia* it is still hard to correct for major alterations in rainfall. It remains, for instance, doubtful how often the energy-demanding task of desalinating sea water could be conducted on the scale required to sustain the pre-existing agriculture on land subject to precipitation decline, never mind that desalination is already invaluable to certain desert townships.

Huntington in decline

All the same, settled communities in salubrious climes have always been influenced less directly by climate change than have, say, nomads in arid hinterlands. So as and when the historical disposition of the latter periodically to surge out against the former has been waning, the Huntington concept of climate variation as a primary driver in human affairs is bound to be less applicable. This is what had happened by 1650 or thereabouts, four centuries after Genghis Khan had led the biggest and ugliest upsurge of them all. By 1650, the well-drilled musketeer had secured his place in the panoplies of Europe. By then also, the artillery cannon was firmly in position. Accordingly a scholarly consensus has arisen which says that what McNeill terms the ‘final eclipse of steppe military power’ (located by him, cautiously, as late as 1750 or thereabouts)[9] took place because, even in the wide open spaces, the new weapons based on explosive energy prevailed in deterrence or defence against nomadic mounted archery. The nomads could neither manufacture nor sufficiently procure these firearms. They were liable, in any case, to face a shortage of gunpowder. Saltpetre, one of its key ingredients, was then a by-product of the farmyard. After 1750 or even 1650, nomadic military successes are localised and transient.

Highly conjectural, however, is what transpired in the several centuries before this eclipse. Why was western Europe never again threatened by nomads after the Mongol withdrawal in 1242? Geographical basics played their part. The gradual assumption by Russia of a bastion role was of cardinal importance. So was the fact that the next inner Eurasian threat to general peace arose in Transoxiana, well off the beaten track to Europe past the Caspian. This threat was in the person of Tamerlane (*c.* 1336–1405), the only leader of Mongolian extraction to rival Genghis Khan and Sabutai in brutal repute.

Admittedly, the materials to hand do not show the tribes Tamerlane galvanised into offensive action to have been afflicted early on by adverse weather the way those who followed Genghis or, indeed, Seljuk had been. Nor would this have been easy to reconcile with the climate analysis here conducted. Moreover, their assembled host boasted fewer horsemen proportionally than the first great Mongol ones.[10] Nevertheless, its operations were often on terrain that will have been still more parched in summer, even allowing for the monsoonal circulation generally being extensive through the decades in question,[11] the year 1403 being the one signal exception.[12] Tamerlane, too, must have felt a compulsion to keep voraciously on the move.

But herein is the nub. The imperium he carved out was essentially south-west Asian. It stretched from the Aral to the Persian Gulf; and from the Ganges to the Euphrates. Nowhere was it *en route* to Europe. Nor did he himself show any interest in the devolution of authority that might have made a wider domain possible. In one of his more careless asides, Edward Gibbon asserted the 'conquest and monarchy of the world was the first object of the ambition of . . . his magnanimous spirit.' Had that been remotely the case, Tamerlane might not have waged a war of attrition for attrition's sake against his Mongol cousins in the Khanate of the Golden Horde.

Next, one should turn to Mongolia itself. In his 1982 study of the roots of Eurasian conflict this last millennium, William McNeill accepted that, in much of Europe at least, the late thirteenth century saw the culmination of a warm and dryish phase. Nevertheless, he did not adduce climate variation to explain the peaking out of Mongol ascendancy. Instead, he stressed greater exposure to plague consequent upon a territorial expansion of continental dimensions.[13]

Previously, McNeill had allowed that there was no direct evidence that bubonic plague becoming more endemic had brought about the sharp fall in population in the fourteenth century inferred for the steppes 'north of the Himalayas' along with China.[14] Nor was a quantum jump in the impact of this killer disease really to be expected. The inner Asian nomads of that generation will have been a sturdy lot; and their forebears never quite so isolated from the outside world as to have passed on to them deficient immunity. Nor does what we do know of the progress of the bubonic outbreak across east Asia as a whole suggest an initially low immunity. It was in 1252–3 that Mongol horsemen first entered Yunnan and Burma, a region which even today may harbour 'inveterate foci' of the plague bacillus. It was 80 years later that the Black Death erupted across China.[15]

Arguably, the fact that the 'universal empire' of Genghis grew so fast sufficiently explains why it fell apart so soon. If that is accepted, however, one has still to account for nothing like it having menaced Europe since, neither in the wake of Tamerlane nor ever subsequently. An obstacle to analysis is a paucity of weather data, past or even present, about the vast and complex Eurasian heartland. But, extrapolating from Lamb, one may surmise thus. The downturn in temperature and rainfall indicated for the Mongolian region for the thirteenth century gave way in the fourteenth to more warmth and moisture, this paradoxically because the Rossby standing wave spanning these longitudes receded somewhat in tune with a reversion to colder conditions across much of the northern hemisphere. A century or two later, as the Siberian High reasserted itself in wintertime, that milder interlude melded into the broader progression towards a cold and (in that part of the world) dry Little Ice Age. Bitter winter winds once again accentuated the chilliness.

To test this hypothesis, one works still from the premise (sound as a first approximation) that much of China is under the same climate regime as Mongolia. But this is subject to the caveat that in some eras the latter has been subject to a longitudinal lag of up to a century compared with, for instance, the Chinese eastern seaboard.[16] Proceeding thus, one may consult three early studies (in 1878, 1926 and 1942) of historical variations in China's rainfall. All see the fourteenth century as moister than either the thirteenth or the fifteenth, certainly in north China.[17] Significant, too, is the fact that temperatures on the Tibetan plateau *c.* 1550 were to reach about their highest turning point in the last 500 years.[18] Allowing for a lag effect, one might say that an interlude of comparative warmth and moistness could have kept Mongolia quiescent through the fifteenth century.

What will by then have been coming increasingly into play as well is cultural convergence. Nomads were finding the ways of settled societies too attractive to wish to traverse thousands of miles simply to obliterate them. To an extent, such ambivalence will always have been present, much as it has been in the attitude towards the West of modern anti-colonial nationalism. Owen Lattimore stressed how, in Han times and even earlier, the peoples in question endlessly fluctuated between the 'true' nomadism of the open steppe and near integration with the Han Chinese.[19] Even so, the warriors of the steppe confederation Genghis created were initially impelled by a single-minded lust for destruction less amenable than anything evinced by the Vikings or Arabs or, indeed, by any of the barbarians that had borne down on the Roman Empire. Yet within half a century Kublai Khan, the grandson of Genghis, was boosting Chinese civilisation to greater heights than ever. Meanwhile many of the Mongols to westward were inclining, for a mix of reasons, towards Islam.

Then a century on came Tamerlane. This inquisitive illiterate would have prominence in any celestial hall of infamy for wanton savagery against communities or sadistic excess against individuals. Yet he rebuilt Samarkand as a resplendent Islamic city wherein to enjoy, in between more primal pleasures, poetry and philosophic disputation. No doubt one here observes a morbidly split personality as with more recent dictators. But one is also talking generically about an emergent dualism in the attitude of inner Eurasian nomads towards urban civilisation.

The founders of the Mogul (Persian for 'Mongol') empire in India from 1526 were culturally Turkish-cum-Persian. Then again, the last nomad dynasty to assume power in China, the Manchu in 1644, had lately been cheek by jowl with Chinese long settled in the south of Manchuria. One estimate is, in fact, that the latter then constituted two-thirds of a population throughout the whole territory of three million.[20]

Those who had ridden out with Genghis had not known much, if any, agriculture. The progress since then of cultural convergence had probably done more than firearms to ensure that grand offensives would no longer be the nomadic response to ecological adversity. That, in its turn, means that, whereas the Gibbon model for climate impact is sometimes less pertinent than the Huntington one for the era 212 to 1350, it can displace it very comprehensively thenceforward.

A GIBBONESQUE ERA

These last six or seven centuries are an era in which Europe's weather and climate are often important variables in historical causation. Yet early on one observes twin shifts in cultural paradigms that relate very uncertainly to the skies and oceans – their trends or, indeed, their norms. The allusion is to the Renaissance and the Reformation.

The elements do not seem then to have entered the consciousness of the age the way they were to as the Little Ice Age approached its nadir *c.* 1700. That manifestly applies to the visual arts. In February 1565, a Flemish artist, Pieter Bruegel the Elder, painted *Hunters in the Snow* in awestruck celebration of a savage winter then in progress. Yet it was not until almost a century later that people like Hendrick Avercamp (1585–1635) developed more fully the Netherlands school of winter landscapes. Nor did extended atmospheric science advance during the Renaissance the way astronomy and some aspects of biology did. Still, one spin-off from astronomy was that, by 1600, comets were known to transit outside the Moon. Their exclusion thus from meteorology gave that subject sharper delineation and served, above all, to separate it from astrology. To that extent, a stage was set for the big advances in instrumentation and physical principles the seventeenth century was to witness.[21]

Like many other recent accounts, this study hears well the revisionist rejection of the Jules Michelet view that the Renaissance was an eruptive event that suddenly 'confronts and destroys' the Middle Ages.[22] Instead, the roots of the former reach deep within the latter. All the same, change both artistic and philosophic did gather pace via an information explosion after 1455, the date by when Johann Gutenberg had produced on his press at Mainz the Mazarin Bible – the first book in Europe to be printed with movable type. Collaterally, one sees the entering and exiting of not a few immensely gifted individuals. To cite just several is again invidious. Yet one is bound to say that Michelangelo, Leonardo da Vinci, Copernicus and Shakespeare stand out even in millennial perspective. There is also something quintessentially High Renaissance about Michel de Nostredame, alias Nostradamus (1503–66). His alluring persona ought to be probed more insistently.

As the fifteenth century progressed, the weather had again turned cooler, damper and more erratic across much of Europe. A critical question is what this connoted for the Mediterranean basin, customarily seen as the mainspring of the High Renaissance. A tentative answer is that it was moister, if not always agreeably so. Two floods of the River Tiber at Rome are recorded from the fourteenth century, nine from the fifteenth, and five from the sixteenth.[23] One can infer that the zonal shift thus connoted helped on balance to sustain the Renaissance throughout the Latin Mediterranean in the face of a European economic recession that was severe through the mid-fifteenth century.[24] A debate continues but the principal cause seems to have been bullion shortage.[25] The striking extent to which the fine arts dimension of the Renaissance was concentrated around the Mediterranean probably owed much to classical ruins and azure skies. This could have applied no less in somewhere like Venice, where Titian, Giorgione and the Bellinis had few ruins locally to inspire them.

From 1410 to 1534, the Spörer Minimum in sunspots might have made the weather cooler. But isotopic analysis shows 1450 was its nadir. Through the first half of the sixteenth century it actually turned warmer across much of Europe. Then severe volcanic eruptions in the 1550s were followed by more general vulcanism as the turn of the century approached. In fact, the last decade or so of the old century was, from Spain to Scandinavia, a time of 'terrible famine, plague, war and disorder'.[26] A Christian Pfister time series from the Swiss Mittelland shows the annual temperature to have fallen sharply and summertime rainfall to have increased markedly since 1555.[27]

Renaissance studies are a growth sector of historical research at present. Deeper elucidations of cause and effect are therefore to be anticipated. Meantime, one may note how, for some decades past, the ultimate inadequacy of the Renaissance has been a theme among the *literati*. In 1992, the late Ted Hughes – by then Britain's Poet Laureate – interpreted the narrative poems and tragedies that Shakespeare wrote from the 1590s as reflecting an anxiety that the unbridled celebration of a reductionist macho rationalism had detached humankind too abruptly from its emotional roots.[28] A similar theme had been pursued in the seminal essay Eric Fromm wrote during the Second World War exploring the interaction between individual psychology and cultural development. Fromm, a refugee from fascism, warned of the sado-masochistical appeal of that credo. He warned, too, of an inner insecurity in modern man that could be traced back to the cavorting of your archetypal Renaissance virtuoso with his ill-judged sanguineness, unsettling learning and restless enterprise. Harried and manipulated by him, the masses may have felt less calm inwardly than ever before.[29] Later, Simone Weil, the French cultural patriot and Christian Jewish humanist, said as much when she ascribed modern 'uprootedness' largely to how the 'Renaissance everywhere brought about a break between people of culture and the mass of the population.'[30] It would be silly to propose, at this stage in our knowledge, that a climate more consistently salubrious through the High Renaissance would have precluded such an outcome. It would be no less silly to rule out the possibility.

By Shakespeare's time, however, one is well into that fissuring of Western Christendom we term the Reformation. The quest for causes has lately been more particularised. But the main strands of argument can still be identified. It was the northern Renaissance that led in the exploitation of the printed word. Duly one finds that Martin Luther, the Augustinian friar from Saxony who set the Reformation in motion, secured his ascendancy within its diverse leadership by tireless recourse to the printed vernacular. Between 1518 and 1525, the formative years, he published more works in German than 17 other major evangelical publicists did. In his lifetime, he published five times as many as did all the Catholic controversialists combined.[31]

No doubt the long winter nights of the north encouraged reading and reflection; and maybe, too, its sombre skies and landscapes encouraged the evolution therefrom of a puritan ethic. In southern Europe oral traditions counted for more, as did colourful modes of display. That north–south divide predates Luther.[32] Therefore even without him, the polyglot Holy Roman Empire could never have aligned Church and body politic to the extent already achieved in Spain, France and England. The Protestant Reformation everywhere made inroads into urban areas, especially those oriented to long-distance commerce as opposed to local trading. In northern Europe, and not least Germany, there were many such, a state of affairs expressive of persisting economic vigour in the face of climate deterioration. Whether an inroad led to takeover could often depend on the strength locally of the landowning nobility.[33] However, the fact that nodal Cologne stayed staunchly Catholic was due more to a civic management that was coherent and firmly defensive.[34]

One could imagine that the climate's visible turn for the worse in the late sixteenth century would have engendered on all sides the sectarian zeal always so liable to descend into atavistic fanaticism. But, in fact, the zeal preceded the worsening. Desiderius Erasmus personified the moderate goal of evolutionary reform within a united Church. But he had died in 1536. That same year John Calvin completed his formulation of the more austere and deterministic Protestantism he propagated via Geneva. By then, too, the Lutherans whom Erasmus had sought to restrain had formally adopted their own separatist creed. On the Counter-Reformation side, the Jesuits were to be founded in 1540–1 and the medieval Inquisition revived in 1542. Thus was polarisation effected regardless of what most people at all levels may have preferred. It has been claimed that 'everyone has always agreed that if ever a writer made an indelible mark on his time, if ever anyone could be said to have given the lead to the most important movements of his day, Erasmus was that man.'[35] In reality, surely, this whole business reminds us how readily, in crunch situations, the pen may lose out to the sword.

The fact that great commercial centres like Cologne, Venice, Florence, Genoa, Marseilles and Seville continued within Rome's orbit confirms that Catholic teaching was not absolutely anti-capitalist. In general, however, the 'Protestant ethic was more welcoming to the amassing of capital and lending it with interest.'[36] But early in the Reformation, a loosely united movement that voiced a chiliastic 'divine law', egalitarianism emerged in the Rhine valley, in the dissected plateau that is south Germany and also in the Tyrol. Its principal leaders were Ulrich Zwingli, a Swiss reformer, and the more radical Thomas Münzer of Saxony, who was close to the Anabaptist utopians and millenarians. In the Peasants' War of 1524–6, their movement was defeated by Imperial forces spurred on by none other than Luther. Many thousands were killed, Münzer among them.

Ever since Friedrich Engels published *The Peasants' War* in 1850, this subject has intrigued historians, German Marxists in particular. The current understanding appears to be as follows. Even in the area of most Anabaptist influence, the south German plateau, perhaps as few as one per cent of the population were radicalised activists.[37] Nevertheless, the movement's main objectives concerned the agrarian economy. This is to be seen against the background of heavy (and, in places, ever rising) pressure of population on farmland; and also of climatic erraticism.[38,39] Soon agricultural frontiers would be receding from uplands gained in the High Middle Ages.

What was by then very much a global trend deepened into the Little Ice Age referred to in many contemporary accounts. Across those centuries, poor harvests (e.g. in 1594–7, 1788 and 1816) readily led to unrest. Whether, as with the 'great fear' that swept a hungry France in 1789, this culminated in a political *bouleversement* would depend on other factors.

Historians have long debated, from various philosophic standpoints, the 'general crisis' of the seventeenth century, a widespread tendency towards revolutionary unrest especially between 1640 and 1660. Several considerations have regularly been adduced, usually as both cause and effect, in a perusal so far focused overmuch on Europe. One has been heavier expenditure by central government, particularly on patronage or in preparation for war – a pursuit then becoming much more esoteric and expensive. A 'universal casualty' of the resultant tension was the 'mixed monarchy', an Aristotelian concept 'so admired in 1600, so utterly extinct by 1700'.[40] That is to say, nations had felt obliged in the interim to choose, probably violently, between making monarchy more absolute or accepting a transference of ultimate power to parliaments or other 'estates', representative in whatever measure.

Observable, too, is a high level of irrationality in some pretty atavistic guises. Thus the period 1550 to 1630 witnessed a strong resurgence of a belief in witchcraft, a phenomenon encouraged by ergotism but which cannot be seen as nineteenth-century liberal historians sought to see it, a mere 'delusion', detachable from 'the social and intellectual structure of the time'.[41] Also to be observed by mid-century is a burgeoning acceptance among the European intelligentsia of the idea that the very cosmos itself was poised to shut down: 'I was born in this setting of time.' This was millenarianism turned on its head.

Mainstream history has thus far given the Little Ice Age short shrift in the quest for causation. In 1965, Eric Hobsbawm, writing from a neo-Marxist perspective, endorsed those who would dismiss 'purely extraneous explanations' of the crisis in terms of climate change, a verbal flourish that served to exclude that factor from his further consideration. But it may be that climate change globally was contributing to the retardation or worse of international trade growth Hobsbawm himself demonstrated was general through mid-century, along with lower crop yields and higher mortality.[42] In 1960, Roland Mousnier had felt it to be 'improbable' that climate variation was a factor.[43] But after a fuller review, he highlighted in 1970 the 'damaging effect of the large-scale agricultural calamities' that beset this 'Century of Revolts all over the World'. Not least did this apply to China.[44] Taking advantage of a veritable spate of rebel movements there from 1627, the Manchu invading from the north-east gained a decisive advantage over the Ming dynasty with the capture of Beijing in 1644.

Across much of China, that second quarter of the seventeenth century had been very exceptionally droughty.[45] Most noticeable in Europe was how things tended to get colder as the century wore on, a state of affairs consistent with the Maunder Sunspot Minimum, 1645–1715. From 1660, however, Europe saw a marked diminution of religious bigotry, witchcraft included. At the same time, scientific enquiry waxed strong, astronomy and mathematics being the spearhead disciplines and atmospheric science a strong beneficiary. Starting with London in 1662 and Paris in 1666, scientific academies sprang up across western Europe, and were to be followed in 1725 by the Academy of Sciences in St Petersburg. As the eighteenth century progressed, the spirit of scientific enquiry flourished, this most remarkably in Scotland and Sweden.

At first sight, this evolution could exemplify that subset of the Huntington conspectus which says the cultural centre of gravity of a developing civilisation tends to move towards cold and storms. But most essentially, the evolution taking place was an intellectual reaction against the disposition of close-minded zealots to kill one another for the love of the same Christian God. Seminal in this respect was the fact that the Thirty Years War in Germany (1618–48) had ended in a negotiated stalemate: 'To each Prince, his own religion.' For 'Prince' sometimes read, elsewhere in Europe, an 'elective assembly'.

The years between 1693 and 1710 saw the nadir of the cold, the 'main cause' being dust loading from volcanic eruptions[46] (e.g. Hekla and Serua in 1693; Amboina in 1694). The bad harvests duly visited upon northern Europe in the middle 1690s did have visible results geopolitically. Thus a weakening of the Scottish economy left Edinburgh more prepared to accept, however dourly, the political union with London enacted in 1707. Then led by David Hume (1711–76), the doyens of the Scottish intelligentsia addressed the attendant identity crisis less through Gaelic romanticism than via the rationalism of the European Enlightenment. James Hutton (1726–97) in earth science and Joseph Black (1728–99) in chemistry were especially outstanding. So was Adam Smith (1723–90) in political economy.[47]

A third of the population of Finland succumbed to epidemics or starvation in the 'famine year' of 1696–7. The culmination of a cluster of cold winters occurring as – it has been suggested – a peak in an 80-year northern cycle[48] had enfeebled the Swedish empire under its bellicose young king, Karl XII. The upshot was the organisation against it of a coalition of forceful containment extending from Norway–Denmark around to Russia. Duly, a Great Northern War broke out in 1700. Stockholm finally lost the initiative with the defeat of its expeditionary force at Poltava, in June 1709, after the same bitter winter which had driven an encompassed France to make initial peace overtures during the War of the Spanish Succession (1701–14). By the peace of 1721, the loss of all Sweden's Baltic possessions bar Finland was confirmed. An endeavour in 1741–2 to restore the old balance led merely to the capitulation of a Swedish army broken by cold and disease through wintering in Finland, and hence to the takeover by Russia of that country.[49] But here, too, scientific discovery proved able to proffer an alternative national identity. In 1741, Carl Linnaeus (1707–78) was made a professor at Uppsala as he continued his revolutionary work on species classification. About the same time, Anders Celsius refined the mercury thermometer and popularised the centigrade (or Celsius) scale.[50] Much else went on besides, the rest of the century.[51]

As to the relationship between the religious ambience and Enlightenment values in Scotland and Sweden respectively, it would be by no means sufficient to say rational enquiry was an aspect of a Protestant ethic nurtured by Scottish Calvinism and Swedish Lutheranism. Protestant Europe was not that *avant-garde*, viewed in the round. It was not, for example, as regards urbanisation, still at that time a good indicator of general progress and – some would say – of progressivism. Nor were either John Calvin or Martin Luther very liberal philosophically. Certainly the visceral reception each of them accorded Copernicus bespoke little empathy with science.

Nevertheless, the Protestant/northern predilection for the printed word must have aided science. Also, in both the countries here being specifically considered, science does appear to have thrived in the context of a climate shift, not so much to cold and storms but towards anticyclonic cold – dry, crisp, calm and often crystal clear. High culture generally flourished most in areas especially under anticyclonic influence: the east coast of Scotland more than the west in spite of the eminence of Glasgow; and Uppsala more than the Swedish south.

Napoleon's invasion of Russia in June 1812 is renowned as a major strategic misjudgement turned into an absolute catastrophe by a winter unexpectedly early and deep. This it was within a secular spell of renewed cooling that the emperor's meteorological adviser, Pierre Laplace, had failed to spot. Laplace was a brilliant mathematician and astronomer but also someone with altogether too uncritical a faith in the potentialities of scientific prediction. He averred that Russian winters 'really' began in January whereas, in 1812, savage cold onset early in November. The French retreat from Moscow had started on 19 October. Cruelly ironic is how a temporary thaw on 20 November almost caused an already desperately depleted Grande Armée to be finally trapped the wrong side of the River Berezina.[52] Surreally symbolic is the fact that its retreat followed, even more exactly than had its advance, the line of the southernmost terminal moraine from the last big Würm/Wisconsin glacial advance.[53]

Taking his cue from winter temperature gain, Lamb judged 1850 to be the least arbitrary end date for the Little Ice Age, at least in Europe.[54] In Britain, grain prices had risen steeply in the years 1836–41, driven by bad harvests connected with a secular fall in temperatures. At that time, there was much vulcanism around the world after which the volcanoes lapsed into near somnolence for two decades. Meanwhile, the warmish and wet Irish summer of 1846 favoured the explosive spread of a potato blight already endemic. This turned critical an agricultural malaise brought on by a further succession of poor harvests (1839–44).[55]

The divide Professor Lamb identified marked the end of 'the hungry forties', a decade of unrest. Mass protests in Britain by the Anti-Corn Law League and the Chartists were to be succeeded, in 1848, by insurrection in certain continental cities. That year also saw the publication by Marx and Engels of *The Communist Manifesto*. By then, too, Ireland was gripped by a potato famine that was to cause its population to fall by a quarter (through starvation and emigration) by 1851. Not till the end of the First World War did so febrile an atmosphere prevail again in Europe.

So let us move forward a century. From 1940 to 1965, the secular rise in global temperatures was subject, in the northern hemisphere at least, to a slight and transient reversal. The consequences for Europe were acute throughout the 1940s. Seasonal mean temperatures 8–10° Celsius below the then norms ravaged the campaign the Soviets so clumsily waged against Finland from November 1939 to March 1940. That 'Winter War' débâcle served to (a) persuade Hitler that the USSR could swiftly be overrun and (b) convince Stalin more must be done to thwart any such endeavour. Those derivatives virtually ensured, albeit at terrible human cost, the Führer's ultimate demise.

Come 1941, the German meteorological service (arguably 'the best and the brightest' at that time) erred, remarkably like Laplace, in endorsing the view that June was not too late in the year to launch an invasion of Russia. That autumn, both Moscow and Leningrad were all but entered. But heavy October rains had made most roads quagmires. Then hard frosts from early November disorganised the railways no less essential to the Wehrmacht's advance. Again, Humanity can be grateful for obstinate resistance and climate perversity (see Figure 11.1).

Just as the Cold War was getting under way in earnest came the winter of 1946–7, the bitterest in Europe for over a century. The acute coal crisis which hit the United Kingdom that February accentuated doubts within the ruling Labour Party about a large British military mission being involved in the war against Communist insurgency in Greece. A decision to disengage was taken, thereby obliging a still reluctant United States to take the commitment over. The immediate outcome was President Truman's enunciation that

Figure 11.1 A Soviet casualty of the winter war

Source: National Defence College, Helsinki

March of his doctrine of the containment of 'direct and indirect aggression'. This, too, was a major geopolitical milestone, whether or not it derived from a sound appreciation of the relationship between Moscow and Balkan Communism.

The launch, a few months later, of the Marshall Plan was a follow-through intended, above all, to stabilise the three Western zones of occupation in Germany, the painful slowness of their post-war recovery having been made still worse by the cold. Meanwhile, in the USSR the ideological fervour engendered by Andrei Zhdanov (the Leningrad party veteran who had returned to Stalin's favour in the spring of 1946) had intensified as the winter cold came hard upon a prolonged summer drought. What the West may have failed to recognise was that Zhdanov's brief ascendancy (he died, ostensibly from natural causes, in August 1948) also ushered in a phase of geopolitical retrenchment by the USSR around its strategic periphery: China, Persia, Turkey, Greece, Germany. . . . Both retrenchment abroad and a frenetic propaganda drive were directed, first and foremost, towards internal consolidation. The adverse weather had made the aftermath of total war all the more agonizing.[56]

A standard measure of winter severity is the cumulative shortfall of monthly mean temperatures. On that basis, the European winter of 1946–7 was indeed the worst since 1840. But that of 1962–3 was the worst since 1740. Yet in the annals of world politics, 1962–3 was unremarkable. This was because all Europe was then at a post-war peak of stability and confidence with sustained economic growth and little unemployment. This contrast well illustrates the precept that, for much of these past two millennia, climate variation has been unlikely to shape human destiny except in situations that were, in some sense or other, marginally poised in any case.[57] What we should therefore ask ourselves at this juncture is how prone the world of the twenty-first century will be to instability for reasons quite apart from global warming.

TRANSLATION TO THE PRESENT

In seeking an answer to the question just posed, it may be instructive to start with the early 1960s. Whatever may be said of the 'stability' of Europe or anywhere else then, it was very much a time when the paradigms through which world events may be interpreted were subject to continual alteration. Above all, they got progressively less geopolitical and more planetary.

Among the various signs were a general renewal from *c.* 1965 of global warming at what soon proved to be a vigorous and sustained pace. But other aspects were remarked more at the time. The Cuba missile crisis broke in 1962; and in its wake, controlling the nuclear arms race came widely to be seen as more pertinent than winning it. That same year, a Nobel Prize was awarded to Francis Crick, John Watson and Maurice Wilkins for their unravelling of the molecular structure of DNA, a discovery that illuminated afresh the vast science of genetics. In 1963, Rachel Carson published *The Silent Spring*, the morning star of the modern ecological movement. The same year, the Beatles hit Broadway. But in November, President Kennedy, acclaimed as leader of a 'New Frontier' in human affairs, was the victim in a murder as yet ill-explained. He left behind a commitment to South Vietnam that the quasi-scientific reductionism of his academic analysts had already rendered inescapable yet irresolvable.[58]

Through the early 1960s, too, the first generation of transistorised advanced computers gave impetus to the development of the first General Circulation Models of the atmosphere. Concurrently, radiative–convective models were computing lapse rates of temperature and humidity. Thus could be derived the vertical motions central to pressure field development, motions impossible to measure directly or deduce mentally. However, the emphasis throughout would remain, for the next decade or two, very much on weather as opposed to climate prediction.[59]

Looming much larger worldwide, in any case, was the flow of information consequent, first and foremost, upon the invention of the transistor in 1948. By the late 1960s, this had led many millions of young people through anger at 'Vietnam' towards a general if temporary rejection of our modern political culture. The full import of this ongoing information boom could not yet be gauged. What became palpable in the 1980s, none the less, was the brittle inability of Marxist regimes to cope with it. Of Mikhail Gorbachev, historians may say that by conceding defeat in the Cold War with grace and even panache, he altered the political structure and complexion of Europe at large more profoundly than has anyone since Martin Luther, each man having acted against the background of a quantum advance in information exchange.[60]

A recognised consequence of this strategic revolution of a decade ago is that Humanity currently faces a very low risk of global conflict. To that extent, the West at least can relax and enjoy all that is positive in the contemporary scene: more prosperity and leisure; more education; much better medicine; fuller democracy; less inequality on grounds of race, gender or age; more concern for individual rights; and, not least, far more opportunity to know other climes and lifestyles. Anyone might think that, against this background, climate change would be a mere irritant amenable to technocratic adjustment.

The rub is that this change is taking place against the background of some decidedly negative tendencies as well. No fewer might be identified for today than apropos the waning of Rome or of the High Middle Ages. Most are in effect the downside of the positive aspects just presented. By 1975 or thereabouts, the proportion of the world's growing population considered to live in towns and cities (most of them badly overcrowded) had passed the half-way mark. By then, too, Arnold Toynbee, himself a Hellenist scholar, had lent his weight to a familiar Hellenic prognosis that the end result of a worldwide tendency for conurbations to merge would be Ecumenopolis, a 'single, globe-encompassing city'.[61]

Hand in hand with all this went a ubiquitous erosion of the time-honoured social bonds, those of territorial community and of the family, nuclear or extended. The alienation thus engendered is aggravated by serious contradictions occupationally. One too little remarked is that, while universities gear up more and more young people for truly challenging tasks, the concentrated handling of data tends to limit the number of posts authentically proffering a real challenge. Among non-graduates, too, job satisfaction is sought more eagerly than ever but can be harder than before to achieve. Above all, there is a burgeoning confusion in all directions over moral values. That is much aggravated by ecological stress and by incessant innovation in biological science. So may it soon be by a burgeoning awareness of the unnatural extent to which our one species has assumed mastery over Nature. Above all, 'by changing the weather, we make every spot on Earth man-made and artificial.'[62] And suffusing everything is an information explosion now gathering pace at a mind-boggling rate.

Nor could one possibly presume power politics to be a thing of the past. The biggest danger remains a general breakdown in relations between the West on the one hand and Russia and/or China on the other, old antagonisms once again finding expression through competitive involvement in local conflicts. Also, William McNeill has well argued that the instabilities latent in the contemporary situation are accentuated by a 'most critical' narrowing everywhere of the customary expectations gap between country and town.[63] But however the geopolitics pans out, the most sombre military possibility is the clandestine delivery of the biological bomb.

One cannot be incorporating all these considerations into every assessment of greenhouse warming. But an awareness of them is a needful corrective to the numbing complacency that can so easily impede precautionary initiatives in this sphere no less than in others. Richard Lindzen of the Massachusetts Institute of Technology (MIT) has been one of the most adept and articulate critics of the greenhouse hypothesis. He has expressed himself satisfied with estimates that a doubling within a century of the carbon dioxide in the atmosphere would (ignoring some problematic feedbacks) cause an equilibrium air temperature rise globally of 0.5 to 1.2°C. He has further claimed to discern a 'general consensus . . . that such warming would present few if any problems.'[64] Never mind that (a) latitudinal differentials in mean changes of temperature will be very important and (b) the pace of climate change globally that example connotes is several times faster than any secular tendencies, certainly in Europe, these last 2,000 years.

However, such historical comparisons may be questioned on two counts. The one is that science has made our generation more understanding of climate change and thereby given us some hope of constraining it. The other is that science pursues the better such ends because society as a whole has become more rational and wise. Shades here of the pre-1914 faith Toynbee well recaptured from his youth. Progress would continue to unfold smoothly and unambiguously. The world would thus become ever more democratic, reasonable, prosperous and just.[65] To many nowadays, that is also too redolent of your Renaissance humanist refurbishing the classic maxim that 'Man is the measure of all things' while astrology was all the rage and witch burning widely endemic and as the polities of Christian Europe consumed themselves in religious strife. There has lately been an upwelling of unease about unreason in the modern world. During the Cold War, many on the radical Left came to see the arms race as veritably driven by a common death wish.[66] More widely, there has been dismay at the purblind cults of personality woven round modern dictators: Adolf Hitler, Joseph Stalin, Mao Zedong, Kim Il-Sung, Kwame Nkrumah. . . . Recently, three biologists, each actively seeking harmony between science and society, have waxed apprehensive about the current mood in the West. Deploring a modish fascination with themes like the paranormal and astrology, Richard Dawkins has warned against being 'so open-minded that our brains drop out'.[67] Meanwhile, Paul and Anne Ehrlich have written of a widespread 'brownlash' disposition rhetorically to ignore or crudify environmentalist arguments rather than respond in accordance with scientific best practice.[68]

The negation the Ehrlichs apprehend stems considerably from a philistine hedonism. But other reactions may be as menacing. The last two or three decades have seen revivals of fundamentalism within several mainstream religions. But so have they, too, a proliferation of cultishness on the religious fringes, not a few of the cults in question being aligned with the ecological Left. Chiliastic prophecy, religious or political, is probably less prevalent today than it was prior to the strategic revolution. But it might readily resurge.

The common theme running through this syndrome is the acceptance or otherwise of science. As ever, human beings are non-rational about things outside the bounds of their comprehension. In medieval times, say, those bounds may have been set mainly by geographical distance. Today they are clearly in the realm of scientific discovery, especially molecular biology. That connects through ecology with climate change.

PERSISTING UNCERTAINTIES

A generic shortcoming of climatologists is that they are too easily thrown on the defensive over a persisting lack of predictive assurance, whether in the retrospective direction or in the prognostic. Apropos retrospection, criticism may come from historians who are themselves strangely far from a sure understanding of matters as basic as the administering of justice in medieval villages or even what can seem more tangible realities such as demographic rise and fall. Then as regards prognostication, the strictures may emanate with equivalent irony from those working in fields notorious even for short-term error: foreign policy, defence, traffic growth, health care demand, balance of trade, world economic development . . . .

Indeed, economic development is where the weakest (yet least remarked) link in climate prognosis is to be found. Especially does this apply to population growth. In 1990, Working Group 1 of the Intergovernmental Panel on Climate Change said world population was 'assumed to approach 10.5 billion in the second half of the next century.'[69] Much the same assumption seems still to be made in such circles, a figure of 10,672 million in 2085 being cited as a benchmark in mid-1998 by the Director of Climate Research at the Hadley Centre of Britain's Meteorological Office.[70] Yet in February 1990, the executive director of the United Nations Population Fund, Dr Nafas Sadik, had said she personally feared that, come the end of the next century, the total could top 14 billion instead of 10 or 11, a prospect with grave connotations for greenhouse warming.[71] Since when, a novel variable has entered the equation in that genetic engineering may before too long make possible a quantum leap (10 or 20 years?) in life expectancy.[72]

Hardly less problematic at this juncture is energy consumption per head. The explosion of information could affect it in either of two ways. The one would be to expand markedly an individual's options within the service sector, with fairly modest incremental demands on energy or other physical resources. The other would be so to stimulate demand and innovation all round that much more energy is consumed. My own hunch is more the former. But nobody can be sure as society embarks on perhaps its biggest paradigm shift since the Neolithic.

Short-term fluctuations

As regards these last two millennia, one can look forward to ever more information coming to hand about weather as registered on the Earth's land surface. So despite a persisting dearth of data from the oceans and upper air or, indeed, about such landward factors as albedo, the use of GCMs to model in outline and with decadal resolution the climate of, say, ten centuries ago should be feasible with moderate confidence. Hubert Lamb would sometimes essay the subjective preparation of synoptic charts to enhance his understanding of historical crises involving weather or climate. In 1966 he inferred 'storm track' and upper trough locations over and around Europe in the Julys of the eleventh century. By depicting the eastern Mediterranean as quite storm-beaten in high summer, he anticipated well the notion of a Crusader cold spell.[73] He also deduced MSL mean pressure in January for (a) the northern North Atlantic and western Europe, 1790–1829 and (b) across the northern hemisphere from 90°W to 75°E for the year 1795.[74] Best known are his synoptic charts gauging (via ships' logs and the contemporary diaries of Tycho Brahe of Denmark, a leading Renaissance astronomer) the weather the Spanish Armada of 1588 encountered in the Narrow Seas.[75]

Whether subjective or electronic, endeavours along these lines may facilitate dynamic interpretation, not least by proffering a goodish indication of wind flow and cloudiness. In due course, they may help explain why causation often appears less regular than one normally expects of a physical science. For instance, if Rossby wave accentuation may explain the steady northerlies that so compromised Harold's strategy in 1066, should there not have been many more such summers around then? The Torneträsk evidence suggests there were none apart from 1066 and 1067. Is this expressive of a temporary phase-locking between two or more disparate tendencies? Eventually, too, synoptic charts in time series may establish whether the climate cycles with a 20-year or so periodicity (not uncommonly identified) relate to either the 18.6-year lunar cycle or, more likely, the 22-year Hale sunspot one.[76] Even more elusive, however, is the suddenness with which established cycles may peter out.

Ongoing, too, is the vexing question of variability – 'erraticism' as this text prefers. That variability can vary has long been agreed. In 1912, Otto Pettersson averred that 'Part of the thirteenth and the whole of the fourteenth century show a record of extreme climate variations. In the cold winters, the rivers Rhine, Danube and Po were frozen for weeks and months.' Less assuredly, he also cited the sixth century.[77] But those examples suffice to illustrate how the span AD 212 to 1350 reveals no consistent correlation between increased erraticism and either upward temperature trends or intensified solar activity. A caveat to enter, in any case, would be that the encroachment of marine ice is always liable to make adjacent regions more prone to erratic weather. However, Lamb eschewed that argument in 1966 when discussing the increased variability registered in Britain since 1940, a tendency he adjudged to be (at least in wintertime) statistically significant.[78] In his bestirring 1977 monograph, Sir Crispin Tickell was non-committal as regards the causes and connotations of a worrisome erraticism he observed worldwide in 1972 and again in 1974.[79] None the less, through 1990 the received 'greenhouse folklore' was that a warmer world would be more prone to weather extremes. Yet in 1995 the IPCC was unable to discern a consistent global trend.[80]

In meteorology, seasonal prediction is now on the agenda. The problem with it, as customarily perceived, was adumbrated by John von Neumann, a pioneer of the computer age, in a presentation at Princeton in 1955. Time ahead was divisible into three. For the first '30 days', prognosis could rest on extrapolation from the status quo. After 180 days, things became independent of these initial conditions. Hardest to cope with was the interim.[81] Later on, Edward Lorenz of MIT, mathematician turned meteorologist by the exigencies of world war, considered how often predicted local tendencies were compounded at regional level as binary computation turned majority results into absolute dispositions. He saw 'an intrinsic upper limit of perhaps three weeks' to the interval across which day-by-day predictions might be essayed.[82]

However, if the constraints can be got round, the implications for understanding better not only a season or more ahead but perhaps also the pre-modern past may be considerable. The time series for 1550–1650 produced by Christian Pfister, for instance, shows clear differences between 11-year moving-average annual trends and those for the four seasons in turn. These differences are not totally systematic and recurrent. But neither do they look entirely random.[83] There are direct implications for crops. Besides which, a clearer comprehension of seasonal modulation may help resolve the general problem of irregular causation referred to above.

The new hopes of a breakthrough in contemporary seasonal forecasts currently reside in the observation and/or simulation of sea temperature anomalies. The limiting condition is the ratio of signal to chaotic noise. Multiple runs may diminish the influence of chaos as may, in due course, more inclusive programming. Thus far, the most promising prognostic results are from within the tropics in association with ENSO.[84] Thus ENSO sea temperature anomalies, plus those in the tropical Atlantic, are now being used to predict west Atlantic hurricane frequency and vigour twelve months ahead. That is not so very surprising, given the correlation long explored between ENSO and the Indian monsoon, not to mention the many other teleconnections with ENSO that have been elucidated (at least tentatively and bilaterally) the last 70 years or so. This encourages speculation as to whether several strong ENSOs these last 20 years have been products of (and maybe, too, enhancements of) the present 'greenhouse effect'.

Translating such lines of argument back to seasonal variations in Europe in the Middle Ages or Late Antiquity will not be easy given (a) albedo uncertainties, (b) the limited ocean data and (c) the thermal inertia of the sea in relation to climate changes even centuries or millennia ago. In principle, however, the fact that one is looking for little more than averages each decade should make cause and effect more determinate. And, of course, the Nile flood records give us a good handle on ENSO.

Not in doubt is the significance to agrarian historians of seasonal norms. They like to define the harvest prospects for given crops very much in terms of monthly sequences. Slicher van Bath has seen the following progression as optimal for autumn wheat in the Netherlands and east England. Until the winter solstice, the weather should be damp though, after September, not too mild. Then till the end of February it should be dry and calm with minimal snow and temperatures never below –10°C. March should be frost-free. Then to mid-June, regular rain and extensive sunshine are desirable, as is increasing warmth. Three or four weeks of cloudiness with moderate rain are then required; and, finally, dryness and warmth (but not scorching heat) till late August. However, J.Z. Titow (using 800 texts from the estates of the Bishop of Winchester, 1209–1350) struck a different balance. His emphasis was on no time, except perhaps early summer, being damp; and on a winter either median or severe temperature-wise. The balance of his sources was, of course, rather more towards the oceanic seaboard.[85]

Wheat was of paramount importance in Roman and medieval Europe. But the grape is more remarked in retrospect. The influence on it of seasonal weather is pervasive, and may be the more so the more wine-making is refined. Dry table wines may thrive when the temperature the last month of ripening averages 15 to 21°C, with delicate whites towards the cooler end (e.g. in Alsace) and full-bodied whites or reds towards the warmer (e.g. in the Rhône). Viticulture does best in central and western Europe mainly where there is above average sunshine and warmth, plus only light rains and freedom from frost after fruit set. In the Mediterranean, one is looking for the cooler and damper of the summer regimes.[86]

Plant and animal diseases usually get short shrift in lay discussion of ecological change, past or future, late medieval murrain and scab being rare exceptions. Even as regards the ultimate obscenity of biological war, the general disposition has been to overlook its potential against other species.[87] Similarly, added exposure to ultra-violet B radiation, due to the anthropogenic depletion of stratospheric ozone, is thought of almost entirely in terms of its direct impact on our species. Yet it menaces many other life forms.[88] To all of them we may feel some obligation; and many more than we immediately realise are, in any case, of real value to us.

Worthy of more attention, too, are soils. A truism to conjure with is that, particularly during times of rapid ecological change (climatic or whatever), soil may be destroyed or degraded much faster than ever it can be restored. Destruction may take days or decades; reconstitution, decades or centuries. This is a primary reason why, in times of global warming, coniferous forests may get squeezed latitudinally as between tundra and deciduous trees/grassland, in a manner akin to the Hudson model as applied to the Mongol context in Chapter 8.[89] Nowadays, the 'loss of soil resources' is treated as a discrete global parameter less regularly than it was, say, from 1935 to 1950.[90] The Brundtland Report focused thus for less than a page.[91]

Wider horizons

As regards the circulation of the air and oceans, three lines of enquiry may yield a deeper understanding of both the new century and the past two millennia. One is how belated but then abrupt can be the circulatory adjustments the high seas make to changes in energy flow. This response is rooted in their conservative properties: the thermal capacity and inertia mentioned in Chapter 2, and also mechanical inertia. An oceanic gyre may cover five or ten times more area than an anticyclone or depression in the air above, while its currents may circulate five or ten times more slowly.

Indicative in this regard is the Younger Dryas subglacial spell, which lasted (more or less worldwide, it seems) nearly a millennium to 10,300 BP. Its termination was especially abrupt, spanning perhaps two decades. Basic to its hardly less abrupt onset had been an acute realignment in the thermohaline circulation in the north-east Atlantic: meaning, in particular, much less advection of warm water into the Norwegian Sea as residual ice and meltwater became stronger. The regional net changes in mean temperature were widely of the order of 5°C in each direction.[92,93] So major an episode so sharply defined encourages one regularly to look out for step-like adjustments of the marine circulation as part and parcel of climate evolution. The same goes for Dansgaard–Oeschger events (see Appendix A). Well-enclosed seas may take smaller steps more often than does the open ocean.

The second priority here identified is Rossby wave analysis. Important fieldwork has lately been done in North America. Climate change over and around the western cordillera between AD 100 and 1400 assumed a sequence that, from 850 onwards, fits an accentuation of the amplitude of the cordillera standing wave until *c.* 1140 but then its retraction,[94] this turning point coinciding closely with the medieval optimum for that part of the world. Moreover, Claudio Vita-Finzi has mapped alluvial filling that bespeaks a secular southward swing (down the eastern limb of the cordillera) of a narrow but active moisture belt, a progression akin to his earlier findings *vis-à-vis* the Mediterranean. Professor Vita-Finzi has acknowledged it could be standing-wave related.[95]

Perhaps, indeed, this approach could proffer the explanatory link still missing in the Vita-Finzi thesis about 'younger fill' in Mediterranean valleys. His account of what happened has withstood scrutiny well.[96] But his endeavour to explain it all simply in terms of displaced depression tracks is less than adequate. Yet so are some of the alternatives or qualifications advanced by others – e.g. blending with the Vita-Finzi thesis the effects of human erosion.[97] Maybe Azorean ridging encouraged depressions to form in the eastern basin in the High Middle Ages. At present few originate there, though many are reinvigorated. Medially, it lies six degrees south of the western basin-cum-Adriatic.

Solar fluctuation is the other research priority proposed. Several basic questions remain unanswered apropos the mechanics.[98] Meanwhile, a radical school of thought contends that, even throughout the twentieth century, a variable Sun has been the main agent forcing the terrestrial climate. Sometimes, alas, their advocacy is suffused with a sectarian zest oddly reminiscent of the Fusion Energy Foundation established by the flamboyant but flawed Lyndon La Roche in the USA of the 1980s to (a) celebrate the thermonuclear fusion reaction that drives the Sun and, it seems, every other star and (b) promote beam weapons, fusion power reactors and fusion-driven space travel.[99] To note this, however, is not to dismiss the present radicalism out of hand. Rather it is to call for a fuller debate, one that is empirical and exploratory all round. Certainly, mainstream climatology should address the solar dimension more fully than, for instance, the Intergovernmental Panel on Climate Change has thus far done. Here again extra insight is needed, both to look forward and to look back.

One mystery may at last be nearer resolution. It concerns the outflow from the Sun (and as detected on Earth) of neutrinos: a genre of sub-nuclear particles deeply fundamental in that they reveal no structure or electrical charge and, at least when at rest, little or no mass. Huge numbers emanate from the Sun's inner furnace. They escape instantly, whereas photons of heat energy take scores of thousands of years to do so. The rub is that the rate of neutrino detection has been a third lower than the 'standard' solar model predicts.[100]

Among the facilities being applied to this problem is the Super-Kamiokande underground trap in Japan. Being directional, it could report in 1998 that many neutrinos passing through the Earth's interior transmute into other forms. If confirmed, these findings could square the 'deficit' and thus underwrite the standard model. Furthermore, the mutations show neutrinos in motion to have significant mass: a conclusion that could also have profound implications, both for cosmology and for particle physics.

Yet of more immediate import is some research at the Danish Meteorological Institute (DMI). While illustrating how the stronger 'solar wind' associated with shorter sunspot cycles protects the Earth better from cosmic rays, it seems also to affirm that these rays do generate within the atmosphere extra solid nuclei that water vapour may condense onto. More nuclei could, in principle, mean that cloud cover becomes more extensive (see Chapter 2) or else denser, at least in terms of an ability to reflect radiation either back into space or back to the Earth's surface. This has generally been expected to favour cooler conditions in that, on balance, sunlight may then be reflected outwards more than the longer-wave infra-red from the Earth's surface is reflected back.

However, icy cirriform clouds reflect sunlight less readily than they do terrestrial infra-red; and the balance between them and the lower watery clouds could alter as other circumstances do. The DMI scientists cite past times (e.g. the High Middle Ages) when low Carbon-14 counts indicate a lower incidence of cosmic radiation to be concurrent with warmer conditions.[101] What might also be considered are any implications for precipitation. For instance, might the same amount of water suspended in more droplets mean less rain formation?

That the Sun can vary in vigour abruptly over centennial timescales has lately been demonstrated with the steep rise in the Carbon-14 presence datable at between 850 and 760 BC. According to a Dutch study team, that was associated with colder, wetter conditions in middle latitudes each side of the equator.[102] Something else that very specifically merits further investigation is the effect on our terrestrial climate of secular variations in solar irradiation associated with variations in the Sun's magnetic field. In the twentieth century, its strength increased no less than 130 per cent; and presumptively associated with this, there may have been a secular increase in solar radiation of just over one part in a thousand.[103]

Holistic security

In the course of the next two or three decades, a combination of research fieldwork and modelling should reveal considerably more about historical climatology these last two millennia. About later this century, we may remain less certain. What cannot yet be ruled out is an eventual return to the Huntington theme of climate change as a prime generator of instability and conflict. That would not depend on our all reverting to nomadic tribalism. It would only require, in principle, substantial shifts in rainfall patterns, coupled with a continuing failure to make the desalination of sea water cheap enough to apply to agriculture in general as well as to city and market garden use. Overcoming that obstacle will probably depend on large-scale energy production being made a lot cheaper still. Disappointing progress with nuclear fusion reactors (apropos cost but safety too) does nothing to make one sanguine.

Nor do the dangers thus latent derive simply from the instabilities notoriously inherent in rainfall distribution. They reside, too, in the proclivity of a rickety world society not to react constructively whenever a big crisis breaks suddenly. Take what contemporaries spoke of, metaphorically, as the 'economic blizzard' – the several years of global recession consequent upon the precipitate Wall Street Crash of October 1929. From 1932, in both the United States and Sweden, the response was to apply the proactive principles of public economic management that were soon to be subsumed by Keynesian economic doctrine. But most other democracies merely groped around, nerve-racked and introverted. Worse, the outcome elsewhere (Germany, Iberia, Italy; and in the Balkans, the Far East and Latin America) was often the ascent or consolidation of fascism.

The grounds for apprehending that a climate crisis could likewise induce a fundamentally irrational response are severalfold. One is what looks like being the febrile state of society in the twenty-first century, within the West as well as across the world beyond. Another is that the onset of climate change may be manifested via clusters of extreme weather events. A third is a probable interaction with other ecological stresses.

Also to reckon with is our mental make-up. Pleistocene roots were adduced in Chapter 1 for apprehending that the kind of general crisis the basic psychology of we 'Children of the Wisconsin' is least attuned to dealing with is ultra-rapid warming. Less deeply embedded, but potent none the less, may be folk memories of Holocene migrations out of rain-deficient Eurasian interiors. Though the geopolitical connotations thereof may not oppress us overmuch today, they may have been mainsprings of concern in the not very distant past. They may help explain, for instance, the strange regularity with which, between 1815 and 1990, the West grossly overestimated the ability of Moscow to project its might across its national borders.[104] More specifically, they could have encouraged a basic misreading of the situation that developed from 1966 along the 7,000-mile frontier between Russia and China. That year, as China launched into the orgy of orchestrated hooliganism known as the 'Cultural Revolution', the Soviet military began an extended border build-up. Analysis readily revealed that Moscow's purpose was to dissuade China from going so ultra-left as to destroy any prospect of reforging Communist unity. None the less, several leading Western statesmen (egged on by certain Soviet publicists) spoke as if the threat China posed to Russia and other neighbours was simply Malthusian overspill – a *Völkerwanderung*.[105] And China's demographic weight continues to hold us in awe.

Hazy folk memories may well condition our whole attitude towards desiccation. There may be a propensity to exaggerate (a) its historical impact even in inner Eurasia, (b) its incidence at this particular time,[106] and (c) the extent to which those directly affected may still seek their remedy in migration, bellicose or otherwise, out of country. By the same token, one needs to be wary of a disposition in eco-minded circles to talk of 'environmental refugees'. Hedged with qualifications, as in the Brundtland Report,[107] the expression may not be too unhelpful. Cast in more absolute terms,[108] it may at once betoken and reinforce an ecological sectarianism that demands we prioritise that sector as a straight alternative to anything more than token military preparedness.[109]

This latter pitch can readily prove counterproductive. By inducing a backlash, it can hamstring attempts by those exercised about ecology to gain political power. It may be even more of a barrier to the application in government of the balanced spread of policies that a strategy for holistic security must rest on, including those for policing a world order within which good remedies may be implemented. Where climate is concerned, these must include not just ones for coping as and when anthropogenic change does turn truly catastrophic, but also ones for preventing it assuming such primacy in the first place.

The poverty of strategy

No small part of the blame for the impasse that has developed must be laid at the portals of the community of intellectual strategists: that body of people who organised themselves into a distinctive discipline after the launch, in the autumn of 1957, of Sputnik I. They did so, above all, to address the novel problems posed by thermonuclear warheads and intercontinental rocketry. Among those who wrote seminal studies about, or bearing on, nuclear deterrence between 1959 and 1963 were Patrick Blackett, Bernard Brodie, Alastair Buchan, Hedley Bull, Pierre Gallois, Margaret Gowing, Samuel Huntington, Henry Kissinger, Klaus Knorr, Basil Liddell Hart, Robert Osgood, Anatol Rapaport, Thomas Schelling, John Strachey and Maxwell Taylor. It was a golden dawn for 'strategic studies'.[110]

Unfortunately, it seems also to have been high noon. Certainly the discipline has failed very comprehensively to adapt to the strategic revolution of 1989–91. It has failed, in particular, to address two of the more intractable threats to world peace in the medium term. The one stems from the instabilities latent not just within the Cambodias of this world but also within advanced 'post-industrial' society. The other is ecological distortion and degradation; and, not least, anthropogenic climate change.

So far as regional situations are concerned, a positive resolution of the intercommunal impasse in the Holy Land may be of singular importance. Negative though the response they invoked undeniably was, the Crusaders may have been wise in their generation to see Jerusalem as the centre of Creation as per the famous Hereford map of *c.* 1285.[111] The Fertile Crescent led the world of pre-history and Antiquity in agriculture, urban settlement, phonetic script, monotheistic religion. . . . Nowadays, the Near East is of ominous moment as a primary source of fossil fuel and, alas, of weaponry, actual or prospective, of genocidal destruction.

Despite the ugly scenes as 2001 dawns, it may not be too much still to hope for a confederal partnership between Israelis and Palestinians based not just on arms control provisions but also on mutual respect and understanding. That was, after all, a dream of the liberal wing of early Zionism, notably of Albert Einstein.[112] It may also be pertinent, even in an age of diminished religious commitment, to recall that the five principal prophets of early Islam (Adam, Noah, Abraham, Moses and Jesus) already were and still are the root inspirations of Judaeo-Christianity.

Besides, the catastrophe theory flip effect is prevalent enough in conflict resolution these days to hold out some prospect. As regards the ecological context, experience from Antiquity as well as the Middle Ages shows how peculiarly difficult it is to predict how the processes of climate change will play in the Levant. But in any case, the forging of a partnership could do much to create the right political atmosphere for planetary environmental management. Ineluctably, war in Palestine has a nodal visibility and a north–south resonance not so readily acquired over the rest of Afro-Asia.

More generally, one can draw some encouragement from the fact that, in the years when the greenhouse effect was still being ignored or discounted even by the great majority of climatologists, it was pointedly warned about by each of the men so often spoken of as being respectively the fathers of the American and Soviet hydrogen bombs. In 1958, Edward Teller noted with a colleague that, if the combustion of hydrocarbon fuels drove up the level of atmospheric CO_2, this would act like 'the glass in a greenhouse', with a melting of the ice caps the ultimate result.[113] Ten years later, Andrei Sakharov was warning that CO_2 'from the burning of coal is altering the heat-reflecting qualities of the atmosphere. Sooner or later, this will reach a dangerous level.'[114] So on each of these occasions, too, an eminent theoretical physicist was a pacemaker *vis-à-vis* the question of international harmony.

More encouragement for according climate change a well-judged measure of recognition, as geopolitical and planetary concerns are brought together within new strategies for survival, may come from the annals of history. Thus in Europe the years from AD 212 to 1350 witnessed a succession of menacing forays impelled by climate flux, especially as regards rainfall. So did they widespread and terrible epidemics, mostly climate-modulated. But in that era, the peace and progress of the continent's various communities much more often rested on a diverse mix of factors, ecological and otherwise. Usually, too, the mix appeared more local and regional than it did continental. To that extent, the day even then went with Edward Gibbon more often than with Ellsworth Huntington.

Yet Gibbon in his generation was ill-placed to appreciate just how critical climate change can be when a situation is poised marginally in other respects. That state of affairs could be very recurrent during this century. What we do not know is how effectively the crises therefore latent may be anticipated and forestalled. It has never been easy to predict how given institutions or particular cultures will respond to the challenges they face. But now we face cultural and, most probably, institutional flux at an unprecedented pace, much as with global warming.

Indeed, the use of climatology as a metaphor for societal trends can be taken further. In his 1912 address to the Royal Meteorological Society cited above, Otto Pettersson spoke of the 'curious fact that we know more about the Earth's climate and its changes thousands and millions of years ago than we do of those changes which occurred a few centuries before our own time.' That may not be true today. It may not have been strictly true then. But the general point can still be taken that chaotic factors loom large in the shorter term, in human affairs and in geophysical. As regards the management of climate change, one can but hope that admonitory discourse, informed by historical perspective, will prove in the final analysis to have been self-defeating prophecy.

Appendix A: Assessing past climates

Only the broader categories of evidence about past climate can be assessed here. In a sense the most basic, not least for extreme weather events, is contemporary documentation. Stone inscriptions about Nile floods go back five millennia, albeit with some uncertainties as to dynastic chronologies. Regular records, year by year, from where Cairo stands today are extant from AD 622, the conquering Muslims taking up what the Persians had lately started.

Nevertheless, quite the most substantial records on the continental scale, in Antiquity or medieval times, come from China. The two earliest weather diaries extant are by Lu Zouqian and Guo Tianxi, and cover 1180–1 and 1308–9 respectively. But imperial chronicles stretch back continuously 2,500 years; and there are many other literary works, a few from as far back. Graphical compilations of several trends over the last 3,000 years can therefore be essayed.[1]

But due allowance needs be made for inconsistencies in registration, not so much with flood records as with more individual observation. More notes are taken as literacy rises. More of what is noted survives the nearer its origins are to the present. Cultural and institutional factors come into play as well. One concern can sometimes be not to overplay natural disaster lest this be read as insinuating the ruler has lost the mandate of Heaven. Another may be to extol the heroic virtues.

The Icelandic sagas veritably invite consideration as a test case. The sense one has is that they were written by men to whom a sober respect for the truth was an integral part of a valued code of honour. So, in this respect as in others, they continue to be well received by the literary historians. They are seen as informed by an early medieval Icelandic tradition of 'astonishing sophistication in geographical description'.[2] They are credited with blending a rich sense of magic and the supernatural with geodetic and geographic accuracy.[3]

In relativist terms, all that is fair. But we have always to remember that the sagas were written two or three centuries after the events they relate. They were written to entertain and inspire very dispersed communities during long, rough winter evenings. They emerge, too, out of a tradition (dating from the tenth century) of writing for profit eulogies of the fame-hungry kings and princes of the northern world. A review of the climatological value of medieval literature, written in the light of modern textual criticism, intimates we need be on our guard about how the sagas blend fact with fiction.[4]

Celestial sequences

For the first 14 centuries AD, celestial sequences (meaning, in particular, meteors, comets and sunspots) may best be gleaned from the Chinese imperial records and them alone. Take a University of Illinois compilation of the number of comets historically visible from somewhere in the northern hemisphere. The estimate averages 78 a century from AD 200 to 499;

then 116 from 500 to 799; then 106 from 800 to 1099; and finally 98 from 1100 to 1399. This considerable variability probably owes too much to how badly the record from Europe and more or less everywhere else outside China has been impoverished and skewed by cultural taboos and political instability. Surprising, none the less, is how wide are the margins of error this scrupulous study felt constrained to allow – between 79 and 153 in the second of the time brackets cited above.[5] The moral is that, except when and where one has to be concerned with individual meteor showers or meteoritic impacts, it is sounder to focus on the Chinese sources (see Chapter 4).

Not that they are foolproof. On the contrary, the absence of recorded sunspots between 590 and 810 could owe much to the destruction of records and other infrastructure during the sacking of Ch'ang-an by a rebel general in AD 755.[6] But in Europe, there are only five surviving reports of sunspots between AD 800 and 1400, the most famous being the very formalised (and studiedly symmetrical) painting by John of Worcester in 1128. In the Arab world, too, sunspots on the Sun are either ignored or viewed as planetary transits, this out of deference to the Aristotelian notion of solar perfection.[7]

A matter of some dispute apropos sunspots has been how far a dusty or misty sky facilitates their observation by reducing solar glare.[8] The optimal conditions are probably those in which a clear and still sky obtains above a thin surface layer of haze or fog. Another striking aspect of the Chinese archives is a complete absence of sunspot reports between 1280 and 1350, a hiatus that lies in between multi-decadal spells of very considerable sunspot occurrence.[9] It closely coincides with, and may have underwritten, the identified bounds of the Wolf Minimum in sunspot clusters. Additionally, it may derive from dustiness due to more north-westerly wind vectoring over much of north China (see Chapter 8). All in all, one must be careful about deducing from ancient archives, even those from China, long solar cycles of 210 years of whatever.[10]

Rings and varves

To the public at large, tree rings are the lead indicators of climate change. The modern concept was worked out in the first three decades of this last century by the Arizona astronomer A.E. Douglass. The premise is that the summer growth of a trunk or branch will be determined by multiple factors. Age and species will obviously be fundamental. But of the others, one or more will be climatic. Sunlight, direct or indirect, is essential to plant growth through photosynthesis but is, as a very general rule, amply profuse. Therefore temperature or rainfall variations are the main climatic controls.

Sometimes trees will be critically located in regard to warmth and/or rain and/or some less tangible aspect of the weather – e.g. wind, cloudiness. If so, climate control will readily gain purchase. At other times, tree populations may be 'complacent' by virtue of being in locales that proffer margins of ecological adequacy all round. Complacent populations may be gauged by wood density. The key here is that, while the early wood each season is lighter than the late, each is subject to annual fluctuations that may considerably be climate-driven. Work has begun, too, on isotopic variations.[11]

At its most assured, tree-ring analysis may be calibrated and cross-dated to yield useful results across hundreds, or indeed thousands, of years. The Torneträsk series much cited herein extends back 1,400 years. Often it yields very exact results, year by year. Witness, too, the famous *Sägesignatur* or 'saw-tooth signature' observable across south Germany from 1530 to 1541, a biennial zig-zag between thin and wide rings.[12] Ring data may also register regeneration, be it spontaneous or through managed replanting. A conspicuous case, across the British Isles at least, was the proliferation anew of the oak after the human catastrophe that was the Black Death.[13] Britain also exhibits a depletion/regeneration gap in the mid-ninth century AD, an episode closely concurrent with the cool interlude identified in Chapter 5.

Nevertheless, there can be complications. Abnormal years can produce a double ring or no ring at all. The effects on a tree of a single good or bad season may last several years.[14] Direct sunshine may, as a rule, stimulate photosynthesis but, if incident to excess, be liable to inhibit it in certain species. Indeed, comparison of growth rates between species in the same locale that respond differentially in this regard may reveal sunshine variations, with inter-decadal or maybe interannual precision. In the south-east of the USA the results to date have been sufficiently good to reveal an ENSO signal from 1700 onwards.[15]

The nitrogen and sulphur dioxides (NO_2 and SO_2) variably present in the atmosphere may also constrain tree growth appreciably, certainly in modern populated areas.[16] More generally, the exact locale can be determinant. The width of oak trees on a watery valley floor are likely to be governed primarily by cumulative warmth through the growing season. On steep slopes with ready run-off, however, oaks may find adequate rain is critical.[17] Most varieties like good drainage but not to excess.

Since oak has been used much in building, it has been used, too, by Bruno Huber and others as the prime datum for tree-ring research in axial Europe. But caution in interpretation is enjoined by the conclusions the Huber team drew about the Dante anomaly (see Chapter 9). Its main years, 1312–19, were ones of 'very wide tree rings' across southern Germany.[18] Granted that closely matches the concurrent evidence from Torneträsk and Ireland (see Chapter 9). But this does not mean the limiting factors were the same. As regards south Germany, one has to allow that the great majority of trees (oaks included) can tolerate excess water better than Europe's staple grainstuffs can.

Within lakes, deposition occurs that varies from season to season in volume and, most characteristically, in the balance between organic and mineral material. This affords a basis for registering secular change in a manner akin to tree-ring analysis. Thus in the Gulf of Bothnia, an annual 'varve' usually consists of (a) a fairly well-developed spring layer composed largely of mineral grains from inflow, (b) a summer one of loosely aggregated organic detritus, and (c) a thin but dark winter layer of decomposed and compacted organic matter. Not seldom, varve series thus presented in lakes near the Bothnian coastline can be traced back five or six millennia. Extended series within these last two millennia (e.g. AD 230 to 1552) can regularly be dated to an accuracy inside 3 per cent,[19] allowing for double or nil varves in certain years.

In any one lake, the volume and/or average particle size of mineral content in a varve may be a non-linear indication of the relative seasonal inflow. The concentration of organic matter will depend on photosynthesis. That may be governed by many variables (e.g. acidity, dissolved gases, water temperature). But the presumption in this context tends to be that a lead factor is the blue–green part of the visible solar spectrum, this light being especially penetrative of water. Even at their best, varves are less surely quantified than tree rings. They are also more prone to erosion. But the two approaches are quite complementary in terms of regional spread. Besides which, varves also indicate the past extent of lakes.

Ice cores

Well over a hundred cores 100 metres or more deep have thus far been extracted from ice caps around the world. About twenty drillings have been in Greenland, while Antarctica has had 50. Canada, Iceland, Spitsbergen, the Alps, Nan Shan and the Pamirs are among the other locations.[20] Dating may be aided by seasonal oscillations of some of the parameters otherwise being tested for secular trends. One tangible distinction is that in summertime larger snow crystals form. The resultant annual layers may perhaps be discernible through 100,000 BP, though not, of course, with precise dating.

Within the Holocene, a layer count correct to one per cent can be expected.[21] Ice cores can be utilised in palaeoclimatology in a whole variety of ways. Measurement of ice accumulation is one. Another is using stable isotopes to indicate past temperatures. Until recently, the one usually selected has been Oxygen-18 though now Deuterium, alias Hydrogen-2, is being turned to more. The link is that, since each isotope has a relatively high atomic weight within its parent element, molecules containing it more readily condense out of water vapour when temperature falls. Therefore the higher the temperature at which condensation starts, the higher the proportion of these heavier isotopes in the resulting cloud droplets will be. That proportion will be apparent in the layer of ice residual from any precipitation the cloud gives rise to.

A further precept is that the mean condensation temperature as thus revealed can be translated into the mean air temperature at surface level throughout the season in question. Here the argument is more problematic, especially at high altitudes and/or latitudes. Determining the mean height at which snowflakes form will be difficult because of (a) limited observational data, (b) the shallowness in high latitudes of the troposphere and (c) the deep cold. Nor will it be easy to judge the temperature gain from the height of flake formation to the surface. As hard will be relating the temperature lapse rate during such shower activity to the average across a season. One thinks, in particular, of the strong temperature inversions that may develop at night above lying snow.

Nevertheless, great reliance is placed on this technique for ascertaining palaeotemperature patterns. Its forte may be the gross measurement of secular trends. Additionally, the thickness of seasonal layers of ice can show that, for example, the rate of net accumulation of new snow in central Greenland during Pleistocene glacial maxima has characteristically been a fifth of what it is today. Foreign particles embedded in cores can also be instructive. If they were airborne, their composition may reveal wind direction and their coarseness wind speed.

An individual volcanic explosion can leave a regional signature in the form of dust deposits in ice, peat or wherever. Of more importance for historical climatology, however, can be a succession of violent and very vertical eruptions that eject large quantities of dust and gas (most indicatively, hydrogen sulphide and sulphur dioxide) partially as far as the stratosphere, where they will disperse around the hemisphere and, in due course, the globe. Fine and persistent stratospheric dust is the agent of climate fluctuation but the sulphur gases yield an acidity record that can be scanned dielectrically to yield tabulations that can systematically be compared across time. For as these gases diffuse outwards and downwards, they oxidise photochemically and dissolve in water droplets, forming sulphurous or sulphuric acid, which soon washes down within precipitation. Take the record back to AD 553 from the Crête core in central Greenland: this rests solely on the acid gas proxy because volcanic dust does not reach that high location at that latitude sufficiently to modulate the general background of continental dust.

One source of imprecision can be the dating of any ice core extracted. A standard accuracy to the nearest year is claimed for this last millennium but to one per cent of the time elapsed in the Holocene before that. Then again, while the Crête record is deemed to embrace everywhere north of 20°S, low-latitude eruptions may take a year to show up clearly therein. Also, some neutralisation of acidic gases within the atmosphere is liable to occur.[22] Nor will the proportion of acidic gas to stratospheric fine dust be at all constant. One should note, too, that the main acid formed (sulphuric) has itself a tropospheric cooling effect.

Another valuable source of ice-core data is air entrapped in the bubbles enclosed within the solid ice that forms below a certain depth. On ice sheets, loose fallen snow gradually becomes firn, a porous material of density 0.5 to 0.8 (the density of water being 1.0). Once compression has raised the density to 0.83, firn turns to ice. This threshold is usually reached at a depth somewhere between 50 and 120 metres or between one and 30 centuries after this newly constituted ice fell as snow flakes.[23] But subject to this lag effect, the bubbles retained afford a good record of the fluctuations over time of the CO_2 and (still more conspicuously, see Chapter 2) the CH_4 content of the atmosphere.

Ice-core analysis across tens of millennia may highlight medium-term oscillations in climate that cannot readily be accounted for via Milankovitch or in any other obvious way. During the Wisconsin glacial era (see Chapter 1), there were some 20 'Dansgaard–Oeschger' interstadial events – comparatively warm phases lasting between 500 and 2,000 years and ushered in by warmings of 5 to 8°C over just a few decades. The return to glacial conditions was more gradual. The most recent such episode was the Younger Dryas.[24] It immediately preceded what we identify as the more stable Holocene.

Just before and after a prefatory temperature hike, there would be 'flickering' – i.e. smaller temperature hops back and forth. With each rise went maybe a doubling of snow accumulation and an order of magnitude increase in dustiness. Concurrent surges in levels of atmospheric methane will have been due to expansions of the equatorial swamps. More ice-core evidence with more accurate dating is needed to resolve a debate about whether tendencies in the southern hemisphere matched this erraticism or mirror-imaged it.[25] That in turn may help to resolve the mechanics of this phenomenon and any bearing it may have on the more recent past and the near future.

Seabed cores

Analysis of planktonic debris from cores of seabed sediment from the deep North Atlantic indicates that the abrupt surface changes just described were regularly associated with switches in the deep water circulation. Accordingly, Hermann Flohn has enunciated the proposition that the chief greenhouse gases, water vapour and carbon dioxide, are more rarified in the atmosphere immediately above where ocean upwelling is occurring and amplified where down-welling is well established, a correlation apparently due to photosynthesis by algae in the nutrient-rich water rising from below the thermocline.[26]

Evidently the global rates of upwelling and down-welling must always be virtually equivalent. But this does not exclude net exchanges, ocean versus atmosphere, of the greenhouse gases at given places and times. However, resolution of this dimension is impeded by (a) the fact that water vapour, unlike atmospheric CO_2, is not distributed at all evenly across the planet, and (b) the amounts of it are hard to quantify in the present, let alone the past.

Glaciers

By comparison to the huge changes that ice cores may record, the advances or retreats of extant glaciers could seem almost trivial. Yet the fact remains these movements are the main way ice sheets on land expand or contract in the short term. Phases of glacier stability are well marked by moraines (i.e. lines of detritus deposition), either lateral or terminal. Yet here again there are problems, dating being one of them. Studying the Alpine glacier advances of the High Middle Ages, Emmanuel Le Roy Ladurie concluded that (a) any time-frame for them must derive from geomorphology and botany, and (b) the result 'is elastic about 50 years either way'.[27] The 5–10 per cent error cited by Bradley as generally representative is congruent.[28]

As regards glacier mechanics, advances and retreats are respectively due to positive or negative changes in mass balances as determined by the inflow, local snowfall and melting. Not that glaciers respond instantly to alterations in ambient temperature. Medium-sized glaciers in Austrian valleys have been shown to take some seven years to adjust.[29] Larger features may take decades. Not a few glaciers are liable to surge periodically because a build-up of their mass has caused melting of their undersurface, thereby providing a lubricant. Several of the glacier lobes on the rim of Iceland's Vatnajökull, the biggest ice cap in Europe, behave thus. Brúarjökull did so in 1625, *c.* 1728, 1810, 1890 and 1963. On the last two occasions it advanced 10 and 8 kilometres respectively.[30]

Other biological proxies

Most of the indicators this study depends on have now been covered. But more must be said about biological proxies. Almost as remarked as tree rings are tree lines, the territorial limits of tree populations. Perforce they are governed by the same parameters, species by species. With tree lines, however, one is more concerned with ambient absolutes as opposed to preferred tendencies. Take the spruce, *Picea abies.* According to a Lamb compilation, the mean temperature of the warmest summer month should be within the range 12.5 to 19.0°C. Hydrological constraints weigh in as well.[31]

Tree 'lines' are, in reality, margins rather than lines. Thus the parkland regions of tropical Africa where the hominids successively evolved represent a very gradual transition from savannah to forest. What must also be borne in mind is the propensity trees often display for advancing during times of climate amelioration more readily than they retreat during deteriorations. The extent of tree coverage, as medially defined, will also be determined by such factors as human activity, landslides and plant disease – factors that may not relate at all simply to climate change. Even so, tree-line displacements (vertical and/or horizontal) do not infrequently afford a vivid if inexact proxy for climate change in the round.

Take a University of Wisconsin study of the limits of a forest dominated by black and white spruce, *Picea mariana* and *Picea glauca*: a forest lying west of Hudson Bay in the Keewatin district of the Northwest Territories of Canada. In 1965, the tree line (only 20 km deep) was close to 61°N at 100°W. Some 5,500 years ago, it had encroached some 225 km north of that, there to remain two millennia, developing a podzol the while. Then, failing to regenerate after natural fires, it fell back to the 60th parallel or thereabouts. By the eleventh century AD, it had progressed 100 km or so north once more, only to retreat again later. In the twentieth century, its lie in that sector has coincided closely with the Arctic frontal zone, this being defined by the median northern edge of depression tracks in summer and the southern in winter. A working assumption may be that the two zonal patterns, the one arboreal and the other geophysical, have been conjoint at least through this last millennium.[32]

Peat bog is an ecosystem sensitive to climate change. Hubert Lamb outlined the salient aspects succinctly.[33] What peat consists of is an acidic decomposition of vegetable matter in situations in which water excludes air. Its stratigraphy reveals 'recurrence surfaces' (Ry) at which fresh layers of peat start to form because of a moister ambience. Evidence from some parts of western Britain points to a Ry around AD 450 with the peat thenceforward thickening at a typical rate of 10 cm a century. By 700, a dry spell had set in. But in 1200 to 1250, another Ry occurred.[34] Bogs and lake sediments are environments that well preserve pollen or spores, the latter being produced by species that are 'cryptogamous' – i.e. not bearing true flowers. Though both forms are structured to resist decay, pollen has so far been used more than spores in the exploration of past climates.

Some of the sequential evidence collated has been impressive. Witness a 14,000-year record from Kirchner Marsh in Minnesota; and an overview thus obtained for Denmark *c.* 11,000 BP (i.e. during the Lower Dryas) which shows it to have been 5 to 7°C colder than today.[35] As always, however, there are complications. Interference by humans or other intruders can savage an otherwise stable ecosystem. Drawing analogies between the fossil assemblages being studied and more familiar ones, past or present, will hinge on exact enough analogues being found; and that will depend, among other things, on being sure when assemblages have 'climaxed' – i.e. attained a stable relationship with their environment. Furthermore, what really matters with precipitation is how much percolates through the soil and is absorbed into plant roots. In the not unlikely event of no satisfactory analogue being found, one is into the irksome business of gauging from first principles what the fossil relics of a given ecosystem reveal about the climate then prevailing. It is not just a question of how the component species individually reacted to climate variation. A further dimension is how that affected their interaction with one another.[36]

Furthermore, the occasional use of pollen surveys to indicate atmospheric circulation is, in effect, an admission that pollen dispersion well away from the parent plants is often marked enough to vitiate routine site mapping. Moreover, the extent of dispersion in a given situation can vary markedly as between different species.

Then again, if one is looking to 'pollen rain' as a measure of wetness trends, one needs to know how the rate of that 'rain' has varied over time. This knowledge may best be gained by stratifying horizontally the pollen distribution within a context (e.g. a lake) in which sedimentation is taking place. Unfortunately, sedimentation rates are hard to ascertain, certainly for times past. Besides, there is basic disagreement among specialists about the prominence pollen analysis should be accorded within palaeoclimatology. In Hubert Lamb's view:

> No branch of field observation has contributed more to our perception of the past climate record than *palynology*: the study of the pollens of seed-bearing plants and the analysis of fossil pollen assemblages, together with the spores of lower plants, and consideration of such macro remains as are to be found.[37]

Conversely, Ray Bradley concluded in 1985 that 'Pollen analysis can be successfully applied to the reconstruction of past vegetation . . . but what does this tell us about past climate? In the vast majority of pollen studies the answer, unfortunately, is very little.'[38] But there does seem to be an emergent consensus that mathematical advances are leading more consistently to definitive results.

Fauna is also important in this connection, particularly fish and insects. Fish, being what we call 'cold-blooded', have lower critical thresholds in regard to water temperature. Meanwhile, the vitaliy of insects tends to correlate positively with air temperature.

According to a tabulation by Lamb, cod (*Gadidae*) is abundant in seas where water surface temperatures are above 2°C and below 15°C. Herring (*Clupea harengus*) is rarely found in water below 3°C or above 13°C. Carp (*Cypririus carpio*), famously associated with medieval monastic fishponds, grow little in freshwater temperatures below 13°C, their optimum being 19°C. Ground beetles (*Oodes gracilis*) look for a mean air temperature in

July not usually below 18°C.[39] Marine fish, at least, will probably be at their most prolific towards the lower end of their temperature range. The phytoplankton that constitute the base of the food chain prefer coolness.

Dating methods

Throughout this overview, emphasis has been placed on the weaknesses peculiar to particular exploratory techniques. But net errors may be minimised by using different techniques concurrently.

This principle of complementary usage well applies to dating. Thus the backdating of an ice core can prove too problematic, even across several centuries. But if, say, a dust trace within the core bespeaks a well-defined volcanic eruption around a certain time, and if the archives indicate the actual year, then calibration is possible. Alternatively, even the repeated use of just the one technique can narrow the odds considerably. Suppose one wishes to locate in time a regional glacial recession that one believes to have been temperature-driven and therefore to have been more or less synchronous. Suppose, too, one can read any one glacier's retreat to the nearest century. Then if one studies ten, say, one will narrow the error to within a decade or two, the actual margin depending on circumstances.

For the time-frames this study is concerned with, however, a king-pin in the dating process is radioactive decay. The point of departure is that chemical elements have nuclear variants known as 'isotopes'. Also many of the isotopes currently extant are unstable – i.e. the nuclei of the atoms of which they are comprised are subject to spontaneous disintegration at an average exponential rate precisely characteristic of the isotope in question. Therefore one can know when, say, half the nuclei in an agglomeration of the said isotope will have decayed. That interval is spoken of as the isotope's 'half life'. Initially, the prime geophysical application of this phenomenon was ascertaining the minimum ages of the Earth and of the cosmos. These were very provisionally determined from there being radioactive minerals extant on Earth demonstrably as old as 1,750 million years, and by similar work on the helium in meteorites.[40] The dating in this case was effected by ascertaining the proportion of an unstable isotope within a given mass relative to that of a stable isotope known to occur as an end product of that particular path of radioactive decay.

Application of the decay principle to the terrestrial biosphere is in accordance with a methodology worked out in the first decade after the Second World War under the leadership of Willard F. Libby of the Institute of Nuclear Studies at the University of Chicago and the Lawrence Livermore Laboratory. It gives a very precise time of death for living forms, which may then serve as dating proxies for palaeoclimatology or for mainstream archaeology. It utilises the Carbon-14, or 'radiocarbon', produced not as part of an original mass of its parent element in a supernoval furnace but by the bombardment by cosmic radiation of nitrogen nuclei in the upper atmosphere. This ^{14}C diffuses very readily as it oxidises into CO_2. It thereby enters into the pathways of all living organisms in contact with the atmosphere. The proportion of ^{14}C to the total carbon mass will be the same for any such form as it is in the air itself. Accordingly, the diminution of ^{14}C that takes place progressively in dead substances through radioactive nuclear decay affords a direct measure of the time since death.

Libby initially assumed the ^{14}C proportion within the atmosphere to be effectively constant. However, in 1970 he allowed that cosmic radiation as received in the Earth's middle atmosphere was subject to significant variation, which was being attributed mainly to fluctuation in the Earth's magnetic field but with a 'fine structure' modulation due to the solar wind – the continuous outpouring from the Sun of subnuclear particles, this outpouring being especially strong from sunspots.[41] Today we would say that the solar wind induces quite marked short- or medium-term changes, but geomagnetic flux more gradual, secular ones plus the very occasional major flip as a result of geomagnetic field reversal. Carbon-14 (^{14}C) incidence has now been plotted decade by decade for at least the last two millennia. Meanwhile, radiocarbon dates have duly been pushed back in time. Thus human sites originally adjudged 5,000 years old are today put at 5,800. But throughout the principle of 'simultaneity' has been upheld. In other words, there has not had to be any basic revision of when widely separated sites are contemporaneous.[42]

What the adjustment of radiocarbon dating has entailed, however, is a revaluation of the 'diffusionist' notion of the attributes of early civilisation spreading out from the salubrious climes of the Near East river lands to the north and west of Europe, chilly and storm-beaten. The reason was that the Near East could always be dated largely from inscriptions, whereas on the other side of Europe it had been a matter of judicious guesswork, latterly underpinned by the ^{14}C test. What was clear by 1970 was that Neolithic sites in north-west Europe, say, were a millennium or more earlier than ^{14}C had previously appeared to suggest. As the point has fancifully been made, it is now accepted that the 'mere barbarians' of Bronze Age Wessex could build Stonehenge 'without a Mycenean overseer'.[43]

Fluctuations in cosmic radiation apart, errors in this radiocarbon dating derive from (a) possible degrading of the fossil sample and (b) the fact that ^{14}C is normally less than one part in a billion of the carbon in the atmosphere. Examples of degradation are a modern root tapping a peat layer or the calcium carbonate in a fossil shell or bone recrystallising in interaction with water, losing some ^{14}C in the process. Nevertheless, radiocarbon dating has secured a central place in this palaeoclimate dating. Moreover, it is assuming a central role in determining past secular variations in solar activity. In particular, the unstable isotope Beryllium-10 (^{10}Be) is 'cosmogenic' – that is to say, it may be formed by cosmic ray bombardment. But if the solar wind waxes stronger, cosmic radiation will be more completely warded off. That extra strength (which will closely correlate with the Sun's being more active overall) will therefore be indicated by a lower registration at the Earth's surface of ^{10}Be (see Chapter 9).

Modelling

A fair amount of modelling has already been done on the Earth's climate extending back beyond 250 million years – i.e. to the time when there was just one supercontinent, Pangaea.[44] Work that looks back tens of millions of years does so, first and foremost, to assess what part movements (vertical as well as horizontal) of the fractured continental mass have had on climate, globally and regionally. Of especial interest has been the progressive uplift, between 40 and five million years ago, of the Tibetan plateau and a similar tendency (mainly in the last 10 million years) within the western cordillera of North America. To ascertain how the emergence of these features altered climate in the past is to help determine how they sustain it in the present.

So far as the Tibetan plateau is concerned, a tentative consensus was emerging by 1990. The gist was that the chief import of this feature was and is as a tableland of surface summer heating that has further broadened and invigorated the Indian monsoon; and that connotes wetter conditions to the south of the Himalayan–Tibetan massif but drier ones to its north and west, with north-easterly winds displacing rain-bearing westerlies.[45] In 1994, a Royal Society symposium warned that too little was yet confirmed of the geological history of that massif to be entirely sure about causation.[46] Since when, however, further progress has been made, particularly with reference to a marked uplift 8 to 10 million BP.[47]

The general notion that the seasonal weather of the Tibetan plateau is exceptionally reactive to such parameters as temperature, pressure, humidity and momentum is well borne out by a 1981 study by the then director of the Lanzhou Institute of Plateau Atmospheric Physics. He confirmed an exposure to solar radiation as high as virtually anywhere on Earth, and an air density under half what obtains at sea level. Accordingly, the summer thermal low extends as high as the 400-millibar pressure level (normally *c.* 25,000 feet) as opposed to the 12,000 feet typical over, say, North Africa or Iran. There are far more thunderstorm days a year than in any other region in that latitude (typically 90 as opposed to five or ten in North Africa or Iran).[48]

Coming into the time-frame of what we term recorded history, a modelling of the Indian monsoon by Reid Bryson is especially instructive, this by virtue of his being convinced of the essentiality for this purpose of a hemispheric perspective. One by-product has been a model of summertime prevailing winds across the Guinea coast of West Africa. On 1,000-year moving averages, the year AD 1200 was the turning point in what had been a secular veer of the prevailing wind direction in summer from south to west. At the turn, the model shows a wind from 240° then, whereas by 1900 it would have backed to 150° once more.[49]

Granted, one must be careful about treating inferential modelling as an array of hard fact. So must one be about changing gear from millennial to decadal units of time. Even so, it should be noted that a representative wind direction of 240° across that coast could connote the Inter-tropical Convergence Zone in that sector of longitude lying in July well south of its 20° lie at present. It is surely not extravagant to see in this a measure of support for the view aired in Chapter 5 that (a) the Sahara was wide in the eleventh century and (b) West Africa was entering upon an ecological crisis. That is not to suggest that, in the very different dynamical situation that obtained during the LGM, an ITCZ well south will have connoted a much expanded version of the Sahara we know today.[50] On the contrary, other modelling shows the two great African desert areas as not extending subtropically at all then but as almost merging within the equatorial hinterland.[51]

Devolution

Burgeoning computer capacity and the steady spread of fieldwork should considerably enhance our understanding of past climates at continental level. More advanced coupled models will take account of such elusive parameters as snow lie and sea ice. A further benefit could be a much better understanding of the local manifestations of general climate trends.

That will be especially important for eras such as the one principally studied here, AD 212 to 1350. For it seems that experience of such aspects of history as wars, epidemics, agricultural improvement and so on were then often subject to pronounced local variations. A lot of scope may be afforded for bringing the inspired amateur back into play more fully in the quest for a better understanding of the interface between human history and climate.

Someone cited a number of times in this text is the late Dr Justin Schove (1913–86). He combined being, by all accounts, an outstanding headmaster of a small preparatory school in Kent with publishing well over a hundred articles for learned journals on the history of climate, not a few of them of lasting value. In the future, straight geophysical research is likely only to be conducted within structured programmes in specialist institutions. But concern with local themes, historical and ecological on the one hand and with the global climate crisis on the other, should afford much interdisciplinary scope for gifted amateurs – for the Schoves, Fraunhofers and Banbury shepherds of the future, not to mention the Montesquieus, Bodins and Aristotles.

Appendix B: An outline chronology, 211–1350

Date	*Event*
211	Death of Emperor Severus
212	All freemen throughout Roman Empire made eligible for Roman citizenship
c. 220	Collapse of Han dynasty in China
270–5	Reign of Emperor Aurelian
272	Palmyra sacked by Romans
305–37	Reign of Emperor Constantine
330	Constantinople becomes capital of Roman Empire
367	Roman Britain attacked on virtually all sides
372	Huns cross Volga
378	Battle of Adrianople
395	Theodosius line splits Empire between East and West
406	Vandals, Sueves and Alani flee into Gaul to escape Huns
429	Vandals land in Africa
444	St Patrick establishes See of Armagh in Ireland
c. 446	British plea to Gaul for assistance
476	Romulus Augustulus, last recognised Emperor of Rome, deposed
c. 515	Battle of Mons Badonicus, Romano-British defeat English
527–65	Reign of Emperor Justinian I in Byzantium
541	Justinian's plague reaches Constantinople
590	Final abandonment Marib Dam, Arabia Felix
590–604	St Gregory the Great as Pope
597	St Augustine lands in Britain
610–12	Persian invasion of Palestine
618–906	Tang dynasty in China
622	Mohammed and his supporters flee from Mecca to Medina
632	Death of Prophet Muhammad
635	Tibetan kingdom consolidated around Lhasa
637	Muslim Arabs seize Ctesiphon, capital of Persia
638	Muslim Arabs seize Jerusalem
644	Muslim Arabs seize Tripoli, Libya
663	Synod of Whitby
711	Muslims enter Spain
730–843	Iconoclast movement in Byzantium
732	Battle of Tours, Franks defeat Muslims
c. 740	Khazars convert to Judaism
751	Battle of Talas, Arabs check Chinese in central Asia
757–96	Offa as king of Mercia
768–814	Charlemagne as Carolingian king

Date	*Event*
786–809	Harun ar-Rashid as caliph in Baghdad
793	Vikings sack Lindisfarne monastery
800	Pope crowns Charlemagne as first Holy Roman Emperor
c. 835	Viking activity starts to increase
836	Norwegians found Dublin
c. 840	Greater Tibet begins to decline
844	Norwegians appear before Seville
860	'Rus' (i.e. Swedish Viking) fleet appears before Constantinople
862	Rus rule established in Novgorod
865	Danes begin to settle in England in large numbers
874	Viking Ingolf Arnarson makes firm lodgement in Iceland
875	Norwegian Vikings visit White Sea
878	Battle of Edington, King Alfred defeats Danes
c. 900	(1) Battle of Jafsfjord, internal opposition crushed by Harald Fairhair, the first king of Norway; (2) Thule (alias Birnick) eskimos begin migration across High Arctic
902	Arabs gain full control of Sicily
911	Viking Rollo is ceded Normandy and establishes a duchy
c. 935–85	Reign of King Harold Bluetooth in Denmark. He is constrained to introduce Christianity
937	Magyars conduct major offensive sweep through western Europe
947–1125	Liao Empire formed by Kitan people on east Asia steppes
955	Battle of Lechfeld, Magyar strength broken
960s	Kievan Rus crush Khazars
968	Poznan, the site of the first episcopal see in Poland
972	Saracen raiders lose base at La Garde Freinet on the Provençal coast
989	First Council of 'Truce of God' meets at Charroux
1000	Icelandic Athling adopts Christianity
1001–38	Reign of St Stephen, first king of Hungary
1011	Imperial edict in Song China approves general use of Champa rice
1019–54	Reign over Kievan Russia of Yaroslav the Wise; switches capital from Kiev to Novgorod
1029	Bishopric founded, Trondheim
1044	Seljuk Turks seize Isfahan
1054	Papal legate presents Bull of Excommunication in Constantinople
1059–91	Norman conquest of Sicily
1066	Battle of Hastings, Normans defeat English
1068	Bishopric founded Uppsala
1071	Battle of Manzikert, Seljuks defeat Byzantium
1080	Kingdom of Ghana overrun by desert tribes
1081	Battle of Durazzo, Normans defeat Byzantines
1095	Emperor Alexius of Byzantium appeals to Pope Urban II for assistance against Turks
1096	Peter the Hermit leads *sans culottes* crusaders, starting from Cologne
1098	Cistercian Order founded
1099	Crusader army captures Jerusalem
1139	Christian kingdom of Portugal comes formally into being
1147–8	Second Crusade
1154–5	First Swedish Crusade against Finland
1155–90	Reign as Holy Roman Emperor of Frederick I (alias Barbarossa)
1161–1263	Series of bloody ethnic conflicts in Sicily
1167	Lombard League formed
1174	Saladin confirms himself as sultan of Egypt
1176	Battle of Legnano, Lombard League defeats imperial forces

Date	*Event*
1187	Saladin destroys Christian army at Hattin. Therefore Muslims regain Jerusalem and several other cities. Therefore Third Crusade launched
1192–1375	Cyprus under French baronial control
1193	Death of Saladin
1198–1216	Innocent III as Pope
1204	(1) Fourth Crusade culminates in sacking of Constantinople; (2) English crown loses Normandy
1208–29	Albigensian Crusade
1210	Franciscans founded by St Francis
1212	(1) Battle of Navas de Tolosa gives Christians a decisive ascendancy in Spain; (2) Children's Crusade
1215	(1) Magna Carta; (2) Peking falls to Mongols
1219–21	Fifth Crusade seizes Damietta, chief port of Egypt
1220–50	Reign as Holy Roman Emperor of Frederick II
1221	Merv sacked by Mongols
c. 1225–74	Life span of St Thomas Aquinas
1226–98	Life span of Averroës
1228–9	Sixth Crusade again against Egypt, Damietta once more being seized
1237–8	Mongol winter campaign against Russia
1241	Treaty of mutual protection between Hamburg and Lübeck
1253	Mongols break Persian wing of the Assassins
1258	Damascus sacked by Mongols
1260	(1) Baghdad sacked by Mongols; (2) Battle of Ain Jalut, Mamelukes defeat Mongols
1261	Greenlanders accept Norwegian sovereignty
1263	Unsuccessful Muslim revolt versus *reconquista* leads to extensive ethnic cleansing in Spain
1274	First Mongol invasion of Japan defeated
1284	Wales falls to Edward I
1291	Acre, the last Christian stronghold in the Levant, falls to Muslims
1294	Death of Kublai Khan
1302	Aragon gains Sicily
1314	(1) Knights Templar disbanded; (2) Scots heavily defeat English at Bannockburn
1324	Pilgrimage to Mecca by Mansa Musa, king of Mali, epitomises gold wealth of West Africa
1337	A challenge to Philip VI of France by Edward III of England precipitates Hundred Years War
1348	Black Death reaches England

Notes

About the author

1 *The Fundamental Issues Study*, Mansfield College, Oxford, 1998.

1 A confluence of disciplines

1 Ellsworth Huntington and Stephen Visher, *Climate Changes: Their Nature and Causes*, New Haven, Yale University Press, 1922, Chapter 1.
2 M.J. Ingram *et al.*, 'Historical Climatology', *Nature*, vol. 276, no. 5686, 23 November 1978, pp. 329–38.
3 James P. Kennett and Robert C. Thunell, 'Global Increase in Quaternary Explosive Vulcanism', *Science*, vol. 187, no. 4176, 14 February 1975, pp. 497–503.
4 Alastair G. Dawson, *Ice Age Earth*, London, Routledge, 1992, Fig. 10.7.
5 *Ibid.*, Fig. 7.4 and p. 149.
6 Joseph Conrad, *Youth, Heart of Darkness, The End of the Tether*, London, J.M. Dent, 1946, pp. 92–8.
7 Steven M. Stanley, *Children of the Ice Age*, New York, Harmony Books, 1996, Chapter 9.
8 Richard G. Klein in Takeru Akazawa *et al.* (eds), *Neandertals and Modern Humans in Western Asia*, New York, Plenum Press, 1998, Chapter 33.
9 Stephanie Pain, 'Cooking up a Storm', *The New Scientist*, vol. 156, no. 2107, 8 November 1997.
10 A.D. Barnosky in Stephen K. Donovan (ed.), *Mass Extinctions: Processes and Evidence*, London, Belhaven Press, 1989, Chapter 12.
11 Paul S. Martin, 'Africa and Pleistocene Overkill', *Nature*, vol. 212, no. 5060, 22 October 1966, pp. 339–42.
12 Jöran Mjöberg in Chapter 8 of David M. Wilson (ed.), *The Northern World*, London, Thames and Hudson, 1980.
13 Vilhjalmur Stefansson, *The Friendly Arctic*, London, Macmillan, 1921, Chapter 2.
14 Linda Parry (ed.), *William Morris*, London, Philip Wilson for Victoria and Albert Museum, 1996, p. 18.
15 For example, W.H. Auden and Louis MacNeice, *Letters from Iceland*, London, Faber and Faber, 1937, p. 139.
16 Humphrey Carpenter, *W.H. Auden. A Biography*, London, George Allen and Unwin, 1981, pp. 196–202.
17 Francis Spufford, *I May Be Some Time. Ice and the English Imagination*, London, Faber and Faber, 1996, p. 187.
18 Elisabeth S. Vrba in Elisabeth S. Vrba *et al.*, *Paleoclimate and Evolution with Emphasis on Human Origins*, New Haven, Yale University Press, 1995, Chapter 3.
19 Robert Ardrey, *The Hunting Hypothesis*, London, Collins, 1976, pp. 146–7.
20 René Albrecht Carrie, *The Meaning of the First World War*, Englewood Cliffs, Prentice Hall, 1965, pp. 42–3.
21 J. Huizinga, *The Waning of the Middle Ages*, London, Edward Arnold, 1924, p. 2.

22 A. Henderson-Sellers and K. McGuffie, *A Climate Modelling Primer*, Chichester, John Wiley, 1987, Table 1.1.
23 Cesare Emiliani, 'Paleotemperature Analysis of Core 280 and Pleistocene Correlations', *Journal of Geology*, vol. 66, no. 3, May 1958, pp. 264–75.
24 John D. Keegan, 'On the Principles of War', *Military Review*, vol. XLI, no. 11, December 1961, pp. 61–72.
25 Huizinga, *op. cit.*, p. 88.
26 Michael Howard, *The Causes of War*, London, Temple Smith, 1983, pp. 188–97.
27 Johan Huizinga, (James S. Holmes and Hans van Marle, trans.), *Men and Ideas*, London, Eyre and Spottiswoode, 1960, p. 255.
28 Edward Freeman, *History of the Norman Conquest*, 6 vols, Oxford, Clarendon Press, 1864–79, Vol. 1, pp. 1–3 and Vol. V, p. 5.
29 'The Several Middle Ages of Jules Michelet' in Jacques Le Goff (Arthus Goldhammer, trans.), *Time, Work and Culture in the Middle Ages*, Chicago, University of Chicago Press, 1980, pp. 3–28.
30 C.P. Snow, *The Two Cultures: and a Second Look*, Cambridge, Cambridge University Press, 1964, p. 3.
31 For example, Chapter V 'Into the Deep Waters' in Sir James Jeans, *The Mysterious Universe*, Cambridge, Cambridge University Press, 1930.
32 For example, Chapter IV, 'The Chorus. Rhythmic Aspects of the Record', in Sir Napier Shaw, *The Drama of the Weather*, Cambridge, Cambridge University Press, 1939.
33 David Cannadine, *G.M. Trevelyan: A Life in History*, London, HarperCollins, 1992, Chapter 3.
34 Epilogue in H.A.L. Fisher, *A History of Europe* (2 vols), London, Collins/Fontana, 1960, Vol. 2, pp. 1321–4. First published 1935.
35 Isaiah Berlin, 'The Concept of Scientific History', *History and Theory*, Vol. 1, 1961, pp. 1–31.
36 Reid A. Bryson, 'All Other Things Being Constant ? A Reconciliation of Several Theories of Climatic Change', *Weatherwise*, vol. 21, no. 2, April 1968, pp. 56–60 and 94.
37 'What Really Killed the Dinosaurs?' *The New Scientist*, vol. 155, no. 2095, 16 August 1997, pp. 23–7.
38 Shin Yabushita and Anthony Allen, 'Did an Impact Alone Kill the Dinosaurs?' *Astronomy and Geophysics*, vol. 38, issue 2, April–May 1997, pp. 15–19.
39 R.J. Berry, 'Ecology: Where Genes and Geography Meet', *Journal of Animal Ecology*, vol. 58, no. 3, October 1989, pp. 733–59.
40 E.C. Zeeman, 'Catastrophe Theory', *Scientific American*, vol. 234, no. 4, April 1976, pp. 65–83.
41 Colin Renfrew in Chapter 21 of Colin Renfrew and Kenneth L. Cooke (eds), *Transformations. Mathematical Approaches to Culture Change*, Academic Press, 1979.
42 A.M. Carr-Saunders, *The Population Problem*, Oxford, Clarendon Press, 1922, p. 302.
43 J.M. Wagstaff, 'A Possible Interpretation of Settlement Pattern Evolution in Terms of Catastrophe Theory', *Transactions of the Institute of British Geographers*, vol. 3, no. 2, 1978, pp. 165–78.
44 Catherine Delano Smith, *Western Mediterranean Europe*, London, Academic Press, 1979, p. 13.
45 Jacob Burckhardt (Harry Zohn, trans.), *Judgements on Modern Historians*, London, George Allen and Unwin, 1959, pp. 64–5.
46 Baron Léon de Rosen, 'National Welfare Indices', *Development Forum*, vol. 1, no. 9, December 1973, pp. 2–4.
47 'Happiness is a Warm Vote', *The Economist*, 17 April 1999.
48 *The Economist*, 22 January 1972.
49 N.E. Davies, 'An Optimum Summer Weather Index', *Weather*, vol. XXIII, no. 8, August 1968, pp. 305–17.
50 For a useful summation apropos the British Isles, see G. Melvyn Howe, *Man, Environment and Disease in Britain*, Newton Abbot, David and Charles, 1972, Chapter 3.
51 B.B. Waddy, 'Climate and Respiratory Infections', *Lancet*, 2, 1952, pp. 974–7.
52 David Marquand, *Ramsay MacDonald*, London, Jonathan Cape, 1977, p. 675.
53 S.F. Markham, *Climate and the Energy of Nations*, London, Oxford University Press, 1944, p. 35.

54 *Ibid*., Chapter VI.
55 Carlo M. Cipolla, *Before the Industrial Revolution. European Society and Economy, 1000–1700*, London, Methuen, 1976, pp. 196–7.
56 Howe, *op. cit*., Fig. 10.
57 James Gleick, *Chaos. Making a New Science*, London, Sphere Books, 1987, p. 5.
58 Carl Murray, Chapter 8 in Nina Hall (ed.), *The New Scientist Guide to Chaos*, Harmondsworth, Penguin, 1992.
59 Arden Reed, *Romantic Weather. The Climates of Coleridge and Baudelaire*, Hanover, University Press of New England, 1983, pp. 274–6.
60 Karl R. Popper, *The Open Universe: An Argument for Indeterminism*, London, Hutchinson, 1982, Chapter 1, Section 6 'Clocks and Clouds'.
61 T.N. Palmer, 'Extended Range Atmospheric Prediction and the Lorenz Model', *Bulletin of the American Meteorological Society*, vol. 74, no. 1, January 1993, pp. 49–65.
62 Tim Palmer, Chapter 6, 'A Weather Eye on Unpredictability' in Nina Hall (ed.), *op. cit.*
63 T.N. Palmer, 'A Non-linear Dynamical Perspective on Climate Change', *Weather*, vol. 48, no. 10, October 1993, pp. 314–26.
64 Stuart Kauffman, 'Anti-chaos and Adaptation', *Scientific American*, vol. 260, no. 8, August 1991.
65 Gleick, *op. cit*., p. 299.
66 Dr Axel Steenberg, 'Archaeological Dating of the Climatic Change in North Europe about 1300 AD', *Nature*, vol. 168, no. 4275, 20 October 1951, pp. 672–4.
67 Jan de Vries, 'Measuring the Impact of Climate on History: The Search for Appropriate Methodologies', *Journal of Interdisciplinary History*, vol. X, no. 4, Spring 1980, pp. 599–630.
68 Peter Burke, *The European Renaissance. Centres and Peripheries*, Oxford, Blackwell, 1998, pp. 176–7.
69 Jancis Robinson (ed.), *The Oxford Companion to Wine*, Oxford, Oxford University Press, 1994, pp. 361, 379 and 565.
70 Robert S. Lopez, 'Hard Times and Investment in Culture' in Karl H. Dannenfeldt (ed.), *The Renaissance, Medieval or Modern?* Boston, D.C. Heath, 1959, pp. 50–61.
71 'Cities, Courts and Artists', *Past and Present*, no. 19, April 1961, pp. 19–25.
72 Denis Cosgrove, 'The Myth and the Stones of Venice: An Historical Geography of a Symbolic Landscape', *Journal of Historical Geography*, vol. 8, no. 2, April 1982, pp. 145–69.
73 M.M. Postan, *Essays on Medieval Agriculture and General Problems of the Medieval Economy*, Cambridge, Cambridge University Press, 1973, p. 15.
74 E.M. Bridges, *World Soils*, Cambridge, Cambridge University Press, 1997, p. 155.
75 Georges Duby (Cynthia Postan, trans.), *Rural Economy and Country Life in the Medieval West*, London, Edward Arnold, 1968, pp. 24–5, 95 and 104.
76 D.F. Putnam in Griffith Taylor (ed.), *Geography in the 20th Century*, New York, Philosophical Library, 1951, Chapter X.
77 Ming-ko Woo *et al*., 'Response of the Canadian Permafrost Environment to Climatic Change', *Physical Geography*, vol. 13, no. 4, 1992, pp. 287–317.
78 Kenneth Pye, 'Loess', *Progress in Physical Geography*, vol. 8, 1984, pp. 176–205.
79 Bridges, *op. cit*., p. 29.
80 US Department of Agriculture Yearbook, *Climate and Man*, Washington, US Government Printing Office, 1941, p. 283.
81 Chapter XIV 'Atlantic Europe: The Perfect Artificial Soil' in Edward Hyams, *Soil and Civilisation*, London, Thames and Hudson, 1952.
82 John C. Rodda, 'Basic to Basics: Hydrology Distilled!' *Weather*, vol. 52, no. 11, November 1997, pp. 330–37, Fig. 3.
83 M.L. Parry *et al.* (eds), *The Effect of Climatic Variations on Agriculture in the Semi-Arid Zone of the European USSR*, Laxenburg, International Institute for Applied Systems Analysis, 1987, Table 2.5.
84 Nick Middleton, *Desertification*, Oxford, Oxford University Press, 1991, Table 1.2.
85 'The Variability of the Annual Rainfall of India', *Quarterly Journal of the Royal Meteorological Society*, vol. 57, no. 238, January 1931, pp. 43–56, Fig. 1.

86 Roger G. Barry and Richard J. Chorley, *Atmosphere, Weather and Climate*, London, Routledge, 1990 (reprint of fifth edition, 1987), p. 56.
87 R.A.S. Ratcliffe, 'Pen Portraits of Presidents . . . ?' *Weather*, vol. 48, no. 8, August 1993, pp. 267–8.
88 Gordon Manley, 'Topographical Features and the Climate of Britain: A Review of Some Outstanding Effects', *The Geographical Journal*, vol. CIII, no. 6, June 1944, pp. 241–63.
89 G. Manley, 'On the Occurrence of Snow-Cover in Great Britain', *Quarterly Journal of the Royal Meteorological Society*, vol. 65, no. 278, January 1939, pp. 2–27.
90 L.C.W. Bonacina, 'Weather Regarded as a Function of Climate', *Quarterly Journal of the Royal Meteorological Society*, vol. XXXIII, no. 143, July 1907, pp. 213–19.
91 J.A. Simpson and E.S.C. Weiner (eds), *The Oxford English Dictionary*, Oxford, Clarendon Press, 1989, Vol. 3, p. 322 and Vol. 20 pp. 55–62.
92 Christopher Dyer, *Standards of Living in the Later Middle Ages*, Cambridge, Cambridge University Press, 1989, Chapter 10.
93 T.M.L. Wigley, 'The Effect of Changing Climate on the Frequency of Absolute Extreme Events', *Climate Monitor*, 17, 1989, pp. 44–55, Table 1.
94 Richard W. Katz and Barbara G. Brown, 'Extreme Events in a Changing Climate: Variability is More Important than Averages', *Climatic Change*, vol. 21, no. 3, July 1992, pp. 289–302.
95 A.B. Pittock, 'How Important are Climatic Changes?' *Weather*, vol. 27, no. 7, July 1972, pp. 262–71.
96 Ronald Hare, 'New Light on the History of Penicillin', *Medical History*, no. 26, 1982, pp. 1–24.
97 Bryan Perrett, *Desert Warfare*, London, Patrick Stephens, 1988, p. 11.
98 Fred McGraw Donner, 'Mecca's Food Supplies and Muhammad's Boycott', *Journal of the Economic and Social History of the Orient*, Vol. XX, Part III, 1977, pp. 249–66.
99 John France, 'The Capture of Jerusalem', *History Today*, vol. 47, no. 4, April 1997, pp. 37–42.
100 Malcolm Cameron Lyons and D.E.P. Jackson, *Saladin*, Cambridge, Cambridge University Press, 1982, pp. 365–74.
101 W.G. Kendrew, *The Climates of the Continents*, London, Oxford University Press, 1937, p. 174.
102 Steven Runciman, *A History of the Crusades* (3 vols), Cambridge, Cambridge University Press, 1957, Vol. I, pp. 280–7.
103 *Ibid.*, pp. 10–11.
104 Alastair Duncan, *The Noble Sanctuary*, London, Longman, 1972, p. 20.
105 Sir John Glubb, *A Short History of the Arab People*, London, Hodder and Stoughton, 1969, pp. 48–9.
106 Letter received from Dr David Chandler in 1994.
107 Neville Brown, 'The Weather for Overlord', *Journal of Meteorology*, vol. 19, no. 189, May/June 1994, pp. 141–9.
108 Williamson Murray, 'Could We Have Lost D-Day?' *Quarterly Journal of Military History*, vol. 6, no. 3, Spring 1994, pp. 6–21.
109 Keith Simpson, 'A Close-Run Thing? D-Day 6 June 1944: the German Perspective', *RUSI Journal*, vol. 139, no. 3, July 1994, pp. 60–71.
110 Peter Tsouris, *Disaster at D-Day*, London, Greenhill, 1994, pp. 23–4 and p. 230.
111 John Man, *The Penguin Atlas of D-Day and the Normandy Campaign*, London, Penguin, 1994, pp. 26–7 and 86–8.
112 Nelson C. Maynard, 'Space Weather Prediction', *Reviews of Geophysics*, vol. 33, no. 2, July 1995, Supplement pp. 547–57.
113 Edward Teller, *Better a Shield than a Sword*, New York, Free Press, 1987, Chapter 12.
114 Henry Rishbeth and Mark Clilverd, 'Long-term Change in the Upper Atmosphere', *Astronomy and Geophysics*, vol. 40, issue 3, June 1999, pp. 26–8.
115 Neville Brown, *The Fundamental Issues Study within the British Ballistic Missile Defence Review*, Oxford, Mansfield College, 1998, Chapters 3, 4 and 9.
116 David Grigg, 'Agriculture in the World Economy: An Historical Geography of Decline', *Geography*, vol. 7, 1992, pp. 210–22, Tables 4 and 5.
117 J.M. Stagg, *Forecast for Overlord*, London, Ian Allan, 1971, p. 80.

118 James Rodger Fleming, *Historical Perspectives on Climate Change*, New York, Oxford University Press, 1998.
119 Robert Graves, Introduction, *New Larousse Encyclopedia of Mythology*, London, Hamlyn, 1974, pp. 481 and 62–3.
120 Mike Baillie, 'Do Irish Bog Oaks Date the Shang Dynasty?' *Current Archaeology*, vol. X, no. 10, November 1989, pp. 310–13.
121 Richard A. Kerr, 'Black Sea Deluge May Have Helped Spread Farming', *Science*, vol. 279, no. 5354, 20 February, 1998, p. 1132.
122 Dawson, *op. cit.*, Fig. 12.4.
123 M.R. Rampino *et al.*, 'Can Rapid Climatic Change Cause Volcanic Eruptions? *Science*, vol. 206, no. 4420, 16 November 1979, pp. 826–9.
124 P. Pirazzoli, 'Sea Level Changes in the Mediterranean', in M.J. Tooley and I. Shannon (eds), *Sea Level Changes*, Oxford, Basil Blackwell, 1987, pp. 152–81.
125 Barbara W. Tuchman, *A Distant Mirror. The Calamitous 14th Century*, Harmondsworth, Penguin Books, 1980, p. 24.
126 Lucretius (R.E. Latham, trans.), *On the Nature of the Universe*, Harmondsworth, Penguin, 1951, p. 226.
127 E.W. Webster (trans.), *The Works of Aristotle* (11 vols), Vol. III, *Meteorologica*, Oxford, Clarendon Press, 1908, Book I, Section 14.
128 Marian J. Tooley, 'Bodin and the Medieval Theory of Climate', *Speculum*, vol. XXVIII, no. 1, January 1953, pp. 64–83.
129 Fleming, *op. cit.*, Chapter 1.
130 Frank T.H. Fletcher, 'Climate and Law. The Influence of Montesquieu on British Writers', *Geography*, vol. XIX, 1934, pp. 29–36.
131 Paul Cartledge, 'The Enlightened Historiography of Edward Gibbon: A Bicentennial Celebration', *The Maynooth Review*, 3 December 1977, pp. 67–93.
132 Peter Burke, 'Tradition and Experience: The Idea of Decline from Bruni to Gibbon', *Daedalus*, vol. 105, no. 3, Summer 1976, pp. 137–52.
133 Norman H. Baynes, 'John Bagnell Bury, 1861–1927', *Proceedings of the British Academy*, Vol. XIII, pp. 3–13.
134 Steven Runciman, 'Gibbon and Byzantium', *Daedalus*, vol. 105, no. 3, Summer 1976, pp. 103–10.
135 Bernard Lewis, 'Gibbon on Muhammad', *Daedalus*, pp. 89–101.
136 Samuel Johnson, *The History of Rasselas, Prince of Abissinia*, Oxford, Oxford University Press, 1988, pp. 100–3. Edited by J.P. Hardy.
137 David Thomson, 'Edward Gibbon: The Master Builder', *The Contemporary Review*, vol. CLI, May 1937, pp. 583–91.
138 Geoffrey J. Martin, *Ellsworth Huntington, His Life and Thought*, Hamden, Archon Books, 1973, p. 238.
139 Fleming, *op. cit.*, Chapter 8.
140 Ellsworth Huntington, *Civilization and Climate*, New Haven, Yale University Press, 1924, Fig. 46.
141 *Ibid.*, pp. 390–1.
142 Ellsworth Huntington and Stephen Visher, *Climate Changes. Their Nature and Causes*, New Haven, Yale University Press, 1924, Chapters IV and VII.
143 Geoffrey J. Martin, *op. cit.*, Chapter XI.
144 In the third and final edition (1924), eugenics is discussed at length only on page 310.
145 *Ibid.*, p. 12.
146 S.C. Gilfillan, 'The Coldward Cause of Progress', *Political Science Quarterly*, vol. XXXV, no. 3, September 1920, pp. 393–410.
147 *Civilization and Climate*, *op. cit.*, pp. 409–11.
148 Ellen Churchill Semple, *The Influences of the Geographical Environment*, 1911, Chapter XVII.
149 E.C. Semple, *The Geography of the Mediterranean Region. Its Relation to Ancient History*, London, Constable, 1932, pp. 99–100.
150 C.E.P. Brooks, *Climate Through the Ages*, London, Ernest Benn, 1926, p. 8.
151 C.E.P. Brooks, 'Present Position of Theories of Climate Change', *Meteorological Magazine*, vol. 84, no. 997, July 1955, pp. 204–6.

152 C.E.P. Brooks, *Climate Through the Ages, op. cit.*, p. 401.
153 Emmanuel Le Roy Ladurie (Barbara Bray, trans.), *Times of Feast, Time of Famine: A History of Climate since the Year 1000*, London, George Allen and Unwin, 1972, p. 17.
154 C.E.P. Brooks, *Climate Through the Ages*, *op. cit.*, pp. 332–4.
155 Albert J. Semtner, 'The Climatic Response of the Arctic Ocean to Soviet River Diversions', *Climate Change*, vol. 6, no. 2, June 1984, pp. 109–30.
156 Fleming, *op. cit.*, p. 134.
157 M.I. Budyko, *Climate and Life*, New York, Academic Press, 1974, pp. 293–5. Edited by David H. Miller.
158 M.I. Budyko, 'The Heat Balance of the Earth' in John Gribbin (ed.), *Climatic Change*, Cambridge, Cambridge University Press, 1978, pp. 85–113.
159 M.I. Budyko, A.B. Ronov, A.L. Yanshin, *History of the Earth's Atmosphere*, Berlin, Springer-Verlag, 1985, pp. 125 and 130.
160 Budyko in Gribbin (ed.), *op. cit.*, Table 5.4.
161 *History of the Earth's Atmosphere*, *op. cit.*, Fig. 24.
162 For example, Ray Wagner (ed.) and Leland Feltzer (trans.), *The Soviet Air Force in World War Two*, Newton Abbot, David and Charles, 1974, Chapter 20.
163 James Lovelock, *The Ages of Gaia*, Oxford, Oxford University Press, 1988, Chapters 4 to 6.
164 Hubert Lamb, *Through All the Changing Scenes of Life*, East Harling, Taverner, 1997, Chapter 9.
165 'Guest Editorial – Hubert Lamb', *Weather*, vol. 53, no. 7, July 1998, pp. 198–201.
166 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1977, Vol. 2, pp. 666 and 677.
167 B.J. Mason, 'Man's Influence on Weather and Climate', *Journal of the Royal Society of Arts*, vol. CXXV, no. 5247, February 1977, pp. 150–65.
168 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, p. 386.
169 *Ibid.*, Figs 95(a) and (b).
170 H.H. Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 1, pp. 21–7.
171 J.T. Houghton *et al.* (eds), *Climate Change 1995*, Cambridge, Cambridge University Press for Intergovernmental Panel on Climate Change, 1996, Figs 6(b) and (c).
172 Alan C. Beckman, 'Hidden Themes in the Frontier Thesis: An Application of Psychoanalysis to Historiography', *Comparative Studies in Society and History*, Vol. VIII, 1965–6, pp. 361–82.
173 Mark Bassin, 'Geographical Determinism in Fin-de-siècle Marxism: Georgii Plekhanov and the Environmental Basis of Russian History', *Annals of the Association of American Geographers*, vol. 82, no. 1, 1992, pp. 3–22.
174 Manuel González Jiménez in Robert Bartlett and Angus Mackay (eds), *Medieval Frontier Societies*, Oxford, Clarendon Press, 1989, pp. 52–74.
175 David E. Lilienthal, *TVA. Democracy on the March*, Harmondsworth, Penguin, 1944, Chapters 1, 14 and 20.
176 'Changes of Climate and History', *American Historical Review*, vol. XVIII, no. 2, January 1913, pp. 213–32.
177 Rhys Carpenter, *Discontinuity in Greek Civilisation*, Cambridge, Cambridge University Press, 1966, pp. 3 and 15–18.
178 Colin Burgess, 'Volcanoes, Catastrophe and the Global Crisis of the Late Second Millennium BC, *Current Archaeology*, vol. X, no. 10, November 1989, pp. 325–9.
179 Herbert Butterfield, *The Origins of History*, London, Eyre Methuen, 1981, Chapter 4, Section 2.
180 Peter Levi, *Atlas of the Greek and Roman World*, Oxford, Phaidon, 1980, pp. 44–60.
181 Carpenter, *op. cit.*, pp. 12–14.
182 Howard Crosby Butler, 'Desert Syria: The Land of a Lost Civilisation', *Geographical Review*, vol. IX, no. 2, February 1920, pp. 77–108.
183 Richard H. Shryock, 'Medical Sources and the Social Historian', *American Historical Review*, vol. XLI, no. 3, April 1936, pp. 458–73.
184 William L. Langer, 'The Next Assignment', *American Historical Review*, vol. LXIII, no. 2, April 1958, pp. 283–305.

185 Peter Burke, *The French Historical Revolution. The Annales School, 1929–89*, Cambridge, Polity Press, 1990, p. 21.
186 P. Vidal de la Blache (Millicent Todd Bingham, trans.), *Principles of Human Geography*, London, Constable, 1926, p. 21.
187 'Dreams in the Culture and Collective Psychology of the Medieval West' in Jacques Le Goff, *op. cit.*, pp. 201–4.
188 Judith N. Shklar, 'Jean D'Alembert and the Rehabilitation of History', *Journal of the History of Ideas*, vol. 42, 1981, pp. 643–64.
189 Fernand Braudel, 'History and the Social Sciences. The Longue Durée', in Maurice Aymard and Harbans Mukhia (eds), *French Studies in History*, Vol. 1, *The Inheritance*, London, Sangam Books, 1988, pp. 69–101.
190 Duby, *op. cit.*, p. 306.
191 Fernand Braudel (Siân Reynolds, trans.), *The Mediterranean and the Mediterranean World in the Age of Philip II* 2 vols, London, HarperCollins, 1972, Vol. 1, pp. 267–75.
192 Fernand Braudel (Sarah Matthews, trans.), *On History*, London, Weidenfeld and Nicolson, 1980, p. 211.
193 'A not so certain idea of France', *The Economist*, 1 November 1997.
194 Peter Geyl, *Encounters in History*, London, Collins, 1963, Chapter 6.
195 William H. McNeill, 'Toynbee, Arnold J.', David L. Sills (ed.), *Encyclopedia of the Social Sciences* (18 vols), New York, Free Press, 1979, Vol. 18, pp. 775–9.
196 O.H.K. Spate, 'Toynbee and Huntington: A Study in Determinism', *Geographical Journal*, vol. CXVIII, January–December 1952, pp. 406–28.
197 Arnold Toynbee and Daisaku Ikeda, *Choose Life*, London, Oxford University Press, 1976, pp. 42–3.
198 Arnold Toynbee, *A Study of History* (one volume abridged), London, Thames and Hudson, 1988, p. 134.
199 Arnold J. Toynbee, *A Study of History* (10 vols), London, Oxford University Press, 1935, Annex II to Volume IIIA.
200 Warren E. Gates, 'The Spread of Ibn Khaldūn's Ideas on Climate and Culture', *Journal of the History of Ideas*, vol. XXVIII, no. 3, July–September 1967, pp. 415–22.
201 Ibn Khaldūn (Franz Rosenthal, trans.), *The Muqaddimah*, London, Routledge and Kegan Paul, 1967, Chapter 2.
202 William H. McNeill, 'World History and the Rise and Fall of the West', *Journal of World History*, vol. 9, no. 2, Fall 1998, pp. 215–36.
203 Brendan O'Leary, *The Asiatic Mode of Production*, Oxford, Basil Blackwell, 1989, Chapter 3.
204 M. Rostovtzeff, *The Social and Economic History of the Roman Empire* (2 vols), Oxford, Clarendon Press, 1957, Vol. 1, pp. 507–10.
205 Ernest Gellner, 'The Last Marxists', *Times Literary Supplement*, no. 4773, 23 September 1994, pp. 3–5.
206 Karl A. Wittfogel, *Oriental Despotism*, New Haven, Yale University Press, 1957, p. 225.
207 *Ibid.*, pp. 213–14.
208 E.R. Leach, 'Hydraulic Society in Ceylon', *Past and Present*, no. 15, April 1959, pp. 2–26.
209 Jared Diamond, *Guns, Germs and Steel*, London, Jonathan Cape, 1997, pp. 283–4.
210 Hyams, *Soil and Civilisation*, London, Thames and Hudson, 1952, Chapter VI.
211 K.A. Wittfogel, 'Meteorological Records from the Divination Inscriptions of Shang', *Geographical Review*, vol. 30, no. 1, January 1940, pp. 110–33.
212 Immanuel Wallerstein, *The Modern World System* (3 vols), New York, Academic Press, 1974, Vol. 1, pp. 34–5.
213 For example, Janet Abu-Lughod on the world economic order, 1250 to 1350, in her chapter 'Discontinuities and Persistence', in André Gunder Frank and Barry K. Gills (eds), *The World System? Five Hundred Years or Five Thousand*, London, Routledge, 1993, Chapter 9.
214 Norman F. Cantor, *Inventing the Middle Ages*, Cambridge, Lutterworth Press, 1991, pp. 149–52.
215 Richard Muir, *History from the Air*, London, Michael Joseph, 1983, p. 68.
216 Reginald Lennard, 'Agrarian History: Some Vistas and Pitfalls', *Agricultural History Review*, vol. XII, 1964, pp. 83–98.

217 J.C. Russell, 'Recent Advances in Medieval Demography', *Speculum*, vol. XL, no. 1, January 1965, pp. 84–101.
218 Mark Bailey, 'Demographic Decline in Late Medieval England: Some Thoughts on Recent Research', *Economic History Review*, vol. XLIX, no. 1, February 1996, pp. 1–19.
219 Sven Hedin, *Across the Gobi Desert*, London, George Routledge, 1931, pp. 250–2.
220 T.R. Oke, *Boundary Layer Climates*, London, Routledge, 1987, Table 6.5.

2 Climate dynamics

1 David Hume, *Of the Rise and Progress of Arts and Sciences*, quoted in Laurence Dudley Stamp and Sidney William Wooldridge (eds), *London Essays in Geography*, New York, Books for Libraries, 1959, p. 169.
2 Gordon Manley, *Climate and the British Scene*, London, Collins, 1952.
3 R.A. Beck, 'Climate, Liberalism and Intolerance', *Weather*, vol. 48, no. 2, February 1993, pp. 63–4.
4 John T. Snow and Amy Lee Wyatt, 'The Tornado, Nature's Most Violent Wind: Part 1', *Weather*, vol. 52, no. 10, October 1997, pp. 298–303.
5 Sir Napier Shaw, *Manual of Meteorology*, Cambridge, Cambridge University Press, 1932, Vol. 1, p. 272.
6 J.W. King, 'Weather and the Earth's Magnetic Field', *Nature*, vol. 247, no. 5437, 18 January 1974, pp. 131–4.
7 Nina Morgan, 'The Earth's Magnetic Field', *The New Scientist*, vol. 123, no. 1683, 23 September 1989, 'Inside Science 26'.
8 Robert Currie, 'Lunar Tides and the Wealth of Nations', *New Scientist*, vol. 120, no. 1627, 5 November 1988, pp. 52–5.
9 L.V. Maksimov and N.P. Smirnov, 'A Contribution to the Study of the Causes of Long-period Variations in the Activity of the Gulf Stream' (American Geophysical Union, trans.), *Oceanology*, vol. 5, no. 2, 1965, pp. 15–24.
10 Robert G. Currie, 'Luni-Solar 18.6 – and Solar Cycle 10–11-year Signals in USA Air Temperature Records', *International Journal of Climatology*, vol. 13, no. 1, January 1993, pp. 31–50.
11 John T. Houghton, *The Physics of Atmospheres*, Cambridge, Cambridge University Press, 1977, Fig. A8.1.
12 F. Möller, 'On the Influence of Changes in the CO_2 Concentration in Air on the Radiation Balance of the Earth's Surface and on the Climate', *Journal of Geophysical Research*, vol. 68, no. 13, July 1963, pp. 3877–86.
13 Kevin E. Trenbeth (ed.), *Climate System Modelling*, Cambridge, Cambridge University Press, 1992, Fig. 7.3.
14 M.I. Budyko, A.B. Ronov and A.L. Yanshin, *History of the Earth's Atmosphere*, Berlin, Springer-Verlag, 1987, Chapter 1, Table 2.
15 Robert E. Dickinson in Trenbeth (ed.), *op. cit.*, p. 149.
16 Roger G. Barry and Richard J. Chorley, *Atmosphere, Weather and Climate*, London, Routledge, 1989 (reprint of fifth edition, 1987), Table 1.3.
17 David H. Miller (ed.), M.I. Budyko, *Climate and Life*, Moscow, Academic Press, 1974, p. 55.
18 C.E.P. Brooks, *Climate Through the Ages*, London, Ernest Benn, 1926, pp. 32–3.
19 Carl Sagan *et al.*, 'Anthropogenic Albedo Changes and the Earth's Climate', *Science*, vol. 206, no. 4425, 21 December 1979, pp. 1363–7.
20 Ann Henderson-Sellers and Peter J. Robinson, *Contemporary Climatology*, Harlow, Longman, 1986, Fig. 2.16.
21 Anders Persson, 'The Coriolis Force According to Coriolis', *Weather*, vol. 55, no. 6, June 2000, pp. 182–7.
22 John G. Lockwood, *World Climatology. An Environmental Approach*, London, Edward Arnold, 1974, p. 178.
23 R.S. Scorer, 'Vorticity', *Weather*, vol. XII, no. 3, March 1957, pp. 72–84.
24 Henderson-Sellers and Robinson, *op. cit.*, pp. 185–7.
25 M.N. Hill (ed.), *The Sea* (2 vols), New York, John Wiley, 1969, Vol. 1, Chapter 1, Table 1.
26 Lennart O. Bengtsson in Trenbeth (ed.), *op. cit.*, p. 716.

27 H.U. Sverdrup, Martin W. Johnson and Richard H. Fleming, *The Oceans. Their Physics, Chemistry and General Biology*, Englewood Cliffs, Prentice Hall, 1942, p. 2.
28 George Kimble, *The Weather*, Harmondsworth, Penguin, 1951, pp. 216–17.
29 John G. Harvey, *Atmosphere and Ocean: Our Fluid Environments*, London, Artemis, 1985, p. 45.
30 *Ibid.*, Fig. 5.12.
31 Alfred Wegener (John Biram, trans.), *The Origin of the Continents and Oceans*, New York, Dover Publications, 1966, Chapter 7 (a translation of the 1929 fourth edition of *Die Entstehung der Kontinente und Ozeane*).
32 'Professor Carl-Gustaf Rossby, Symons Medallist, 1953', *Weather*, vol. VIII, no. 6, June 1953, p. 168.
33 John G. Harvey, *op. cit.*, Figs 12.7a and 12.7b.
34 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1972, Vol. 1, p. 88.
35 E. Reiter in Chapter 4 of Vol. 4 of D.F. Rex (ed.), *World Survey of Climatology* (15 vols) (General Editor, H.E. Landsberg), Amsterdam, Elsevier Scientific, 1981, Fig. 17.
36 H.H. Lamb, *The Changing Climate*, London, Methuen, 1968, Fig. 16.
37 Ann Henderson-Sellers and Peter Robinson, *op. cit.*, p. 181.
38 H.H. Lamb, *Climate: Present, Past and Future*, Vol. 1, *op. cit.*, p. 92.
39 Harvey, *op. cit.*, Fig. 12.8a.
40 C.G. Rossby, 'The Scientific Basis of Modern Meteorology', *Yearbook of Agriculture, 1941*, Washington, US Dept. of Agriculture, 1941, p. 613.
41 *Ibid.*
42 Vilhelm Bjerknes, 'The Structure of the Atmosphere when Rain is Falling', *Quarterly Journal of the Royal Meteorological Society*, vol. XLVI, no. 194, April 1920, pp. 119–40.
43 Elizabeth M. Shaw, 'An Analysis of the Origins of Precipitation in Northern England, 1956–1960', *Quarterly Journal of the Royal Meteorological Society*, vol. 88, no. 378, October 1962, pp. 539–47, Table 2.
44 Michael Bridges in Russell D. Thompson and Allen Perry (eds), *Applied Climatology*, London, Routledge, 1997, p. 121.
45 J.S. Krebs and R.G. Barry, 'The Arctic Front and the Tundra–Taiga Boundary in Eurasia', *The Geographical Journal*, vol. LX, no. 4, October 1970, pp. 548–54, Fig. 3.
46 Wayne M. Wendland and Reid A. Bryson, 'Northern Hemisphere Airstream Regions', *Monthly Weather Review*, vol. 109, no. 2, February 1981, pp. 255–70, Fig. 7.
47 F. Kenneth Hare in Laurence Dudley Stamp and Sidney William Wooldridge (eds), *op. cit.*, Chapter VII.
48 Barry and Chorley, *op. cit.*, Appendix 1.
49 F. Kenneth Hare, 'The Arctic', *Quarterly Journal of the Royal Meteorological Society*, vol. 94, no. 402, October 1968, pp. 439–59.
50 Chapter 12, 'The Availability of Water in Soils' in David L. Rowell, *Soil Science, Methods and Applications*, Harlow, Longman, 1994.
51 For example, Donald Matthew, *Atlas of Medieval Europe*, Oxford, Equinox, 1983, pp. 206–17.
52 W.G. Kendrew, *The Climates of the Continent*, London, Oxford University Press, 1937, Fig. 70.
53 *Ibid.*, Fig. 72.
54 Wincenty Okolowicz in Chapter 3 of C.C. Wallén (ed.), Vol. 6 of *World Survey of Climatology*, *op. cit.*, p. 82.
55 W.H. Parker, 'Europe: How Far?' *Geographical Journal*, vol. CXXVI, part 3, September 1960, pp. 278–97.
56 Derek K. Elsom, *Journal of Meteorology*, vol. 25, no. 250, July/August 2000, p. 183.
57 Gordon Manley in Chapter 3 of C.C. Wallén (ed.), Vol. 5 of *World Survey of Climatology, op. cit.*, p. 91.
58 E.J. Sumner, 'Blocking Anticyclones in the Atlantic-European Sector of the Northern Hemisphere', *Meteorological Magazine*, vol. 88, no. 1048, November 1959, pp. 300–31.
59 Thor Werner Johannessen in Chapter 2 of C.C. Wallén (ed.), Vol. 5, *op. cit.*, p. 44.
60 Fernand Braudel (Siân Reynolds, trans.), *The Mediterranean and the Mediterranean World in the Age of Philip II*, 2 vols, London, Collins, 1972, Vol. 1, p. 235.

61 D.G. Tout and Vivienne Kemp, 'The Named Winds of Spain', *Weather*, vol. 40, no. 10, October 1985, pp. 522–9.
62 Braudel, Vol. 1, *op. cit.*, p. 238.
63 A. Linés Escardó in Chapter 5 of C.C. Wallén (ed.), Vol. 5, *op. cit.*, p. 212.
64 Intergovernmental Panel on Climate Change, *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, Cambridge, Cambridge University Press, 1998, Summary for Policymakers, Sections 6.5 and 6.3.
65 Intergovernmental Panel on Climate Change, *Climate Change 1995*, Cambridge, Cambridge University Press, 1996, Technical Summary, Figs 8 and 9.
66 Braudel, *op. cit.*, Vol. 1, p. 233.
67 M.O.391, *Weather in the Mediterranean* (2 vols), London, Her Majesty's Stationery Office for Meteorological Office, 1962, Vol. 1, Chapter 3, Fig. 1.6.
68 Kendrew, *op. cit.*, p. 272.
69 *Ibid.*, p. 231.
70 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 1, Table 4.3.
71 Kimble *op. cit.*, pp. 143–6.
72 George F. Chambers, *The Story of the Weather*, London, George Newnes, 1897, p. 211.
73 Richard A. Kerr, 'Why the Ice Ages Don't Keep Time', *Science*, vol. 285, no. 5427, 23 July 1999, pp. 503–5.
74 William James Burroughs, *Weather Cycles. Real or Imaginary?* Cambridge, Cambridge University Press, 1992, p. xi.
75 Paul A. Samuelson, *Economics*, New York, McGraw-Hill, 1973, p. 257.
76 Harry Van Loon and Karin Labitske, 'When the Wind Blows', *The New Scientist*, vol. 119, no. 1629, 8 September 1988, pp. 58–60.
77 Kevin E. Trenberth (ed.), *Climate System Modelling*, Cambridge, Cambridge University Press, 1992, Fig. 3.3.
78 Burroughs, *op. cit.*, Fig. 1.3.
79 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, Fig. 17.
80 For 1920 to 1990 matching sequences, see Kevin E. Trenberth (ed.), *op. cit.*, Figs 18.1a and 18.1b.
81 Sir Gilbert Walker, 'World Weather', Presidential Address to the Royal Meteorological Society, *Quarterly Journal of the Royal Meteorological Society*, vol. 54, no. 226, April 1928, pp. 79–87.
82 *The El Niño Phenomenon*, UNEP/GEMS Environment Library, Nairobi, United Nations Environment Programme, 1992, p. 8.
83 J.M. Walker, 'Pen Portraits of Presidents – Sir Gilbert Walker CSI, ScD, MA, FRS', *Weather*, vol. 52, no. 7, July 1997, pp. 217–20.
84 Jianhua Ju and Julia Slingo, 'The Asian Summer Monsoon and ENSO', *Quarterly Journal of the Royal Meteorological Society*, vol. 121, no. 525, July 1995, pp. 1133–68.
85 George Sarton, *A History of Science. Ancient Science through the Golden Age of Greece*, Cambridge, Harvard University Press, 1959, p. ix.
86 Lamb, *Climate, Present, Past and Future*, Vol. 1, *op. cit.*, Table 8.2.
87 John A. Whitehead, 'Great Ocean Cataracts', *Scientific American*, vol. 260, no. 2, February 1989, pp. 36–43.
88 Presentation at the Royal Astronomical Society conference 'The Cryosphere and Climate Change', London, 10 January 1997.
89 Vincent Moron and M. Neil Ward, 'ENSO Teleconnections with Climate Variability in the European and African Sectors', *Weather*, vol. 53, no. 9, September 1998, pp. 287–95.
90 Robert Wilby, 'Evidence of ENSO in the Synoptic Climate of the British Isles since 1880', *Weather*, vol. 48, no. 8, August 1993, pp. 234–9.
91 Moron and Ward, *op. cit.*, p. 293.
92 Henrik Feddersen, 'Impact of Global Sea Surface Temperatures on Summer and Winter Temperatures in Europe in a Set of Seasonal Ensemble Simulations', *Quarterly Journal of the Royal Meteorological Society*, vol. 126, no. 563, July 2000, pp. 2089–2109.
93 R.W. Wilby *et al.*, 'The North Atlantic Oscillation and British Isles Climate Variability, 1865–1996', *Weather*, vol. 52, no. 9, September 1997, pp. 266–76, Fig. 2.

94 M.J. Rodwell *et al.*, 'Oceanic Forcing of the Wintertime North Atlantic Oscillation and European Climate', *Nature*, vol. 398, no. 6725, 25 March 1999, pp. 320–3, Fig. 1.
95 Harold Zirin, *The Astrophysics of the Sun*, Cambridge, Cambridge University Press, 1988, p. 107.
96 G. Wesley Lockwood, 'Irradiance Variations of Stars', in J.M. Pap, H.S. Hudson and S.K. Solanki (eds), *The Sun as a Variable Star*, IAU Colloquium 143, Cambridge, Cambridge University Press, 1994, pp. 20–7.
97 A. Barrie Pittock, 'Cycles in the Pre-Cambrian', *Nature*, vol. 318, no. 6047, 12 December 1985, pp. 509–10.
98 M.N. Gnevyshev and A.I. Oi (eds), E. Vilim (trans.), *Effects of Solar Activity on the Earth's Atmosphere and Biosphere*, Jerusalem, Keter Publishing, 1977.
99 H.J. Eysenck and D.K.B. Dias, *Astrology and Superstition*, London, Maurice Temple Smith, 1982, Chapter 7.
100 *Scientific Assessment of Climate Change*, Working Group I of IPCC, Geneva and Nairobi, WMO and UNEP, June 1990, Fig. 2.5.
101 Ellsworth Huntington and Stephen Visher, *Climate Changes: Their Nature and Causes*, New Haven, Yale University Press, 1922, p. 28.
102 Dario Camuffo and Silvia Enzi, 'Climatic Features during the Spörer and Maunder Minima' in Burkhard Frenzel (ed.), *Solar Output and Climate during the Holocene*, Stuttgart, Gustav Fischer Verlag, 1995, pp. 105–24.
103 'Climate Change – the Solar Connection', *The New Scientist*, vol. 132, no. 1796, 23 November 1991, p. 22.
104 D. Justin Schove, 'The Sunspot Cycle, 649 BC to AD 2000', *Journal of Geophysical Research*, vol. 60, no. 2, June 1955, pp. 127–46, Table 2.
105 Richard A. Kerr, 'Sun, Weather and Climate: A Connection?' *Science*, vol. 217, no. 4563, 3 September 1982, pp. 917–19.
106 W. Gleissberg, 'The Eighty-Year Sunspot Cycle', *Journal of the British Astronomical Association*, vol. 68, no. 4, Session 1957–8, pp. 148–52, Fig. 2.
107 J.L. Jirikowic and P.E. Damon, 'The Medieval Solar Activity Maximum', *Climate Change*, no. 26, July 1994, pp. 309–16.
108 E. Pallé Bagó and J.C. Butler, 'The Influence of Cosmic Rays on Terrestrial Clouds and Global Warming', *Astronomy and Geophysics*, vol. 41, issue 4, August 2000, pp. 18–22.
109 B.J. Mason, *Clouds, Rain and Rainmaking*, Cambridge, Cambridge University Press, 1962, p. 22.
110 Peter R. Jones, *Weather*, vol. 49, no. 5, May 1994, p. 176.
111 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 1, Table 10.1.
112 Jonathan Cape, 'What Happened at Qaqortog?' *Astronomy and Geophysics*, vol. 39, Issue 1, February 1998, pp. 1.17–1.18.
113 Carl Sagan and Steven J. Astro, 'The Long-range Consequences of Interplanetary Collisions', *Issues in Science and Technology*, vol. X, no. 4, Summer 1994, pp. 67–72.
114 D.J. Asher and S.V.M. Clube, 'An Extraterrestrial Influence during the Current Glacial–Interglacial', *Quarterly Journal of the Royal Astronomical Society*, vol. 34, no. 4, December 1993, pp. 481–511.
115 Jean M. Grove, *The Little Ice Age*, London, Methuen, 1988, Fig. 11.6c.
116 Michael R. Rampino *et al.*, 'Can Rapid Climatic Change Cause Volcanic Eruptions?' *Science*, vol. 206, no. 4420, 16 November 1979, pp. 826–9, Fig. 1c.
117 Shuji Yamakawa, 'The Impact of the Pinatubo Eruption on Global and Regional Systems', *1997 Japanese Progress in Climatology*, December 1997, pp. 29–32.
118 J.L. Houghton *et al.* (eds), *Climate Change 1995. The Science of Climate Change*, Cambridge, Cambridge University Press for Intergovernmental Panel on Climate Change, 1996, Fig. 3.7a and para. 3.2.6.
119 Yamakawa, *op. cit.*
120 Peter Molnar, 'The Rise of the Tibetan Plateau: From Mantle Dynamics to Indian Monsoon', *Astronomy and Geophysics*, vol. 38, no. 3, June/July 1997, pp. 10–15.
121 M.I. Budyko, 'Climate Conditions of the Future', *Conference on Climate and Water*, Helsinki, Valtion Painatuskeskus, 1989, Vol. 1, pp. 9–25.

122 *Scientific Assessment of Climate Change*, Working Group I of IPCC, Geneva and Nairobi, WMO and UNEP, June 1990, Fig. 1.9.
123 H.H. Lamb, *Climate: Present, Past and Future*, Vol. 1, *op. cit.*, Fig. 2.5.
124 J. Huizinga, *The Waning of the Middle Ages*, London, Edward Arnold, 1924, p. 2.
125 Bagó and Butler, *op. cit.*, Fig. 1.

3 Empires and barbarians

1 Edward Gibbon, *Decline and Fall of the Roman Empire* (6 vols), W. Strahan and T. Cadell (eds), 1776, Vol. 1, Chapter III.
2 Shelby T. McCloy, *Gibbon's Antagonism to Christianity*, New York, Burt Franklin, 1933, p. 48.
3 A. Lentin, 'Edward Gibbon and "The Golden Age of the Antonines" ', *History Today*, vol. 31, no. 7, July 1981, pp. 33–9.
4 *Decline and Fall*, *op. cit.*
5 W.G. Hoskins (Introduction by Christopher Taylor), *The Making of the English Landscape*, London, Guild Publishing, 1988, p. 17.
6 R. Latouche (E.M. Wilkinson, trans.), *The Birth of the Western Economy*, London, Methuen, 1961, p. 189.
7 Della Hooke, 'Pre-Conquest Woodland: Its Distribution and Usage', *Agricultural History Review*, vol. 37, part 2, 1989, pp. 113–29.
8 Heinrich Fichtenau (Patrick J. Geary, trans.), *Living in the Tenth Century*, Chicago, University of Chicago Press, 1991, p. 338.
9 Albert Kolb (C.A.M. Sym, trans.), *East Asia*, Methuen, London, 1971, pp. 70 and 47.
10 Geoffrey Barraclough (ed.), *The Times Atlas of World History*, London, Times Books, 1979, p. 127.
11 Peter Hopkirk, *Foreign Devils on the Silk Road*, London, John Murray, 1980, pp. 20–1.
12 Co-Ching Chu, 'Climatic Pulsations during Historic Time in China', *The Geographical Review*, vol. XVI, no. 2, April 1926, pp. 274–82.
13 Joseph Needham (with Wang Ling), *Science and Civilisation in China*, Cambridge, Cambridge University Press, 1959, Vol. 3, Table 39.
14 Tu-cheng Yeh *et al.*, 'An International Symposium on Climate in Beijing . . . ', *Bulletin of the American Meteorological Society*, vol. 66, no. 9, September 1985, pp. 1147–52.
15 Zhaodong Feng *et al.*, 'Temporal and Spatial Variations of Climate in China during the Last 10,000 Years', *The Holocene*, vol. 3, no. 2, 1993, pp. 174–80.
16 Jin-Qi Fang, 'Establishment of a Data Bank from Records of Climatic Disasters and Anomalies in Ancient Chinese Documents', *International Journal of Climatology*, vol. 12, July–August 1992, pp. 499–519, Figs 2d and 2g.
17 Tu-cheng Yeh *et al.*, *op. cit.*, p. 1148.
18 M. Rostovtzeff, 'The Decay of the Ancient World and its Economic Explanations', *Economic History Review*, vol. II, no. 2, January 1930, pp. 197–214.
19 Ellsworth Huntington, *Palestine and its Transformation*, Boston, Houghton Mifflin, 1911, Chapter XIV.
20 John Hare, *The Lost Camels of Tartary*, London, Abacus, 1999, pp. 77–80.
21 Rhoads Murphey, 'The Decline of North Africa since the Roman Occupation: Climatic or Human?' *Annals of the Association of American Geographers*, vol. XLI, no. 2, June 1951, pp. 116–32.
22 H.J.L. Beadnell, 'Remarks on the Prehistoric Geography and Underground Waters of Kharga Oasis', *Geographical Journal*, vol. LXXXI, no. 2, February, 1933, pp. 128–30.
23 Gertrude Caton-Thompson and E.W. Gardner, 'The Pre-historic Geography of the Kharga Oasis', *Geographical Journal*, vol. LXXX, no. 5, November 1932, pp. 369–409.
24 John E. Chappell, 'Climatic Change Reconsidered: Another Look at 'the Pulse of Asia" ', *The Geographical Review*, vol. LX, no. 3, July 1970, pp. 347–73.
25 L.N. Gumilëv, 'Heterochronism in the Moisture Supply of Eurasia in the Middle Ages', *Soviet Geography. Review and Translation*, vol. IX, no. 1, January 1968, pp. 23–35.
26 J. Neumann, 'Climate of the Black Sea around 0 CE', *Climate Change*, vol. 18, no. 4, June 1991, pp. 453–65.

27 Huntington, *op. cit.*, Chapter XVII.
28 M.M. Chernavskaya, 'Moistening Changes on the Russian Plain during the Historical Period', in R. Bradzil (ed.), *Climate Change in the Historical and Instrumental Period*, Brno, Masaryk University, 1990, pp. 130–3.
29 Leszek Starkel in Arie S. Issar and Neville Brown (eds), *Water, Environment and Society in Times of Climatic Change*, Dordrecht, Kluwer, 1998, Chapter 12.
30 Peter Heather, *The Goths*, Oxford, Blackwell, 1998, pp. 76–7.
31 Alessandra Sperenska *et al.*, 'Late Holocene Human Impact Peat Development in the Cerná, Hora Bog, Krkosnose Mountains, Czech Republic', *The Holocene*, vol. 10, no. 5, 2000, pp. 575–85.
32 Chappell, *op. cit.*, pp. 369–71.
33 Justine Davis Randers-Pehrson, *Barbarians and Romans*, London, Croom Helm, 1983, pp. 41–7.
34 Arthur N. Waldron, 'The Problem of the Great Wall of China', *The Harvard Journal of Asiatic Studies*, vol. 43, no. 2, December 1983, pp. 642–63.
35 E.A. Thompson, *The Huns*, Oxford, Blackwell, 1996 (revised by Peter Heather), pp. 6–9.
36 Peter Heather, 'The Huns and the End of the Roman Empire in Western Europe', *English Historical Review*, vol. CX, no. 435, February 1995, pp. 4–41.
37 Owen Lattimore, *Inner Asian Frontiers of China*, New York and Irvington-on-Hudson, American Geographical Society and Capitol Publishing, 1951, Chapter XVI.
38 Zhaodong Feng *et al.*, *op. cit.*, Fig. 4.
39 Jin-Qi Fang, 'Lake Evolution during the last 3000 Years . . . ', *Quaternary Research*, vol. 39, no. 2, March 1993, pp. 175–185.
40 Gibbon, Vol. 3, *op. cit.*, Chapter XXVI.
41 Chin-Fu Hung, *The Harvard Journal of Asiatic Studies*, vol. 41, no. 2, December 1981, p. 605.
42 John C. Bartholomew, *The Advanced Atlas of Modern Geography*, Edinburgh, Oliver and Boyd, 1967, p. 28.
43 Gibbon, Vol. 3, *op. cit.*
44 Hans-Joachim Diesner (C.S.V. Salt, trans.), *The Great Migration*, London, Orbis, 1982, pp. 72–4 (originally published in East Germany in 1978).
45 Gibbon, Vol. 1, *op. cit.*, Chapter X.
46 Jin-Qi Fang and Guo Liu, 'Relationship between Climatic Change and the Nomadic Southward Migrations in Eastern Asia during Historical Times', *Climatic Change*, vol. 22, no. 2, October 1992, pp. 151–68.
47 M. Cary, *The Geographic Background of Greek and Roman History*, Oxford, Clarendon Press, 1949, p. 3.
48 Yigael Yadin, *Masada*, Weidenfeld and Nicolson, London, 1966, pp. 32–5.
49 A. Frumkin *et al.*, 'The Holocene Climatic Record of the Salt Caves of Mount Sedom, Israel, *The Holocene*, vol. 1, no. 3, 1991, pp. 191–200.
50 Christoph Heim *et al.*, 'Near East Desertification: Evidence from the Dead Sea', *Naturwissenschaften*, no. 84, 1997, pp. 398–401.
51 Geoffrey Rickman, *The Corn Supply of Ancient Rome*, Oxford, Clarendon Press, 1980, pp. 104–6.
52 Cary, *op. cit.*, pp. 144–5.
53 Rickman, *op. cit.*, p. 103.
54 Dan Yakir *et al.*, '^{13}C and ^{18}O of Wood from the Roman Siege Rampart in Masada, Israel (AD 70–73): Evidence for a Less Arid Climate for the Region', *Geochimica et Cosmochimica Acta*, vol. 58, no. 16, 1994, pp. 3535–3539.
55 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, p. 157.
56 Gibbon, Vol. 1, *op. cit.*, Chapter IX.
57 Thomas Arnold, 'Hannibal's Passage of the Alps', in L. Valentine (ed.), *Half Hours with Standard Authors*, London, The Library Press, undated, pp. 133–64.
58 J. Neumann, 'Climatic Conditions in the Alps in the Years about the Year of Hannibal's Crossing (218 BC), *Climate Change*, vol. 22, no. 2, October 1992, pp. 139–50.
59 Lamb, *op. cit.*, p. 159.
60 Arie S. Issar, *The Impact of Climate Variations on Water Management Systems*, Sede Boker, Ben-Gurion University of the Negev, 1992, Fig. 13.

61 Atle Nesje and Svein Olaf Dahl, 'Late Holocene Glacier Fluctuations in Bevringsdalen, Jostedalsbreen Region, Western Norway (ca. 3200–1400 BP)', *The Holocene*, vol. 1, no. 1, 1991, pp. 1–7.
62 Lotte Hedeager (John Hines, trans.), *Iron Age Societies. From Tribe to State in Northern Europe, 500 BC to AD 700*, Oxford, Blackwell, 1992, pp. 208–9.
63 C.E.P. Brooks, *Climate Through the Ages*, London, Ernest Benn, 1926, p. 340.
64 B.J. Horne, 'Aquifers in Roman Britain', *Journal of Meteorology*, vol. 18, no. 177, March 1993, p. 92.
65 Andrew Hayes, *Archaeology of the British Isles*, London, B.T. Batsford, 1993, Fig. 64.
66 Stephen H. Schneider and Richard L. Temkin in John Gribbin (ed.), *Climate Change*, Cambridge, Cambridge University Press, 1978, pp. 228–9.
67 Walter Dragoni, 'Response of some Hydrological Systems in Central Italy in Climatic Variations', in Andreas N. Angelakis and Arie S. Issar (eds), *Diachronic Climatic Impacts on Water Resources*, Heidelberg, Springer-Verlag, NATO-ASI Series, 1(36), 1996, pp. 193–229.
68 Walter Dragoni in Issar and Brown (eds), *op. cit.*, Chapter 11, Fig. 11.3.
69 Issar, *op. cit.*, Fig. 5.
70 Morris Bishop, *The Horizon Book of the Middle Ages*, London, Cassell, 1959, p. 13.
71 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1977, Vol. 2, pp. 256–8.
72 Issar, *op. cit.*, Fig. 4.
73 S.A.M. Adshead, *Salt and Civilisation*, Basingstoke, Macmillan, 1992, pp. 29–31.
74 Hans Zinsser, *Rats, Lice and History*, London, Routledge, 1935, Chapter VII.
75 W.H.S. Jones, *Malaria. A Neglected Factor in the History of Greece and Rome*, London, Macmillan, 1907, pp. 64–85.
76 Sir Napier Shaw, *Manual of Meteorology*, Cambridge, Cambridge University Press, 1932, Vol. 1, *Meteorology in History*, pp. 89–90.
77 For a very clear map plus explanation, see J.D. Fage, *An Atlas of African History*, London, Edward Arnold, 1978, Section 6.
78 Murphey, *op. cit.*, pp. 129–30.
79 Brent D. Shaw, Chapter 16, 'Climate and History: The Case of Roman Africa', in T.M.L. Wigley (ed.), *Climate and History*, Cambridge, Cambridge University Press, 1981.
80 Rickman, *op. cit.*, pp. 98–9.
81 *Ibid.*, Appendix 4.
82 James Westfall Thompson, *Economic and Social History of the Middle Ages*, Vol. 1, New York, Frederick Ungar, 1928, pp. 10–11.
83 Rickman, *op. cit.*, p. 112.
84 G.W. Murray, 'The Egyptian Climate: An Historical Outline', *The Geographical Journal*, vol. CXVII, part 4, December 1951, pp. 422–34.
85 Shaw, *op. cit.*, p. 382.
86 Professor K. Branigan (ed.), *The Atlas of Archaeology*, London, MacDonald, 1982, pp. 88–91.
87 Josiah C. Russell, *Medieval Demography*, New York, AMS, 1987, Chapter VI.
88 Quoted in R.W. Fairbridge, 'The Nile Floods as a Global Climatic Solar Proxy', in N.A. Mörner and W. Karlén (eds), *Climatic Changes on a Yearly to Millennial Basis*, Dordrecht, D. Reidel, 1984, pp. 181–90.
89 T.H. Hollingsworth, *Historical Demography*, Cambridge, Cambridge University Press, 1969, Fig. 5.
90 Russell, *op. cit.*, p. 79.
91 Thomas W. Africa, 'Urban Violence in Imperial Rome', *The Journal of Interdisciplinary History*, vol. II, no. 1, Summer 1971, pp. 3–21.
92 Wolfgang Liebeschuetz, Chapter 1, 'The End of the Ancient City', in John Rich (ed.), *The City in Late Antiquity*, London, Routledge, 1993.
93 James Westfall Thompson, *op. cit.*, Vol. 1, pp. 50–1.
94 Chester C. Starr, *The Roman Empire, 27 BC to AD 476*, New York, Oxford University Press, 1982, pp. 102–6.
95 V. Castellani and Walter Dragoni, 'Contribution to the History of Underground Structures: Ancient Rome Tunnels in Central Italy', in Raghupati S. Sinha (ed.), *Proceedings of*

International Symposium on Unique Underground Structures, Denver, Colorado School of Mines, 1991, Vol. 2, Chapter 80, Table 1.
96 Gibbon, Vol. 3, *op. cit.*, Chapter XXXVI.
97 Hayes, *op. cit.*, p. 109.
98 Peter Brown, *The World of Late Antiquity*, London, Thames and Hudson, 1971, pp. 41–4.
99 *Ibid.*, p. 68.
100 A.H.M. Jones, *The Later Roman Empire, 284–602* 3 vols, Oxford, Basil Blackwell, 1964, Vol. II, p. 1027.
101 E.A. Thompson, 'Early Germanic Warfare', *Past and Present*, no. 14, November 1958, pp. 2–29.
102 Edward N. Luttwak, *The Grand Strategy of the Roman Empire*, Baltimore, Johns Hopkins University Press, 1976, p. 190.
103 A.D. Lee, *Information and Frontiers: Roman Foreign Relations in Late Antiquity*, Cambridge, Cambridge University Press, 1993, pp. 95–9.
104 Ramsay MacMullen, *Christianizing the Roman Empire*, New Haven, Yale University Press, 1984, p. 119.
105 Arter Ferrill, *The Fall of the Roman Empire, the Military Explanation*, London, Thames and Hudson, 1986, pp. 60–5.
106 Heather, *English Historical Review, op. cit.*, p. 15.
107 Ferrill, *op. cit.*, pp. 62–3.
108 James Lawford (ed.), *The Cavalry*, Abingdon, Purnell, 1976, p. 44.
109 E.A. Thompson, *op. cit.*, pp. 5–11.
110 E.A. Thompson, *A History of Attila and the Huns*, Oxford, 1948, p. 51.
111 Rudi Paul Lindner, 'Nomadism, Horses and Huns', *Past and Present*, no. 92, August 1981, pp. 3–19.
112 John Morris, 'The Later Roman Empire', *Past and Present*, no. 29, December 1964, pp. 98–104.
113 Heather, *The Goths, op. cit.*, Chapter 6.
114 Barraclough, *op. cit.*, p. 98, Map 3.
115 Ramsay MacMullen, *Corruption and the Decline of Rome*, New Haven, Yale University Press, 1988, pp. 8–11.
116 Peter Garnsey, *Famine and Food Supply in the Graeco-Roman World*, Cambridge, Cambridge University Press, 1988, pp. 271–3.
117 Morris, *Past and Present, op. cit.*, p. 102.
118 Colin O'Connor, *Roman Bridges*, Cambridge, Cambridge University Press, 1993.
119 P.A. Brunt, 'The Roman Mob', *Past and Present*, no. 35, December 1966, pp. 3–27.
120 Susanna Van Rose, 'Water Problems of the Past, *Geographical Magazine*, vol. LXI, no. 10, October 1989, p. 36.
121 Harry B. Evans, *Water Distribution in Ancient Rome*, Ann Arbor, University of Michigan Press, 1994, p. 4.
122 Peter Brown, *op. cit.*, pp. 34–6.
123 MacMullen, *op. cit.*, p. 53.
124 Gibbon, *Decline and Fall, op. cit.*, Vol. 2, Chapter XVII.
125 Andre Gunder Frank and Barry K. Gills, 'World System Economic Cycles and Hegemonial Shift to Europe, 100 BC to 1500 AD', *The Journal of European Economic History*, vol. 22, no. 1, Spring 1993, pp. 155–83.
126 *Ibid.*, p. 162.
127 As confirmed in a conversation with Barry Gills, 1994.
128 Albert Kolb, *op. cit.*, p. 34.
129 Karl Wittfogel, *Oriental Despotism*, New Haven, Yale University Press, 1957, p. 168.
130 A.B. Lloyd, 'The Late Period, 664–323', in B.G. Trigger *et al.* (eds), *Ancient Egypt: A Social History*, Cambridge, Cambridge University Press, 1983, pp. 279–364.

4 Antiquity melds

1 Leslie Alcock, *Arthur's Britain, History and Archaeology, AD 367–634*, Harmondsworth, Pelican, 1973, p. 311.

2 Josiah Cox Russell, *The Control of Late Ancient and Medieval Population*, Philadelphia, The American Philosophical Society, 1985, p. 82.
3 Catherine Hills, 'Roman Britain to Anglo-Saxon England', *History Today*, vol. 40, no. 10, October 1990, pp. 46–52.
4 Michael Winterbottom (ed.), *Gildas. The Ruin of Britain and Other Works*, London, Phillimore, 1978, pp. 16–17.
5 *Ibid.*, p. 13.
6 *Ibid.*, p. 27.
7 Victor Clube and Bill Napier, *The Cosmic Winter*, Oxford, Basil Blackwell, 1990, pp. 107–10.
8 K. Rutherford Davis, *Britons and Saxons, The Chiltern Region, 400–700*, Chichester, Phillimore, 1982, p. 9.
9 For example, Hector Munro Chadwick in H.M. Chadwick *et al.*, *Studies in Early Church History*, Cambridge, Cambridge University Press, 1959, p. 21.
10 Article reprinted in English in *Chinese Astronomy*, no. 1, 1977, pp. 197–200.
11 M.G.L. Baillie, *A Slice Through Time*, London, B.T. Batsford, 1995, Chapter 6.
12 M.G.L. Baillie, 'Dendrochronology Raises Questions about the Nature of the AD 536 Dust Veil Event', *The Holocene*, vol. 4, no. 2, 1994, pp. 212–17.
13 C.U. Hammer *et al.*, 'Greenland Ice Sheet Evidence of Post-glacial Volcanism and its Climatic Impact', *Nature*, vol. 288, no. 5788, 20 November 1980, pp. 230–5.
14 David Keys, *Catastrophe*, London, Century Books, 1999, Chapters 32 and 33.
15 Hans Zinsser, *Rats, Lice and History*, London, Routledge, 1935, pp. 144–5.
16 Pauline Allen, 'The Justianic Plague', *Byzanton*, Vol. XLIX, 1979, pp. 5–20.
17 Russell, *op. cit.*, pp. 135–6.
18 Robert S. Gottfried, *The Black Death*, London, Robert Hale, 1993, pp. 10–12.
19 Russell, *op. cit.*, Chapter VI.
20 *Ibid.*, p. 135.
21 Warren Treadgold, *Byzantium and its Army*, Stanford, Stanford University Press, 1995, p. 16.
22 Gottfried, *op. cit.*, p. 9.
23 K.R. Briffa *et al.*, 'A 1,400-year Tree-ring Record of Summer Temperatures in Fennoscandia', *Nature*, vol. 346, no. 6283, 2 August 1990, pp. 434–9.
24 *Bartholomew's Advanced Atlas of Modern Geography*, Edinburgh, Oliver and Boyd, 1967, p. 4.
25 Ian Wood in Michael Lapidge and David Dumville (eds), *Gildas. New Approaches*, Woodbridge, Boydell Press, 1984, p. 23.
26 Winterbottom, *op. cit.*, p. 1.
27 Martyn J. Whittock, *The Origins of England, 410–600*, Beckenham, Croom Helm, 1986, p. 198.
28 John Morris, *The Age of Arthur*, London, Weidenfeld and Nicolson, 1973, pp. 112–13.
29 The successive bluffs of the Oxfordshire Chilterns have northward-facing defensive earthworks dating from that time. On my native Watlington Hill the landscape and the earthwork plan would be quite compatible with locally recruited British infantry backed up by cavalry resisting investment by the English. Interestingly, Gildas talks of 'the siege' of Badon Hill. One might add that large numbers of Saxon weapons have been found in the nearby ford across the Thames (i.e. Wallingford), which would be the route back to the West Saxon realm.
30 Rutherford Davis, *op. cit.*, p. 17.
31 Russell, *op. cit.*, p. 123.
32 Anne Savage (trans.), *The Anglo-Saxon Chronicles*, London, Phoebe Phillips, 1982, p. 51.
33 Alfred P. Smyth, *King Alfred the Great*, London, Oxford University Press, 1995, pp. 478–9.
34 Whittock, *op. cit.*, p. 206.
35 J.J. Blackford and F.M. Chambers, 'Proxy Records of Climate from Blanket Mires: Evidence for a Dark Age (1400 BP) Climatic Deterioration in the British Isles', *The Holocene*, vol. 1, no. 1, 1991, pp. 63–7.
36 Frank Mitchell, *The Shell Guide to Reading the Irish Landscape*, London, Michael Joseph, 1986, pp. 153 and 158.
37 B.J. Graham in B.J. Graham and L.J. Proudfoot (eds), *An Historical Geography of Ireland*, London, Academic Press, 1993, Chapter 1.

38 Nora K. Chadwick, *The Age of the Saints in the Early Celtic Church*, London, Oxford University Press, 1961, pp. 30–9.
39 Paul Johnson, *A History of Christianity*, Harmondsworth, Pelican, 1980, pp. 139–41.
40 Donald Matthew, *Atlas of Medieval Europe*, Oxford, Equinox, 1983, p. 48.
41 Kenneth Clark, *Civilisation*, London, BBC and John Murray, 1969, Chapter 1.
42 Willi Dansgaard *et al.*, 'Climatic Changes, Norsemen and Modern Man', *Nature*, vol. 255, no. 5503, 1 May 1975, pp. 24–8.
43 Geoffrey Ashe *et al.*, *The Quest for America*, New York, Praeger, 1971, pp. 271–2.
44 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1972, Vol. 1, Figs 7.15a and 7.15b.
45 C.E.P. Brooks and W.A. Quennell, *The Influence of Arctic Ice on the Subsequent Distribution of Pressure over the Eastern North Atlantic and Western Europe*, Geophysical Memorandum No. 41, London, Meteorological Office, 1928.
46 W.H. Babcock, 'St Brendan's Explorations and Islands', *The Geographical Review*, vol. VIII, no. 1, July 1919, pp. 37–46.
47 Hubert Lamb, 'Climate and its variability in the North Sea–Northwest Atlantic Region', in Arne Bang-Andersen *et al.* (eds), *The North Sea. A Highway of Economic and Cultural Exchange, Character and History*, Stavanger, Norwegian University Press, 1985, pp. 27–38, Fig. 3.
48 C.E.P. Brooks, *Climate Through the Ages*, London, Ernest Benn, 1926, p. 417.
49 See e.g. Richard Joel Russell in United States Department of Agriculture Yearbook, *Climate and Man*, Washington, US Government Printing Office, 1941, p. 91.
50 Jean M. Grove, 'The Glacial History of the Holocene', *Progress in Physical Geography*, vol. 3, no. 1, March 1979, pp. 1–54, Fig. 15.
51 Dansgaard *et al., op. cit.*, Fig. 3 and p. 27.
52 Otto Pettersson, 'The Connection between Hydrographical and Meteorological Phenomena', *QJRMS*, vol. xxxviii, no. 163, July 1912, pp. 173–91.
53 Sir Napier Shaw, *Manual of Meteorology* (4 vols), Cambridge, Cambridge University Press, 1932, vol. 1, Chapter 6.
54 Grove, *op. cit.*, Figs 4 and 5.
55 Hubert H. Lamb, 'Climate and History in Northern Europe and Elsewhere', in N.-A. Mörner and W. Karlen (eds), *Climatic Changes on a Yearly to Millennial Basis*, Dordrecht, D. Reidel, 1984, pp. 225–40.
56 K.R. Dark, *Civitas to Kingdom: British Political Continuity, 300–800*, London, Leicester University Press, p. 233.
57 Robert S. Gottfried in Joseph R. Strayer (editor-in-chief), *Dictionary of the Middle Ages* (13 vols), New York, Charles Scribner's, 1985, Vol. 5, p. 453.
58 W.G. Hoskins (Introduction by Christopher Taylor), *The Making of the English Landscape*, London, Guild Publishing, 1988, p. 41.
59 Arie S. Issar *et al.*, *Impacts of Climate Variations on Water Management and Related Socio-economic Systems*, Paris, International Hydrological Programme, UNESCO, 1995, Fig. 2.
60 Dario Camuffo, 'Freezing of the Venetian Lagoon since the Ninth Century AD in Comparison to the Climate of Western Europe and England', *Climatic Change*, vol. 10, no. 1, February 1987, pp. 42–66.
61 J.L. Bintliff in A.F. Harding (ed.), *Climatic Change in Later Pre-History*, Edinburgh, Edinburgh University Press, 1982, p. 153.
62 L. Starkel *et al.* (eds), *Temperate Palaeohydrology*, Chichester, John Wiley, 1991, p. 76.
63 N.J.G. Pounds, *An Historical Geography of Europe, 450 BC to AD 1330*, Cambridge, Cambridge University Press, 1973, p. 208.
64 Robert S. Gottfried in Joseph R. Strayer, *op.cit.*, vol. 3, p. 454.
65 D. Justin Schove, 'Droughts of the Dark Ages and Tree Rings (AD 714–835)', *Weather*, vol. X, no. 11, November 1955, pp. 368–71.
66 Xavier De Planhol and Paul Claval (Janet Lloyd, trans.), *An Historical Geography of France*, Cambridge, Cambridge University Press, 1994, pp. 67–8.
67 Dark, *op. cit.*, p. 244.
68 *Ibid.*, pp. 231–2.
69 Robert S. Gottfried in Joseph R. Strayer, *op. cit.*, Vol. 5, pp. 3–9.

70 Christopher Dawson, *The Making of Europe*, London, Sheed and Ward, 1932, pp. 206–7.
71 Dark, *op. cit.*, pp. 235–45.
72 Dirk Jellema, 'Frisian Trade in the Dark Ages', *Speculum*, vol. XXX, no. 1, January 1955, pp. 15–36.
73 James R. Coull, *The Fisheries of Europe*, London, G. Bell, 1972, p. 63.
74 Alan M. Stahl, 'Numismatic and Medieval Archaeology', in Charles L. Redman (ed.), *Medieval Archaeology*, Binghamton, State University of New York, 1989, pp. 118–26.
75 Peter Brown, 'Gibbon's Views on Culture and Society in the Fifth and Sixth Centuries', *Daedalus*, vol. 105, no. 3, Summer 1976, pp. 73–88.
76 Roger Collins, *Early Medieval Europe, AD 300–1000*, Basingstoke, Macmillan, 1991, Chapter 13.
77 Archibald Lewis, *The Northern Seas*, Princeton, Princeton University Press, 1958, pp. 117–18.
78 A.D. Lee, *Information and Frontiers, Roman Foreign Relations in Late Antiquity*, Cambridge, Cambridge University Press, 1993, p. 97.
79 Lewis, *op. cit.*, pp. 173–4.
80 Richard Hodges, *Dark Age Economics. The Origins of Towns and Trade, AD 600–1000*, London, Gerald Duckworth, 1989, Chapter 8.
81 Briffa *et al.*, *op. cit.*, Fig. 2.
82 Hammer *et al.*, *op. cit.*, Fig. 1.
83 Hodges, *op. cit.*, p. 196.
84 *Ibid.*, p. 139.
85 B.J. Graham, *op. cit.*
86 For example, Jacques Pirenne (Lovett Edwards, trans.), *The Tides of History*, London, George Allen and Unwin, 1963, Vol. II, Part 2, Book VIII, 'Europe Split between the Call of the Sea and the Continent'.
87 Coull, *op. cit.*
88 Dr T. Peisker in H.M. Gwatkin and J.P. Whitney (eds), *The Cambridge Medieval History*, Vol. II, Cambridge, Cambridge University Press, 1913, Chapter XIV.
89 Paul Johnson, *op. cit.*, pp. 181–8.
90 Leo Kouteniemi in L. Starkel *et al.* (eds), *op. cit.*, Chapter 4.
91 Arie S. Issar in Arie S. Issar and Neville Brown (eds), *Water, Environment and Society in Times of Climatic Change*, Dordrecht, Kluwer, 1998, Chapter 6.
92 Amos Frumkin *et al.*, in *ibid.*, Chapter 5.
93 Fig. 9 in H.H. Lamb, 'Reconstruction of the Course of Post-glacial Climate over the World', in A.F. Harding (ed.), *Climate Change in Later Pre-History*, Edinburgh, Edinburgh University Press, 1982, pp. 11–32.
94 Lee, *op. cit.*, pp. 93–4.
95 Cyril Mango, *Byzantium, The Empire of New Rome*, New York, Charles Scribner's, 1980, p. 66.
96 J.F. Haldon, *Byzantium in the 7th Century*, Cambridge, Cambridge University Press, 1990, p. 443.
97 Steven Runciman in M. Postan and E.E. Rich (eds), *The Cambridge Economic History of Europe* (8 vols), Cambridge, Cambridge University Press, 1952, Vol. II, p. 51.
98 Geoffrey Barraclough (ed.), *The Times Atlas of World History*, London, Times Books, 1979, p. 108.
99 Steven Runciman, 'Gibbon and Byzantium', in G.W. Bowerstock *et al.* (eds), *Edward Gibbon and the Decline and Fall of the Roman Empire*, Cambridge, Harvard University Press, 1977, pp. 53–60.
100 Edward N. Luttwak, *The Grand Strategy of the Roman Empire*, Baltimore, Johns Hopkins University Press, 1976, p. 190.
101 Edward Gibbon, *The Decline and Fall of the Roman Empire* (6 vols), London, J.M. Dent, 1987, Vol. 3, p. 6.
102 Alan Harvey, *Economic Expansion in the Byzantine Empire, 900–1200*, Cambridge, Cambridge University Press, 1989, p. 24.
103 Alexander D. Kadzhan (editor-in-chief), *The Oxford Dictionary of Byzantium*, Oxford, Oxford University Press, 1991, Vol. 2, p. 778.

104 R.N. Frye in Ehsan Yarshater (ed.), *The Cambridge History of Iran* (7 vols), Cambridge, Cambridge University Press, 1983, Vol. 3(1), p. 155.
105 J. Oliver Thomson, *The History of Ancient Geography*, Cambridge, Cambridge University Press, 1948, pp. 335–45 and Fig. 51.
106 Gus W. Van Beek, 'The Rise and Fall of Arabia Felix', *Scientific American*, vol. 221, no. 6, December 1969, pp. 36–46.
107 Keys, *op. cit.*, pp. 61–4.
108 Roger G. Barry and Richard J. Chorley, *Atmosphere, Weather and Climate*, London, Routledge, 1987, Fig. 6.1.
109 Fekri A. Hassan, 'Historical Nile Floods and their Implications for Climate Change', *Science*, vol. 212, no. 4499, 5 June 1981, pp. 1142–5.
110 Neil Roberts and H.E. Wright in H.E. Wright *et al.* (eds), *Global Climates Since the Last Glacial Maximum*, Minneapolis, University of Minnesota Press, 1993, Chapter 9.
111 Albertine Gaur, *A History of Writing*, London, The British Library, 1984, p. 97.
112 T.E. Lawrence, *Seven Pillars of Wisdom*, London, Jonathan Cape, 1935, p. 357.
113 George Adam Smith, *The Historical Geography of the Holy Land*, London, Hodder and Stoughton, 1894, pp. 29–30.
114 M.A. Shaban, *Islamic History, AD 600 to 750*, Cambridge, Cambridge University Press, 1971, Chapter 1.
115 C.H. Becker, 'The Expansion of the Saracens – The East', in H.M. Gwatkin and J.P. Whitney (eds), *The Cambridge Medieval History*, Cambridge, Cambridge University Press, 1913, Vol. II, Chapter XI, p. 331.
116 Brooks, *Climate Through the Ages*, *op. cit.*, pp. 333–4.
117 Fred McGraw Donner, *The Early Islamic Conquests*, Princeton, Princeton University Press, 1981, p. 279.
118 James Westfall Thompson, *Economic and Social History of the Middle Ages, 300–1300*, New York, Frederick Ungar, 1959, Vol. I, pp. 185–6.
119 Josiah C. Russell, *Medieval Demography*, New York, AMS, 1987, p. 80.
120 Howard Crosby Butler, 'Desert Syria: The Land of a Lost Civilisation', *Geographical Review*, vol. IX, no. 2, February 1920, pp. 77–108.
121 A. Issar and H. Tsoar, 'Who is to Blame for the Desertification of the Negev, Israel?' in *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources, Proceedings of the Vancouver Symposium, August 1987*, IAHS Publication, no. 168, 1987, pp. 577–82.
122 Andrew M. Watson, *Agriculture Innovation in the Early Islamic World. The Diffusion of Crops and Farming Techniques, 700 to 1100*, London, Cambridge University Press, 1973, p. 141.
123 William H. Quinn in Henry F. Diaz and Vera Markgraf (eds), *El Niño*, Cambridge, Cambridge University Press, 1992, Table 6.7.
124 D.A. Adamson *et al.*, 'The Late Quaternary History of the Nile', *Nature*, vol. 288, no. 5786, 6 November 1980, pp. 50–5.
125 Lamb, *op. cit.*, vol. 2, Fig. 13.32.
126 Hassan, *op. cit.*, Figs. 1d and 1e.
127 *Ibid.*, p. 1143.
128 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 2, Fig. 17.1.
129 Michael W. Dols in Joseph R. Strayer (ed.), *op. cit.*, Vol. 5, pp. 1–3.
130 Quinn, *op. cit.*, Table 6.6.
131 Claudio Vita-Finzi, *The Mediterranean Valleys*, Cambridge, Cambridge University Press, 1969, Chapter 12.
132 C. Vita-Finzi, 'Diachronism in Old World Alluvial Sequences', *Nature*, vol. 263, no. 5574, 16 September 1976, pp. 218–19, Fig. 2.
133 Ritchie Calder, *Men Against the Desert*, London, George Allen and Unwin, 1951, Chapters 8 and 10.
134 Albert Einstein, *The World As I See It*, London, Watts, 1940, pp. 96 and 105.
135 Walter Clay Lowdermilk, *Palestine, Land of Promise*, London, Victor Gollancz, 1944, pp. 55–6.
136 E. Ashtor, *A Social and Economic History of the Near East in the Middle Ages*, London, Collins, 1976, Chapter II (d).

137 Hendrik J. Bruins, *Desert Environment and Agriculture in the Central Negev and Kadesh-Barnea during Historical Times*, Nijkerk, MIDBAR Foundation, 1986, pp. 37–8.
138 Rehav Rubin, 'The Romanization of the Negev, Israel: Geographical and Cultural Changes in the Desert Frontier in Late Antiquity', *Journal of Historical Geography*, vol. 23, no. 3, July 1997, pp. 267–83.
139 Arie S. Issar *et al.*, UNESCO, 1995, Fig. 2, *op. cit.*
140 Ashtor, *op. cit.*, pp. 61–2.
141 Karl A. Wittfogel, *Oriental Despotism*, New Haven, Yale University Press, 1957, p. 53, footnote b.
142 Steven Runciman, *A History of the Crusades* (3 vols), Vol. 1, Cambridge, Cambridge University Press, 1957, p. 10.
143 Butler, *op. cit.*, p. 79.
144 Allen, *op. cit.*, pp. 5–20.
145 Rhoads Murphey, 'The Decline of North Africa since the Roman Occupation: Climatic or Human?' *Annals of the Association of American Geographers*, vol. XLI, no. 1, March 1951, pp. 116–32.
146 Richard Hodges and David Whitehouse, *Mohammed, Charlemagne and the Origins of Europe*, London, Duckworth, 1989, pp. 169–70.
147 Mango, *op. cit.*, p. 69.
148 Steven Runciman in Postan and Rich (eds), *op. cit.*, pp. 86–7.
149 Catherine Delano Smith, *Western Mediterranean Europe. A Historical Geography of Italy, Spain and Southern France since the Neolithic*, London, Academic Press, 1979, Chapter 6.
150 Russell, *Medieval Demography*, *op. cit.*, p. 79.
151 Quinn, *op. cit.*, Table 6.6.
152 Hassan, *op. cit.*, Fig. 1.
153 Quinn, *op. cit.*
154 Xavier de Planhol, *The World of Islam*, Ithaca, Cornell University Press, 1959, especially pp. 2–8.
155 Bernard Lewis, 'Gibbon on Muhammad', in Bowerstock *et al.* (eds), *op. cit.*, pp. 61–73.
156 S.D. Goitein, *Studies in Islamic History and Institutions*, Leiden, E.J. Brill, 1966, Chapter VII.
157 David E. Sopher, *Geography of Religions*, Englewood Cliffs, Prentice Hall, 1967, pp. 22–3.
158 Jaime Vicens Vives (Frances M. López-Morillas, trans.), *An Economic History of Spain*, Princeton, Princeton University Press, 1969, pp. 108–10.
159 Planhol, *op. cit.*, pp. 42–3.
160 Michael Rostovtzeff (P.M. Fraser, revised), *The Social and Economic History of the Roman Empire* (2 vols), Oxford, 1957, Vol. 1, p. 311.
161 Roger Collins, *Early Medieval Spain, Unity in Diversity, 400–1000*, London, Macmillan, 1983, pp. 164–5.
162 Collins, *Early Medieval Europe, 300–1000*, *op. cit.*, pp. 207–8.

5 Northerly engagement

1 Sir John Glubb, *A Short History of the Arab Peoples*, London, Hodder and Stoughton, 1969, pp. 104–5.
2 Peter Burke, *The French Historical Revolution*, Cambridge, Polity Press, 1990, p. 21.
3 Henri Pirenne, 'Medieval Cities', in Alfred F. Havighurst (ed.), *The Pirenne Thesis*, Lexington, D.C. Heath, 1976, pp. 1–26.
4 George F. Hourani, *Arab Seafaring*, Princeton, Princeton University Press, 1995, pp. 51–2.
5 Richard Koebner in J.H. Clapham and Eileen Power (eds), *The Cambridge Economic History of Europe* (6 vols), Cambridge, Cambridge University Press, 1942, Vol. 1, Chapter 1, p. 33, footnote 2.
6 Robert S. Lopez, 'Mohammed and Charlemagne: A Revision', *Speculum*, vol. XVIII, no. 1, January 1943, pp. 14–38.
7 Henri Pirenne (Bernard Miall, trans.), *Mohammed and Charlemagne*, London, George Allen and Unwin, 1939, p. 184.
8 *Ibid.*, pp. 174–86.

9 Joseph DeSomogyi, *A Short History of Oriental Trade*, Hildesheim, Georg Olms Verlagsbuchhandlung, 1968, p. 64.
10 Armand O. Citarella, 'The Relations of Amalfi with the Arab World before the Crusades', *Speculum*, vol. XLII, no. 2, April 1967, pp. 299–312.
11 E. Ashtor, *A Social and Economic History of the Near East in the Middle Ages*, London, Collins, 1976, p. 102.
12 Edward Gibbon, *The Decline and Fall of the Roman Empire* (6 vols), London, J.M. Dent, 1987, Vol. 5, pp. 385–95.
13 H. Pirenne, 'The Place of the Netherlands in the Economic History of Medieval Europe', *Economic History Review*, vol. II (1929–30), no. 1, January 1929, pp. 20–40.
14 Norman J.G. Pounds, 'North-West Europe in the Ninth Century: Its Geography in the Light of the Polyptyques', *Annals of the Association of American Geographers*, vol. 57, no. 3, September 1967, pp. 439–61.
15 N.J.G. Pounds, *An Historical Geography of Europe, 450 BC to AD 1330*, Cambridge, Cambridge University Press, 1973, p. 208.
16 Lynn White, 'The Northward Shift of Europe's Focus', in Alfred F. Havighurst (ed.), *The Pirenne Thesis*, Lexington, D.C. Heath, 1976, pp. 166–8.
17 Peter Brown, 'The Later Roman Empire', *Economic History Review*, vol. XX, no. 2, 1967, pp. 327–43.
18 Pounds, 'North-West Europe in the Ninth Century', *op. cit.*, Fig. 6.
19 Jancis Robinson (ed.), *The Oxford Companion to Wine*, Oxford, Oxford University Press, 1994, p. 110.
20 Pirenne, *Mohammed and Charlemagne*, *op. cit.*, pp. 253–6.
21 W. Karlén in L. Starkel, K.J. Gregory and J.B. Thornes (eds), *Temperate Palaeohydrology*, Chichester, John Wiley, 1991, Chapter 18.
22 Jacques Le Goff (Julia Barrow, trans.), *Medieval Civilisation, 400–1500*, Oxford, Basil Blackwell, 1988, p. 179.
23 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, Fig. 59.
24 Pounds, *An Historical Geography of Europe*, *op. cit.*, p. 14.
25 Paul Dutton in Del Sweeney (ed.), *Agriculture in the Middle Ages*, Philadelphia, University of Pennsylvania Press, 1995, Chapter 6.
26 Jin-Qi Fang, 'Establishment of a Data Bank from Records of Climatic Disasters and Anomalies in Ancient Chinese Documents', *International Journal of Climatology*, vol. 12, July–August 1992, pp. 499–519, Fig. 2e.
27 Christopher Dawson, *The Making of Europe*, London, Sheed and Ward, 1932, Chapter XI.
28 Albertine Gaur, *A History of Writing*, London, The British Library, 1984, pp. 172–3.
29 Archibald Lewis, *The Northern Seas*, Princeton, Princeton University Press, 1958, Chapter 4.
30 D.J.A. Matthew, 'Reflections on the Medieval Roman Empire', *History*, vol. 77, no. 251, October 1992, pp. 363–90.
31 Philippe Contamine (Michael Jones, trans.), *War in the Middle Ages*, Oxford, Basil Blackwell, 1984, pp. 32–4.
32 Klavs Randsborg, *The Viking Age in Denmark*, London, Gerald Duckworth, 1980, Chapter 7, Figs 42 and 44.
33 D.M. Metcalf, 'The Prosperity of North-Western Europe in the Eighth and Ninth Centuries', *Economic History Review*, vol. XX, no. 2, 1967, pp. 344–57.
34 W. Dansgaard *et al.*, 'Climatic Changes, Norsemen and Modern Men', *Nature*, vol. 255, no. 5503, 1 May 1975, pp. 24–8.
35 *Ibid.*, Fig. 3.
36 John C. Bartholomew, *The Advanced Atlas of Modern Geography*, Edinburgh, Oliver and Boyd, 1967, p. 26.
37 Vilhjamur Stefansson, *Greenland*, London, George G. Harrap, 1943, pp. 18–19.
38 Michael Coe *et al.*, *Atlas of Ancient America*, Oxford, Equinox, 1986, pp. 46–8.
39 Therkel Mathiassen, 'Eskimo Migrations in Greenland', *Geographical Review*, vol. XXV, no. 3, July 1935, pp. 408–22.
40 H.H. Lamb, *The Changing Climate*, London, Methuen, 1966, p. 64.
41 H.H. Lamb, 'Volcanic Dust in the Atmosphere; with a Chronology and Assessment of its

Meteorological Significance', *Philosophical Transactions of the Royal Society of London*, Series A, vol. 266, 1970, pp. 425–533, Fig. 21b.

42 Paper by Climate Research Unit, University of Keele, presented at Royal Astronomical Society conference on 'The Cryosphere and Climate Change', 2 October 1996.

43 A.E.J. Ogilvie *et al.*, 'North Atlantic Climate c. AD 1000: Millennial Reflections . . .', *Weather*, vol. 55, no. 2, February 2000, pp. 34–45.

44 A.E.J. Ogilvie, 'The Past Climate and Sea-Ice Record from Iceland. Pt. 1. Data to AD 1780', *Climatic Change*, vol. 6, no. 2, June 1984, pp. 131–52.

45 C.U. Hammer *et al.*, 'Greenland Ice Sheet Evidence of Post-glacial Volcanism and its Climatic Impact', *Nature*, vol. 288, no. 5788, 20 November, 1980, pp. 230–5.

46 Victor Clube and Bill Napier, *The Cosmic Winter*, Oxford, Basil Blackwell, 1990, pp. 110–12.

47 Alfred P. Smyth, *King Alfred the Great*, Oxford, Oxford University Press, 1995, pp. 478–9.

48 Hubert H. Lamb, 'Climate and its Variability in the North Sea–Northeast Atlantic Region', in Arne Bang-Andersen, Basil Greenhill and Egil Harald Grude (eds), *The North Sea. A Highway of Economic and Cultural Exchange*, Stavanger, Norwegian University Press, 1985, pp. 27–37.

49 Randsborg, *The Viking Age in Denmark*, *op. cit.*, p. 167.

50 Björn Ambrosiani, 'Settlement Expansion – Settlement Contraction: A Question of War, Plague, Ecology or Climate?' in N.-A. Mörner and W. Karlén (eds), *Climatic Changes on a Yearly to Millennial Basis*, Dordrecht, D. Reidel, 1984, pp. 241–7.

51 I. Renberg *et al.*, 'Climatic Reflection in Varved Lake Sediments', in *ibid.*, pp. 249–56.

52 K.R. Briffa *et al.*, 'A 1400-year Tree-ring Record of Summer Temperatures in Fennoscandia', *Nature*, vol. 346, no. 6283, 2 August 1990, pp. 434–9.

53 *Ibid.*, Fig. 2.

54 Pounds, *An Historical Geography of Europe*, *op. cit.*, p. 208.

55 J.A. Matthews, 'Limitations of 14C Dates from Buried Soils in Reconstructing Glacier Variations and Holocene Climate', in Mörner and Karlén (eds), *op. cit.*, pp. 281–90.

56 Reijo Solantie, 'Climatic Conditions for the Cultivation of Rye with Reference to the History of Settlement in Finland', *Fennoscandia Archaeologica*, V, 1988, pp. 3–20.

57 Leo Koutaniemi in L. Starkel, K.J. Gregory and J.B. Thornes (eds), *Temperate Palaeohydrology*, Chichester, John Wiley, 1991, Chapter 4.

58 G.M. Trevelyan, *History of England*, London, Longman Green, 1942, p. 73.

59 F. Donald Logan, 'Vikings', in Joseph R. Strayer (ed.), *Dictionary of the Middle Ages*, 13 vols, New York, Charles Scribner's, 1989, Vol. 12, pp. 422–32.

60 David M. Wilson, *The Vikings and their Origins*, London, Thames and Hudson, 1989, p. 78.

61 Richard F. Tomasson, 'A Millennium of Misery: the Demography of the Icelanders', *Population Studies*, vol. XXX1, no. 3, November 1977, pp. 405–27.

62 James Bryce, *Studies in History and Jurisprudence*, 2 vols, Freeport, Books for Libraries Press, 1968, Vol. 1, p. 263.

63 T.D. Kendrick, *A History of the Vikings*, London, Methuen, 1930, p. 342.

64 Jesse L. Byock, *Medieval Iceland. Society, Sagas and Power*, Enfield Lock, Hisarlik Press, 1993, p. 70.

65 Michael Haseloch Kirkby, *The Vikings*, Oxford, Phaidon, 1977, p. 157.

66 Lamb in Bang-Andersen *et al.*, *op. cit.*, p. 35.

67 David Spurgeon, 'Canada's Cod Leaves Science In Hot Water', *Nature*, vol. 386, no. 6621, 13 March 1997, p. 107.

68 Dr J. Georgi, 'Greenland as a Switch for Cyclones', *Geographical Journal*, vol. LXXXI, no. 4, April 1933, pp. 344–5.

69 Kevin P. Smith, 'Landnám: the Settlement of Iceland in Archaeological and Historical Perspective', *World Archaeology*, vol. 26, no. 3, February 1995, pp. 319–47.

70 From the translation by Gwyn Jones of the twelfth-century *Landnámabók*. Quoted in Richard F. Tomasson, *op. cit.*, p. 409.

71 Minze Stuvier *et al.*, 'The GISP2 δ^{18}O Climate Record of the Past 16,500 Years and the Role of the Sun, Ocean and Volcanoes', *Quaternary Research*, vol. 44, no. 3, November 1995, pp. 341–54.

72 Birgitta Linderoth Wallace, 'The Vikings in North America: Myth and Reality', in Ross Samson (ed.), *Social Approaches to Viking Studies*, Glasgow, Cruithne Press, 1991, pp. 207–19.

73 Fridtjof Nansen (Artus C. Chater, trans.), *In Northern Mists*, 2 vols, London, William Heinemann, 1911, Vol. 1, Chapter IX.
74 Wallace, *op. cit.*, pp. 213–19.
75 Lesley Abrams, *Times Literary Supplement*, no. 5074, 30 June 2000, p. 3.
76 Geoffrey Ashe *et al.*, *The Quest for America*, New York, Praeger, 1971, pp. 271–2.
77 Jancis Robinson (ed.), *op. cit.*, pp. 28–9.
78 Vilhjalmur Stefansson, 'The Colonization of Northern Lands', in *Climate and Man. Yearbook of Agriculture 1941*, Washington, US Government Printing Office, 1941, pp. 205–16.
79 The zonal theory is not systematically discussed in Aristotle's *Meteorologia*. See E.W. Webster's translation in W.D. Ross (ed.), *The Works of Aristotle*, Oxford, Clarendon Press, 1931.
80 Nansen, *op. cit.*, Vol. 2, Chapter XII.
81 F.N. Stagg, *North Norway. A History*, London, George Allen and Unwin, 1952, pp. 51–2.
82 Øivind Lunde, 'Archaeology and the Medieval Towns of Norway', *Medieval Archaeology*, Vol. XXIX, 1985, pp. 120–35.
83 Sidney Cohen, 'The Earliest Scandinavian Towns', in Harry A. Miskimin *et al.* (eds), *Medieval City*, New Haven, Yale University Press, 1977, pp. 313–25.
84 Geoffrey Barraclough (ed.), *The Times Atlas of World History*, London, Times Books, 1979, p. 110, Map 3.
85 Thomas S. Noonan, 'The Vikings and Russia', in Ross Samson (ed.), *op. cit.*, pp. 201–6.
86 David M. Wilson in David M. Wilson (ed.), *The Vikings*, London, Thames and Hudson, 1980, p. 172.
87 W.H. Parker, *An Historical Geography of Russia*, London, University of London, 1968, pp. 38–9 and 44–5.
88 Paddy Griffith, *The Viking Expansion*, London, Greenhill, 1995, pp. 51–2.
89 H.H. Lamb, *Climate: Present, Past and Future*, 2 vols, London, Methuen, 1977, Vol. 2, Fig. 13.32.
90 Kendrick, *op. cit.*, pp. 160–3.
91 Smyth, *op. cit.*
92 Briffa *et al.*, *op. cit.*, Fig. 2.
93 N.P. Brooks, 'England in the Ninth Century: The Crucible of Defeat', *Transactions of the Royal Historical Society*, fifth series, vol. 29, 1979, pp. 1–20.
94 James B. Johnston, *The Place Names of England*, London, John Murray, 1915, p. 41.
95 Dr Eilert Ekwall in H.C. Darby (ed.), *An Historical Geography of England before 1600*, Cambridge, Cambridge University Press, 1936, Chapter 4.
96 Randsborg, *op. cit.*, pp. 46–8.
97 *Ibid.*, Fig. 10 and p. 48.
98 Logan, *op. cit.*
99 Arie S. Issar, *Impacts of Climate Variations on Water Management and Related Socio-Economic Systems*, Paris, UNESCO, 1995, Fig. 5.
100 Klavs Randsborg, 'Viking Raiders: The Transformation of Scandinavian Society', in Charles L. Redman (ed.), *Medieval Archaeology*, Birmingham, State University of New York, 1989, pp. 23–56.
101 Wilson, *The Vikings and their Origins*, *op. cit.*, p. 46.
102 Irene Scobbie, *Sweden*, London, Ernest Benn, 1972, p. 17.
103 Tomasson, *op. cit.*, p. 414.
104 Kendrick, *op. cit.*, p. 24.
105 Anne Savage (trans.), *The Anglo-Saxon Chronicles*, London, Phoebe Phillips, 1982, p. 107.
106 Dr Alan Binns in Arne Bang-Andersen, Basil Greenhill and Egil Harald Grude (eds), *The North Sea. A Highway of Economic and Cultural Exchange. Its Character and History*, Stavanger, Norwegian University Press, 1985, p. 51.
107 Angela Evans, 'The Clinker-built Boats of the North Sea', in *ibid.*, pp. 63–77.
108 John R. Hale, 'The Viking Longship', *Scientific American*, vol. 278, no. 2, February 1998, pp. 46–53.
109 Lewis, *op. cit.*, pp. 168–71.
110 G.J. Marcus, 'The Mariner's Compass: Its Influence upon Navigation in the Later Middle Ages', *History*, vol. XLI, February–October 1956, pp. 16–24.
111 Kirkby, *op. cit.*, p. 56.

112 Angela Evans, *op. cit.*, hints at 750 or so as far as sails are concerned.
113 Johannes Brondsted (Estrid Bannister-Good, trans.), *The Vikings*, Harmondsworth, Penguin, 1960, p. 25.
114 I. Renberg *et al.*, 'Climate Reflection in Varved Lake Sediments', in Mörner and Karlén (eds), *op. cit.*, pp. 249–56.
115 W.G. Kendrew, *The Climates of the Continents*, Oxford, Oxford University Press, 1937, pp. 253–4.
116 Jacques Le Goff, *Medieval Civilisation, 400–1500*, Dordrecht, D. Reidel, 1984, 249–56.
117 Trevelyan, *op. cit.*, p. 74.
118 J.H. Mackinder, *Britain and the British Seas*, Oxford, Clarendon Press, 1907, pp. 357–8.
119 Owen Lattimore, *Inner Asian Frontiers of China*, Irvington-on-Hudson, Capitol Publishing for American Geographical Society, 1951, p. 45.
120 Zhaodong Feng *et al.*, 'Temporal and Spatial Variations of Climate in China during the Last 10,000 Years', *The Holocene*, vol. 3, no. 2, 1993, pp. 174–80.
121 Jin-Qi Fang, *op. cit.*, p. 509.
122 Co-Ching Chu, 'Climatic Pulsations during Historic Times in China', *Geographical Review*, vol. XVI, no. 2, April 1926, pp. 274–82.
123 Zhaodong Feng *et al.*, *op. cit.*, p. 178.
124 Hammer *et al.*, *op. cit.*, Fig. 1.
125 D. Justin Schove, 'The Sunspot Cycle, 649 BC to AD 2000', *The Journal of Geophysical Research*, vol. 60, no. 2, June 1955, pp. 127–50.
126 Co-Ching Chu, *op. cit.*, Table VI.
127 Jin-Qi Fang, 'Lake Evolution During the Past 3000 Years in China and its Implications for Environmental Change Based on Historical Sources', *Quaternary Research*, vol. 39, no. 2, March 1993, pp. 175–85.
128 Barraclough (ed.), *op. cit.*, p. 127, graph 4.
129 Jin-Qi Fang, *International Journal of Climatology, op. cit.*, Fig. 2e.
130 Jin-Qi Fang, *Quaternary Research*, *op. cit.*, Fig. 5.
131 Albert Kolb (C.A.M. Sym, trans.), *East Asia. Geography of a Cultural Region*, London, Methuen, 1971, p. 41.
132 Jin-Qi Fang and Guo Liu, 'Relationship between Climatic Change and the Nomadic Southwards Migrations in Eastern Asia during Historical Times', *Climatic Change*, vol. 22, no. 2, October 1992, pp. 151–69.
133 Kolb, *op. cit.*, p. 41.
134 Arthur N. Waldron, 'The Problem of the Great Wall of China', *Harvard Journal of Asiatic Studies*, vol. 43, no. 2, December 1983, pp. 642–63.
135 Barraclough, *op. cit.*, p. 126, Map 1.
136 Zhaodong Feng *et al.*, *op. cit.*, p. 177.
137 Kolb, *op. cit.*, p. 363.
138 Roderick Whitfield (ed.), *Treasures from Korea*, London, British Museum, 1984, Chapters 2 and 3.
139 Reid A. Bryson, 'Modelling the NW India monsoon for the last 40,000 years', *Climate Dynamics*, no. 3, 1989, pp. 169–77.
140 William H. Quinn in Henry F. Diaz and Vera Markgraf (eds), *El Niño. Historical and Palaeoclimatic Aspects of the Southern Oscillation*, Cambridge, Cambridge University Press, 1992, Chapter 6, Table 6.6.
141 Luc Kwanten, *A History of Central Asia*, Leicester, Leicester University Press, 1979, p. 7.
142 H.G. Creel, 'The Role of the Horse in Chinese History', *American Historical Review*, vol. LXX, no. 3, April 1965, pp. 647–72.
143 *Kodansha Encyclopedia of Japan* (9 vols), Tokyo, Kodansha, 1983, Vol. 5, p. 303.
144 Edwin O. Reischauer in Rushton Coulborn (ed.), *Feudalism in History*, Hamden, Archon Books, 1965, Chapter III.
145 E. Fukui (ed.), *The Climate of Japan*, Tokyo, Kodansha, 1977, Fig. 13.4.
146 H. Arakawa, 'Climate Change as Revealed by the Data from the Far East', *Weather*, vol. XII, no. 1, January 1957, pp. 46–51.
147 Roger G. Barry and Richard J. Chorley, *Atmosphere, Weather and Climate*, London, Routledge, 1990, p. 195.

148 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 2, p. 431.
149 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, p. 185.
150 W.J. Van Liere, 'Traditional Water Management in the Lower Mekong Basin', *World Archaeology*, vol. 11, no. 3, February 1980, pp. 265–80.
151 Hourani, *op. cit.*, p. 78.
152 Quinn, *op. cit.*, Table 6.7.

6 Towards the optimum

1 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, p. 179.
2 See also Norman J.G. Pounds, *An Historical Geography of Europe, 450 BC to AD 1330*, Cambridge, Cambridge University Press, 1973, p. 15.
3 See Jean M. Grove, *The Little Ice Age*, London, Routledge, 1988, p. 3.
4 B.H. Slicher van Bath, *The Agrarian History of Western Europe,* AD *500–1850*, London, Edward Arnold, 1963, p. 8.
5 Georges Duby (Cynthia Postan, trans.), *Rural Economy and Country Life in the Medieval West*, London, Edward Arnold, 1968, pp. 305–6.
6 Emmanuel Le Roy Ladurie (Barbara Bray, trans.), *Times of Feast, Times of Famine*, London, George Allen and Unwin, 1971, p. 255.
7 W.T. Bell and A.E.J. Ogilvie, 'Weather Compilations as a Source of Data for the Reconstruction of the European Climate during the Medieval Period', *Climatic Change*, vol. 1, no. 4, 1978, pp. 331–48.
8 M.J. Ingram *et al.*, 'Historical Climatology', *Nature*, vol. 276, no. 5686, 23 November 1978, pp. 329–34.
9 Malcolm K. Hughes and Henry F. Diaz, 'Was there a "Medieval Warm Period", and if so, where and when?' *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, pp. 109–42.
10 J.T. Houghton *et al.* (eds), *Climate Change 1995* (2 vols), Cambridge, Cambridge University Press for Intergovernmental Panel on Climate Change, 1996, Fig. 3.4a.
11 H.H. Lamb, *Climate: Present, Past and Future*, London, Methuen, 1977, Vol. 1, Fig. 2.5.
12 Victor Clube and Bill Napier, *The Cosmic Winter*, Oxford, Basil Blackwell, 1990, pp. 112–13.
13 C.U. Hammer *et al.*, 'Greenland Ice Sheet Evidence of Post-glacial Vulcanism and its Climatic Impact', *Nature*, vol. 288, no. 5788, 20 November 1980, pp. 230–5.
14 J.A. Eddy, 'Historical Evidence for the Existence of the Solar Cycle', in O.R. White (ed.), *The Solar Output and its Variations*, Boulder, Associated University Press, 1977, pp. 22–5.
15 J.L. Jirikowic and P.E. Damon, 'The Medieval Solar Activity Maximum', *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, 309–16.
16 *Ibid.*, Fig. 3.
17 *Ibid.*, Fig. 2.
18 Lamb, *Climate: Past, Present and Future*, *op. cit.*, Vol. 1, Part 1, Appendix 1.1, Fig. at p. 474.
19 W. Dansgaard *et al.*, 'Climatic Changes, Norsemen and Modern Man', *Nature*, vol. 255, no. 5503, 1 May 1975, pp. 24–8.
20 A.E.J. Ogilvie, 'The Past Climate and Sea-Ice Record from Iceland, Part 1: Data to AD 1780', *Climatic Change*, vol. 6, no. 2, June 1984, pp. 131–52.
21 *Ibid.*, p. 141.
22 Dansgaard *et al.*, *op. cit.*, Fig. 3.
23 *Ibid.*, p. 26.
24 Wibjörn Karlén, 'Dendrochronology, Mass Balance and Glacier Front Fluctuations in Northern Sweden', in N.-A. Mörner and W. Karlén (eds), *Climate Changes on a Yearly to Millennial Basis*, Dordrecht, D. Reidel, 1984, pp. 263–71.
25 W. Karlén, 'Glacier Fluctuations in Scandinavia during the Last 9000 Years', Fig. 18.3 in L. Starkel, K.J. Gregory and J.B. Thornes (eds), *Temperate Palaeohydrology*, Chichester, John Wiley, 1991, Chapter 18.
26 K.R. Briffa *et al.*, 'A 1400-year Tree-ring Record of Summer Temperatures', *Nature*, vol. 346, no. 6283, 2 August 1990, pp. 434–9.
27 See also Hughes and Diaz, *op. cit.*, Fig. 3.
28 Pounds, *op. cit.*, p. 15.
29 V.N. Adamenko, 'On the Similarity in the Growth of Trees in Northern Scandinavia and

in the Polar Ural Mountains', *Journal of Glaciology*, vol. 4, no. 34, February 1963, pp. 449–51.
30 Hughes and Diaz, *op. cit.*, Fig. 3.
31 Jonathan D. Kahl *et al.*, 'Absence of Evidence for Greenhouse Warming over the Arctic Ocean in the Past 40 Years', *Nature*, vol. 361, no. 6410, 28 January 1993, pp. 335–7.
32 Donald Matthew, *Atlas of Medieval Europe*, Oxford, Equinox, 1983, p. 63.
33 Irene Scobbie, *Sweden*, London, Ernest Benn, 1972, p. 24.
34 Björn Ambrosiani, 'Settlement Expansion – Settlement Contraction: A Question of War, Plague, Ecology or Climate', in Mörner and Karlén (eds), *op. cit.*, pp. 241–7.
35 B. Jones, S. Boudjelas and E.G. Mitchelson-Jacob, 'Topographic Steering of Winds in Vestfjorden, Norway', *Weather*, vol. 52, no. 10, October 1997, pp. 304–11.
36 Jean M. Grove and Roy Switsur, 'Glacial Geological Evidence for the Medieval Warm Period', *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, pp. 143–69.
37 Table 1 in C.J.E. Schuurmans, 'Climate of the Last 1000 Years', in A. Berger (ed.), *Climatic Variations and Variability: Facts and Theories*, Dordrecht, D. Reidel, 1981, pp. 245–58.
38 Emmanuel Le Roy Ladurie in Maurice Aymard and Harbans Mukhia (eds), *French Studies in History*, London, Sangam Books, 1988, Vol. 1, p. 212.
39 Le Roy Ladurie, *op. cit.*, pp. 255–6.
40 Hubert H. Lamb, 'Climate and History in Northern Europe and Elsewhere', in Mörner and Karlén (eds), *op. cit.*, pp. 225–40, Figs. 1 and 2.
41 Lamb, *Climate, History and the Modern World*, *op. cit.*, Fig. 31.
42 H.H. Lamb, *The Changing Climate*, London, Methuen, 1966, p. 105.
43 *Ibid.*, Appendix 2, Table I.
44 David Hill, *An Atlas of Anglo-Saxon England*, Oxford, Basil Blackwell, 1990, p. 11.
45 H.E. Hallam, 'The Climate of Eastern England, 1250–1350', *Agricultural History Review*, vol. 32, 1984, pp. 124–32.
46 J.Z. Titow, 'Evidence of Weather in the Account Rolls of the Bishopric of Winchester, 1209–1350', *Economic History Review*, vol. XII, no. 3, 1960, pp. 360–407.
47 Robert S. Gottfried, 'Climatology', in Joseph R. Strayer (ed.), *Dictionary of the Middle Ages* (13 vols), New York, Charles Scribner's, 1983, vol. 3, p. 454.
48 Le Roy Ladurie, *op. cit.*, pp. 105–7 and 254–64.
49 L. Reynaud, 'Recent Fluctuations of Alpine Glaciers and their Natural Causes, 1880–1980', in A. Street-Perrott, M. Beran and R. Ratcliff (eds), *Variations in the Global Water Balance*, Dordrecht, Reidel, 1988, pp. 195–202.
50 Grove and Switsur, *op. cit.*, p. 158.
51 Grzegorz Skrzypek and Mariusz O. Jędrysek, 'Climatic Variation in the Last Millennium in Poland: δ^{13}C Peat Profiles', in Barbara Obrębska-Starkel, *Reconstructions of Climate and its Modelling*, Kraków, Jagiellonian University, 2000, pp. 130–6.
52 P. Mick Kelly, Phil Jones and Keith Briffa in Mike Hulme and Elaine Barrow (eds), *Climates of the British Isles*, London, Routledge, 1997, Chapter 8.
53 Julian Mayes, 'United Kingdom Summer Weather over 50 Years – Continuity or Change?', *Weather*, vol. 53, no. 1, January 1998, pp. 2–11.
54 G.H. Hughes, 'Weather in Northern Scotland in the Blocked Summers, 1967–82', *Weather*, vol. 39, no. 5, May 1984, pp. 136–9.
55 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 1, p. 92.
56 George Kimble, *The Weather*, Harmondsworth, Penguin, 1951, p. 115.
57 Zhang De'er, 'Evidence for the Existence of the Medieval Warm Period in China', *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, pp. 289–97.
58 H. Arakawa, 'Climate Change as Revealed by the Data from the Far East', *Weather*, vol. 12, no. 1, January 1957, pp. 46–52.
59 Eiichiro Fukui in E. Fukui (ed.), *The Climate of Japan. Developments in Atmospheric Science 8*, Tokyo, Kodansha, 1977, Chapter 13, Fig. 13.3.
60 Barbara M. Gray, 'Japanese and European Winter Temperatures', *Weather*, vol. 30, no. 11, November 1975, pp. 359–68.
61 Midori Nishi, 'Regional Variations in Japanese Farmhouses', *Annals of the Association of American Geographers*, vol. 57, no. 2, June 1967, pp. 239–66.

62 John Bartholomew, *The Advanced Atlas of Modern Geography*, Edinburgh, Oliver and Boyd, 1967, p. 4.
63 Andrew Carden in H.R. Hitchcock *et al.*, *World Architecture*, London, Paul Hamlyn, 1963, p. 113.
64 *Kodansha Encyclopedia of Japan* (9 vols), Tokyo, Kodansha, 1983, Vol. 1, p. 81.
65 Carden, *op. cit.*, pp. 114–21.
66 I. Nabuo in *Kodansha Enyclopedia of Japan* (9 vols), Vol. 7, 1983, pp. 110–11.
67 J.E. Spencer, 'The Houses of the Chinese', *The Geographical Review*, vol. XXXVII, no. 2, April 1947, pp. 254–73.
68 Ping-Ti Ho, 'Early Ripening Rice in Chinese History', *Economic History Review*, vol. IX, no. 2, 1956, pp. 200–18.
69 William H. McNeill, *The Pursuit of Power*, Oxford, Basil Blackwell, 1983, p. 50.
70 Sally and David Dugan, *The Day the World Took Off*, Basingstoke, Macmillan, 2000, pp. 128–33.
71 Adriaan Verhulst, 'Medieval Socio-Economic Historiography in Western Europe: Towards an Integrated Approach', *Journal of Medieval History*, vol. 23, no. 1, 1997, pp. 89–101.
72 Harald Hveburg (Pat Shaw Iversen, trans.), *Of Gods and Giants*, Oslo, Johan Grundt Tanum Forlag, 1961, pp. 82–5.
73 D.J.A. Matthew, *The Norman Conquest*, London, B.T. Batsford, 1966, Chapter 1.
74 Frank Barlow, *The Norman Conquest and Beyond*, London, Hambledon Press, 1983, pp. 154–7.
75 George Morey, *The North Sea*, London, Frederick Muller, 1968, Chapter 2.
76 P.H. Sawyer, 'The Wealth of England in the Eleventh Century', *Transactions of the Royal Historical Society*, vol. 15, 1965, pp. 145–64.
77 Elisabeth Van Houts, 'The Trauma of 1066', *History Today*, vol. 46, no. 10, October 1996, pp. 9–15.
78 Michael Lynch, *Scotland. A New History*, London, Century, 1991, pp. 6–7.
79 H.C. Darby in H.C. Darby and I.S. Maxwell (eds), *The Domesday Geography of Northern England*, Cambridge, Cambridge University Press, 1962, Chapter VIII.
80 Anne Savage (trans.), *The Anglo-Saxon Chronicles*, London, William Heinemann, 1982, pp. 198–221.
81 D.J. Schove, 'Dark Age Tree Ring Dates, AD 490–850', *Medieval Archaeology*, vol. 73, 1979, pp. 219–23, Appendix 3.
82 Barraclough (ed.), *op. cit.*, p. 121, Map 5.
83 See the author's 'The Weather for Overlord', *Journal of Meteorology*, vol. 19, no. 189, May/June 1994, pp. 141–9.
84 Keith Briffa *et al.*, *op. cit.*, Fig 2a.
85 Stephen Morillo (ed.), *The Battle of Hastings, Sources and Interpretations*, Woodbridge, Boydell Press, 1996, Chapters 1, 6 and 11.
86 R.H.C. Davis, 'The Carmen de Hastingae Proelio: A Discussion', *English Historical Review*, vol. 93, no. 367, 1978, pp. 241–61.
87 Norman Davies, *God's Playground. A History of Poland*, Oxford, Clarendon Press, 1981, Vol. I, p. 49.
88 Bronislaw Geremek (Jan Aleksandrowicz *et al.*, trans.), *The Common Roots of Europe*, Cambridge, Polity Press, 1996, Chapter 4.
89 Susan Reynolds in Michael Bentley (ed.), *Companion to Historiography*, London, Routledge, 1997, Chapter 7.
90 Jacques Pirenne (Lovett Edwards, trans.), *The Tides of History*, London, George Allen and Unwin, 1963, Vol. II, Book III, p. 200.
91 Elena Lourie, 'A Society Organised for War, Medieval Spain', *Past and Present*, no. 35, December 1966, pp. 54–76.
92 Hugh Kennedy, *Muslim Spain and Portugal*, London, Longman, 1996, p. 308.
93 Donald Matthew, *Atlas of Medieval Europe*, Oxford, Equinox, 1983, pp. 78–9.
94 *Ibid.*
95 Gino Luzzatto (Philip Jones, trans.), *An Economic History of Italy. From the Fall of the Roman Empire to the Beginning of the Sixteenth Century*, London, Routledge and Kegan Paul, 1961, p. 48.

96 Edward Coleman, 'Italy's First Northern League?' *History Today*, vol. 46, no. 10, October 1996, pp. 6–8.
97 Luzzatto, *op. cit.*, p. 56.
98 Heinrich Fichtenau (Patrick J. Geary, trans.), *Living in the Tenth Century*, Chicago, University of Chicago Press, 1989, p. xvi.
99 Giuliano Procacci (Anthony Paul, trans.), *The History of the Italian People*, London, Weidenfeld and Nicolson, 1970, p. 9.
100 Fichtenau, *op. cit.*, p. 338.
101 *Climate: Present, Past and Future*, *op. cit.*, Vol. 2, Fig. 17.2.
102 Walter Dragoni in Arie Issar and Neville Brown (eds), *Water, Environment and Society in Times of Climate Change*, Dordrecht, Kluwer, 1998, Chapter 11.
103 Françoise Serre-Bachet, 'Middle Ages Temperature Reconstructions in Europe, A Focus on Northeastern Italy', *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, pp. 213–24.
104 David Herlihy, 'The Agrarian Revolution in Southern France and Italy', *Speculum*, vol. XXXIII, no. 1, January 1958, pp. 23–41 and especially Graph 1.
105 James Westfall Thompson, *An Economic and Social History of the Middle Ages* (2 vols), New York, Frederick Ungar, 1959, Vol. 1, p. 388.
106 'Pilgrimage to Compostela', in Matthew, *Atlas of Medieval Europe*, *op. cit.*, pp. 102–5.
107 Henri Focillon, *The Year 1000*, New York, Harper and Row, 1971, p. 60.
108 Norman Cohn, *The Pursuit of the Millennium*, London, Paladin, 1972, p. 282.
109 Fichtenau, *op. cit.*, pp. 385–7 and Epilogue.
110 Norman Hammond, 'The Emergence of Maya Civilisation', *Scientific American*, vol. 255, no. 2, August 1986, pp. 98–107.
111 E.W. Webster (ed.), *Meteorologica*, Oxford, Clarendon Press, 1931, Book 1, Section 7.
112 G.G. Coulton, *The Medieval Scene*, Cambridge, Cambridge University Press, 1965, p. 103.
113 Kenneth Clark, *Civilisation*, London, BBC and John Murray, 1969, p. 33.
114 André Gunder Frank and Barry K. Gills (eds), 'World System Economic Cycles and Hegemonical Shift to Europe, 100 BC to 1500 AD', *Journal of European Economic History*, vol. 22, no. 1, Spring 1993, pp. 155–83.
115 André Gunder Frank and Barry K. Gills (eds), *The World System. Five Hundred Years or Five Thousand*, London, Routledge, 1993, Chapter 5.
116 Jacques Le Goff, *Medieval Civilisation, 400–1500*, Oxford, Basil Blackwell, 1988, pp. 194–6.
117 S.R. Jones, 'Devaluation and the Balance of Payments in Eleventh-century England: An Exercise in Dark Age Economics', *Economic History Review*, vol. XLIV, no. 4, November 1991, pp. 594–607, Table 2.
118 McNeill, *op. cit.*, p. 71.
119 Henry L. Misbach, 'The Balanced Economic Growth of Carolingian Europe: Suggestions for a New Interpretation', *Journal of Interdisciplinary History*, vol. III, no. 2, Autumn 1972, pp. 261–73.
120 Herlihy, *op. cit.*, p. 31.
121 Robert S. Gottfried in Joseph R. Strayer (Editor-in-Chief), *Dictionary of the Middle Ages*, *op. cit.*, Vol. 5, pp. 3–9.
122 Barraclough (ed.), *op. cit.*, p. 121, Map 3.
123 Timothy Reuter, *Germany in the Early Middle Ages, c. 800–1056*, London, Longman, 1991, p. 98.
124 Barraclough (ed.), *op. cit.*, p. 134.
125 Michael W. Dols in *A Dictionary of the Middle Ages*, *op. cit.*, Vol. 5, pp. 1–3.
126 Andrew M. Watson, *Agricultural Innovation in the Early Islamic World*, Cambridge, Cambridge University Press, 1983, p. 141.
127 J.D. Fage, *A History of Africa*, London, Hutchinson, 1978, p. 150.
128 Fekri A. Hassan, 'The Dynamics of a Riverine Civilisation: A Geoarchaeological Perspective on the Nile Valley, Egypt', *World Archaeology*, vol. 29, no. 1, June 1997, pp. 51–74, Table 1 and Fig. 3.
129 Josiah C. Russell, *Medieval Demography*, New York, AMS, 1987, Chapter VI, Fig. 1.
130 William H. Quinn in Henry F. Diaz and Vera Markgraf (eds), *El Niño. Historical and Palaeoclimatic Aspects of the Southern Oscillation*, Cambridge, Cambridge University Press, 1992, Table 6.6.

131 'The Dollar of the Middle Ages', in Robert S. Lopez, *Byzantium and the World Around It: Economic and Institutional Relations*, London, Variorum Reprints, 1978, pp. 209–34.
132 Hughes and Diaz, *op. cit.*
133 Alastair G. Dawson, *Ice Age Earth*, London, Routledge, 1992, p. 172 and Fig. 9.5.
134 H.H. Lamb, *Climate: Past, Present and Future*, *op. cit.*, Vol. 2, Fig. 13.32.
135 Henri Bresc and Pierre Guichard in Robert Fossier (ed.) (Stuart Airlie and Robyn Marsack, trans.), *The Cambridge Illustrated History of the Middle Ages*, Cambridge, Cambridge University Press (2 vols to date), 1997, Vol. II, Chapter 4, pp. 199–202.
136 *Climate: Past, Present and Future*, *op. cit.*, Vol. 2, p. 439.
137 Lamb, *Climate, History and the Modern World*, *op. cit.*, pp. 207–8.
138 Claudine Till and Joël Guiot, 'Reconstruction of Precipitation in Morocco since 1100 AD. Based on *Cedrus atlantica* Tree-ring Widths', *Quaternary Research*, vol. 33, no. 3, May 1990, pp. 337–51.
139 Bresc and Guichard, *op. cit.*
140 John Gladstone 'Mesoclimate', in Jancis Robinson (ed.), *The Oxford Companion to Wine*, Oxford, Oxford University Press, 1994, p. 618.
141 W. Gordon East, *An Historical Geography of Europe*, London, Methuen, 1962, p. 290.
142 Catherine Delano Smith, *Western Mediterranean Europe. A Historical Geography of Italy, Spain and Southern France since the Neolithic*, London, Academic Press, 1979, p. 198.
143 Lynn White in Carlo M. Cipolla (ed.), *The Middle Ages*, Fontana Economic History of Europe, Vol. 1, Hassocks, Harvester Press, 1976, Chapter 4.
144 M.M. Postan (ed.), *The Cambridge Economic History of Europe* (6 vols), Cambridge, Cambridge University Press, 1966, Vol. 1, *The Agrarian Life of the Middle Ages*, p. 342.
145 Delano Smith, *op. cit.*, pp. 12–16.
146 For example, Brian W. Blouet, 'The Impact of Armed Conflict on the Rural Settlement Pattern of Malta (AD 1400 to 1800)', *Transactions of the Institute of British Geographers*, vol. 3, no. 3, 1978, pp. 367–80.
147 Carlo M. Cipolla, *Before the Industrial Revolution: European Society and Economy, 1000–1700*, London, Methuen, 1976, p. 144.
148 Paul R. Hyams, 'The End of Feudalism', *Journal of Interdisciplinary History*, vol. XXVII, no. 4, Spring 1997, pp. 655–62.
149 Klavs Randsborg, 'Viking Raiders: The Transformation of Scandinavian Society', in Charles L. Redman (ed.), *Medieval Archaeology*, Binghamton, State University of New York, 1989, pp. 23–39.
150 U. Göranson, 'Land Use and Settlement Patterns in the Mälar Area of Sweden before the Foundation of Villages', in Alan R.H. Baker and Mark Billinge (eds), *Period and Place*, Cambridge, Cambridge University Press, 1982, pp. 155–63.
151 Fossier (ed.), *op. cit.*, p. 258.
152 Philippe Contamine, *La Guerre au moyen âge*, Paris, Presses Universitaires de France, 1980, Chapter 2.
153 Davies, *op. cit.*, pp. 50–1.
154 Pounds, *op. cit.*, pp. 244–5.
155 Piotr Górecki, *Economy, Society and Lordship in Medieval Poland, 1100–1250*, New York, Holmes and Meier, 1992, Chapter 5.
156 *Ibid.*, pp. 288–9.
157 David Nicholas, 'Of Poverty and Primacy: Demand, Liquidity and the Flemish Economic Miracle, 1050–1200', *American Historical Review*, vol. 96, no. 1, February 1991, pp. 17–41.
158 B.J. Graham in B.J. Graham and L.J. Proudfoot (eds), *An Historical Geography of Ireland*, London, Academic Press, 1993, p. 46.
159 Karl Gunnar Persson, 'Was Feudalism Inevitable?' *Scandinavian Economic History Review*, vol. XXXIX, no. 1, 1991, pp. 68–76.
160 Joseph J. Strayer, *On the Medieval Origins of the Modern State*, Princeton, Princeton University Press, 1980, pp. 36–41.
161 Jean-Pierre Poly in Fossier (ed.), *op. cit.*, pp. 70–9.
162 Ralph E. Turner, 'Economic Discontent in Medieval Western Europe', *Journal of Economic History*, Vol. VII, 1948, pp. 85–100.

163 Loren C. Mackinney, 'The People and Public Opinion in the 11th-century Peace Movement', *Speculum*, V, 1930, pp. 181–206.
164 Dagmar Riaîn-Raedel, 'The Irish Medieval Pilgrimage to Santiago de Compostela', *History Today*, vol. 6, no. 3, Autumn 1998, pp. 17–21.
165 Jonathan Riley-Smith, *The First Crusade and the Idea of Crusading*, London, The Athlone Press, 1986, pp. 33–4.
166 Rupert Willoughby, 'The Shock of the New', *History Today*, vol. 49, no. 8, August 1999, pp. 37–42.
167 Steven Runciman, *A History of the Crusades* (3 vols), Cambridge, Cambridge University Press, 1957, Vol. 1, pp. 107–12.
168 A.C. Krey, 'Urban's Crusade – Success or Failure?' *American Historical Review*, vol. LIII, no. 2, January 1948, pp. 235–50.
169 Richard Mayne, '1. East and West in 1054', *The Cambridge Historical Journal*, vol. XI, no. 2, 1954, pp. 133–48.
170 Norman Cohn, 'The Appeal of the Crusade to the Poor', reprinted in James A. Brundage (ed.), *The Crusades. Motives and Achievements*, Lexington, D.C. Heath, 1964, pp. 34–41.
171 Anna Sapir Abulafia, *Christians and Jews in the Twelfth Century Renaissance*, London, Routledge, 1995, pp. 128–33 and 90–1.
172 Edward Gibbon, 'Motives of the Crusaders', in Brundage (ed.), *op. cit.*, pp. 4–6.
173 Poly, *op. cit.*, Map 3.
174 Jonathan Riley-Smith, 'Religious Warriors: Reinterpreting the Crusades', *The Economist*, vol. 337, no. 7946, 23 December 1995, pp. 37–41.
175 Norman J.G. Pounds and Charles C. Roome, 'Population Density in 15th-century France and the Low Countries', *Annals of the Association of American Geographers*, vol. 61, no. 1, March 1971, pp. 117–30.
176 Houghton *et al.* (eds), *op. cit.*
177 T.M.L. Wigley in L. Jeftic *et al.* (eds), *Climatic Change and the Mediterranean*, London, Edward Arnold, 1992, Chapter 1.
178 G. Sestini in *ibid.*, Chapter 12.
179 *Ibid.*, p. 481.
180 Kevin E. Trenbeth (ed.), *Climate System Modelling*, Cambridge, Cambridge University Press, 1992, pp. 139 and 406.

7 The Near East in crisis

1 Jacques Pirenne (Lovett Edwards, trans.), *The Tides of History*, London, George Allen and Unwin, 1963, Vol. II, p. 81.
2 Deno J. Geanakoplos, *Byzantine East and Latin West: Two Worlds of Christendom in the Middle Ages*, Oxford, Basil Blackwell, 1966, Part 1, Chapter 1.
3 Robert Sabatino Lopez, 'Silk Industry in the Byzantine Empire', *Speculum*, vol. XX, no. 1, January 1945, pp. 1–42.
4 Robert Browning, 'Byzantine Scholarship', *Past and Present*, no. 28, July 1964, pp. 3–20.
5 D.V. Ainalov (Elizabeth and Serge Sobolevitch, trans.), *The Hellenistic Origins of Byzantine Art*, New Brunswick, Rutgers University Press, 1961. A magisterial study commissioned by the Imperial Russian Archaeological Society in 1900–1.
6 Steven Runciman, *Byzantine Civilisation*, London, Edward Arnold, 1933, pp. 270–1 and 150–1.
7 W.G. Kendrew, *Climates of the Continents*, Oxford, Oxford University Press, 1947, p. 176.
8 Appendix, 'The Problem of Erosion', in Michael F. Hendy, *Studies in the Byzantine Monetary Economy, c. 300–1450*, Cambridge, Cambridge University Press, 1985, pp. 58–67.
9 Rosemary Morris, 'The Powerful and the Poor in Tenth-century Byzantium: Law and Reality', *Past and Present*, no. 73, November 1976, pp. 3–27.
10 C.U. Hammer *et al.*, 'Greenland Ice Sheet Evidence of Post-glacial Volcanism and its Climatic Impact', *Nature*, vol. 288, no. 5788, 20 November 1980, pp. 230–5.
11 Alexander D. Kadzhan (Editor-in-Chief), *The Oxford Dictionary of Byzantium*, Oxford, Oxford University Press, 1991, Vol. 2, p. 778.

12 Robert Browning, 'Enlightenment and Repression in Byzantium in the Eleventh and Twelfth Centuries', *Past and Present*, no. 69, November 1975, pp. 3–23.
13 Hendy, *op. cit.*, p. 68.
14 Alan Harvey, *Economic Expansion in the Byzantine Empire, 900 to 1200*, Cambridge, Cambridge University Press, 1989, pp. 12 and 47.
15 G. Brett, 'Byzantine Water Mill', *Antiquity*, vol. XIII, no. 51, September 1939, pp. 354–6.
16 Alain Ducellier in Robert Fossier (ed.), *The Cambridge Illustrated History of the Middle Ages* (3 vols), Cambridge, Cambridge University Press, 1997, Vol. II, Chapter 5, pp. 211, 216–17 and 226–7.
17 *Ibid.*, p. 214.
18 Charles Diehl (Naomi Walford, trans.), *Byzantium, Greatness and Decline*, New Brunswick, Rutgers University Press, 1957, p. 92.
19 Peter Charanis, 'Economic Factors in the Decline of the Byzantine Empire', *Journal of Economic History*, vol. XIII, no. 1, Winter 1953, pp. 412–24.
20 Steven Runciman in M. Postan and E.E. Rich (eds.), *The Cambridge Economic History of Europe*, Vol. II, *Trade and Industry in the Middle Ages*, Cambridge, Cambridge University Press, 1952, pp. 91–2.
21 Harvey, *op. cit.*, pp. 20–1.
22 'The Dollar of the Middle Ages' in Robert S. Lopez, *Byzantium and the World Around It*, London, Variorum Reprints, London, 1978, pp. 419–34.
23 Ducellier, *op. cit.*, Chapter 5.
24 Nikolaj Gumilëv, 'Where Was She, the Country of Khazaria?' *Nedelja*, vol. 24, 7–13 July 1964. Translated by Vassil Karloukovski of the University of East Anglia.
25 A.M. Khazanov (Julia Crookenden, trans.), *Nomads and the Outside World*, Cambridge, Cambridge University Press, 1983, p. 112.
26 X. de Planhol in W.B. Fisher (ed.), *The Cambridge History of Iran* (7 vols), Cambridge, Cambridge University Press, 1968, Vol. 1, Chapter 13.
27 Ellsworth Huntington in Raphael Pumpelly, *Explorations in Turkmenistan*, Washington, Carnegie Institution of Washington, Report 26, April 1905, pp. 303–15.
28 David Dilks, *Curzon in India* (2 vols), London, Rupert Hart-Davis, 1970, Vol. 1, p. 143.
29 Extract from the Viceroy's Budget Speech, 30 March 1904, in Sir Thomas Raleigh (ed.), *Lord Curzon in India, Being a Selection of his Speeches as Viceroy and Governor-General of India, 1898–1905*, London, Macmillan, 1906, pp. 408–9.
30 Dilks, *op.cit.*, Vol. 1, p. 144, and Vol. 2, p. 53.
31 Kendrew, *op. cit.*, p. 173.
32 M.H. Ganji in Fisher (ed.), *op. cit.*, Chapter 5.
33 M. Bottomley *et al.*, *Global Ocean Surface Temperature Atlas*, Bracknell and Cambridge, Mass., Meteorological Office and MIT, March 1990, Plates 12, 1 and 2.
34 *Ibid.*, Plate 298.
35 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, Fig. 45.
36 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1972, Vol. 2, Figs 17.8 and 17.9.
37 Hendrik J. Bruins, *Desert Environment and Agriculture in the Central Negev and Kadesh-Barnea during Historical Times*, Nijkerk, The Midbar Foundation, 1986, pp. 190–3.
38 Amos Frumkin *et al.*, 'The Holocene Climatic Record of the Salt-caves of Mount Sedom, Israel', *The Holocene*, vol. 1, no. 3 (1991), pp. 191–200.
39 Arie S. Issar, *The Impact of Climate Variations on Water Management Systems*, Sede Boker, The Jacob Blaustein Institute, 1992, p. 18.
40 Arie S. Issar, *Impacts of Climate Variations on Water Management and Related Socio-economic Systems*, Paris, UNESCO International Hydrological Programme, 1995, pp. 69–70.
41 F. Serre-Bachet and J. Guiot, 'Summer Temperature Changes from Tree Rings in the Mediterranean during the Last 800 Years', in W.H. Berger and L.D. Labeyrie (eds), *Abrupt Climate Change*, Dordrecht, Reidel and NATO, 1987, pp. 89–97.
42 Karl A. Wittfogel, *Oriental Despotism*, New Haven, Yale University Press, 1957, p. 53 with footnote b.
43 Issar, *op. cit.*, *The Impact of Variations on Water Management Systems*, Fig. 5.

44 I.G. Simmonds, *Environmental History. A Concise Introduction*, Oxford, Blackwell, 1993, p. 13.
45 Fred Pearce, *The Dammed*, London, The Bodley Head, 1992, Chapter 1.
46 Thorkild Jacobsen and Robert M. Adams, 'Salt and Silt in Ancient Mesopotamian Agriculture', *Science*, vol. 128, no. 3334, 21 November 1958, pp. 1251–8.
47 E. Ashtor, *A Social and Economic History of the Near East in the Middle Ages*, London, Collins, 1976, pp. 217–20.
48 Andrew M. Watson, *Agricultural Innovation in the Early Islamic World. The Diffusion of Crops and Farming Techniques, 700–1100*, London, Cambridge University Press, 1983, p. 133.
49 Sir John Glubb, *A Short History of the Arab Peoples*, London, Hodder and Stoughton, 1969, p. 119.
50 *The Cambridge Illustrated History of the Middle Ages*, *op. cit*., Vol. 2, p. 164.
51 Pirenne, *op. cit*., Vol. II, p. 107.
52 Glubb, *op. cit*., Chapters III and IV.
53 Fekri A. Hassan, 'The Dynamics of a Riverine Civilisation: A Geoarchaeological Perspective on the Nile Valley, Egypt', *World Archaeology*, vol. 29, no. 1, June 1997, pp. 51–74.
54 Michael W. Dols, 'Famine in the Islamic World', in Joseph R. Strayer (Editor-in-Chief), *Dictionary of the Middle Ages*, New York, Charles Scribner's, 1985, Vol. 5, pp. 1–3.
55 Josiah C. Russell, *Medieval Demography*, New York, AMS, 1987, p. 92.
56 J.R.S. Phillips, *The Medieval Expansion of Europe*, Oxford, Oxford University Press, 1988, Chapter 3.
57 John H. Pryor, *Geography, Technology and War. Studies in the Maritime History of the Mediterranean, 649–1571*, Cambridge, Cambridge University Press, 1992, pp. 105–9.
58 Robert Irwin, 'Muslim Responses to the Crusades', *History Today*, vol. 47, no. 4, April 1997, pp. 43–9.
59 Malcolm Cameron Lyons and D.E.P. Jackson, *Saladin*, Cambridge, Cambridge University Press, 1982, pp. 368–9.
60 C.J. Tyerman, 'Were there any Crusades in the Twelfth Century?' *English Historical Review*, vol. CX, no. 437, June 1995, pp. 553–77.
61 Norman Cohn, 'The Appeal of the Crusade to the Poor', in James A. Brundage (ed.), *The Crusades, Motives and Achievements*, Lexington, D.C. Heath, 1964, pp. 34–41.
62 Jonathan Riley-Smith, *The First Crusade and the Idea of Crusading*, London, Athlone Press, 1993, Chapter 3.
63 Paul Johnson, *A History of Christianity*, Harmondsworth, Penguin, 1980, p. 247.
64 Bryan Perrett, *Desert Warfare*, London, Patrick Stephens, 1988, pp. 14–15.
65 Lyons and Jackson, *op. cit*., Chapter 22.
66 George F. Bass, 'Underwater Archaeology and Medieval Mediterranean Ships', in Charles R. Redman (ed.), *Medieval Archaeology*, Binghamton, State University of New York, 1989, pp. 139–54.
67 Pryor, *op. cit*., Chapter 1.
68 Riley-Smith, *op. cit*., pp. 63–5.
69 Marc Bloch (L.A. Manyon, trans.), *Feudal Society*, London, Routledge and Kegan Paul, 1961, p. 4.
70 Steven Runciman, *A History of the Crusades* (3 vols), Cambridge, Cambridge University Press, 1955, Vol. III, p. 469.
71 Noted by Carole Hillenbrand in Jonathan Phillips (ed.), *The First Crusade. Origins and Impact*, Manchester, Manchester University Press, 1997, Chapter 7.
72 Benjamin Z. Kedar in James M. Powell (ed.), *Muslims under Latin Rule, 1100–1300*, Princeton, Princeton University Press, 1990, Chapter 4.
73 George Adam Smith, *The Historical Geography of the Holy Land*, London, Hodder and Stoughton, 1894.
74 Y. Ben-Arieh, 'Historical Geography in Israel: Retrospect and Prospect', in Alan R.H. Baker and Mark Billinge (eds), *Period and Place*, Cambridge, Cambridge University Press, 1982, pp. 3–9.
75 Stewart Perowne, *The Life and Times of Herod the Great*, London, Hodder and Stoughton, 1956, Chapters XVIII and XIX.

76 Joshua Prawer in Harry A Miskimin *et al.* (eds), *The Medieval City*, New Haven, Yale University Press, 1977, Chapter 10.
77 Watson, *op. cit.*, Chapter 25.
78 Runciman, *A History of the Crusades*, *op. cit.*, 1957, Vol. I, p. 51.
79 John Kenneth Galbraith, *The Age of Uncertainty*, London, British Broadcasting Corporation and André Deutsch, 1977, p. 116.
80 Michael F. Hendy, *The Economy, Fiscal Administration and Coinage of Byzantium*, Northampton, Variorum Reprints, 1989, Section 3, p. 48.
81 Runciman, *Byzantine Civilisation*, *op. cit.*, p. 55.
82 William H. Quinn in Henry F. Diaz and Vera Markgraf (eds), *El Niño. Historical and Palaeoclimatic Aspects of the Southern Oscillation*, Cambridge, Cambridge University Press, 1992, Chapter 6.

8 How savage a culmination?

1 C.E.P. Brooks, *Climate Through the Ages*, London, Ernest Benn, 1926, Table 22.
2 *Ibid.*, p. 344.
3 W.T. Bell and A.E.J. Ogilvie, 'Weather Compilations as a Source of Data for the Reconstruction of European Climate during the Medieval Period', *Climatic Change*, vol. 1, no. 4, 1978, pp. 331–48.
4 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1977, Vol. 2, p. 425.
5 *Ibid.*, Table 13.3.
6 H.H. Lamb, *The Changing Scenes of Life*, East Harling, Taverner Publications, 1997.
7 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, Fig. 70.
8 H.E. Hallam, 'The Population Density in Medieval Fenland', *Economic History Review*, 2nd Series, vol. XIV, no. 1, 1961, pp. 71–8.
9 J.A. Van Houtte, *An Economic History of the Low Countries, 800–1800*, London, Weidenfeld and Nicolson, 1977, p. 62.
10 C.E. Britton, Geophysical Memoirs No. 70, *A Meteorological Chronology to AD 1450*, London, HMSO for Meteorological Office, 1937, pp. 77–87.
11 K.R. Briffa *et al.*, 'A 1400-year Tree-ring Record of Summer Temperatures in Fenno-Scandinavia', *Nature*, vol. 346, no. 6283, 2 August 1990, pp. 434–9.
12 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 2, Table 13.3.
13 *Ibid.*
14 J.H. Brazell, Meteorological Office 783, *London Weather*, London, Her Majesty's Stationery Office, 1968, Chapter 1.
15 H. Pirenne, 'The Place of the Netherlands in the Economic History of Medieval Europe', *Economic History Review*, vol. II, no. 1, January 1929, pp. 20–40.
16 B.H. Slicher van Bath (Olive Ordish, trans.), *The Agrarian History of Western Europe, AD 500 to 1850*, London, Edward Arnold, 1963, p. 161.
17 D.J. Schove, *Medieval Archaeology*, vol. 73, 1979, pp. 222–3.
18 C.J.E. Schuurmans, 'Climate of the Last 1000 Years', in A. Berger (ed.), *Climate Variations and Variability: Facts and Theories*, Dordrecht, D. Reidel, 1981, pp. 245–58, Table 2.
19 Bell and Ogilvie, *op. cit.*
20 David Nicholas, *Medieval Flanders*, London, Longman, 1992, pp. 98 and 124–8.
21 Van Houtte, *op. cit.*, pp. 5 and 72–3.
22 Henri Pirenne (I.E. Clegg, trans.), *Economic and Social History of Medieval Europe*, London, Routledge and Kegan Paul, 1936, Chapter VII, Part 1.
23 Briffa *et al., op.cit*, Fig. 2a.
24 Britton, *op. cit.*, pp. 122–4.
25 H.E. Hallam (ed.), *The Agrarian History of England and Wales*, Cambridge, Cambridge University Press, 1988, Vol. II, 1042–1350, p. 505.
26 R.A.L. Smith, 'Marsh Embankment and Sea Defence in Medieval Kent', *Economic History Review*, vol. 10, 1940, pp. 29–37.
27 Pierre Alexandre, *Le Climat en Europe au moyen âge*, Paris, École des Hautes Études en Sciences Sociales, 1987, Table des Sigles du Catalogue, pp. 371–424.

28 *Ibid*., Fig. 5, p. 769.
29 Ian Shennan, Chapter 4, 'Holocene Sea-level Changes in the North Sea Region', in Michael J. Tooley and Ian Shennan (eds), *Sea Level Changes*, Oxford, Basil Blackwell, 1987, Table 4.4.
30 Charles Green, 'East Anglian Coast-line Levels since Roman Times', *Antiquity*, vol. XXXV, no. 137, March 1961, pp. 21–8.
31 H.A.P. Jensen, 'Tidal Inundations, Past and Present, Part 1', *Weather*, vol. VIII, no. 3, March 1953, pp. 85–9.
32 J.T. Houghton *et al.* (eds), *Climate Change 1995*, Cambridge, Cambridge University Press, 1996, Technical Summary, Figs 16, 18.
33 Lamb, *Climate, History and the Modern World, op. cit.*, Figs 52 and 53.
34 M. Caputo and L. Pieri, 'Eustatic Sea Variation in the Last 2000 Years in the Mediterranean', *Journal of Geophysical Research*, vol. 81, no. 33, 20 November 1976, pp. 5787–90.
35 Dr L.P. Louwe Kooijmans, 'Archaeology and Coastal Change in the Netherlands', in F.H. Thompson (ed.), *Archaeology and Coastal Change*, London, Society of Antiquaries, 1980, pp. 106–33, Fig. 50.
36 H.C. Darby, *The Draining of the Fens*, Cambridge, Cambridge University Press, 1956, p. 104.
37 David Nicholas, 'Of Poverty and Primacy: Demand, Liquidity, and the Flemish Economic Miracle, 1050–1200', *American Historical Review*, vol. 96, no. 1, February 1991, pp. 17–41.
38 S.J. Fockema Andreae, 'Embanking and Drainage Authorities in the Netherlands during the Middle Ages', *Speculum*, vol. XXVII, no. 2, April 1952, pp. 158–67.
39 Van Houtte, *op. cit.*, p. 7.
40 J.A. Van Houtte, 'The Rise and Decline of the Market of Bruges', *Economic History Review*, vol. XIX, no. 1, 1966, pp. 29–47.
41 William H. Tebake, *Medieval Frontier, Culture and Ecology in Rijnland*, College Station, Texas A&M University Press, 1985, p. 206.
42 Audrey M. Lambert, *The Making of the Dutch Landscape*, Academic Press, London, 1985, p. 115.
43 A.M.J. de Kraker, 'A Method to Assess the Impact of High Tides, Storms and Storm Surges as Vital Elements in Climatic History. The Case of Stormy Weather and Dikes in the Northern Part of Flanders, 1488–1609', *Climatic Change*, vol. 43, no. 1, September 1999, pp. 287–302.
44 See a paper by Aryan van Engelen of the KNMI presented at the Silmu International Conference on Past, Present and Future Climate, Helsinki, August 1995.
45 J.R. Ravensdale, *Liable to Floods. Village Landscape on the Edge of the Fens, AD 450–1850*, Cambridge, Cambridge University Press, 1974, pp. 6–9.
46 George H.T. Kimble, *The Weather*, Harmondsworth, Penguin Books, 1951, p. 224.
47 Ravensdale, *op. cit.*
48 W.G. Hoskins, *The Making of the English Landscape*, London, Hodder and Stoughton, 1965, p. 78.
49 P.F. Brandon, 'Late Medieval Weather in Sussex and its Agricultural Significance', *Transactions of the Institute of British Geographers*, no. 54, November 1971, pp. 1–17.
50 Carlo M. Cipolla (Elizabeth Potter, trans.), *Miasmas and Disease*, New Haven, Yale University Press, 1992, pp. 4–5.
51 *The Kodansha Encyclopedia of Japan* (9 vols), Tokyo, Kodansha, 1983, Vol. 8, p. 122.
52 J. Neumann, 'Great Historical Events that Were Significantly Affected by the Weather. 1. The Mongol Invasions of Japan', *Bulletin of the American Meteorological Society*, vol. 56, no. 11, November 1975, pp. 1167–71.
53 S.R. Turnbull, *The Samurai. A Military History*, London, Osprey, 1977, p. 92.
54 H.E. Landsberg (Editor-in-Chief), *World Survey of Climatology* (15 vols), Amsterdam, Elsevier, 1984, Vol. 15, *Climates of the Oceans*, Figs 18, 23 and 24.
55 Ishii Susumu, *The Kodansha Encyclopedia*, *op. cit.*, Vol. 4, p. 122.
56 Co-Ching Chu, 'Climatic Pulsations during Historic Time in China', *The Geographical Review*, vol. XVI, no. 2, April 1926, pp. 274–82, Table 1.
57 Arthur N. Waldron, 'The Problem of the Great Wall of China', *Harvard Journal of Asiatic Studies*, vol. 43, no. 2, December 1983, pp. 642–63.
58 Albert Kolb (C.A.M. Sym, trans.), *East Asia*, London, Methuen, 1971, p. 66.

59 Joseph H. Cha in William H. McNeill, *Plagues and People*, New York, Doubleday, 1976, Appendix.
60 Co-Ching Chu, *op. cit.*, Tables III and IV.
61 Andrea Kiss, 'Weather Events during the First Tartar Invasion in Hungary, 1241–2', Department of Medieval Studies, Central European University, 1051 Budapest.
62 S.R. Turnbull and Angus McBride, *The Mongols*, London, Osprey, 1980, p. 3.
63 Kolb, *op. cit.*, Map 19.
64 Anatoly M. Khazanov, 'Muhammad and Jenghiz Khan Compared: the Religious Factor in World Empire Building', *Comparative Studies in Society and History*, vol. 35, no. 3, July 1993, pp. 461–79.
65 B.H. Liddell Hart, *Great Captains Unveiled*, London, Greenhill Books, 1989, Chapter 1.
66 English translation by T.C. Marwick of I.E. Buchinskiy, *O Klimate Proshlogo Russkoy Ravniny*, Leningrad, Gidrometeoizdat, 1957, p. 126. (This text is held at the UK National Meteorological Library, Bracknell. The translation of the title is 'Past Climate of the Russian Plains'.)
67 Ellsworth Huntington, *The Pulse of Asia*, London, Archibald Constable, 1907, pp. 14–15.
68 Lamb, *Climate: History and the Modern World, op. cit.*, pp. 184–5.
69 Note by G.F. Hudson in A.J. Toynbee, *A Study of History*, New York, Oxford University Press, 1962, Vol. III, Annex II, p. 453.
70 Alasdair Whittle, 'Climate, Grazing and Man: Notes Towards the Definition of a Relationship' in A.F. Harding (ed.), *Climatic Change in Later Pre-History*, Edinburgh, Edinburgh University Press, 1982, pp. 192–203.
71 L.N. Gumilëv, 'Hetrochronism in the Moisture Supply of Eurasia in the Middle Ages', *Soviet Geography*, vol. IX, no. 1, January 1968, pp. 23–35.
72 H.H. Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 2, p. 133.
73 Huntington, *op. cit.*, pp. 349–50.
74 Gareth Jenkins, 'A Note on Climatic Cycles and the Rise of Chinggis Khan', *Central Asian Journal*, vol. 18, no. 4, 1974, pp. 217–26, Fig. 1.
75 Jin-Qi Fang and Guo Liu, 'The Relationship between Climatic Change and the Nomadic Southwards Migrations in Eastern Asia during Historical Times,' *Climatic Change*, vol. 22, no. 2, October 1992, pp. 151–68.
76 Zhenyao Lin and X.D. Wu as reported in Tu-cheng Yeh *et al.*, 'An International Symposium on Climate in Beijing, People's Republic of China,' *Bulletin of the American Meteorological Society*, vol. 66, no. 9, September 1985, pp. 1147–52.
77 Zhaodong Feng *et al.*, 'Temporal and Spatial Variations of Climate in China during the Last 10,000 Years', *The Holocene*, vol. 3, no. 2, 1993, pp. 174–80, Fig. 4.
78 Jin-Qi Fang, 'Establishment of a Data Bank from Records of Climatic Disasters and Anomalies in Ancient Chinese Documents', *International Journal of Climatology*, vol. 12, July–August 1992, pp. 499–519.
79 Jin-Qi Fang, 'Lake Evolution during the Last 3,000 Years in China and its Implications for Environmental Change, Based on Historical Sources', *Quaternary Research*, vol. 39, no. 2, March 1993.
80 D. Justin Schove, 'Chinese "Raininess" through the Centuries', *Meteorological Magazine*, vol. 78, no. 919, January 1949, pp. 11–16, Fig. 2.
81 Co-Ching Chu, *op. cit.*, Table 5.
82 L.G. Thompson in Raymond S. Bradley and Philip D. Jones (eds), *Climate Since AD 1500*, London, Routledge, 1995, Fig. 27.19.
83 Chapter 6, 'Human Lemmings: The Army that Genghis led', in Paul Colinvaux, *The Fates of Nations. A Biological Theory of History*, Harmondsworth, Pelican, 1983.
84 Colin McEvedy and Richard Jones, *Atlas of World Population History*, London, Allen Lane, 1978, p. 128.
85 Owen Lattimore, 'The Geographical Factor in Mongol History', *The Geographical Journal*, vol. XCI, no. 1, January 1938, pp. 1–20.
86 Huntington, *op. cit.*, p. 343.
87 Joseph Needham, *Science and Civilisation in China*, Cambridge, Cambridge University Press, 1971, Vol. 4, Part III, pp. 241–5.

88 Hou Ren-zhi, 'Ancient City Ruins in the Deserts of the Inner Mongolia Autonomous Region of China', *Journal of Historical Geography*, vol. 11, no. 3, July 1985, pp. 241–52.
89 Arthur Waley, *The Secret History of the Mongols and Other Pieces*, London, George Allen and Unwin, 1963, pp. 6–7.
90 Owen Lattimore, 'Chingis Khan and the Mongol Conquests', *Scientific American*, vol. 209, no. 8, August 1963, pp. 54–68.
91 John K. Fairbank *et al.*, *East Asia. Tradition and Transformation*, London, George Allen and Unwin, 1973, pp. 157–8.
92 David Morgan, *The Mongols*, Oxford, Basil Blackwell, 1986, pp. 44–50.
93 Geoffrey Barraclough (ed.), *The Times Atlas of World History*, London, Times Books, 1979, p. 127.
94 Jean M. Grove, *The Little Ice Age*, London, Routledge, 1990, pp. 201–4.
95 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 2, Fig. 13.33.
96 R.A. French in James A. Bater and R.A. French (eds), *Studies in Russian Historical Geography* (2 vols), London, Academic Press, 1983, Chapter 10, Fig. 10.3.
97 Leo de Hartog, *Russia and the Mongol Yoke*, London, I.B. Tauris, 1996, p. 5.
98 M.M. Postan (ed.), *Cambridge Economic History of Europe*, Cambridge, Cambridge University Press, 1966, Vol. 1, pp. 524–8.
99 A.N. Vyssotsky, *Astronomical Records in the Russian Chronicles from 1000 to 1600 AD*, Historical Notes and Papers 22, Lund, The Observatory, 1949, p. 4.
100 George Vernadsky, *A History of Russia* (3 vols), New Haven, Yale University Press, 1953, Vol. III, Chapter 5.
101 Buchinskiy, *op. cit.*, pp. 75–8.
102 Alexander Krenke and Margarita Chernavskaya, 'Extreme Climatic Phenomena over the Russian Plain during the Medieval Warming and the Little Ice Age according to Documentary Records' in Barbara Obrębska-Starkel (ed.), *Reconstructions of Climate and its Modelling*, Kraków, Jagiellonian University, 2000, pp. 79–83.
103 Vernadsky, *op. cit.*, p. 337.
104 R.W. Davies, 'Russia in the Early Middle Ages', *Economic History Review*, vol. V, no. 1, 1952, pp. 116–27.
105 Tibor Szamuely, *The Russian Tradition*, London, Secker and Warburg, 1974, p. 19.
106 Charles J. Halperin, 'Russia in the Mongol Empire in Comparative Perspective', *Harvard Journal of Asiatic Studies*, vol. 43, no. 1, 1983, pp. 239–61.
107 Karl A. Wittfogel, *Oriental Despotism*, New Haven, Yale University Press, 1957, pp. 206–7 and 219–25.
108 Alfred Guillaume, *Islam*, Harmondsworth, Penguin, 1954, pp. 66–7.
109 J.R.S. Phillips, *The Medieval Expansion of Europe*, Oxford, Oxford University Press, 1988, Chapter 7.
110 Benjamin Z. Kedar in James M. Powell (ed.), *Muslims under Latin Rule, 1100–1300*, Princeton, Princeton University Press, 1990, Chapter 4.
111 Arie S. Issar, *The Impact of Climate Variations on Water Management Systems*, Sede Boker, Jacob Blaustein Institute for Desert Research, 1992, Figs 3 and 5.
112 Peter Jackson, 'The Crisis in the Holy Land in 1260', *English Historical Review*, vol. XCV, no. CCCLXXVI, July 1980, pp. 481–513.
113 Jacques Pirenne (Lovett Edwards, trans.), *The Tides of History*, London, George Allen and Unwin, 1963, Vol. II, Chapter XV
114 Edward Gibbon, *The Decline and Fall of the Roman Empire* (6 vols), London, David Campbell, 1994, Vol. 6, p. 311.
115 Jacques Pirenne, *op. cit.*
116 Phillips, *The Medieval Expansion of Europe*, *op. cit.*, p. 87.
117 Frances Wood, *Did Marco Polo Go to China?* London, Secker and Warburg, 1995.
118 James Pringle, 'Outraged Chinese Historians Insist Marco Polo Went East', *The Times*, 19 April 1996.
119 William H. McNeill, *Plagues and Peoples*, Oxford, Basil Blackwell, 1976, Chapter 4.
120 Turnbull and McBride, *op. cit.*, p. 22.
121 Jackson, *op.cit.*, pp. 510–11.
122 Kiss, *op. cit.*

123 Peter C. Perdue, 'Boundaries, Maps and Movement: Chinese, Russian and Mongolian Empires in Early Modern Central Eurasia', *International History Review*, vol. XX, no. 2, June 1998, pp. 263–86.
124 A.J.P. Taylor, *War by Timetable: How the First World War Began*, London, MacDonald, 1969, p. 100.
125 William H. Quinn in Henry F. Diaz and Vera Markgraf (eds), *El Niño. Historical and Palaeoclimatic Aspects of the Southern Oscillation*, Cambridge, Cambridge University Press, 1992, Chapter 6.
126 John Fennell, *The Crisis in Medieval Russia, 1200–1304*, London, Longman, 1983, p. 74.

9 Through the optimum

1 Archibald Lewis, 'The Closing of the Medieval Frontier, 1250 to 1350', *Speculum*, vol. XXXIII, no. 4, October 1958, pp. 475–83.
2 Mark Bailey, 'The Concept of the Margin in the Medieval English Economy', *Economic History Review*, vol. XLII, no. 1, February 1989, pp. 1–17.
3 D. Roden, 'Demesne Farming in the Chiltern Hills', *Agricultural History Review*, vol. 17, part 1, 1969, pp. 9–23.
4 Anna Sapir Abulafia, *Jews and Christians in the 12th Century Renaissance*, London, Routledge, 1995, p. 19.
5 Charles Homer Haskins, *The Renaissance of the 12th Century*, Cambridge, Mass., Harvard University Press, 1927, p. 11.
6 F.H. Fobes, 'Medieval Versions of Aristotle's Meteorology', *Classical Philology*, vol. X, no. 3, July 1915, pp. 297–314.
7 R.I. Moore, 'Literacy and the Making of Heresy, *c.* 1000–*c.* 1150', in Lester K. Little and Barbara H. Rosenwein (eds), *Debating the Middle Ages*, Oxford, Blackwell, 1998, Chapter 21.
8 William A. Nitze, 'The So-called Twelfth Century Renaissance', *Speculum*, vol. XXIII, no. 3, July 1948, pp. 464–71.
9 Steven Runciman, *The Sicilian Vespers*, Cambridge, Cambridge University Press, 1958, p. 20.
10 Bertrand Russell, *History of Western Philosophy*, London, Unwin University Books, undated, Book Two, Chapter XII.
11 Haskins, *op. cit.*, p. 10.
12 James L. Goldsmith, 'The Crisis of the Late Middle Ages: The Case of France', *French History*, vol. 9, no. 4, December 1995, pp. 417–50.
13 Estimates quoted in Karl A. Wittfogel, *Oriental Despotism*, New Haven, Yale University Press, 1957, pp. 217–18.
14 John Beeler, *Warfare in Feudal Europe, 730–1200*, Ithaca, Cornell University Press, 1971, pp. 180–3.
15 J.L. Bintliff in Anthony Harding (ed.), *Climate Change in Later Pre-History*, Edinburgh, Edinburgh University Press, 1982, p. 153.
16 C.T. Smith, *An Historical Geography of Western Europe Before 1800*, London, Longman, 1967, pp. 248–51.
17 Robert S. Lopez, *Byzantium and the World around It*, London, Variorum, 1978, p. 163.
18 N.J.G. Pounds, *An Historical and Political Geography of Europe*, London, George G. Harrap, 1947, Fig. 72.
19 Jaime Vicens Vives (Frances M. López-Morillas, trans.), *An Economic History of Spain*, Princeton, Princeton University Press, 1969, Chapter 20.
20 Amos Frumkin *et al.*, in Arie S. Issar and Neville Brown (eds), *Water, Environment and Society in Times of Climatic Change*, Dordrecht, Kluwer, 1998, Fig. 5.4.
21 Michael Netser, in *ibid.*, Fig. 7.2.
22 Arie Issar, in *ibid.*, p. 125.
23 Beeler, *op. cit.*, pp. 25–6.
24 Josiah C. Russell, *Medieval Demography*, New York, AMS Press, 1987, p. 92.
25 T.H. Hollingsworth, *Historical Demography*, London, Cambridge University Press, 1969, Fig. 5.
26 Fekri A. Hassan, 'The Dynamics of a Riverine Civilisation: A Geoarchaeological Perspective on the Nile Valley, Egypt', *World Archaeology*, vol. 29, no. 1, June 1997, pp. 51–74, Fig. 1.

27 William H. Quinn in Henry F. Diaz and Vera Markgraf (eds), *El Niño. Historical and Palaeoclimatic Aspects of the Southern Oscillation*, Cambridge, Cambridge University Press, 1992, Chapter 6, Table 6.6.
28 Henri Grégoire, 'The Question of the Diversion of the 4th Crusade', *Byzantion*, Vol. XV, 1940–1, pp. 158–66.
29 Steven Runciman, *A History of the Crusades* (3 vols), Vol. III, Cambridge University Press, 1955, pp. 115–22.
30 Hugh Trevor-Roper, *The Rise of Christian Europe*, London, Thames and Hudson, 1965, p. 110.
31 Julien Green (Peter Heinegg, trans.), *God's Fool*, London, Hodder and Stoughton, 1986, pp. 151–3.
32 Giles Constable, *The Reformation of the 12th Century*, Cambridge, Cambridge University Press, 1996, Chapter 2.
33 Lynn White, 'Science and the Sense of Self: The Medieval Background of a Modern Confrontation', *Daedalus*, vol. 107, no. 2, Spring 1978, pp. 47–59.
34 Jan Read, *The Moors in Spain and Portugal*, London, Faber and Faber, 1974, Chapter XX.
35 Joseph Needham, *Science and Civilisation in China*, Cambridge, Cambridge University Press, 1959, Vol. 3, p. 462.
36 E.W. Webster, 'Meteorologica', in W.R. Ross (ed.), *The Works of Aristotle*, Oxford, Clarendon Press, 1931, Book 1, Section 10.
37 J.A. Kington, 'A Historical Review of Cloud Study', *Weather*, vol. XXIII, no. 9, September 1968, pp. 349–61.
38 W.E. Knowles Middleton, *A History of Theories of Rain*, London, Oldbourne, 1965, Chapter 1.
39 Norman Cohn, *Noah's Flood*, New Haven, Yale University Press, 1996, Chapter 3.
40 Tina Stiefel, *The Intellectual Revolution in 12th Century Europe*, London, Croom Helm, 1985, p. 51.
41 F. Richard Stephenson and David A. Green, 'The Supernova of AD 1181 – An Update', *Astronomy and Geophysics*, vol. 40, issue 2, April 1999, pp. 27–8.
42 E.N. Lawrence, 'The Earliest Known Journal of the Weather', *Weather*, vol. 27, no. 6, June 1972, pp. 494–501.
43 John Glenn, 'The World Map of Pierre D'Ailly', in Daniel Williams (ed.), *England in the 15th Century. Proceedings of the 1986 Harlaxton Symposium*, Woodbridge, Boydell Press, 1987, pp. 103–10.
44 Evelyn Edson, *Mapping Time and Space*, London, The British Library, 1999, p. 121.
45 Alastair C. Crombie, *Science, Art and Nature in Medieval and Modern Thought*, London, Hambledon Press, 1996, Chapter 4.
46 J.K. Wright, *The Geographical Lore of the Time of The Crusades*, New York, Dover Publications, 1965, pp. 156–65.
47 'The Medieval West and the Indian Ocean: An Oneiric Horizon', in Jacques Le Goff (Arthur Goldhammer, trans.), *Time, Work and Culture in the Middle Ages*, Chicago, University of Chicago Press, 1980, pp. 189–200.
48 John Claridge, Shepherd of Banbury (annotated by G.H.T. Kimble), *The Country Calendar or the Shepherd of Banbury's Rules*, London, Sylvan Press, 1946, pp. 20, 27 and 136.
49 Paul Edward Dutton in Del Sweeney (ed.), *Agriculture in the Middle Ages*, Philadelphia, University of Pennsylvania Press, 1995, Chapter 3.
50 Lynn White, 'Natural Science and Naturalistic Art in the Middle Ages', *American Historical Review*, vol. LII, no. 3, April 1947, pp. 421–35.
51 Freeman J. Dyson, 'The Inventor of Modern Science', *Nature*, vol. 400, no. 6739, 1 July 1999, p. 27.
52 G.E. Fussell, 'The Classical Tradition in West European Farming: the 14th and 15th Centuries', *Agricultural History Review*, vol. 17, part 1, 1969, pp. 1–8.
53 Jean Gimpel, *The Medieval Machine*, London, Victor Gollancz, 1977, pp. 37–40.
54 Mavis Mate, 'Medieval Agrarian Practices: The Determining Factors?' *Agricultural History Review*, vol. 33, 1985, pp. 22–31.
55 Sándor Bökönyi in Sweeney (ed.), *op. cit.*, pp. 42–3.
56 M.M. Postan, 'Investment in Medieval Agriculture', *Journal of Economic History*, vol. XXVII, no. 4, December 1967, pp. 576–87.

57 A.R. Bridbury, *Economic Growth: England in the Later Middle Ages*, Hassocks, Harvester Press, 1975, p. xiii.
58 But for a more positive view of your archetypal English landlord of the thirteenth century see Edward Miller, 'England in the 12th and 13th centuries: An Economic Contrast?' *Economic History Review*, vol. XXIV, no. 1, February 1971, pp. 1–12.
59 Jacques Le Goff (Julia Barrow, trans.), *Medieval Civilisation, 400–1500*, Oxford, Basil Blackwell, 1988, pp. 174–5.
60 Stiefel, *op. cit.*, p. 65.
61 Carlo M. Cipolla, *Clocks and Culture, 1300–1700*, London, Collins, 1967, p. 26.
62 M.M. Postan, 'The Rise of a Money Economy', in E.M. Carus-Wilson (ed.), *Essays in Economic History*, London, Edward Arnold, 1954, pp. 3–12.
63 Alexander Murray, *Reason and Society in the Middle Ages*, Oxford, Clarendon Press, 1978, p. 165.
64 Andrew M. Watson in Sweeney (ed.), *op. cit.*, Chapter 4.
65 Reginald Lennard, 'The Alleged Exhaustion of the Soil in Medieval England', *Economic Journal*, vol. XXXII, 1922, pp. 12–27.
66 M.M. Postan, *Essays on Medieval Agriculture and General Problems of the Medieval Economy*, Cambridge, Cambridge University Press, 1973, p. 15.
67 Gregory Clark, 'The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution', *Journal of Economic History*, vol. 52, no. 1, March 1992, pp. 61–84.
68 William S. Cooter, R.S. Loomis and J.A. Raftis, *Agricultural History*, vol. 52, no. 4, October 1978, pp. 465–87.
69 E.I. Newman and P.D.A. Harvey, 'Did Soil Fertility Decline in Medieval English Farms? Evidence from Cuxham, Oxfordshire, 1320–1340', *Agricultural History Review*, vol. 45, no. 2, 1997, pp. 119–36.
70 Ellen Churchill Semple, *The Geography of the Mediterranean Region. Its Relationship to Ancient History*, New York, Henry Holt, 1932, Chapter XV.
71 Lynn White, 'The Historic Roots of our Ecologic Crisis', *Science*, vol. 155, no. 3767, 10 March 1967, pp. 1203–7.
72 William H. McNeill, *The Pursuit of Power*, Oxford, Basil Blackwell, 1983, Chapter 2.
73 Massimo Montanari (Carl Ipsen, trans.), *The Culture of Food*, Oxford, Blackwell, 1994, p. 9.
74 Sir James George Frazer, *The Golden Bough* (single-volume edition), London, Macmillan, 1922, p. 160.
75 W.R. Mead, *An Historical Geography of Scandinavia*, London, Academic Press, 1981, p. 47.
76 George Caspar Homans, *English Villagers of the 13th Century*, New York, Russell and Russell, 1960, pp. 23–5.
77 Alexander Gieysztor in Geoffrey Barraclough (ed.), *Eastern and Western Europe in the Middle Ages*, London, Thames and Hudson, 1970, Chapter 4.
78 Teresa Dunin-Wasowicz, 'Environnement et habitat: la rupture d'équilibre du XIII[e] siècle dans la Grande Plaine Européenne', *Annales E.S.C.*, vol. 35, no. 5, September–October 1980, pp. 1026–45.
79 Bronislaw Geremek (Jan Aleksandrowicz *et al.*, trans.), *The Common Roots of Europe*, Cambridge, Polity Press, 1996, p. 146.
80 Carole L. Crumley, 'Historical Ecology', in Carole L. Crumley and William H. Marquardt (eds), *Regional Dynamics. Burgundian Landscapes in Historical Perspective*, San Diego, Academic Press, 1987, pp. 237–64.
81 Catherine Delano Smith, *Western Mediterranean Europe. A Historical Geography of Italy, Spain and Southern France from the Neolithic*, London, Academic Press, 1979, Chapter 9.
82 C.T. Smith, *op. cit.*, p. 104.
83 Delano Smith, *op. cit.*
84 Crumley, *op. cit.*, Fig. 1.
85 David J. Breeze in T.C. Smout (ed.), *Scottish Woodland History*, Edinburgh, Scottish Cultural Press, 1997, Chapter 4.
86 A. Indermühle, 'Holocene Carbon-cycle Dynamics Based on CO_2 Trapped in Ice at Taylor Dome, Antarctica', *Nature*, vol. 398, no. 6723, 11 March 1999, pp. 121–6.
87 Catherine Lis (James Coonan, trans.), *Poverty and Capitalism in Pre-Industrial Europe*, Atlantic Highlands, Humanities Press, 1979, p. 16.

88 David Herlihy, 'Three Patterns of Social Mobility in Medieval History', *Journal of Interdisciplinary History*, vol. III, no. 4, Spring 1973, pp. 623–47.
89 Crumley, *op. cit.*, Fig. 2.
90 Kathleen A. Biddick, 'Malthus in a Straitjacket? Analyzing Agrarian Change in Medieval England', *Journal of Interdisciplinary History*, vol. XX, no. 4, Spring 1990, pp. 623–35.
91 Le Goff , *Medieval Civilisation*, *op. cit.*, p. 59.
92 Hollingsworth, *op. cit.*, p. 387.
93 Abbott Payson Usher, 'The History of Population and Settlement in Eurasia', *Geographical Review*, vol. XX, 1930, pp. 110–32.
94 Russell, *Medieval Demography*, *op. cit.*, p. 126.
95 Postan, *Essays on Medieval Agriculture, op. cit.*, p. 212.
96 Josiah Cox Russell, *The Control of Late Ancient and Medieval Population*, Philadelphia, American Philosophical Society, 1985, p. 191.
97 Stephan R. Epstein, *An Island for Itself. Economic Development and Social Change in Late Medieval Sicily*, Cambridge, Cambridge University Press, 1992, p. 55.
98 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1977, Vol. 2, p. 271 and Plate V.
99 Georges Duby (Howard Clarke, trans.), *The Early Growth of the European Economy*, Ithaca, Cornell University Press, 1974, Chapter 9.
100 Georges Duby in Carlo M. Cipolla (ed.), *The Middle Ages*, The Fontana Economic History of Europe, Vol. 1, London, Harvester, 1976, p. 196.
101 Lynn White in *ibid.*, Chapter 2.
102 Carlo M. Cipolla, *Before the Industrial Revolution, European Society and Economy 1000–1700*, London, Methuen, 1976, p. 169.
103 Jared D. Diamond, 'The Earliest Horsemen', *Nature*, vol. 350, no. 6316, 28 March 1991, pp. 275–6.
104 Gimpel, *op. cit.*, pp. 33–8.
105 John Langdon, 'Horse-Hauling: A Revolution in Vehicle Transport in 12th- and 13th-century England', *Past and Present*, no. 103, 1984, pp. 37–66.
106 Gimpel, *op. cit.*, p. 32.
107 J.Z. Titow, *Winchester Yields. A Study in Medieval Agricultural Productivity*, Cambridge, Cambridge University Press, 1972, p. 31.
108 J.E. Thorold Rogers, *A History of Agriculture and Prices in England, 1259–1793* (7 vols), Oxford, Clarendon Press, 1866.
109 Gregory Clark, 'Yields per Acre in English Agriculture, 1250–1860: Evidence from Labour Inputs', *Economic History Review*, vol. XLIV, no. 3, August 1991, pp. 445–60, Table 5.
110 D.L. Farmer, 'Some Grain Price Movements in Thirteenth-century England', *Economic History Review*, vol. X, no. 2, May 1957, pp. 207–20.
111 Christopher Dyer, *Standards of Living in the Later Middle Ages*, Cambridge, Cambridge University Press, 1989, p. 159.
112 *Ibid.*, pp. 124–5.
113 *Ibid.*, Chapter 6, Fig. 4.
114 J. Grace, 'Tree Lines', in P.G. Travis *et al.* (eds), *Forests, Weather and Climate*, London, The Royal Society, 1989, pp. 233–45.
115 Jules N. Pretty, 'Sustainable Agriculture in the Middle Ages: The English Manor', *Agricultural History Review*, vol. 38, no. 1, 1990, pp. 1–19.
116 M.M. Postan, *The Medieval Economy and Society*, London, Weidenfeld and Nicolson, 1972, p. 17.
117 Eileen Power, *The Wool Trade in English Medieval History*, Oxford, Oxford University Press, 1941, p. 6.
118 R.A. Donkin, 'Settlement and Depopulation on Cistercian Estates during the 12th and 13th Centuries Especially in Yorkshire', *Bulletin of the Institute of Historical Research*, vol. XXXIII, no. 88, November 1960, pp. 141–57.
119 Edward Miller, 'Farming in Northern England during the 12th and 13th Centuries', *Northern History*, vol. XI, 1976, pp. 1–16.
120 Bruce M.S. Campbell and John P. Power, 'Mapping the Agricultural Geography of Medieval England', *Journal of Historical Geography*, vol. 15, no. 1, January 1989, pp. 24–39.

121 John Gladstones in Jancis Robinson (ed.), *The Oxford Companion to Wine*, Oxford, Oxford University Press, 1994, pp. 256–7.
122 Tim Unwin, *Wine and the Vine*, London, Routledge, 1991, pp. 150–5.
123 Tom Scott in Robinson (ed.), *op. cit.*, pp. 429–35.
124 *Ibid.*, map on p. 431.
125 Unwin, *op. cit.*, p. 158.
126 Hanneke Wirtjes in Robinson (ed.), *op. cit.*, pp. 360–2.
127 Sir Maurice Powicke, *The Thirteenth Century, 1216–1307*, Oxford, Clarendon Press, 1953, p. 669, footnote 3.
128 *Ibid.*, Chapter VII.
129 Wirtjes, *op. cit.*, p. 361.
130 C.T. Smith, *op. cit.*, p. 500.
131 Unwin, *op. cit.*, Fig. 32.
132 James R. Coull, *The Fisheries of Europe*, London, G. Bell, 1972, p. 72.
133 James H. Barrett, 'Fish Trade in Norse Orkney and Caithness: A Zoo Archaeological Approach', *Antiquity*, vol. 71, no. 273, September 1997, pp. 616–38.
134 *Ibid.*
135 Hubert Lamb, *op. cit.*, Vol. 2, p. 437.
136 Emmanuel Le Roy Ladurie (Barbara Bray, trans.), *Times of Feast, Times of Famine*, London, George Allen and Unwin, 1972, p. 266.
137 John Nef, *The Conquest of the Material World*, Chicago, University of Chicago Press, 1964, p. 11.
138 Dr Axel Steensburg, 'Archaeological Dating of the Climatic Change in North Europe about AD 1300', *Nature*, vol. 168, no. 4277, 20 October 1951, pp. 672–4.
139 *Ibid.*
140 John Langdon, 'Water-mills and Windmills in the West Midlands, 1086–1500', *Economic History Review*, vol. XLIV, no. 3, August 1991, pp. 424–44.
141 Marc Bloch (J.E. Andersen, trans.), *Land and Work in Medieval Europe*, London, Routledge and Kegan Paul, 1966, p. 149.
142 Cipolla, *Before the Industrial Revolution*, *op. cit.*, Table A-1.
143 Christopher Dyer, 'The Hidden Trade of the Middle Ages: Evidence from the West Midlands of England', *Journal of Historical Geography*, vol. 18, no. 2, 1992, pp. 141–57.
144 Christopher Dyer, 'How Urban was Medieval England?' *History Today*, vol. 47, no. 1, January 1997, pp. 37–43.
145 Richard H. Britnell in Richard H. Britnell and Bruce M.S. Campbell (eds), *A Commercialising Economy: England 1086 to c. 1300*, Manchester, Manchester University Press, 1995, pp. 12–13.
146 Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (2 vols), London, W. Strahan and T. Cadell, 1776, Vol. I, p. 489.
147 J.T. Houghton *et al.* (eds), *Climate Change 1995. The Science of Climate Change*, Cambridge, Cambridge University Press for Intergovernmental Panel on Climate Change, 1996, Fig. 6.37.
148 Walter Dragoni in Issar and Brown (eds), *op. cit.*, Fig. 11.3D.
149 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, Fig. 59.
150 W. Gordon East, *An Historical Geography of Europe*, London, Methuen, 1962, p. 318.
151 Robert S. Lopez in M. Postan and E.E. Rich (eds), *The Cambridge Economic History of Europe*, Cambridge, Cambridge University Press, 1952, Vol. II, p. 301.
152 *Ibid.*, 1966, Vol. I, edited by M.M. Postan, pp. 353–60.
153 Douglas F. Dowd, 'The Economic Expansion, 1300–1500: A Study in Political Stimuli to Economic Change', *Journal of Economic History*, vol. XXI, no. 2, June 1961, pp. 143–60.
154 Postan (ed.), Vol. I, *op. cit.*, p. 359.
155 Robert Coates-Stephens, 'The Walls and Aqueducts of Rome in the Early Middle Ages AD 500–1000', *Journal of Roman Studies*, vol. LXXXVIII, 1998, pp. 166–78.
156 David Nicholas, 'Of Poverty and Primacy: Demand, Liquidity and the Flemish Economic Miracle, 1050–1200', *American Historical Review*, vol. 96, no. 1, February 1991, pp. 17–41.
157 J.A. Van Houtte, *An Economic History of the Low Countries, 800–1800*, London, Weidenfeld and Nicolson, 1977, p. 3.

158 Adriaan Verhulst, 'The Origins of Towns in the Low Countries and the Pirenne Thesis', *Past and Present*, no. 122, February 1989, pp. 3–35.
159 Patrick Chorley, 'The Cloth Exports of Flanders and Northern France during the 13th Century: A Luxury Trade?' *Economic History Review*, vol. XL, no. 3, August 1987, pp. 349–79.
160 H.H. Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 2, Fig. 17.7.
161 Jerrold Atlas, 'Medieval Crime, Violence and Superstition: Symptomatic Dysfunction', *Journal of Psychohistory*, vol. 26, no. 1, Summer 1998, pp. 514–29.
162 R. Schoental, 'Climatic Changes, Mycotoxins, Plagues and Genius', *Journal of the Royal Society of Medicine*, vol. 88, no. 10, October 1995, pp. 560–1.
163 Sylvia L. Thrupp in Vaclav Murdoch and G.S. Couse (eds), *Essays on the Reconstruction of Medieval History*, Montreal, McGill-Queens, 1974, p. 123.
164 R.H. Hilton, 'Peasant Movements in England before 1381', *Economic History Review*, vol. II, no. 2, 1949, pp. 117–36.
165 Ralph E. Turner, 'Economic Discontent in Medieval Western Europe', *Journal of Economic History*, vol. VIII, 1948, Supplement, pp. 85–100.
166 Norman Cohn, *The Pursuit of the Millennium*, St Alban's, Paladin, 1970, pp. 282–4.
167 Guy Fourquin (Anne Chesters, trans.), *The Anatomy of Popular Rebellion in the Middle Ages*, Amsterdam, North-Holland, 1978, p. 87.
168 A.L. Lloyd, *Folk Song in England*, St Alban's, Paladin, 1975, p. 104.
169 Nef, *op. cit.*, pp. 15–29.
170 Robert S. Lopez, 'Italian Leadership in the Medieval Business World', *Journal of Economic History*, vol. VIII, no. 1, May 1948, pp. 63–8.
171 Pierre Bonnassie in Lester K. Little and Barbara H. Rosenwein (eds), *Debating the Middle Ages*, Oxford, Blackwell, 1998, pp. 132–3.
172 Beeler, *op. cit.*, pp. 210–14.
173 Edward Coleman, 'Italy's First Northern League, *History Today*, vol. 46, no. 10, October 1996, pp. 6–8.
174 Sir Steven Runciman in James A. Brundage (ed.), *The Crusades, Motives and Achievements*, Lexington, D.C. Heath, 1964, p. 81.
175 Edward P. Cheney, *The Dawn of a New Era, 1250–1453*, New York, Harper, 1936, pp. 180–1.
176 Joseph R. Strayer, *On the Medieval Origins of the Modern State*, Princeton, Princeton University Press, 1980, p. 56.
177 Jacques Pirenne (Lovett Edwards, trans.), *The Tides of History*, Vol. II, London, George Allen and Unwin, 1963, p. 170.
178 H.C. Darby, 'The Medieval Sea State', *Scottish Geographical Magazine*, vol. XLVIII, no. 3, 16 May 1932, pp. 136–49.
179 Pirenne, *op. cit.*, Vols IX and X.
180 Dauvit Broun, 'When did Scotland become Scotland?' *History Today*, vol. 46, no. 10, October 1996, pp. 16–21.
181 Angus J.L. Winchester, *Landscape and Society in Medieval Cumbria*, Edinburgh, John Donald, 1987, Chapter 1.
182 Geoffrey Barrow in Roger Bartlett and Angus Mackay (eds), *Medieval Frontier Societies*, Oxford, Clarendon Press, 1989, Chapter 1.
183 Richard Lomas, 'The Impact of Border Warfare: the Scots and South Tweedside, c. 1290–1520', *Scottish Historical Review*, vol. LXXV, no. 200, October 1996, pp. 143–67.
184 Philip Jones, *The Italian City State. From Commune to Signoria*, Oxford, Clarendon Press, 1997, pp. 255–6.
185 Strayer, *op. cit.*, p. 57. The interpretation of state development here enunciated owes much to this text.
186 David Hackett Fischer, *The Great Wave. Price Revolutions and the Rhythm of History*, New York, Oxford University Press, 1996, Fig. 1.08.
187 Peter Brimblecombe, *The Big Smoke*, London, Routledge, 1988, pp. 7–16.
188 Albert Kolb (C.A.M. Sym, trans.), *East Asia*, London, Methuen, 1971, p. 66.
189 Peter S. Swann, *Art of China, Korea and Japan*, London, Thames and Hudson, 1974, pp. 169–70.

190 André Gunder Frank and Barry K. Gills, 'World System Economic Cycles and Hegemonical Shift to Europe, 100 BC to 1500 AD', *Journal of European Economic History*, vol. 22, no. 1, Spring 1993, pp. 155–83.
191 Richard C. Hoffman, 'Economic Development and Aquatic Ecosystems in Medieval Europe', *American Historical Review*, vol. 101, no. 3, June 1996, pp. 631–69.
192 Teresa Dunin-Wasowicz, 'Climate as a Factor Affecting the Human Environment in the Middle Ages', *Journal of European Economic History*, vol. 4, no. 3, Winter 1975, pp. 691–706.
193 Hoffman, *op. cit.*
194 C.U. Hammer *et al.*, 'Greenland Ice Sheet Evidence of Post-glacial Volcanism and its Climate Impact', *Nature*, vol. 288, no. 5788, 20 November 1980, pp. 230–5.
195 C. Pfister *et al.*, 'Winter Severity in Europe: the 14th Century', *Climatic Change*, vol. 34, no. 1, September 1996, pp. 91–104.
196 A.E.J. Ogilvie, 'The Past Climate and Sea-Ice Record from Iceland. Part I: Data to AD 1780', *Climatic Change*, vol. 6, no. 2, June 1984, pp. 131–52.
197 Gustaf Utterström, 'Climatic Fluctuations and Population Problems in Early Modern History', *Scandinavian Economic History Review*, vol. III, no. 1, 1955, pp. 3–47.
198 Lamb, *Climate: Present, Past and Future*, *op. cit.*, Vol. 1, pp. 220–2.
199 J.L. Jirikowic and P.E. Damon, 'The Medieval Solar Activity Maximum', *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, pp. 309–16.
200 Otto Pettersson, 'The Connection between Hydrographical and Meteorological Phenomena', *Quarterly Journal of the Royal Meteorological Society*, vol. 38, no. 163, July 1912, pp. 173–91.
201 Ellsworth Huntington and Stephen Visher, *Climatic Changes. Their Nature and Causes*, New Haven, Yale University Press, 1922, Chapter VI.
202 Michael E. Goodrich, *Violence and Miracle in the 14th Century*, Chicago, University of Chicago Press, 1995, Chapter 6.
203 Pierre Alexandre, *Le Climat en Europe au moyen âge*, Paris, L'École des Hautes Études en Sciences Sociales, 1987, p. 769.
204 H.E. Hallam, 'The Climate of Eastern England, 1250–1350', *Agricultural History Review*, vol. 32, 1984, pp. 124–32.
205 C.E. Britton, *A Meteorological Chronology to AD 1450*, Meteorological Office Geophysical Memoirs, no. 70, Vol. VIII, no. 1, 1937, pp. 70–105.
206 Alexandre, *op. cit.*, pp. 371–424.
207 Pfister *et al.*, *op. cit.*, pp. 99–101.
208 I.E. Buchinsky (T.C. Marwick, trans.), *O Klimate Proshlogo Russkoy Ravniny*, Leningrad, Gidrometeoizdat, 1957, pp. 74–80.
209 W. Karlén in L. Starkel *et al.* (eds), *Temperate Palaeohydrology*, Chichester, John Wiley, 1991, Fig. 18–3.
210 Maurice Beresford, *The Lost Villages of England*, London, Lutterworth Press, 1965, p. 162.
211 Alan R.H. Baker, 'Evidence in the *Nonarum Inquisitiones* of Contracting Arable Lands in England during the Early 14th Century', *Economic History Review*, vol. XIX, no. 3, 1966, pp. 518–32.
212 Guy Beresford in Catherine Delano Smith and Martin Parry (eds), *Consequences of Climatic Change*, Nottingham, University of Nottingham Press, 1981, pp. 31–2.
213 Hugh D. Clout in Hugh D. Clout (ed.), *Themes in the Historical Geography of France*, London, Academic Press, 1977, p. 117.
214 Cited in H.H. Lamb, 'What Can Historical Records Tell Us About the Breakdown of the Medieval Warm Climate in the 14th and 15th Centuries – An Experiment', *Beiträge zur Physik der Atmosphäre*, vol. 60, no. 2, May 1987, pp. 131–43.
215 Alexandre, *op. cit.*, p. 768.
216 W. Dansgaard *et al.*, 'Climatic Changes, Norsemen and Modern Man', *Nature*, vol. 255, no. 5503, 1 May 1975, pp. 24–8, Fig. 2.
217 Hammer *et al.*, *op. cit.*, Fig. 1.
218 K.R. Briffa *et al.*, 'A 1400-year Tree-ring Record of Summer Temperatures in Fenno-Scandia', *Nature*, vol. 346, no. 6283, 2 August 1990, pp. 434–9.
219 Hans-Rudolf Bork and Berno Faust in John Boardman and David Favis-Mortlock (eds), *Climate Change and Soil Erosion*, London, Imperial College, 2001, Chapter 2.7.

220 Buchinsky, *op. cit.*, pp. 79–80.
221 William Chester Jordan, *The Great Famine. Northern Europe in the Early 14th Century*, Princeton, Princeton University Press, 1996, p. 17.
222 Lamb in *Beiträge*, *op. cit.*, Figs 3 and 4a.
223 Utterström, *op. cit.*, p. 20.
224 Françoise Serre-Bachet, 'Middle Ages Temperature Reconstructions in Europe, A Focus on Northeastern Italy', *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, pp. 213–24, Figs 3a and 3b.
225 Henry S. Lucas, 'The Great European Famine of 1315, 1316 and 1317', *Speculum*, vol. V, no. 4, October 1930, pp. 343–77.
226 Ian Kershaw, 'The Great Famine and Agrarian Crisis in England, 1315–1322', *Past and Present*, no. 59, May 1973, pp. 3–50.
227 Barbara W. Tuchman, *A Distant Mirror*, Harmondsworth, Penguin, 1979, pp. 40–2.
228 J.Z. Titow, 'Evidence of Weather in the Account Rolls of the Bishopric of Winchester, 1209–1350', *Economic History Review*, vol. XII, no. 3, 1960, pp. 360–407.
229 Chester Jordan, *op. cit.*, p. 19.
230 Kershaw, *op. cit.*, p. 49.
231 Edward Miller and John Hatcher, *Medieval England: Towns, Commerce and Craft*, London, Longman, 1995, p. 419.
232 Chester Jordan, *op. cit.*, p. 186.
233 David Arnold, *Famine, Social Crisis and Historical Change*, Oxford, Basil Blackwell, 1988, p. 55.
234 R.H. Britnell, 'Agricultural Technology and the Margin of Cultivation in the 14th Century', *Economic History Review*, vol. XXX, no. 1, 1977, pp. 53–6.
235 Kershaw, *op. cit.*, pp. 14–15 and 24–9.
236 Langdon, 'Horse Hauling', *op. cit.*, pp. 37–45.
237 John Langdon, 'Inland Water Transport in Medieval England', *Journal of Historical Geography*, vol. 19, no. 1, January 1993, pp. 1–11.
238 M.L. Parry, *Climate Change, Agriculture and Settlement*, Hamden, Archon Books, 1978, pp. 160–1.
239 *Ibid.*, Fig. 40.
240 Gino Luzzatto (Philip Jones, trans.), *An Economic History of Italy from the Fall of the Roman Empire to the Beginning of the 16th Century*, London, Routledge and Kegan Paul, 1961, p. 106.
241 M.I. Stephenson, 'Wool Yields in the Medieval Economy', *Economic History Review*, vol. XLI, no. 3, August 1988, pp. 368–91.
242 C.M. Cipolla, 'The Trends in Italian Economic History in the Later Middle Ages', *Economic History Review*, vol. II, no. 3, August 1950, pp. 181–4.
243 M. Postan and E.E. Rich (eds), *op. cit.*, Vol. II, p. 404.
244 Chester Jordan, *op. cit.*, pp. 142–3.
245 Kershaw, *op. cit.*, pp. 47 and 6.
246 Emmanuel Le Roy Ladurie (Siân and Ben Reynolds, trans.), *The Mind and Method of the Historian*, Brighton, Harvester Press, 1981, p. 274.
247 Quinn in Diaz and Markgraf (eds), *op. cit.*, Chapter 6, Table 6.6.
248 R.H. Kripalani and Ashwini Kulkarni, 'Climate Impact of El Niño on the Indian Monsoon: A New Perspective', *Weather*, vol. 52, no. 2, February 1997, pp. 39–46.
249 Hassan, *World Archaeology*, *op. cit.*, Table 1.
250 Huntington and Visher, *op. cit.*, pp. 103–7.
251 Fischer, *The Great Wave*, *op. cit.*, Appendix B.
252 Wilhelm Abel (Olive Ordish, trans.), *Agricultural Fluctuations in Europe from the 13th Century to the 20th*, London, Methuen, 1980, Chapter 1, Table 5.
253 Joseph R. Strayer, *Medieval Statecraft and the Perspectives of History*, Princeton, Princeton University Press, 1971, Chapter 20.
254 Astrik L. Gabriel in Francis Lee Utley (ed.), *The Forward Movement of the 14th Century*, Columbus, Ohio State University, 1961, p. 82.
255 J.R. Strayer, 'The Laicization of French and English Society in the 13th Century', *Speculum*, vol. XV, no. 1, January 1940, pp. 76–86.

256 Utley (ed.), *op. cit.*, p. 108.
257 David Abulafia, *The Western Mediterranean Kingdoms. The Struggle for Dominion*, London, Longman, 1997, p. 3.
258 Powicke, *op. cit.*, pp. 231–2.
259 Richard F. Tomasson, 'A Millennium of Misery: The Demography of the Icelanders', *Population Studies*, vol. XXXI, no. 3, November 1977, pp. 405–27.
260 T.D. Kendrick, *A History of the Vikings*, London, Methuen, 1930, pp. 358–9.
261 W. Glyn-Jones, *Denmark. A Modern History*, London, Croom Helm, 1986, p. 7.
262 Kåre Lunden, 'Some Causes of Change in a Peasant Economy: Interactions between Cultivated Area, Farming Population, Climate, Taxation and Technology', *Scandinavian Economic History Review*, vol. XXII, no. 2, 1974, pp. 117–35.
263 Jean M. Grove, *The Little Ice Age*, London, Routledge, 1988, p. 107.
264 Aksel E. Christensen, 'Scandinavia and the Advance of the Hanseatics', *Scandinavian Economic History Review*, vol. V, no. 2, 1957, pp. 89–116.
265 A. von Brandt, 'Recent Trends in Research on Hanseatic History', *History*, vol. XLI, February–October 1956, pp. 25–37.
266 David D. Bjork, 'Piracy in the Baltic, 1375–1398', *Speculum*, vol. XVIII, no. 1, January 1943, pp. 39–68.
267 Jerah Johnson and William Percy, *The Age of Recovery, the 15th Century*, Ithaca, Cornell University Press, 1970, Chapter IV.
268 M. Malowist, 'The Problem of the Inequality of Economic Development in Europe in the Later Middle Ages', *Economic History Review*, vol. XIX, no. 1, February 1966, pp. 15–28.
269 Kees Terlouw, 'A General Perspective on the Regional Development of Europe from 1300 to 1500', *Journal of Historical Geography*, vol. 22, no. 2, April 1996, pp. 129–46, Fig. 10.
270 W.H. Parker, *An Historical Geography of Russia*, London, University of London Press, 1968, Chapter 4.
271 Buchinsky, *op. cit.*, p. 120.
272 D.J. Schove, 'Medieval Dendrochronology in the USSR', *Medieval Archaeology*, vol. 8, 1964, pp. 216–17.
273 William A. Dando, *The Geography of Famine*, London, Edward Arnold, 1980, Chapter 9.
274 Peter Charanis, 'Economic Factors in the Decline of the Byzantine Empire', *Journal of Economic History*, vol. XIII, no. 1, Winter 1953, pp. 412–24.
275 Peter Charanis, 'Internal Strife in Byzantium during the 14th Century', *Byzantion*, vol. XV, 1940–1, pp. 208–30.
276 E. Ashtor, *A Social and Economic History of the Near East in the Middle Ages*, London, Collins, 1976, p. 277.
277 Bintliff, *op. cit.*, p. 152.
278 Dr Peter Denley in George Holmes (ed.), *The Oxford Illustrated History of Medieval Europe*, Oxford, Oxford University Press, 1988, pp. 255–6.
279 Epstein, *op. cit.*, p. 55.
280 A.T. Grove in C. Jane Brandt and John B. Thornes (eds), *Mediterranean Desertification and Land Use*, Chichester, John Wiley, 1996, Chapter 2.
281 Mavis Mate in Bruce M.S. Campbell (ed.), *Before the Black Death: Studies in the Crisis of the Early 14th Century*, Manchester, Manchester University Press, 1991, Chapter 3.
282 Guy Fourquin (Anne Chester, trans.), *The Anatomy of Popular Rebellion in the Middle Ages*, Amsterdam, North-Holland, 1978, p. 134.
283 William H. McNeill, *Plagues and People*, Garden City, Doubleday, 1976, pp. 161–5.
284 J.Z. Titow, *English Rural Society, 1200–1350*, London, George Allen and Unwin, 1969, pp. 67–9.
285 George Deaux, *The Black Death, 1347*, London, Hamish Hamilton, 1969, Chapter III.
286 Philip Zeigler, *The Black Death*, London, Collins, 1969, Chapter 5.
287 J. Huizinga, *The Waning of the Middle Ages*, London, Edward Arnold, 1955, p. 40.
288 Barbara F. Harvey in Campbell (ed.), *op. cit.*, Chapter 1.
289 Dan Stanislawski, 'Dark Age Contributions to the Mediterranean Way of Life', *Annals of the Association of American Geographers*, vol. 63, no. 4, December 1973, pp. 397 and 410.
290 Harvey, *op. cit.*, p. 23.

10 Water, warmth and emergent Europe

1. For a creditable exception, see Peter H. Gleick, 'Water and Conflict', *International Security*, vol. 18, no. 1, Summer 1993, pp. 79–112.
2. Peter Kropotkin, 'The Desiccation of Eur-Asia', *The Geographical Journal*, vol. XXIII, no. 6, June 1904, pp. 722–41.
3. Jin-Qi Fang, 'Establishment of a Data Bank from Records of Climatic Disasters and Anomalies in Ancient Chinese Documents', *International Journal of Climatology*, vol. 12, no. 4, July–August 1992, pp. 499–519, Fig. 3.
4. J.W. Gregory, 'Is the Earth Drying Up?' *The Geographical Journal*, vol. XLIII, no. 2, February 1914, pp. 148–72 and vol. XLIII, no. 3, March 1914, pp. 293–318.
5. A.A. Kurkov, 'Is there a Problem of Desiccation of Asia?' *Soviet Geography*, vol. 9, 1968, pp. 47–54.
6. Vasant K. Saberwal, 'Science and the Desiccationist Discourse of the 20th Century', *Environment and History*, Vol. 3, 1997, pp. 309–43.
7. Nick Middleton, *Desertification*, Oxford, Oxford University Press, 1991, Chapter 3.
8. E.A. Thompson (postumously revised by Peter Heather), *The Huns*, Oxford, Blackwell, 1996, Chapters 2 and 4.
9. A.V. Meshcherskaya and V.G. Blazhevich, 'The Drought and Excessive Moisture Indices in a Historical Perspective in the Principal Grain-producing Regions of the Former Soviet Union', *Journal of Climate*, vol. 10, no. 10, October 1997, pp. 2670–82, Fig. 2.
10. A.H.M. Jones, *The Later Roman Empire* (2 vols), Oxford, Basil Blackwell, 1973, Vol. II, pp. 1058–62.
11. *Ibid.*, p. 1065.
12. N.J.G. Pounds, *An Historical and Political Geography of Europe*, London, George G. Harrap, 1947, Fig. 3.
13. Dr Thomas Brown in George Holmes (ed.), *The Oxford Illustrated History of Medieval Europe*, Oxford, Oxford University Press, 1988, p. 26.
14. Robert Coates-Stephens, 'The Walls and Aqueducts of Rome in the Early Middle Ages, AD 500–1000', *The Journal of Roman Studies*, vol. LXXXVIII, 1998, pp. 166–78.
15. Special Faculty Lecture at Oxford, 27 November 1998.
16. Jean-Pierre Poly in Robert Fossier (ed.) (Stuart Airlie and Robyn Marsack, trans.), *The Cambridge Illustrated History of the Middle Ages* (3 vols), Vol. II, *950 to 1250*, Cambridge, Cambridge University Press, 1997, p. 25.
17. Brown, in Holmes (ed.), *op. cit.*, p. 21.
18. Richard Hodges, *Dark Age Economics*, London, Duckworth, 1989, Fig. 5.
19. *Ibid.*, Chapters 8 and 10.
20. Ellsworth Huntington, *Civilisation and Climate*, New Haven, Yale University Press, 1924, Chapter XV.
21. Zhang De'er, 'Evidence for the Existence of the Medieval Warm Period in China', *Climatic Change*, vol. 26, nos. 2 and 3, March 1994, pp. 289–97.
22. Frederick J. Teggart, *Rome and China. A Study of Correlations in Historical Events*, Berkeley, University of California Press, 1939, pp. 236–9.
23. H.G. Creel, 'The Role of the Horse in Chinese History', *American Historical Review*, vol. LXX, no. 3, April 1965, pp. 647–72.
24. Jared Diamond, 'The Earliest Horsemen', *Nature*, vol. 350, no. 6316, 28 March 1991, pp. 275–6.
25. Gari Ledyard, 'Horse Rider Theory', in *Kodansha Encyclopedia of Japan* (9 vols), Tokyo, Kodansha, 1983, Vol. 3, pp. 229–31.
26. Albert Kolb (C.A.M. Sym, trans.), *East Asia*, London, Methuen, 1971, p. 367.
27. Albertine Gaur, *A History of Writing*, London, The British Library, 1984, pp. 112–13.
28. N.J. Shackleton in J.R.L. Allen *et al.* (eds), *Palaeoclimates and Their Modelling*, London, Chapman and Hall for the Royal Society, 1994, p. 3.
29. L.G. Thompson in Raymond S. Bradley and Philip D. Jones (eds), *Climate Since AD 1500*, London, Routledge, 1995, Chapter 27.
30. William H. Quinn, 'A Study of Southern Oscillation-related Climatic Activity for AD 622–1900 Incorporating Nile River Flood Data', in Henry F. Diaz and Vera Markgraf (eds), *El Niño*, Cambridge, Cambridge University Press, 1992, pp. 119–49, Table 6.6.

31 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1977, Vol. 2, Fig. 17.1.
32 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, p. 168.
33 Emmanuel Le Roy Ladurie (Barbara Bray, trans.), *Times of Feast, Times of Famine*, London, George Allen and Unwin, 1972, p. 293.
34 Brown, in Holmes (ed.), *op. cit.*, Chapter 1.
35 Colin McEvedy and Richard Jones, *Atlas of World Population History*, London, Allen Lane, 1978, p. 128.
36 Robert Clairborne, *Climate, Man and History*, London, Angus and Robertson, 1973, pp. 344–6.
37 Guoyu Ren, 'Pollen Evidence for Increased Summer Rainfall in the Medieval Warm Period at Maili, Northeast China', *Geophysical Research Letters*, vol. 25, no. 11, 1 June 1998, pp. 1931–4.
38 Gaur, *op. cit.*, pp. 103–4.
39 *Ibid.*, map on p. 47.
40 W.G. Kendrew, *The Climates of the Continents*, London, Oxford University Press, 1937, pp. 125–7.
41 George F. Hourani (revised by John Carswell), *Arab Seafaring in the Indian Ocean in Ancient and Early Medieval Times*, Princeton, Princeton University Press, 1995, pp. 74–5.
42 *Ibid.*, pp. 91–105.
43 Kevin P. Smith, 'Landnám: the Settlement of Iceland', *World Archaeology*, vol. 26, no. 3, February 1995, pp. 319–47.
44 Lecture by Tom McGovern to the Second International Conference on Climate and History, Climate Research Unit, University of East Anglia, September 1998.
45 Carl O. Sauer, *Northern Mists*, Berkeley, University of California Press, 1968, Chapter VII.
46 Thomas H. McGovern, 'The Economics of Extinction in Norse Greenland', in T.M.L. Wigley *et al.* (eds), *Climate and History*, Cambridge, Cambridge University Press, 1981, Chapter 17.
47 Hermann Flohn (B.V. de G. Walden, trans.), *Climate and Weather*, London, Weidenfeld and Nicolson, 1969, p. 210.
48 Michael J. Ford, 'Some Biological Effects of Recent Climate Changes', *Journal of Meteorology*, vol. 2, no. 20, June/July 1977, pp. 225–30, Fig. 4.
49 G.J. Marcus, 'The Greenland Trade Route', *Economic History Review*, Vol. VII, 1954–5, pp. 71–80.
50 *Ibid.*, p. 79.
51 McGovern, in Wigley *et al.* (eds), *op. cit.*, p. 421.
52 Vilhjalmur Stefansson, *Greenland*, London, George G. Harrap, 1943, pp. 123–43.
53 Bernt Balchen, *War Below Zero*, Boston, Houghton Mifflin, 1944.
54 Essay reproduced in full translation in Stefansson, *op. cit.*, pp. 122–4.
55 Chapter 3, 'The Norse and the Crusaders', in Alfred W. Crosby, *Ecological Imperialism. The Biological Expansion of Europe, 900–1900*, Cambridge, Cambridge University Press, 1986, p. 425.
56 McGovern, in Wigley *et al.* (eds), *op. cit.*
57 Crosby, *op. cit.*, p. 66.
58 Ellsworth Huntington, 'Changes of Climate and History', *The American Historical Review*, vol. XVIII, no. 2, January 1913, pp. 213–32.
59 *The Economist*, 31 October 1992.
60 William McNeill, *Plagues and People*, Garden City, Doubleday, 1976, Chapter III.
61 Kolb, *op. cit.*, p. 27.
62 Arlene Miller Rosen in Arie S. Issar and Neville Brown (eds), *Water, Environment and Society in Times of Climate Change*, Dordrecht, Kluwer, 1998, Chapter 10.
63 'Bringing Home the Harvest', *The Economist*, 15 November 1997, p. 126.
64 McNeill, *op. cit.*, pp. 187–8.
65 William H. McNeill, *The Pursuit of Power*, Oxford, Basil Blackwell, 1983, p. 60.
66 Ivan Hrbek of the University of Prague in J.D. Fage and Roland Oliver (eds), *The Cambridge History of Africa* (8 vols), Cambridge, Cambridge University Press, 1977, Vol. 3, p. 41.
67 Quinn, *op. cit.*

68 Hrbek, *op. cit.*
69 Michael W. Dols, *The Black Death in the Middle East*, Princeton, Princeton University Press, 1977.
70 Susan Scott *et al.*, 'The Origins, Interactions and Causes of Grain Prices in England, 1450–1812', *Agricultural History Review*, vol. 46, 1998, pp. 1–14.
71 Robert E. Ricklep, *The Economy of Nature*, New York, W.H. Freeman, 1993, Table 25.3.
72 Andrew M. Watson, 'The Arab Agricultural Revolution and its Diffusion, 700–1100', *Journal of Economic History*, vol. XXXIV, no. 1, March 1974, pp. 8–35.
73 William H. McNeill, 'World History and the Rise and Fall of the West', *Journal of World History*, vol. 9, no. 2, Fall 1998, pp. 215–34.
74 Robert S. Lopez, *Byzantium and the World around it*, London, Variorum, 1978, Chapter VII.
75 Robert Fossier in Fossier (ed.), *op. cit.*, Vol. II, pp. 320–6.
76 Richard Louis Edmonds, *Times Literary Supplement*, No. 4917, 27 June 1997, p. 4.
77 Sir Maurice Powicke, *The Thirteenth Century, 1216–1307*, Oxford, Clarendon Press, 1953, pp. 632–4.
78 David Hackett Fischer, *The Great Wave*, New York, Oxford University Press, 1996, Appendix B.
79 John H. Pryor, *Geography, Technology and War. Studies in the Maritime History of the Mediterranean, 649 to 1571*, Cambridge, Cambridge University Press, 1992, pp. 88–9.
80 Frederick C. Lane, 'The Economic Meaning of the Invention of the Compass', *The American Historical Review*, vol. LXVIII, no. 3, April 1963, pp. 605–17.
81 Pryor, *op. cit.*, pp. 39–51.
82 Map 'Commerce in the 14th Century', in Donald Matthew, *Atlas of Medieval Europe*, Oxford, Equinox, 1983, p. 133.
83 C.E. Bennett (trans.), *Horace, Odes and Epodes*, Cambridge, Mass., Harvard University Press, 1968, p. 13.
84 Arie S. Issar in Issar and Brown (eds), *op. cit.*, p. 125.
85 J. Neumann, 'Climate of the Black Sea Region around 0 C.E.', *Climatic Change*, vol. 18, no. 4, June 1991, pp. 453–65.
86 J.E. Chappell, 'Another Look at the Pulse of Asia', *Geographical Review*, vol. LX, no. 3, July 1970, pp. 347–73.
87 Jean M. Grove, *The Little Ice Age*, London, Routledge, 1990, p. 201.
88 Arie S. Issar, *Impacts of Climate Variations on Water Management and Related Socio-economic Systems*, Paris, UNESCO International Hydrological Programme, 1995, Fig. 5.
89 Peter Hopkirk, *Foreign Devils on the Silk Road*, London, John Murray, 1980, Map I.
90 McNeill, *Plagues and People*, *op. cit.*, pp. 195–6.
91 Edward Gibbon, *The Decline and Fall of the Roman Empire* (6 vols), London, Everyman's Library for David Campbell, 1994, Vol. 6, p. 378.
92 M. Malowist, 'The Social and Economic Stability of the Western Sudan in the Middle Ages', *Past and Present*, no. 33, April 1966, pp. 3–5 and 14–15.
93 Geoffrey Barraclough (ed.), *The Times Atlas of World History*, London, Times Books, 1978, pp. 140–1.
94 See the presentation by Constanta Boroneant and Marieta Chiper to the Second International Climate and History Conference, *op. cit.*
95 Leszek Starkel in Issar and Brown (eds), *op. cit.*, Fig. 12.4.
96 Pryor, *op. cit.*, p. 146.
97 Robert S. Lopez in M. Postan and E.E. Rich (eds), *Cambridge Economic History of Europe* (3 vols), Cambridge, Cambridge University Press, 1952, Vol. II, p. 353.
98 Pryor, *op. cit.*, p. 45.
99 *Ibid.*, p. 191.
100 H.H. Lamb, *Climate, History and the Modern World*, *op. cit.*, p. 207.
101 A. Mackay in Wigley *et al.* (eds), *op. cit.*, Chapter 15.
102 W.H. Parker, 'Europe: How Far?', *Geographical Journal*, vol. 126, Part 3, September 1960, pp. 278–97.

11 Pointers to a future

1 A.W. Ruddock, 'John Day of Bristol and the English Voyages across the Atlantic before 1497', *Geographical Journal*, vol. 132, 1966, pp. 225–33.
2 Jin-Qi Fang and Guo Liu, 'Relationship between Climatic Change and the Nomadic Southward Migrations in Eastern Asia during Historical Times', *Climatic Change*, vol. 22, no. 2, October 1992, pp. 151–68.
3 Nayan Chanda, 'Sailing into Oblivion', *Far Eastern Economic Review*, vol. 162, no. 36, 9 September 1999, pp. 44–6.
4 Malcolm Mackintosh, *Juggernaut*, London, Secker and Warburg, 1967, p. 200.
5 Walter Lord, *Incredible Victory*, London, Hamish Hamilton, 1968, p. 288.
6 A.R. Ubbelohde, *Man and Energy*, Harmondsworth, Pelican, 1963, pp. 25–7.
7 I.G. Simmons, *Environmental History. A Concise Introduction*, Oxford, Blackwell, 1983, p. 31.
8 Carlo Cipolla, *The Economic History of World Population*, Harmondsworth, Penguin, 1964, pp. 50, 52 and 58.
9 William H. McNeill, *The Pursuit of Power*, Oxford, Basil Blackwell, 1983, pp. 60–1.
10 Tony Allan (ed.), *The Age of Calamity, AD 1300–1400*, Amsterdam, Time–Life, 1989, Chapter 3.
11 Fekri A. Hassan, 'The Dynamics of a Riverine Civilisation: A Geoarchaeological Perspective on the Nile Valley, Egypt, *World Archaeology*, vol. 29, no. 1, June 1997, pp. 51–74, Table I.
12 William H. Quinn in Henry F. Diaz and Vera Markgraf (eds), *El Niño. Historical and Palaeoclimatic Aspects of the Southern Oscillation*, Cambridge, Cambridge University Press, 1992, Table 6.6.
13 McNeill, *op. cit.*, pp. 59–61 and 70.
14 William H. McNeill, *Plagues and People*, New York, Anchor Press, 1976, pp. 190–1.
15 *Ibid.*, pp. 160–2.
16 Tu-cheng Yeh *et al.*, 'An International Symposium on Climate in Beijing, People's Republic of China', *Bulletin of the American Meteorological Society*, vol. 66, no. 9, September 1985, pp. 1147–52.
17 D. Justin Schove, 'Chinese "Rainfall" through the Centuries', *Meteorological Magazine*, vol. 78, no. 919, January 1949, pp. 11–16.
18 X.D. Wu in Raymond S. Bradley and Philip D. Jones (eds), *Climate Since AD 1500*, London, Routledge, 1995, Fig. 22.4a.
19 Owen Lattimore, *Inner Asian Frontiers of China*, New York, Capitol Publishing for American Geographical Society, 1951, Chapter XVI.
20 Albert Kolb (C.A.M. Sym, trans.), *East Asia*, London, Methuen, 1971, p. 58.
21 From the author's 'Climate Change' in David Rundle (ed.), *The Hutchinson Encyclopedia of the Renaissance*, Oxford, Helicon, 1999, pp. 98–9.
22 Peter Burke (ed.) (K. Folca, trans.), *A New Kind of History from the Writings of Lucien Lefebvre*, London, Routledge and Kegan Paul, 1973, p. 266.
23 M.R. Pavese *et al.* in Bradley and Jones (eds), *op. cit.*, Chapter 8, Fig. 8.2.
24 Pamela Nightingale, 'England and the European Depression of the Mid-15th Century', *Journal of European Economic History*, vol. 26, no. 3, Winter 1997, pp. 631–51.
25 John Day, 'The Great Bullion Famine of the 15th Century', *Past and Present*, no. 79, May 1978, pp. 3–54.
26 Peter Clark in Peter Clark (ed.), *The European Crisis of the 1590s*, London, George Allen and Unwin, 1985, p. 4.
27 Christian Pfister in Bradley and Jones (eds), *op. cit.*, Fig. 6.4.
28 Ted Hughes, *Shakespeare and the Goddess of Complete Being*, London, Faber and Faber, 1992, Appendix II.
29 Eric Fromm, *Escape from Freedom*, London, Kegan Paul, 1942, p. 40.
30 Simone Weil, *The Need for Roots*, New York, Harper and Row, 1971, p. 45.
31 Marc U. Edwards, *Printing, Propaganda and Martin Luther*, Berkeley, University of California Press, 1994, p. 1.
32 Jean-François Gilmont in *Oxford Encyclopedia of the Reformation* (4 vols.), New York, Oxford University Press, 1996, Vol. 3, pp. 364–9.

33 Robert Wuthnow in Eugene D. Genovese and Leonard Hochberg (eds), *Geographic Perspectives in History*, Oxford, Basil Blackwell, 1989, Chapter 2.
34 R.W. Scribner, 'Why Was There No Reformation in Cologne?' *Bulletin of the Institute of Historical Research*, vol. XLIX, 1976, pp. 217–41.
35 Margaret Mann Phillips, *Erasmus and the Northern Renaissance*, London, Hodder and Stoughton, 1949, p. xii.
36 David E. Sopher, *The Geography of Religions*, Englewood Cliffs, Prentice Hall, 1967, p. 41.
37 Wuthnow, *op. cit.*, p. 37.
38 Henry J. Cohn, 'Anticlericalism in the German Peasants' War', *Past and Present*, no. 83, May 1979, pp. 3–31.
39 For a study of climate erraticism in north Italy then, see Emmanuela Guidoboni, 'Human Factors, Extreme Events and Floods in the Lower Po Plain in the 16th Century', *Environment and History*, vol. 4, no. 3, October 1998, pp. 279–308.
40 H.R. Trevor-Roper, 'The General Crisis of the 17th Century', *Past and Present*, no. 16, November 1959, pp. 31–64.
41 H.R. Trevor-Roper, *The European Witch Craze of the 16th and 17th Centuries*, Harmondsworth, Penguin, 1969, p. 112.
42 E.J. Hobsbawm in Trevor Aston (ed.), *Crisis in Europe, 1560–1660*, London, Routledge and Kegan Paul, 1965, Chapter 2.
43 *Past and Present*, no. 18, November 1960, p. 23.
44 Roland Mousnier (Brian Pearce trans.), *Peasant Uprisings in 17th-century France, Russia and China*, New York, Harper and Row, 1970, pp. xvii–xx, 312 and 331–2.
45 Zhaodong Feng *et al.*, 'Temporal and Spatial Variations of Climate in China during the Last 10,000 Years', *Holocene*, vol. 3, no. 2, 1993, pp. 174–80.
46 Russell D. Thompson, 'Short-term Climate Change: Evidence, Causes, Environmental Consequences and Strategies for Action', *Progress in Physical Geography*, vol. 13, no. 3, 1989, pp. 313–47.
47 Michael Bartholomew and Peter Morris in David Goodman and Colin A. Russell (eds), *The Rise of Scientific Europe, 1500–1800*, Milton Keynes, The Open University, 1991, Chapter 11.
48 Eino Jutikkala, 'The Great Finnish Famine in 1696–7', *Scandinavian Economic History Review*, vol. III, no. 1, 1955, pp. 48–63.
49 Irene Scobbie, *Sweden*, London, Ernest Benn, 1972, Chapter 2.
50 Hans Bergstrom, 'The Early Climatological Records of Uppsala', *Geografiska Annaler*, 72A 2, 1990, pp. 143–9.
51 Colin A. Russell in Goodman and Russell (eds), *op. cit.*, Chapter 12.
52 David G. Chandler, *The Campaigns of Napoleon*, London, Weidenfeld and Nicolson, 1967, Chapters 71 to 73.
53 W.H. Parker, *An Historical Geography of Russia*, London, University of London Press, 1968, Fig. 39.
54 H.H. Lamb, *The Changing Climate*, London, Methuen, 1966, pp. 65, 174–5 *passim*.
55 C.O. Grada, 'Irish Agricultural History: Recent Research', *The Agricultural History Review*, vol. 38, no. 2, 1990, pp. 165–73.
56 For a fuller account of the author's interpretation of these events, see D.C. Watt, Frank Spencer and Neville Brown, *A History of the World in the Twentieth Century*, New York, William Morrow, 1968, Part Three, Chapter III.
57 See the author's Chapter 24 in Russell D. Thompson and Allen Perry (eds), *Applied Climatology*, London, Routledge, 1997.
58 See the author's *The Strategic Revolution*, London, Brassey's, 1992, pp. 22–3.
59 A. Henderson-Sellers and K. McGuffie, *A Climate Modelling Primer*, Chichester, John Wiley, 1987, Chapter 2.
60 *The Strategic Revolution*, *op. cit.*, pp. 4–5.
61 Arnold Toynbee, *Cities on the Move*, London, Oxford University Press, 1970, p. 8.
62 Bill McKibben, *The End of Nature*, Viking Penguin, New York, 1990, Chapter 2.
63 William H. McNeill, 'Winds of Change', in Nicholas X. Rizopoulos (ed.), *Sea-Changes*, New York, Council on Foreign Relations, 1990, pp. 163–203.
64 R.S. Lindzen, 'On the Scientific Basis for Global Warming Scenarios', *Environmental Pollution*, vol. 83, nos. 1 and 2, 1994, pp. 125–34.

65 Arnold Toynbee, *Surviving the Future*, London, Oxford University Press, 1971, pp. 106–7.
66 E.P. Thompson, 'Notes on Exterminism, the Last Stage of Civilisation', *New Left Review*, 121, May–June 1980, pp. 3–31.
67 *21st Dimbleby Lecture* on BBC Channel 1, 12 November 1996.
68 Paul R. Ehrlich and Anne H. Ehrlich, *Betrayal of Science and Reason*, Washington, Island Press, 1996, especially Appendix A 'Brownlash Literature'.
69 J.T. Houghton (Chair), *Scientific Assessment of Climate Change, Report Prepared for the IPCC by Working Group 1*, Geneva and Nairobi, World Meteorological Organisation and United Nations Environment Programme, June 1990, Appendix I.
70 Lecture by Dr D.J. Carson at New Frontiers in Using Atmospheric Predictive Models, first National Conference by the Royal Meteorological Society and the Institute of Physics, University of Reading, July 1998.
71 Quoted in *Daily Telegraph*, 22 February 1990.
72 '*Scientific American*, vol. 283, no. 1, July 2000, p. 12.
73 Lamb, *op. cit*., p. 184, Fig. 8a.
74 *Ibid*., p. 70, Fig. 1a and p. 137, Fig. 17a.
75 H.H. Lamb, *Climate, History and the Modern World*, London, Routledge, 1995, Fig. 78.
76 William James Burroughs, *Weather Cycles, Real or Imaginary*? Cambridge, Cambridge University Press, 1992, pp. 61 and 92.
77 Otto Pettersson, 'The Connection between Hydrological and Meteorological Phenomena', *Quarterly Journal of the Royal Meteorological Society*, vol. 38, no. 163, 1912, pp. 173–91.
78 Lamb, *The Changing Climate*, *op. cit*., p. 180.
79 Crispin Tickell, *Climate Change and World Affairs*, Harvard Studies in International Affairs, No. 37, Cambridge, Mass., Harvard Centre for International Affairs, 1977, p. 45.
80 J.T. Houghton (ed.), *Climate Change 1995, The Science of Climate Change*, Cambridge, Cambridge University Press for IPCC, p. 173.
81 Joseph Smagorinsky, 'Problems and Promises of Deterministic Extended Range Forecasting', *Bulletin of the American Meteorological Society*, vol. 50, no. 5, May 1969, pp. 286–311.
82 Dr Edward N. Lorenz, 'The Future of Weather Forecasting', *The New Scientist*, vol. 42, no. 648, 8 May 1969, pp. 290–1.
83 Pfister, *op. cit.*
84 M.R. Dix and R.G. Hunt, 'Chaotic Influences and the Problem of Deterministic Seasonal Predictions', *International Journal of Climatology*, vol. 15, no. 7, July 1995, pp. 729–52.
85 Each authority cited in Joseph R. Strayer (ed.), *Dictionary of the Middle Ages* (13 vols), New York, Charles Scribner's, 1983, Vol. 3, p. 456.
86 Dr John Gladstones and Dr Richard Smart in Jancis Robinson (ed.), *The Oxford Companion to Wine*, Oxford, Oxford University Press, 1994, pp. 251–4.
87 Graham Pearson, former Director-General at the UK Chemical and Biological Defence Establishment at Porton Down, cited in the author's *Fundamental Issues Study within the British BMD Review*, Oxford, Mansfield College, February 1998, p. 66.
88 Alan H. Teramura and Joe H. Sullivan, 'How Increased Solar Ultra-violet B Radiation May Impact Agricultural Productivity', in John R. Topping (ed.), *Coping with Climate Change*, Washington, Climate Institute, June 1989, pp. 203–7.
89 James R. Harrington, 'Climate Change and the Canadian Forest, in Topping (ed.), *op. cit*., pp. 297–302.
90 A review that put soil firmly *primus inter pares* as a determinant of progress while seeking to steer between 'thoughtless optimism or blind pessimism' (p. 307) was Charles E. Kellogg, *The Soils That Support Us*, New York, Macmillan, 1943.
91 Gro Harlem Brundtland (Chair), *Our Common Future*, Oxford, Oxford University Press for World Commission on Environment and Development, 1987, pp. 125–6.
92 David E. Anderson, 'Younger Dryas Research and its Implications for Understanding Abrupt Climatic Change', *Progress in Physical Geography*, vol. 21, no. 2, June 1997, pp. 230–49.
93 W. Dansgaard *et al*., 'The Abrupt Termination of the Younger Dryas Climate Event', *Nature*, vol. 339, no. 6225, 15 June 1989, pp. 532–3.
94 Scott Stine in Arie Issar and Neville Brown (eds), *Water, Environment and Society in Times of Climatic Change*, Dordrecht, Kluwer, 1998, Chapter 3.
95 His Linacre lecture at Oxford, Michaelmas 1998.

96 For an excellent résumé of the debate thus far see A.T. Grove, *Progress in Physical Geography*, vol. 21, no. 2, June 1997, pp. 251–6.
97 J.L. Bintliff in Anthony Harding (ed.), *Climate Change in Later Pre-History*, Edinburgh, Edinburgh University Press, 1982, pp. 156.
98 Eric Priest, 'A Startling New Sun from Soho', *Astronomy and Geophysics*, vol. 39, issue 3, June 1998, pp. 3.10 to 3.13.
99 Neville Brown, *New Strategy Through Space*, Leicester, Leicester University Press, 1990, pp. 39 and 102.
100 Roger J. Tayler, *The Sun as a Star*, Cambridge, Cambridge University Press, 1997, pp. 55–60.
101 Nigel Calder, *The Manic Sun*, London, Pilkington Press, 1997, pp. 124–9 and 176–9.
102 B. van Geel, J. Buurman and H.T. Waterbolk, 'Archaeological and Palaeoecological Indicators of an Abrupt Climate Change in The Netherlands and Evidence for Climatological Connections around 2620 BP', *Journal of Quaternary Science*, vol. 11, 1996, pp. 451–60.
103 M. Lockwood *et al.*, 'Our Changing Sun', *Astronomy and Geophysics*, vol. 40, issue 4, August 1999, pp. 10–16.
104 See the author's *The Strategic Revolution*, *op. cit.*, pp. 60–2.
105 The author's 'The Myth of an Asian Diversion', *The Journal of the Royal United Services Institute for Defence Studies*, vol. 118, no. 3, September 1973, pp. 48–51.
106 Bill Forse, 'The Myth of the Marching Desert, *New Scientist*, vol. 121, no. 1650, 4 February 1989, pp. 31–2.
107 *Our Common Future*, *op. cit.*, pp. 291–2.
108 Norman Myers with Jennifer Kent, *Environmental Exodus*, Washington, The Climate Institute, 1995, Chapter 1, seems to me to err thus.
109 Sara Parkin, 'Environmental Security: Issues and Agenda for an Incoming Government', *Journal of the Royal United Services Institute for Defence Studies*, vol. 142, no. 3, June 1997, pp. 24–8.
110 *The Strategic Revolution*, *op. cit.*, pp. 23–4.
111 Evelyn Edson, *Mapping Time and Space*, London, The British Library, 1999, Plate VII and p. 40.
112 Albert Einstein, *The World As I See It*, London, Watts, 1940, pp. 96 and 105.
113 Edward Teller and Albert L. Latter, *Our Nuclear Future . . . Facts, Dangers and Opportunities*, London, Secker and Warburg, 1958, p. 167.
114 *New York Times* translation of Andrei Sakharov, *Progress, Co-existence and Intellectual Freedom*, New York, New York Times Book Service, 1968, p. 49.

Appendix A: Assessing past climates

1 Jin-Qi Fang, 'Establishment of a Data Bank from Records of Climatic Disasters and Anomalies in Ancient Chinese Documents', *International Journal of Climatology*, vol. 12, July–August 1992, pp. 499–519.
2 Magnus Magnusson and Hermann Palsson (trans.), *The Vinland Sagas*, Harmondsworth, Penguin, 1965, p. 15.
3 Jane Smiley and Robert Kellogg (trans.), *The Sagas of the Icelanders*, London, Allen Lane, 2000, p. xxxiii.
4 W.T. Bell and A.E.J. Ogilvie, 'Weather Compilations as a Source of Data for the Reconstruction of Climate during the Medieval Period', *Climatic Change*, 1, 1978, pp. 331–48.
5 A. Lewis Licht, 'The Rate of Naked Eye Comets from 101 BC to 1970 AD', *Icarus*, vol. 2, no. 137, February 1999, pp. 355–6.
6 F.R. Stephenson, 'Historical Evidence Concerning the Sun: Interpretation of Sunspot Records during the Telescopic and Pretelescopic Eras', *Philosophical Transactions of Royal Society of London*, A 330, 1990, pp. 499–512.
7 F. Richard Stephenson and David M. Willis, 'The Earliest Drawing of Sunspots', *Astronomy and Geophysics*, vol. 40, issue 6, December 1999, pp. 6.21 to 6.22.
8 H.U. Keller and T.K. Friedli, 'Visibility Limits of Naked-eye Sunspots', *Quarterly Journal of the Royal Astronomical Society*, vol. 33, no. 2, June 1992, pp. 83–9.
9 Stephenson, *op. cit.*, Fig. 4.

10 Xu Zhentao, 'Solar Observations in Ancient China and Solar Variability', *Philosophical Transactions of Royal Society*, A330, 1990, pp. 513–15.
11 R.S. Bradley, *Quaternary Paleoclimatology*, London, Chapman and Hall, 1985, pp. 369–79.
12 Emmanuel Le Roy Ladurie (Barbara Bray, trans.), *Times of Feast, Times of Famine*, London, George Allen and Unwin, 1972, pp. 43–4.
13 M.G.L. Baillie, *Tree-Ring Dating and Archaeology*, London, Croom Helm, 1982, pp. 213–17.
14 Harold C. Fritts *et al.*, 'Past Climate Reconstructed from Tree-rings', *Journal of Interdisciplinary History*, vol. X, no. 4, Spring 1980, pp. 773–93.
15 David W. Stahle *et al.*, 'Tree-ring Reconstructed Sunshine Duration over Central USA', *International Journal of Climatology*, vol. 11, 1991, pp. 285–95.
16 Akio Tsuchiya *et al.*, 'A Dendrochronological Study on the Influence of Environments upon Tree Growth in Chugoku District, Western Japan', *Japan Journal of Biometeorology*, vol. 33, no. 1, 1996. pp. 41–53.
17 Le Roy Ladurie, *op. cit.*, pp. 42–3.
18 *Ibid.*, p. 45.
19 I. Renberg, U. Segerström and J.E. Wallen, 'Climatic Reflections in Varved Lake Sediments', in N.-A. Mörner and W. Karlén (eds), *Climatic Changes on a Yearly to Millennial Basis*, Dordrecht, D. Reidel, 1984, pp. 249–56.
20 Bradley, *op. cit.*, Table 5.2.
21 Richard B. Alley and Michael L. Bender, 'Greenland Ice Cores: Frozen in Time', *Scientific American*, vol. 278, no. 2, February 1998, pp. 66–71.
22 C.U. Hammer *et al.*, 'Greenland Ice Sheet Evidence of Post-glacial Volcanism and its Climatic Impact', *Nature*, vol. 288, no. 5788, 20 November 1980, pp. 230–6.
23 J. Schwander and B. Stauffer, 'Age Difference between Polar Ice and the Air Trapped in its Bubbles', *Nature*, vol. 311, no. 5981, 6 September 1984, pp. 45–7.
24 David A. Peel, 'The Greenland Ice-core Project (GRIP)', *Natural Environment Research Council News*, April 1994, pp. 26–9.
25 Alley and Bender, *op. cit.*, pp. 69–71.
26 H. Flohn, 'A Possible Mechanism of Abrupt Climatic Changes', in Mörner and Karlén (eds), *op. cit.*, pp. 521–31.
27 Le Roy Ladurie, *op. cit.*, p. 266.
28 Bradley, *op. cit.*, Table 1.2.
29 Jean M. Grove, *The Little Ice Age*, London, Routledge, 1988, p. 2.
30 *Ibid.*, Table 2.2.
31 H.H. Lamb, *Climate: Present, Past and Future* (2 vols), London, Methuen, 1977, Vol. 2, Table 13.10.
32 Reid A. Bryson *et al.*, 'Radiocarbon and Soil Evidence of Former Forest in the Southern Canadian Tundra', *Science*, vol. 147, no. 3653, 1 January 1965, pp. 46–8.
33 Lamb, *op. cit.*, Vol. 2, pp. 208–13.
34 *Ibid.*, p. 210.
35 Thompson Webb, 'The Reconstruction of Climatic Sequences from Botanical Data', *Journal of Interdisciplinary History*, vol. X, no. 4, Spring 1980, pp. 749–72.
36 Andrew J. Davis *et al.*, 'Making Mistakes when Predicting Shifts in Species Range in Response to Global Warming', *Nature*, vol. 391, no. 6669, 19 February 1998, pp. 783–6.
37 Lamb, *op. cit.*, Vol. 2, p. 193.
38 Bradley, *op. cit.*, p. 317.
39 Lamb, *op. cit.*, Vol. 2, Table 13.11.
40 Frederick E. Zeuner, *Dating the Past*, London, Methuen, 1946, pp. 335–7.
41 W.F. Libby, 'Radiocarbon Dating', *Philosophical Transactions of Royal Society*, Series A, vol. 269, 1971, pp. 1–10.
42 Bradley, *op. cit.*, Fig. 3.7.
43 Dr David Miles in K. Branigan (ed.), *The Atlas of Archaeology*, London, MacDonald, 1982, p. 18.
44 Ivette Useinova, 'The Astounding Continental Factor', *Geographical Magazine*, vol. LXI, no. 10, October 1989, pp. 24–6.

45 William F. Ruddiman and John E. Kutzback, 'Plateau Uplift and Climatic Change', *Scientific American*, vol. 264, no. 3, March 1991, pp. 42–9.
46 N.J. Shackleton in J.R.L. Allen *et al.* (eds), *Palaeoclimates and Their Modelling*, London, Chapman and Hall for Royal Society, 1994, p. 3.
47 Peter Molnar, 'The Rise of the Tibetan Plateau', *Astronomy and Geophysics*, vol. 38, issue 3, June–July 1997, pp. 10–15.
48 You-xi Gao *et al.*, 'Some Aspects of Recent Research on the Qinghai–Xizang Plateau Meteorology', *Bulletin of the American Meteorological Society*, vol. 62, no. 1, January 1981, pp. 31–5.
49 Reid A. Bryson, 'Modelling the NW India Monsoon for the Last 40,000 Years', *Climate Dynamics*, no. 3, 1989, pp. 169–77.
50 Alastair Dawson, *Ice Age Earth. Late Quaternary Geology and Climate*, London, Routledge, 1992, Fig. 3.3.
51 I.C. Prentice *et al.* Quoted in Russell D. Thompson and Allen Perry (eds), *Applied Climatology*, London, Routledge, 1997, Fig. 10.4a.

Select bibliography

Pierre Alexandre, *Le Climat en Europe au moyen âge*, Paris, École des Hautes Études en Sciences Sociales, 1987.

J.R.L. Allen *et al.* (eds), *Palaeoclimates and their Modelling*, London, Chapman and Hall, 1994.

M.G.L. Baillie, *A Slice Through Time*, London, B.T. Batsford, 1995.

Roger G. Barry and Richard J. Chorley, *Atmosphere, Weather and Climate*, London, Routledge, 1998.

A. Berger (ed.), *Climatic Variations and Variability: Facts and Theories*, Dordrecht, D. Reidel, 1961.

John Boardman and David Favis-Mortlock (eds), *Climate Change and Soil Erosion*, London, Imperial College, 2001.

R.S. Bradley, *Quaternary Palaeoclimatology*, London, Chapman and Hall, 1985.

Raymond S. Bradley and Philip D. Jones (eds), *Climate Since AD 1500*, London, Routledge, 1995.

Rudolf Brázdil (ed.), *Climate Change in the Historical and Instrumental Periods*, Brno, Masaryk University, 1990.

J.H. Brazell, *London Weather*, Meteorological Office 783, London, Her Majesty's Stationery Office, 1968.

Peter Brimblecombe, *The Big Smoke*, London, Routledge, 1988.

C.E. Britton, *A Meteorological Chronology to AD 1450*, Geophysical Memoirs No. 70, London, HMSO for Meteorological Office, 1937.

C.E.P. Brooks, *Climate Through the Ages*, London, Ernest Benn, 1926.

I.E. Buchinsky (T.C. Marwick, trans.), *O Klimate Proshlogo Russkoy Ravniny*, Leningrad, Gidrometeoizdat, 1957.

M.I. Budyko, *Climate and Life*, New York, Academic Press, 1974.

William James Burroughs, *Weather Cycles. Real or Imaginary?* Cambridge, Cambridge University Press, 1992.

Nigel Calder, *The Manic Sun*, London, Pilkington Press, 1997.

Rhys Carpenter, *Discontinuity in Greek Civilisation*, Cambridge, Cambridge University Press, 1966.

John Claridge, *The Country Calendar or the Shepherd of Banbury's Rules*, London, Sylvan Press, 1946.

Victor Clube and Bill Napier, *The Cosmic Winter*, Oxford, Basil Blackwell, 1990.

Alastair G. Dawson, *Ice Age Earth*, London, Routledge, 1995.

Henry F. Diaz and Vera Markgraf (eds), *El Niño*, Cambridge, Cambridge University Press, 1992.

Hermann Flohn (B.V. de G. Walden, trans.), *Climate and Weather*, London, Weidenfeld and Nicolson, 1969.

E. Fukui (ed.), *The Climate of Japan*, Tokyo, Kodansha, 1977.

Jean M. Grove, *The Little Ice Age*, London, Methuen, 1988.

A.F. Harding (ed.), *Climate Change 1995*, Edinburgh, Edinburgh University Press, 1982.

John T. Houghton (ed.), *Climate Change 1995*, Cambridge, Cambridge University Press for Intergovernmental Panel on Climate Change, 1996.

Ellsworth Huntington, *Civilisation and Climate*, New Haven, Yale University Press, 1924.

Arie S. Issar, *Impact of Climate Variations on Water Management and Related Socio-economic Systems*, Paris, UNESCO, 1995.

Aris S. Issar and Neville Brown (eds), *Water, Environment and Society in Times of Climate Change*, Dordrecht, Kluwer, 1998.

L. Jeftic *et al.* (eds), *Climate Change and the Mediterranean*, London, Edward Arnold, 1992.

W.G. Kendrew, *Climates of the Continents*, London, Oxford University Press, 1937.

David Keys, *Catastrophe*, London, Century Books, 1999.

H.H. Lamb, *Climate: Present Past and Future* (2 vols), London, Methuen, 1977.

H.H. Lamb, *Climate: History and the Modern World*, London, Routledge, 1995.

H.E. Landsberg (ed.), *World Survey of Climatology* (15 vols), Amsterdam, Elsevier Scientific, 1981.

Emmanuel Le Roy Ladurie (Barbara Bray, trans.), *Times of Feast, Times of Famine*, London, George Allen and Unwin, 1972.

S.F. Markham, *Climate and the Energy of Nations*, London, Oxford University Press, 1944.

Nick Middleton, *Desertification*, Oxford University Press, 1991.

N.-A. Mörner and W. Karlén (eds), *Climate Changes on a Yearly or Millennial Basis*, Dordrecht, Reidel, 1984.

M.L. Parry, *Climate Change, Agriculture and Settlement*, Hamden, Archon Books, 1978.

W.D. Ross (ed.), *The Works of Aristotle*, Oxford, Clarendon Press, 1931.

L. Starkel *et al.* (eds), *Temperate Palaeohydrology*, Chichester, John Wiley, 1991.

F.H. Thompson (ed.), *Archaeology and Coastal Change*, London, Society of Antiquaries, 1980.

Russell D. Thompson and Allen Perry (eds), *Applied Climatology*, London, Routledge, 1997.

Kevin E. Trenbeth (ed.), *Climate System Modelling*, Cambridge, Cambridge University Press, 1992.

Claudio Vita-Finzi, *The Mediterranean Valleys*, Cambridge, Cambridge University Press, 1969.

T.M.L. Wigley *et al.*, *Climate and History*, Cambridge, Cambridge University Press, 1985.

Index

Note: page numbers in **bold** type refer to **figures**