A STUDENT GUIDE TO CLIMATE AND WEATHER

VOLUME 1

ANGUS M. GUNN

WEATHER EXTREMES

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Angus M. Gunn

GREENWOOD

AN IMPRINT OF ABC-CLIO, LLC
Santa Barbara, California • Denver, Colorado • Oxford, England

Library of Congress Cataloging-in-Publication Data
Gunn, Angus M. (Angus Macleod), 1920-
A student guide to climate and weather / Angus M. Gunn.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-313-35568-4 (set: hardcover: alk. paper) — ISBN 978-0-313-35569-1 (set: ebook: alk. paper) — ISBN 978-0-313-35570-7 (v. 1: hardcover: alk paper) — ISBN 978-0-313-35571-4 (v. 1: ebook) — ISBN 978-0-313-35572-1 (v. 2: hardcover: alk paper) — ISBN 978-0-313-35573-8 (v. 2: ebook) — ISBN 978-0-313-35574-5 (v. 3: hardcover: alk paper) — ISBN 978-0-313-35575-2 (v. 3: ebook) — ISBN 978-0-313-35576-9 (v. 4: hardcover: alk paper) — ISBN 978-0-313-35577-6 (v. 4: ebook) — ISBN 978-0-313-35578-3 (v. 5: hardcover: alk paper) — ISBN 978-0-313-35579-0 (v. 5: ebook)
1. Climatology. 2. Meteorology. 3. Climatic changes—Effect of human beings on. I. Title.
QC861.3.G86 2010
551.5—dc22 2009042256

14 13 12 11 10 1 2 3 4 5

This book is also available on the World Wide Web as an eBook.
Visit www.abc-clio.com for details.

ABC-CLIO, LLC
130 Cremona Drive, P.O. Box 1911
Santa Barbara, California 93116-1911

This book is printed on acid-free paper ♾

Manufactured in the United States of America

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INTRODUCTION

This is Volume One of a set of five books on weather and climate designed for schools and universities. These books are intended to provide two kinds of information: an understanding of the scientific processes at work in weather and climate, and an analysis of the ways in which weather and climate impact human life and the places where we live. The second of these goals is the more important of the two, as there are a number of books in print dealing with the scientific processes involved in weather and climate, but few on how weather influences our lives. Beginning in the first volume with aspects of the subject that impinge on us daily, such as the unpredictable nature of weather, we go on in the second and third volumes to deal with characteristic global weather patterns, before moving, in the last two books, into more general themes such as global warming and earth-sun relationships. A list of reference materials will appear at the end of each book to assist in linking together the different aspects dealt with in individual volumes.

The element of weather that catches our attention immediately is the extreme event, something that is unexpected, and so this aspect of the field is the subject of Volume One. Weather is what we experience day by day, and climate is what we expect to experience in a given season or in a particular part of the year. Generally the statistical average is what we use to calculate climate, and we define the different climatic regions of the world according to these averages. However, the things we remember and the things that get the most attention in the media are always the extreme events—floods, droughts, heat waves—and it is easy to forget that these rare events are as much a part of climate as the conditions that come close to the average. Furthermore, in many parts of the world on a regular basis, and over time in other places, it is the extreme events that have the greatest impacts on human life. For these reasons this first volume of the set on climate and weather is focused on extremes, beginning with the extremes we experience in the amount of energy from the sun.

The reason for our preoccupation with sudden extremes, even though they may occupy only a brief period of time, relates to our physical nature. If we are born into a place that is very hot or cold or dry, or have lived there for some years, our bodies gradually adjust to the environment, and we discover ways of living in it. The Kalahari Desert of southern Africa is extremely hot and very dry. Months often pass with no rain. One of the ways the native people who have lived there for thousands of years, known as Bushmen, coped with securing enough water for their needs was by finding plants that had deep roots and were able to draw up and store water from far below ground level. When we read about places such as the Kalahari Desert or the permanently frozen lands of northern Siberia, we think we could never live a normal life there because it is so different from where we now live. Our reactions to sudden extremes of weather where we live are exactly the same as our reactions to these distant locations. We react negatively because our bodies cannot adjust quickly to big changes.

The impacts of weather and climate extremes are multifaceted: they affect us, positively and negatively, in windstorms with the full range of form and speed; in disturbances in the atmosphere such as haze from burning fires, volcanic ash from eruptions, and reduction in energy received from the sun; and in temperature changes. Of all of these, the last-named is the one that interests us most, because temperature changes affect our bodies directly and immediately. The other types of events touch us less directly. For this reason, Chapter Seven is dedicated to experiences of extreme heat and cold that were seen to be very serious problems, in most cases problems with which people were ill-prepared to deal. We usually talk about weather extremes as hundred-year or two-hundred-year events, meaning experiences that, on the average, come once in every one hundred or two hundred years. The French heat wave of 2003 was a five-hundred-year event, and the Arctic cold wave was seen in northern Europe as a hundred-year event, even though comparable cold waves were experienced with less frequency than one hundred years.

The implication of these anomalies in timing is this: the global weather and climate system is enormously complicated, as we will see in Volume Four when we discuss ways of coping with global warming. Although we may assess recurrence rates based on averages, we always have to allow for rare combinations of different elements. Consider, for example, the fires in southern California from the Santa Ana winds of 2007. The total acreage burned was less than in the major fire seasons of 1889 and 2003. but more people than ever—one million—had to be evacuated. Both the size and duration of the average fire was greater than in earlier seasons, and the season as a whole was longer. Furthermore, the Santa Ana winds were described as being unusually fierce. Many people had to act very quickly to get out of their homes and stay ahead of the flames. What explanations for these changes did subsequent research provide? The main one was that the average annual temperature of the area had increased by 1.5°F since the previous fire season. A secondary explanation was twofold: increased population, and with that an increase in crime. Authorities suspect that arson was partly responsible for the fires.

Fires are frequent in southwest California, often in the coldest season. (Department of Defense)

CHANGING TEMPERATURES IN ANCIENT TIMES

The Great Ice Age, the theme of Chapter One, is included because it represents a time of extreme cold long before present-day humans lived on planet earth. If we want to show how weather influences human behavior, why should we include an example that is unrelated to our lives? The answer to this question is that these events of a million years ago will almost certainly come back again, as is explained in Chapter One. If humans live long enough, people in the future will have to cope with these extremes. Experts are so sure that they will recur that they describe the present time as an interglacial period, one that will be followed, thousands of years in the future, by a cold period like the one described in Chapter One. The chapter explains the many causal factors that created these ancient and longstanding spells of cold weather, factors that are as active today as they were a million years ago. We are not aware of most of them because their activities take place at a very slow pace.

One of these factors is volcanic eruptions, and we can readily understand these because we observe them at the present time. Fortunately, the eruptions that we see now are less violent than those that occurred in the earlier history of the earth. Toba, the violent eruption that happened in the place we now call Indonesia about 76,000 years ago, and about which we have gathered a lot of information from present-day research, is discussed in Chapter One because it had such a powerful influence on humans. It was so powerful that it almost destroyed the total human population of that time. Toba's gases and dust circled the whole earth for many years, cutting off all sunlight from the earth and thus drastically lowering the temperature. Later in this introduction reference is made to the influence, on a smaller scale, of a volcano on a U.S. flood. When we come to Chapter Two, about the Little Ice Age, another period of low temperatures extending over long stretches of time, we discover that an average change of as little as 3°F can profoundly alter the way of life of a whole country. This chapter describes the many aspects of human life in Europe that were changed when average temperatures changed by a few degrees.

The story of the Vikings from Scandinavia, who first appeared during the medieval warm period before 1300, provides a good illustration of European human life before and after the Little Ice Age. These pirates, named from a Norse word for pirate, roamed all over Europe and as far as the Mediterranean, the Middle East, and Russia, plundering cathedrals and homes during this warm period of prosperity and wealth. They traveled from Scandinavia by ship, not only to places in Europe but also to islands farther west, to Iceland, Greenland, and even to North America, five hundred years before Columbus. They lived and farmed for hundreds of years in the place now known as L'Anse aux Meadows, on the northern tip of the island of Newfoundland, in Canada. No historical records of their wanderings were kept, but archeological explorations in Newfoundland in the 1960s uncovered details of their lifestyle and homes. This place is now listed by the United Nations as a Heritage site. Had the Vikings learned to catch seals, like the Inuit, they could have lived on in Newfoundland when the cold period of the Little Ice Age began and they lost fodder for their animals. Instead they left North America, Greenland, and Iceland and returned to Scandinavia by 1450.

WEATHER AND WARS

Chapter Three relates to a rarely studied aspect of human behavior, the influence of weather on warfare. In ancient times, and right up to the twentieth century, warfare almost always involved moving an army or a navy from its familiar home base to a less familiar place. Past styles of warfare were usually launched in spring or fall because food supplies and good weather could be counted on at these times. All planning was devoted to tactics and knowledge of the enemy's resources. Weather, although probably an unknown quantity in the enemy's terrain, was not considered important. Meteorological equipment that could help in forecasting was not available throughout most of history, but even when such equipment was available it was often not used. The example in Chapter Three of Admiral Halsey being caught in a typhoon could have been avoided. The tools needed to track these destructive storms were available. Demand for these tools, in that case, followed rather than preceded the event.

A disaster similar to the one experienced by Admiral Halsey occurred in Russia in 1854 during the Crimean War between Britain and Russia. Although little was known at that time about weather forecasting, the effects of the Russian winter on Napoleon's army in 1812 were well known. In 1854, as winter camp was being prepared in the Crimea, the whole area was overwhelmed by a major storm. The entire British camp was destroyed, and a fleet of supply ships in the neighboring Black Sea was sunk. The results were catastrophic: horses died of hunger, and more than 20,000 British soldiers died from exposure and lack of food. The officer in charge immediately ordered an investigation into the source of the storm and requested that a weather station be built, one of the first known attempts in military strategy to take an accurate account of weather conditions.

Weather was a critical element in the United States during conflicts over both independence and national unity. Both of these were fought within the Little Ice Age. Reference is made in Chapter Three to the courageous action of Washington in the face of very rough weather conditions. During the Civil War, there were occasions when weather decided the outcome of an attack. General Burnside, late in 1862, made a special effort to get to Fredericksburg ahead of the Confederate Army. His men marched 40 miles in two and a half days, arriving opposite Fredericksburg on November 17, well ahead of his enemy. Unfortunately, the pontoons he had ordered to bridge the Rappahannock were not there, leaving him with few options. He could try to cross upstream, but heavy rains rendered the river impassable. He could try to cross downstream, under the protection of Union gunboats, but miles of bad road lay between. Finally he decided to wait for the pontoons—and, while he waited, his enemy organized a defense across the river. Civil War battles were rarely fought in winter, and this one, delayed by weather until December 12, resulted in the loss of more than 12,000 men.

DROUGHTS, FLOODS, AND ATMOSPHERIC DUST

Chapter Four deals with the dramatic story of the Dust Bowl, the extensive desertification of the Midwestern United States in the 1930s that left its mark on American literature and movies. It cast a shadow on both immigration and the development of the West, because it was the newcomers from Europe and those from the east coast who ventured westward to build a new life. The Dust Bowl coincided with the global Great Depression, so the tragedies of the lives that were ruined appeared to America and the rest of the world within a much larger setting. In fact, droughts in America's Midwest are regular occurrences, as is pointed out in Chapter Four, but none of those that came later have carried the pathos of the one in the 1930s. Droughts, periods with too little water, are phenomena that occur all over the world. The opposite of droughts—that is, floods, when there is too much water—are equally ubiquitous. Areas that were part of the Dust Bowl are also the places where America's worst floods have occurred.

Chapter Five deals with major floods on three different continents, each triggered by weather events. China, in Asia, comes first because it has experienced greater damage from floods than any other major country in the world. The other two continents examined are North America and Europe; examples of floods are taken from the United States and the Netherlands. For the most part, floods are not immediately caused by specific weather conditions, but in these three examples, they were—and each example begins with a description of the weather before and during the time of the flood. In the U.S. flood, a volcanic eruption played a role as a modifier of temperature and rainfall. Over the long period of the earth's history, volcanic eruptions have been frequent modifiers of weather. In the example of the flood in the United States described in Chapter Five, the volcano in question was Pinatubo, which is in the Philippines. Its 1991 eruption was one of the most powerful of the twentieth century. Its ash circled the globe for at least two years, so drastically reducing the amount of energy reaching the earth from the sun that it lowered the average world temperatures by 2°F.

In addition to the influence of volcanic eruptions on rainfall, tropical cyclones—or hurricanes, as we know them in the United States—are responsible for serious flooding. Floods caused by hurricanes have not been on the scale of the Mississippi floods, but the volume of water involved is sufficient to demand much more attention. We will examine hurricanes in Volume Three of this series of books.

Students standing on the roof of their school after mud-swollen rivers had destroyed it, following the eruption of Mount Pinatubo. (U.S. Geological Survey)

The National Oceanic and Atmospheric Administration (NOAA), in their concern over flooding from this source, began in 2005 to compile details of all U.S. hurricanes that brought nine or more inches of rain to their landfall site within two days of touching down.

Chapter Six deals with drought in Kenya as well as in the broad sub-Sahara region of the Sahel, a part of Africa that frequently experiences droughts. Kenya is south of the Sahel. Its exceptional drought was caused by yet another element that influences weather, the arrival of the El Niño/La Niña pair.

There is one more very extreme event that is described in Chapter Seven: it is the heat we receive from the sun, warmth that is generated by nuclear explosions, just like atomic bombs, at the center of the sun, then radiated out into space. Fortunately there are filters, including the ozone layer high in the upper atmosphere, that protect us from the parts of the sun's radiation that would harm us. By examining the nuclear explosions that we have created on earth, we can better understand the nature of the radiation that comes to us from the sun and the urgency of protecting protective layers such as the ozone that are constantly under threat from the aerosols emitted by industrial operations and volcanic activities.

ARCTIC WARMING AND EUROPEAN COOLING

Chapter Eight is an introduction to the important contemporary problem of global warming and changing climates, a theme that will be described in more detail in Volume Four of this set. It is included in this volume because it is also an example of extreme temperature changes. Both Chapter Eight and Chapter Nine deal with the extraordinary, very fast rate of melting of Arctic ice. It is being seen by the United Nations and expert climatologists everywhere as an example of what might happen in he future all over the Arctic and Antarctic regions unless something is done to control the causes of the melting. The government of Canada, the country that is most affected by global warming in the Arctic, has an Internet atlas that outlines future possible levels of temperature and precipitation in places all over the world. How to access this atlas is explained in Chapter Nine, which describes conditions on the island of Kivalina. At the time of this writing, this atlas is available to anyone at no cost.

The fate of the polar bear is one of the more poignant outcomes of what is happening now in the Arctic. This animal is an icon of the Arctic, an object of fascination for young and old alike. It is the world's biggest land predator, and it has no natural enemies. The male bear can weigh as much as one thousand pounds. It hunts only from *sea ice,* from which it can catch fish and seals. For this reason it spends much of the year on the frozen sea or on ice floes. Although polar bears are born on land, their survival depends on access to masses of ice floating in the Arctic Ocean. As recently as 2008, their total numbers were considerably below normal, and typical weights were also below average. The Arctic Climate Impact Assessment Council reported in 2004 that the average weight of polar bears had dropped by 15 percent since 1985. A few years later, Western governments talked about making polar bears an endangered species.

Earlier in this introduction the interconnectedness of all aspects of weather was pointed out; that is to say, if one aspect of weather or climate is changed, other parts of the whole system may also change. The reality of this characteristic is particularly evident when the Arctic region begins to warm up. There is an ocean conveyor belt called the Gulf Stream that brings warm water to the Arctic along the east coast of the United States. It flows close to the surface, and its warmth raises temperatures on both sides of the Atlantic Ocean. As it reaches Arctic waters, it cools down and therefore becomes heavier. It also becomes saltier and thus heavier as water is withdrawn from the ocean to form ice. The heavier water sinks and creates a return flow of water that maintains the whole circulation. Now consider what happens when Arctic water gets warmer and ice melts. Already for some years now, experts are seeing that the Gulf Stream is slowing down. Its warmth is decreasing as this happens, and there are fears that if this continues, the climate regimes of the eastern United States and northwest Europe might change into much colder ones.

TOMORROW'S NORTHWEST PASSAGE

It is already quite evident, as will be explained in Chapter Eight, that a sea passage to Asia via northern Canada is now available, at least for part of each year. Such a route had been dreamed about by European nations for centuries, because they needed the spices, especially pepper, from the islands of Indonesia to flavor meats that were stored all winter. Peppercorns were considered in these earlier times to be as valuable as their weight in gold, and stevedores at ports had their pockets tied shut to prevent the theft of them. In modern times the value of a Northwest Passage (NWP) has taken on new meaning. Cargo ships going from the eastern United States or from Europe to Asia can save time and costs by using the NWP rather than the present one, the Panama Canal. The advantage is the same for Asian nations shipping goods to the United States or Europe. However, there is an emerging interest that may prove to be far more attractive financially than any reduction in the cost of shipping. It is the prospect of brand-new oil and gas fields in the Arctic seabed.

On either side of the International Date Line, west of Alaska, exploration for oil and gas in the seabed has been going on for some years, led by U.S. scientists and probably also by Russian ones, although Russia is still at capacity exploiting its land-based resources. Preliminary findings indicate that there are enormous potential quantities available. The only two uncertainties remaining are the speed of Arctic warming so that easy access to the seafloor can be anticipated and permissions that must be obtained from the relevant governments. The huge increase in the price of oil over the past few years makes it economically easy to venture into uncharted territory, as long as there is firm evidence that oil is available in some form. This relates to the story of Alberta's Tar Sands. Everyone knew that, potentially, these sands contained almost unlimited amounts of oil, but they remained untouched until the price of oil rose above fifty dollars a barrel. Now these oil reservoirs rival in production most of the oil-producing countries of the world. Will we see before long another oil bonanza like the Tar Sands, this time in the Arctic?

Both the advantages for shipping and the glittering prospect of new oil resources are creating fresh conflicts over national rights throughout the Arctic. Historically, not much attention was paid to such questions. Canada claims full rights over those parts of the NWP that pass through its territory, but this view is rejected by the United States and the European Union. They argue that it must be treated as an international strait, open to vessels of any nation. Even tiny Hans Island in Baffin Bay led to conflict between Canada and Denmark in 2007, with both Canada and Denmark claiming it, something that would never have reached the public press fifty years ago. In 2007 Russia sent a submarine into the Arctic to plant a Russian flag on the ocean floor, and in the same year Norway and Russia argued over the rights to an area of ocean north of Norway in the Barents Sea. It is unlikely that any of these disputes will be resolved soon, because very little surveying has been done throughout this vast area, and it is doubtful that United Nations resolutions on ownership apply in these waters.

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CHAPTER 1

The Great Ice Age and Volcanoes

The most extreme experience of weather and climate in all of human history took place during the Great Ice Age, the period of time within the last million years in which both North America and Europe were covered with massive sheets of ice. Earlier glaciations had covered the earth from time to time as far back as two billion years ago, but they occurred long before the appearance of humans. As many as nine glaciations took place within the million years of the Great Ice Age, each lasting for 80,000 years or more, and each separated from the others by interglacial phases of less than 20,000 years each. Ice sheets were often thousands of feet thick, and climatic conditions were much

Can You Make a Thermometer?

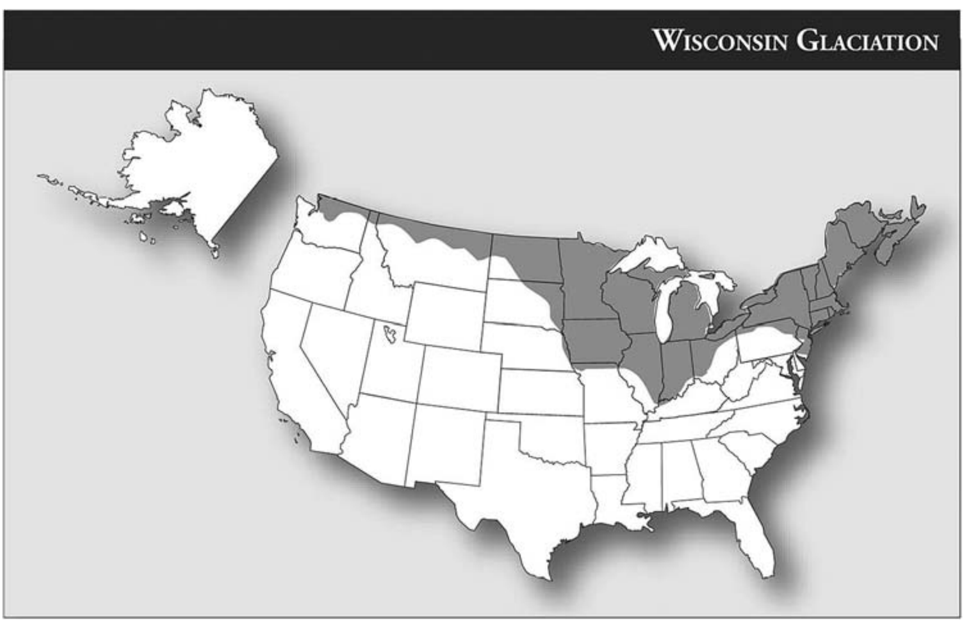
We can measure the temperature of the surrounding air wherever we are by using an instrument called a thermometer. One of the best ways to understand how this measuring instrument works is to make one. To do this, you need the following things: water, rubbing alcohol, a clear narrow-neck plastic bottle, food coloring, a drinking straw, and a small piece of modeling clay.

Pour equal parts of water and rubbing alcohol into the bottle, filling about one quarter of the bottle. Add a little food coloring and mix all three components. Put a straw in the bottle, making sure as you do this that it does not touch the bottom of the bottle. Avoid any contact with the rubbing alcohol, because it is a harmful liquid, and be sure to recycle the bottle after you have completed the experiment to ensure that no other person touches the alcohol. While holding the straw so that it does not touch the bottom of the bottle, use the modeling clay to seal the neck of the bottle and, at the same time, to fix the straw into place. You now have a thermometer. This is not a complete thermometer, because that would require finding the scale marks for the side of the bottle to tell the real temperature. However, you do have a thermometer that works, even if it is not complete.

Place your hands around the thermometer you have made. What happens? Just like in any other thermometer, the mixture expanded when it was made warmer by the heat from your hands. The liquid was no longer able to fit into the space it previously occupied, so it moved upward into the straw. If the bottle were to be exposed to greater and greater amounts of heat, the liquid in the straw would rise higher and higher until it poured out at the top. Test out your thermometer in different locations to see that the liquid goes down in the straw when you place the instrument in a colder place and up in the straw when in a warmer one.

colder and wetter than those of today. During the interglacial phases—the periods of time when the ice had melted—climates were frequently warmer and drier than those of today. The Great Ice Age finally ended, in North America, in a rapid melting of the Wisconsin ice about 15,000 years ago. Many geologists describe our present situation as an interglacial one, which will be followed sometime within the next few thousand years by another glacial period.

What causes these extraordinary, longstanding changes in weather and climate, and why was the final phase of the Wisconsin glaciation so important for humans? These are two quite different questions, each stemming from different causes, so they will be examined separately, beginning with the problem of the very large longstanding changes. Everything that happens in climate and weather is dependent in one way or another on the energy that comes from the sun. On the whole, our sun is very stable, sending out a steady stream of energy that sustains life on our planet. Sometimes part of the energy that would normally reach the earth is absorbed by or reflected from clouds or other gases in the atmosphere, and so the earth receives less than the usual amount. Thus from day to day there may be temperature fluctuations, even though the energy output from the sun is generally constant. Because humans have been on the earth for only a very small part of the earth's history, we tend to focus on changes that happen within short periods of time. What happens if there are changes in the amount of energy reaching us from the sun that occur once in eleven years or once in thousands of years?



Maximum extent of glaciation in the U.S. during the Great Ice Age. (ABC-CLIO)

LONG-TERM CHANGES IN EARTH-SUN RELATIONS

One change that is repeated on average every eleven years is what we know as sunspot cycles. It is the shortest of these long-term changes, and it is familiar to scientists. Huge magnetic storms occur in the sun at these times, some of them so big that their effects, dark spots on the face of the sun, are visible on a clear day without the aid of a telescope. When these storms are at their maximum, they can extend across an area greater than the width of the earth. These storms radiate highly charged atoms from the sun that collide with the earth's magnetic field and create the well-known auroras, which are brightest around the North and South Poles. The amount of energy that the sun emits increases and then decreases as a sunspot event builds up to a maximum and then fades to a minimum. The total amount of energy involved may be very small when compared with the total output of the sun, usually less than one thousandth of the normal amount, but it represents a large change in the amount of energy available on earth.

Scientists do not know the causes of these sunspot cycles. Occasionally in the long history of the earth, exceptional phases have occurred. One of these happened during the Little Ice Age: the minimum phase of a sunspot cycle stayed constant for seventy years, from 1645 to 1715. In both Europe and North America, rivers stayed frozen for longer periods every year.

A second change in earth-sun relationships comes from changes in the earth's orbit around the sun. Every year slight changes in the earth's orbit gradually move the earth farther away from the sun. This occurs over a period of time that is approximately 100,000 years. By the end of this period, because the sun is farther from the earth, the earth's temperature decreases, and ice sheets form. These glaciers stay in place until the earth's orbit returns closer to its present position. These orbital changes are always happening; they are the reason that geologists call the present time an interglacial phase.

A third change relates entirely to the movement of tectonic plates on the surface of the earth, a phenomenon that is unique to earth. Other nearby planets in our solar system do not have tectonic plates. Over millions of years continents are forced to change locations by the movements of these tectonic plates. At one time North America, Europe, and Asia were all much closer to the North Pole than they are now. As a result of the movement of the continents southward, the warm ocean currents that normally flow into north polar seas were cut off. This caused temperatures to drop, and ice sheets began to form on parts of these continents. These slow changes in the locations of continents are taking place all the time as the great tectonic plates move around the earth, changing the prevailing temperature patterns. About once in every 250 million years they manage to bring all of the continents together into a single mass, forming one continent.

There is a fourth long-term change that needs to be included here because of its extraordinary impact on human life. It is unique in the class of volcanic eruptions. It is the eruption of Mount Toba in the country we now know as Indonesia. The general problem and influence of volcanic eruptions will be discussed in the next section, and further descriptions of eruptions like Toba, to which we give the name supervolcanoes, will come in Volume Four when future prospects are discussed in the light of climate changes. Toba will give us a good introduction to these because it will show what did happen in the past and will certainly happen again in the future—hopefully far in the future, but that is uncertain. Volume Four explains why theis uncertainty exists when it describes the dangers associated with Yellowstone, the site of a past supereruption. Reference has already been made to the Wisconsin phase of ice; it is because Toba's eruption coincided with this phase that it is such an important eruption.

The eruption of Toba impacted human life more powerfully than any other known event within the past 100,000 years. Geological research in modern times has uncovered extensive evidence of its action. As the mass of material from the eruption circled the earth, it blocked out the sun's rays all over the world for six years, lowering the already low temperature caused by the ice to –44°F. Global temperatures stayed very low for a further thousand years. During this period of time, drought and famine were widespread. Many of the larger forms of life, including humans, died. This was the first volcanic eruption to threaten the whole human race. Fewer than 30,000 humans are estimated to have survived by moving to warmer climates in southern Africa. Rapid evolutionary changes occurred among them, as always happens in very small populations. In time, as climatic conditions improved, this remnant of humanity spread out across the whole world to form the human population of today.

Geneticists believe that Toba's catastrophic effect on humans 74,000 years ago, when they were still at an early stage of development, almost amounted to the total destruction of hominids of that time. The population may have been reduced to a few thousand people, pushing humanity to the edge of extinction. *Homo sapiens* had become an endangered species. The evidence for the catastrophic reduction in the human population around the time of Toba comes from an analysis of mitochondrial DNA that revealed a limited genetic diversity, far lower than the known age of humans would indicate. Not until 50,000 years ago, 20,000 years after Toba, is there evidence of a rapid and widespread increase in the numbers of humans. In order to test the validity of their calculations regarding humans, geneticists examined the mitochondrial DNA of chimpanzees to find out if they too had been victims of the same environmental disaster. The results were conclusive. They had experienced a disastrous reduction similar to that of humans.

VOLCANIC ERUPTIONS AND EXTREMES OF WEATHER

The big differences between ancient eruptions and those that have happened during the past two thousand years can be seen in the volcanic explosivity index (VEI), the scale we now use to compare the strengths of different eruptions. The Tambora eruption that will be described later in this chapter had a value of 7. All others within historical records had VEIs of 6 or less. Fortunately for us, the small stretch of time occupied by humans in the billions of years of the earth's history has experienced only minor eruptions. Far greater ones appeared again and again in earlier times. Recently, a team of international scientists, including some from Oregon State University, investigated volcanoes off the coast of Greenland and in the western British Isles from about 55 million years ago. They discovered evidence of ancient, unknown eruptions that were so powerful that the volumes of carbon dioxide and methane they sent into the atmosphere triggered a 200,000-year period of warming. Ocean temperatures rose 9°F higher in tropical regions, and 11°F higher in the Arctic areas, during this 200,000-year period. There was a planetary emergency in terms of life forms. Almost half of all the bigger forms of life in the oceans died. This particular period of time in the earth's history represented the beginnings of very great volcanic eruptions.

The huge impact of volcanic eruptions on our atmosphere has intrigued scientists for centuries. Volcanic eruptions are as unpredictable as earthquakes in their time of arrival, and in their outcomes in the various effects they cause in weather, wind systems, and precipitation they are equally unpredictable. One of the earliest observers of volcanic eruptions was Benjamin Franklin. He suggested that the very

Why Is Temperature Measured in Degrees Fahrenheit?

In the United States, temperature is measured in degrees Fahrenheit, usually written as °F. Fahrenheit is a temperature scale named after Daniel Gabriel Fahrenheit, the German physicist who proposed it in 1724. In this scale, the freezing point of water is defined as 32°F and the boiling point as 212°F, which places the boiling and freezing points of water 180 degrees apart. For more than two centuries Fahrenheit's system was used throughout the English-speaking world. Then, in the second half of the twentieth century, during and after the 1960s, most of the countries that had been using Fahrenheit switched to a different scale, the Celsius scale in which the freezing point of water is defined as 0°C and the boiling point as 100°C. The United States retained the Fahrenheit scale for most purposes. The change to Celsius in many countries was related to the introduction of the metric system. It uses a multiples of 10 or 100 in most measurements.

It is often necessary, in dealing internationally, for U.S. companies and scientists to change measurements in Fahrenheit to Celsius. Since the Fahrenheit scale extends over a range of 180 degrees, from 32 to 212, each degree is 1.8 times larger than a Celsius one. Thus to convert to Celsius, a person needs to subtract 32 from the Fahrenheit measurement and divide the remainder by 1.8. The following example of changing 212°F to degrees Celsius shows how the calculation is done: first subtract 32 from 212, which gives 180. Divide 180 by 1.8, and you get 100°C. To change 100°C back to Fahrenheit, you multiply 100 by 1.8 to get 180. You then add 32, which gives 212°F. These two calculations are easy. In most instances the answer is not a whole number. The coldest place was recorded in Antarctica in 1983: –128.2°F, or –89°C. The hottest place was found in Libya in 1922: 136.4°F, or 58°C.

cold winter of 1784 in northern Europe was caused by an eruption in Iceland, a place that, because it is situated on top of two great tectonic plates, frequently experiences volcanic eruptions. We know that eruptions inject dust and sulfur dioxide into the upper atmosphere, leading to the formation of sulfuric acid aerosols that remain aloft for years and circle the entire globe. These tiny dust veils cut off some of the sun's incoming radiation, but they allow the longer-wave radiation from earth to escape into space.

Hubert Lamb, an expert British meteorologist, pointed out that the path taken by dust veils in the atmosphere depends on whether the eruption occurred near the equator or near the North Pole. For the former, the slow drift northward of air in the stratosphere takes several months, but the dust reaches the whole earth. For the latter, only the northern hemisphere is affected. In both instances, the effects persist longest in northern areas. Sometimes, a volcanic eruption could occur without being observed, and therefore it was difficult to explain the unusual changes in weather. In the years 1981–1982, for instance, an important dust cloud appeared in an area close to the equator, but there was no information available on any eruptions. Two volcanic eruptions had occurred in these two years, one in Zaire (now the Democratic Republic of Congo) and one in the Mariana Islands, but cloudy weather had hindered detection by regular satellite photography. This is something that would not happen now because aerial photography is no longer completely dependent on visual observation.

Large numbers of people are killed in eruptions. The reason for this goes back to historical times. Volcanic soils are the richest on earth, and in centuries past, agriculture was the main source of income for people. People lived close to volcanoes, often on their slopes. Over time, as other sources of livelihood emerged, people remained in their traditional locations. Indonesia, with its many volcanic mountains, is a rich agricultural area. Often, villagers were able, and still are able, to plant and harvest three crops on the same piece of land. In order to compare the magnitude of one eruption with another, scientists use the VEI scale, which is similar to the one used for measuring earthquakes, the Richter Scale. Each number on the VEI represents an increase in power by a factor of ten; that is, an eruption with a VEI of 6 is ten times more powerful than one with a 5.

Fortunately, the eruptions that have occurred during the period of recorded human history have been small in comparison with the massively destructive events that shook the earth in earlier times. Some of these huge eruptions will almost certainly reappear in the future. Keeping in mind the factor of ten that is added with each increasing VEI number, the following numbers for some well-known eruptions will confirm the typical lower strengths that were experienced within the period of recorded human history: Krakatau, Indonesia (1883), 6; Mount St. Helens, Washington, United States (1980), 5; Mount Pelée, Martinique (1902), 4; Surtsey, Iceland (1963), 3.

Volcanic deposits from volcanoes help create rich, productive soils. (Shanin/Dreamstime.com)

TAMBORA ERUPTION

The only eruption of magnitude 7VEI within recorded human history was Tambora, in eastern Indonesia, in 1815. Tambora was a huge mountain, 13,000 feet high and 38 miles wide at its base. Four thousand feet were blown off the top of this mountain by the eruption, and two million tons of debris rose into the sky as high as 28 miles, darkening the sky for several days as it circled the earth. The heavier particles fell back to earth, crushing many homes. Overall, in eastern Indonesia, there were more than 90,000 deaths, most of them a result of starvation and disease after everything around their homes had been obliterated. Mount Tambora burned for three months before coming to rest. The effects of this event were felt around the world because the finer particles continued to circle the earth for years, thus reducing the amount of heat received from the sun.

Temperatures dropped all over the world, and crops failed in many countries. In the United States, the year after Tambora, 1816, came to be known as the year without a summer because of the widespread reduction in the amount of crops and the poor quality of the crops that were grown. The sound of the eruption had been heard in western Sumatra, a thousand miles away. The heavier fragments of lava that fell back into the ocean created mini eruptions from which quantities of fine dust were added to the already darkened atmosphere. The actual volume of ash produced by these secondary eruptions was ten times greater than the amount generated by the original eruption. The devastation locally in places within a hundred miles of the eruption is well illustrated in the experiences of the villagers of Bima, a small community at the eastern end of Sumbawa, the island on which Tambora stood. For several days following the eruption, they were shaken day and night by the ongoing explosions that followed the main eruption.

A dense ash cloud in the atmosphere above Bima completely shut out the sun for four days, a reminder of Vesuvius, where the people also experienced total darkness at midday after an eruption. The weight of fallen ash was too much for most of the homes, and they collapsed. At the same time, throughout the early hours following the eruption, tsunamis flooded the village, just as they had done elsewhere on the island of Sumbawa. Later, government officials found innumerable corpses of people and animals on the ground around Bima or floating nearby in the sea. In different places around the world, the impact of Tambora was not as dramatic as it was in Bima, but it was nonetheless enormously destructive. Reports from northern Europe described the harvests for the year that followed as being so poor that starvation was common among poorer families. The Industrial Revolution was still young, and people for the most part were totally dependent on what they could wrest from the soil. Many were reduced to eating rats. Grain prices rose fourfold in that part of the world, and, when other countries tried to be capitalize on the shortage, the price of grain on the international market rose extremely high.

France suffered more than other countries of western Europe because it had been involved in the Napoleonic wars right up to the year 1815, and the whole social life of the country had been severely strained from the stresses of warfare. In the year 1816 farmers were afraid to take their produce to market because of the danger of being robbed by hungry people along the way. Government troops had to be called in frequently to protect these farmers. In the United States, farmers in New England had so many crop failures over such large areas that many of them migrated westward to Ohio and elsewhere. All over Indonesia, in addition to the immediate destructive effects of the eruption, masses of ash, rock particles, and sulfur dioxide gas were deposited everywhere, and they continued to cause problems year after year for some time. Sulfur dioxide is a colorless, poisonous gas used in the manufacture of sulfuric acid, a highly toxic substance. Its presence in the air created complications for the digestive systems of both humans and animals, causing many deaths. Lack of rain was another consequence of the disaster. New soil forms quickly in tropical areas that experience volcanic eruptions because of the rich soil.

The collection of thousands of islands we now call the nation of Indonesia always held a fascination for the people of Europe, largely the result of the value of spices in centuries past. Marco Polo was the first to acquaint the West with what was then called the Spice Islands. That was about eight hundred years ago, long before spices gained in importance. By the middle of the nineteenth century, and after considerable success in both farming and stock rearing, Europeans were faced with the problem of preserving meat in winter. Animals were slaughtered in the fall to reduce the cost of feeding them. The meat was then salted away in iceboxes to preserve it for six or more months. The taste of salted meat after all that time was, to say the least, not very attractive, and Europeans discovered that one specific item from the Spice Islands, pepper, profoundly enhanced the meat's flavor. Trade in pepper between Indonesia and Europe became a top priority. So great was the value of this commodity that a single peppercorn was considered to be worth its weight in gold. The spice trade was still going strong in 1815, when the eruption of Tambora affected Europe and the rest of the world, and every effort was being made to sustain this spice trade, because Europe, with its developed agricultural industry, had suffered more than anywhere else from the eruption.

FUTURE SUPERERUPTIONS

The island chain that is now known as Indonesia extends in a curved form for more than four thousand miles. Closely following the islands on their south side but deep below sea level stands the tectonic boundary between the Indo-Australian tectonic plate and the Eurasian one. The Indo-Australian plate is moving northeastward beneath and slightly faster than the bigger Eurasian one, and this subduction is the main cause of the numerous volcanic eruptions and earthquakes that occur in Indonesia. Within the overall picture of these two huge tectonic plates, there are movements of smaller components of each that can at times be extraordinarily destructive. The gigantic earthquake of 2004 off the coast of Sumatra was caused by the Indian portion of the Indo-Australian Plate

Damage to a Sumatran village after Indonesia's massive tsunami of 2004. (U.S. Navy) subducting under the Burma portion of the Eurasian Plate. This created one of the most powerful earthquakes of all time.

None of this was known at the time of the Tambora eruption, but now it is vital information for meteorologists as they seek to anticipate future events. The tsunami that accompanied the 2004 earthquake, which radiated outward from the entire 750 miles of plate that had been displaced, is also likely to go down in history as the most destructive. It was literally an earth-shattering wave, and it took several minutes for the displacement to be completed. The island on which Tambora stands is more than two hundred miles north of the tectonic boundary. The magma that rises from below this boundary has to travel upward from far below that boundary, and then about two hundred miles north of it to reach the summit of Tambora and cause the eruption. It is the work of meteorologists to trace as completely as they can both the source of the magma and its age. Only by doing this can information be found on the past history of volcanic activity as big as Tambora's, which can be used to forecast when another eruption might occur.

The sea floor is the top of the outermost solid layer of the earth's surface, known as the crust, which is often several miles thick. Below the crust is where the magma exists, and there have to be weaknesses or fault lines in the crust for the magma to rise to the surface. One such fault line stretches northwestward for 150 miles from the island of Sumba across the tectonic boundary to the island of Sumbawa, the site of Tambora. It was through breaks in this fault line that magma built up over the centuries. Scientists did not know very much about either tectonic plates or subduction at the time of Tambora's eruption. It was about 150 years later that the secrets of the earth's mosaic of tectonic plates became known. Ever since that time, scientists have been busy making use of this new knowledge to trace the history of eruptions. The age of the oldest lava from previous eruptions on the site of Tambora is about 50,000 years, and the youngest are the layers of ash and rock that were deposited on Indonesia in 1815. Beneath these deposits are some older rocks, about five thousand years old.

These discoveries, although only partial, give meteorologists at least one clue to the likelihood of another Tambora-type eruption arriving soon. If the time difference between the 1815 event and the one that came before it is five thousand years, then one possibility is that there will not be another one before another five thousand years. Much more work needs to be done by scientists on the history of eruptions in this part of Indonesia in order to obtain the average time between these destructive events over the millions of years during which they have occurred. Only when armed with data of that kind are we able to estimate possible future eruptions. Even before Tambora erupted, people had some warning of what was about to happen, but they did not know how to interpret the information. There were noisy steam explosions, sometimes followed by dark clouds of volcanic ash, from time to time before 1815. These things were the result of hot magma encountering moisture as it rose within the mountain.

CHAPTER 2

The Little Ice Age

As other times and locations are examined, it soon becomes clear that extremes of weather and climate are as frequent as the averages. Furthermore, any change in weather is more disruptive than a continuation of an existing pattern. Over time we adjust to a particular regime of weather and get used to living with it, but a sudden change upsets life for some time. Between the years 1450 and 1850, Europe and North America experienced temperature levels that were much lower than those of today. This four-hundred-year period came to be known as the Little Ice Age because, like the Great Ice Age, it extended over a long period of time. The extremes of temperature, and the variations in rainfall that were caused by them, were not consistent over the four hundred years. There were short stretches of time in which temperatures reached the levels of the earlier warm years, but, during the time of lowest temperatures, from about 1350 onward in Britain, the story of life there is one of great hardship. Famines were frequent, and epidemics took hold because people were unable to resist disease.

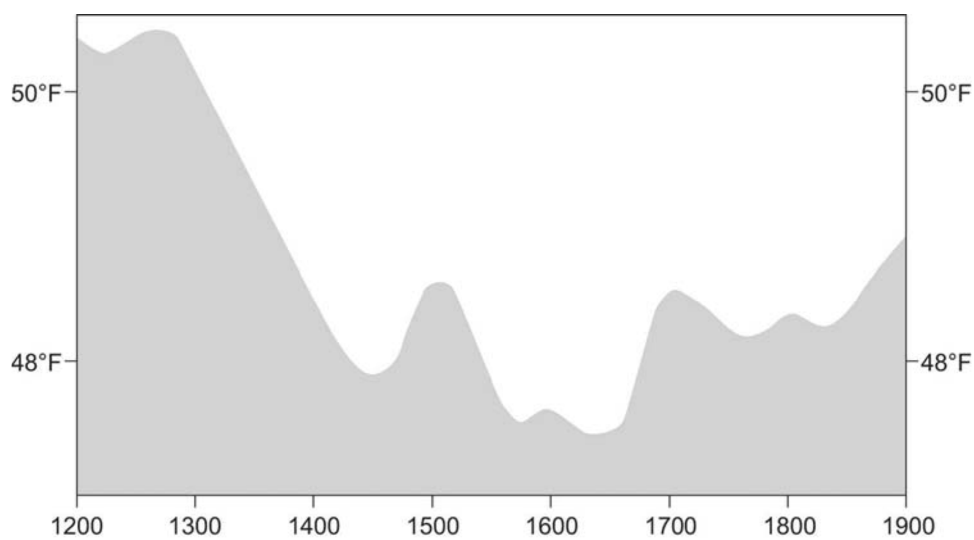


Figure 2-1 Average annual northern hemisphere temperatures during mild Medieval times and colder Little Ice Age period. (ABC-CLIO)

On Roanoke Island, near the coast of North Carolina, Sir Walter Raleigh sought, in 1585, to establish England's first settlement in the new world. Everything had to be abandoned after six years because of the low temperatures. Even when the Jamestown colony was established in 1607, it had to endure several years of drought. Conditions were probably similar in other parts of the northern hemisphere and in a few southern regions, but there are few records of these compared with those available in Europe, so scientists turned to this part of the world to find descriptions of prevailing conditions. In those times there were no instruments for documenting the weather of the kind with which we are familiar today, so we rely on descriptions of daily life, particularly agricultural activities, as most people lived and worked on farmland, to discover the effects of weather. Only a small percentage of a nation's population lived in cities at this period of history. One example of the impact of weather was the disappearance of grape cultivation in southern England. Prior to 1350 this was a major industry. By 1450 the nearest location where grapes were still grown commercially lay three hundred miles farther south, in France. The cargoes carried by ships and the taxation levels imposed by governments were other useful sources of information from which temperature and precipitation levels could be inferred.

BEFORE THE LITTLE ICE AGE

Between the years 900 and 1300, all of Europe experienced great prosperity. The overall population was estimated to have increased fourfold over these four centuries. In England, between 1200 and 1300, there was a threefold increase in population. The contrast between these times, often referred to as the Medieval Warm Period, and the Little Ice Age, is very great. In the latter, the widespread devastation reduced Europe's population by 1715 to what it had been in 1315. The Medieval Warm Period was also marked by ventures beyond their borders by some European countries. There was sufficient wealth to make these explorations possible. The most extensive of these ventures were the pillages of the Vikings all over Europe, and in their eventual settlement in Newfoundland, Canada, the first European contact with North America, about five hundred years before Columbus.

The Crusades were a different kind of venture by Europeans, a series of military campaigns against Muslims in the Middle East, who, in 1076, had captured Jerusalem. This city was seen by Christians of that time as the most holy of holy places, so, with strong support from the Catholic Church, armies were organized so that Christians could get Jerusalem back. The Muslim occupiers of the city fought back, and conflicts ensued. The several Crusades, as these wars were called, continued for two hundred years. It is an interesting coincidence that they all ended before 1300, that is to say, before the Little Ice Age. It may be that some of the debilitating effects of the changing weather had some influence on the ending of these wars. The enormous influence they had on the countries of southern Europe and the Middle East did not end in 1300. They persisted right up into modern times.

EUROPE AFTER 1300

Beginning with the Great Famine of 1315 to 1317, Europe, from Russia and Scandinavia in the east to Britain and Ireland in the west, experienced a succession of crises that would last for a very long time. Millions of people died, a sharp contrast to the earlier period of prosperity. There were crop failures that began in the spring of 1315 and continued into the summer of 1317. Overall, the Little Ice Age was a period marked by extreme levels of hunger, criminal activity, disease, and at times even cannibalism. Famines became familiar events at different times in different places. During the Great Famine, 50,000 people died in London, partly due to the onset of what came to be known as the Black Death, a scourge that recurred again and again in succeeding years. The average life expectancy in Britain in 1276 was 35.28 years. Between 1301 and 1325 it was 29.84 years, and between 1348 and 1375, during the initial experience of the Black Death, it dropped to 17.33 years. In addition to the reduced life expectancy, the average height of people was substantially less than it is today.

The Black Death first appeared in Europe in Italy, carried from Asia, probably in fleas that traveled with cargoes. They passed on the pestilence to rats, and when the rats died, the fleas passed on the disease to humans. In 1347 a ship arrived in Italy with everyone aboard dead. The last to die apparently was able to get the ship into port before he passed away. Very little was understood at that time about contagious diseases, so all the port authorities could do was take the ship out to sea and sink it, but by then it was too late to stop the spread of the disease. The illness quickly spread across Europe, crossing the English Channel and reaching London by 1348. The new pestilence was named the Black Death because those affected by it developed black boils all over their bodies after infection, caused by dried blood accumulating under the skin. Soon after infection the victims experienced fevers and the disruption of their digestive systems. Finally their lungs failed, and they died.

The new infection spread quickly across London, carried from person to person through the air as they breathed. Before the year 1348 ended, almost half of London's population was dead. Periodically over the three centuries that followed, wave after wave of the Black Death bacteria swept over London and other parts of England, taking many lives. The reasons for the continued success of the illness lay in the cold weather that had ravaged agriculture all over northern Europe. Had people been better fed, they might have been able to resist the disease. In addition, the carriers of the infection, fleas and through them black rats, thrived in the poor hygienic conditions that characterized London. The last and most violent of all the waves of

Engraving of a plague victim. Bubonic plague was widespread during the Little Ice Age. (Library of Congress)

infection that reached London arrived in 1665. At that time London had a population of half a million. Throughout the warm summer months of 1665, seven thousand lives were lost every week. Panic set in; as many as could fled the city. The number of dead became so great that it was impossible to bury them all.

An interesting but puzzling report was found in later years among the public records of 1665: some individuals never caught the disease even though they had been exposed to infected individuals. In one case it was a gravedigger who seemed to be immune. Hundreds of years later, in the 1990s, a member of the staff of the U.S. National Institute of Health (NIH) who had heard about this report decided to find out if there were any people living today who were direct descendants of those who had not been infected in the epidemic of 1665. He located several, and when he took DNA samples, he discovered that all of them carried a certain gene that was not present in the general population. This was the secret of their ancestors' immunity. To his amazement, the NIH scientist subsequently found that this same gene gives people immunity to the human immunodeficiency virus (HIV).

THE FIRST EUROPEANS REACH NORTH AMERICA

The Vikings of Scandinavia broke onto the European stage around the beginning of the warm period prior to 1300. They were a violent people, plundering churches and monasteries from Norway to Greece and from Russia to England. They defined a large stretch of European history as the Viking age. They traveled farther than other Europeans had gone, and they established a network of communication over great distances, exploiting the wealth of the continent and exploring the uncharted waters of the North Atlantic. They were pirates, and their name was derived from a Norse word meaning pirate. Along the paths they traveled, particularly in rural areas near the sea, the traditional prayer of the people was, "Lord save us from the Norsemen." The towering "brochs" of northern Scotland, cylindrical stone towers into which people fled at any sign of a Viking raid, bear witness to the terror they evoked.

Beyond the confines of Europe, Viking sailors traveled west across the northern Atlantic, first to the Faeroe Islands, then to Iceland and beyond that to Greenland, so named by them because, in those warmer climates of early Medieval times, they found large areas near the coast where farming was possible. They settled in these places and farmed. Around the year 1000 a small group of them sailed westward from Greenland as far as the northern coast of the place we now know as Newfoundland, Canada. They had no maps and no knowledge of the vast area west of the place at which they landed. They were the first Europeans to reach North America. In all probability they had no understanding of the significance of their achievement. In the 1960s the site of this ancient settlement, known as L'Anse aux Meadows, was excavated, and the location is now a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage site. Six house sites were identified, the largest being about 60 feet in length and containing several rooms.

During the approximately three hundred years of their stay in L'Anse aux Meadows, the Viking settlers hunted and maintained their livestock-raising lifestyle. They made contact with both Inuit and Indian communities and traded with them. As the long period of

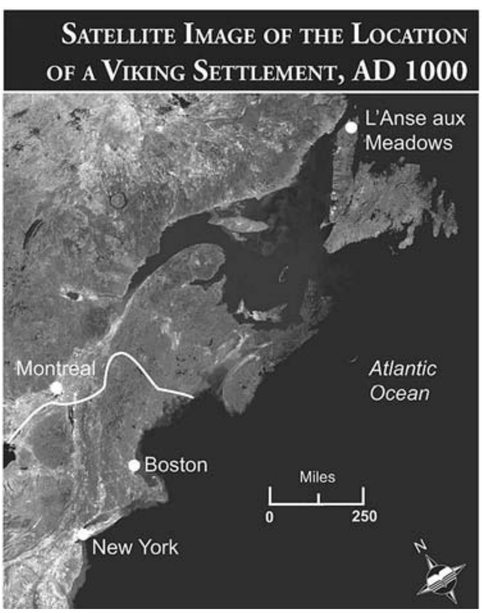


Figure 2-2 We do not have much information about the lifestyles of the first Europeans to settle in North America, because L'Anse aux Meadows was only discovered and excavated in the 1960s. (NASA)

warmer climates gave way to the approaching Little Ice Age, they tried to survive by hunting animals and catching fish because their grazing land no longer provided enough food for their animals. By 1450 this Viking society that had existed on the edge of the European world in Iceland and Greenland for almost five hundred years, and for three hundred years in L'Anse aux Meadows, came to an end within a short period of time. All three Viking locations were abandoned. Regular communication between North America and Europe was not restored for another three hundred years.

Had they learned from the Inuit to hunt seals, they could have lived on in the New World, but in all probability they were already in conflict with the native people because of competition for marine mammals. The experience of the Vikings was an example of a large series of settlements in three places having to close down because of climate change. Changes like these influenced the first settlements in North America to a greater degree than societies in Europe, because the newcomers knew very little about their new environment. Small changes in temperature could have extreme effects on human settlement. The Viking settlement in Canada had to be abandoned as the Little Ice Age arrived.

THE IRISH POTATO FAMINE

At the very end of the Little Ice Age, it was a minor and comparatively short-lived change of weather that caused the worst social and economic crisis ever experienced by one small European country, Ireland. In the first half of the nineteenth century this country was poor, and largely dependent on potatoes for its main food supply because its damp climate could not support the cultivation of wheat. In 1845, in a cargo of potatoes that arrived in Belgium from South America, a potato disease was discovered on the ship, one that was new to everyone in Europe, so there was neither interest nor ability to do anything about it. Before long, prevailing winds carried the germs of this disease all over Europe. In colder countries, farther north, the disease could not take hold, but in southern areas, especially in Ireland, it flourished, almost entirely due to a warm spell that reached Ireland in 1845 and stayed for several years. It created the perfect conditions for the spread of the disease. Year after year potato crops were ruined all across the country. Ireland's population had been growing fast in the years before 1845, from 6.5 million to 8.5 million within 25 years. Most of the people lived on small rural plots of land that were barely sufficient to prevent starvation. Over a period of two years after 1845 famine appeared everywhere in Ireland. Relief measures in the form of corn shipments from the United States failed to cope with the widespread devastation. Thousands died every year. By 1851 the national death toll had reached a million, but before that date millions had already left the country to settle in North America.

CHAPTER 3

Weather and Warfare

The influence of weather and climate is often overlooked in reports of warfare. Successes and failures are accounted for by the actions of great leaders. In reality, weather and climate are often the factors that determine success or failure. It was at Christmas time in 1776, at a low point of morale among the troops because of the series of losses they had experienced, that George Washington led his forces across the Delaware at night. The ice-clogged water and the fierce winds from a northeast blizzard made the crossing a dangerous venture. British forces, encamped at Trenton, were convinced that no one would try to cross on that night. Early the next morning, while it was still dark, Washington marched with his forces for nine miles, taking the British forces at Trenton by surprise and routing them, thereby restoring confidence among the rest of the army.

Military leaders, when faced with conflict, give a lot of attention to the kind of weather they might encounter, and they generally conclude that it is likely to conform to what they know or can predict.

Figure 3-1 George Washington crossing the Delaware River, 1776. Painting by Emanuel Leutze. (National Archives)

That usually means the average, the kind that happens most of the time. However, as we have already noted, the exceptional or the extreme occurs frequently, and, because it is exceptional, it seriously disrupts our lives. An unexpected delay, a common event in warfare, is often sufficient to cause major changes in the weather and thereby, often, changes in the outcome of the war. The experiences of Napoleon in 1812 and Hitler in 1941 are outstanding examples of huge armies failing because of the extremes of temperature they encountered but had not anticipated.

In 1812, Napoleon invaded Russia with a huge army, tens of thousands of horses, and abundant supplies. He planned to bring the war to a conclusion within three weeks by forcing the Russians to fight a major battle. It did not happen that way. There were delays because of the narrow roads, exhaustion of soldiers because of the summer heat, and the failure of foraging for food as they traveled. Foraging was part of the plan to minimize the amount of food they had to carry. Napoleon discovered that the agricultural areas of Russia were very poor, and the Russians had already used their scorched-earth tactics to make sure that nothing would be left for the advancing French troops. All of these things slowed down the army, and the dream of ending the invasion in less than a month faded into the reality of having to cope with a Russian winter.

In addition, there was no army to fight and no resources to pillage. The Russians had abandoned Moscow, leaving behind nothing that could be of value to the invading army. There was no other choice for Napoleon than retreat, and he began this painful march in mid-October. The Russian winter had arrived by that time with all of its severity. Ice and snow covered the roads, making transport nearly impossible. Horses slipped on the ice and could not be lifted back to their feet. Men began dying of exposure, freezing to death where they fell as the temperature dropped lower and lower. Starvation began to devastate the ranks. By the time they reached home, only one out of every six of the original army survived. Tchaikovsky's 1812 Overture, a celebration of Russia's triumph over France, was a painful reminder of the disaster.

The German invasion of the Soviet Union began in June 1941. Like that of Napoleon it began in June with the expectation that the conquest of Moscow would be complete before winter, and like Napoleon's experience, this hope was frustrated by unexpected developments: the guerilla-type attacks by Russian soldiers and arbitrary changes in plans by the direct involvement of Hitler. At one point the army was ordered to stop its advance on Moscow for about six weeks in order to give help to other advancing German forces. The various delays meant that the German Army was still some distance from Moscow by mid-November, when, because neither men nor machines had been outfitted for extreme cold and the Russian winter had fully set in, the general in charge wanted to turn back. Hitler insisted that he continue to advance. Finally, in the face of the army's inability to cope with the cold weather, Hitler permitted a retreat. The returning soldiers faced the same appalling suffering as those that overwhelmed Napoleon's troops in 1812.

THE SPANISH ARMADA

At a time of powerful nations and even more powerful kings, Philip II, King of Spain, and Elizabeth I, Queen of England, warring against one another, created one of the largest conflicts of the sixteenth century. The development of this hostile relationship involved both personal and political issues. Spain thought it was the most powerful nation on earth, partly due to its Armada, a fleet of armed ships that was seen to be invincible, a power with which it felt it could rule the world. At the time this Armada was launched Spain had control of most of South and Central America and many of the countries of Europe. Philip II was anxious to add Britain to his list of possessions because he felt he was already its king on the basis of his marriage to the sister of Elizabeth I. However, Philip I was a Catholic, and England was a Protestant country, a very important difference in those days.

In 1587 Elizabeth had Mary, Queen of Scots, executed. In Philip's mind she was the one hope of making England a Catholic country. He

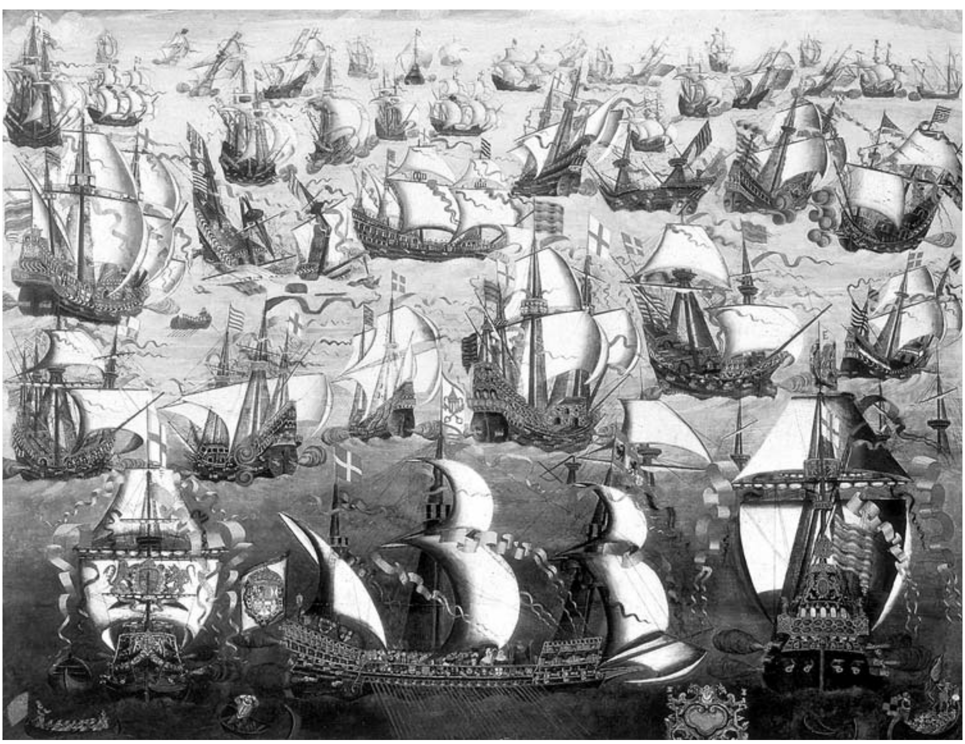


Figure 3-2 Half of the Spanish Armada was lost due to extremely bad weather as it tried to circumnavigate Britain. (Photos.com)

immediately organized his Armada and set off to conquer England. The British Navy was no match for Spain at this time, but Elizabeth I, despite that limitation, was determined to prevent England from becoming a Catholic country again. She had one outstanding naval captain, Sir Walter Raleigh, who had fought skirmishes with the Spanish Navy, capturing some of their ships as they came back from South America with cargoes of gold. The Spaniards hated him. Queen Elizabeth gave him the job of advising her captains on the best way of coping with the Armada. Raleigh had several boats filled with firewood and set alight. They drifted toward the Armada as it approached England, terrifying its captain, who fled.

The Spanish captain decided to take his ships and men back to Spain and try again at a later date. The only route he could take lay around the north coast of Scotland and down the west coast of Ireland. The winds would not let them head back down the English Channel to head straight home to Spain. However, as records revealed later, weather conditions all around Britain had never been worse than they were in 1588. This was a time of low temperature in the middle of the Little Ice Age, and Arctic ice had greatly increased in volume and extent. Large volumes of ice lay close to the coasts of Ireland and Scotland. The sea ice extending southward from Greenland had moved so close to the Scottish coast that Inuit canoes were observed along these coasts searching for seals. The increased ice cover greatly strengthened the winds circulating around the cyclonic storms. The captain of

How Are Wind Speed and Direction Measured?

Before the nineteenth century almost every ocean-going vessel was a sailing ship, dependent on wind as the source of power to propel the ship. It was therefore extremely important that captains of ships knew the strengths of the winds they might encounter. They also needed to know the directions from which the prevailing winds might come. Lack of this knowledge caused many disasters at sea. The anemometer is one of the many instruments used to measure wind strength. It employs three rotating cups and dates from the seventeenth century. Over the years different people made changes to improve its accuracy, but the basic model remained very much the same. Wind speed was calculated from the average speed of the cups. Until the year 1991, wind direction was obtained by the use a weather vane, a freewheeling arrow mounted on a post. The arrow indicated the direction in which the prevailing wind was blowing.

In 1991 an Australian nautical engineer added a small curved attachment to one of the cups of the anemometer. It was a simple modification, but it gave information about wind direction without having to also consult a weather vane, which was never a very accurate instrument at sea because of the constant motion of the ship. As the cups spun around under pressure from the wind, the cup with the extra attachment would move faster at one point in the cycle and slower at another depending on the orientation of the attachment toward the wind. Wind speed continued to be calculated as before on the basis of the average speed of the cups, but now wind direction could be found by measuring the cyclical changes in the speed of the cup with the attachment.

the Spanish fleet, a massive armada of 130 vessels, was completely unaware of these weather conditions. His ships, able to sail successfully in the milder latitudes south of the English Channel, were quite unsuitable for the weather they were about to encounter as they sailed around Scotland and Ireland. Half of his ships and most of the 30,000 men who had sailed in them were lost.

THE KAMIKAZE WIND

The Mongol emperor Kublai Khan, who was introduced to the West by Marco Polo when he traveled from Italy to China in the thirteenth century, tried in 1281 to capture Japan by invading it from the sea. He had tried earlier and failed, so this time he greatly increased the size of his fleet, expanding it to more than 4,000 vessels with a total crew of about 100,000. He planned to land on the west side of the island of Kyushu, but some time before reaching that place his fleet was struck by a strong typhoon. Many of the ships in his fleet were not able to withstand the winds, and they sank. So great was the loss of men and ships that the invasion was abandoned. To the Japanese of the time the typhoon was a divine wind sent to save Japan and so the word "kamikaze," meaning divine wind, was added to the Japanese language. In 1981, seven hundred years after the failed invasion, Japanese scholars uncovered parts of 70 ships from Kublai Khan's fleet that were submerged off the south coast of Japan, embedded in mud about six feet below the seabed.

In World War Two, the term "kamikaze" was given new meaning and new prestige as a description of young Japanese pilots who made suicide attacks on U.S. ships with planes that were loaded with bombs. This approach was taken as military pressure increased against Japan, and its military leaders felt unable to oppose the U.S. warships in open conflict at sea. The young kamikaze pilots flew their planes directly into their targets, killing themselves in the process. These young fliers volunteered for their missions out of loyalty to their Emperor and country, and their actions met with considerable success. On December 18, 1944, yet another kamikaze-type typhoon damaged ships at sea, this time a naval task force under the command of Admiral Halsey. Halsey and his task force were caught unaware while refueling their ships in the Philippines. Once again, as has been the case in so many other places, the weather experts failed to understand the track of the typhoon they had sighted. Halsey and his task force sailed directly into its path.

Heavy ocean swells that were thrown up by the typhoon tossed his ships around like toys. Before he could alert the other ships, he lost three destroyers. Aboard the aircraft carrier Monterey, the planes in the hangar deck slammed into one another and started fires. Halsey gave orders for the crew to abandon ship, but the carrier's captain decided to fight the fires and save the ship. He succeeded. On the carrier Cowpens, it was a story similar to the Monterey. When the fleet finally emerged from the typhoon, Halsey found seven more ships seriously damaged and 146 aircraft lost or unusable. In the course of all this, eight hundred lives had been lost. One immediate action that followed this tragedy was the establishment of new weather stations in the Caroline Islands. Later, weather stations were set up on Manila, Okinawa, and Guam.

D-DAY WEATHER FORECASTS

Near the end of World War Two in Europe, as the D-day invasion of France by thousands of ships was approaching, the whole enterprise was totally dependent on an accurate prediction of weather. The lives of more than half a million soldiers were at stake, but predicting a stretch of good weather was an extraordinary challenge. All of Britain's summer up to the time scheduled for the invasion had been the worst in living memory, with nearly constant rain and high winds. Six meteorologists worked in different teams to come up with a forecast for June 5, the day proposed by General Eisenhower for launching the invasion. The U.S. team, using the traditional analog method of forecasting, was overly optimistic and said that June 5 would be clear with low levels of wind. The other team, with experts from both

Soldiers landing on the beaches of France: D-Day, June 6, 1944. (National Archives)

Britain and the Norwegian school of meteorology, had been using the method of air mass analysis, and they urged a delay. There was much debate and tension as these two viewpoints were discussed.

The analog method, still in use by the United States in 1944, searched for a type of weather from the past that matched present conditions and used that particular historical event to forecast the next day's weather. Weather satellites and radar did not exist at that time. Most weather observations were made using weather instruments stationed on the ground. This made it difficult to track and study a storm that had high winds and high temperatures thousands of feet above the earth. Such a situation needed the air mass analysis method, and, fortunately, this was the one that was selected. Had the other option been followed, the entire enterprise might have been a catastrophic disaster. No other event in modern warfare was more dependent than this one on accurate weather forecasts. (We will examine in more detail the differences between these two methods of weather forecasting in Volume Two when we examine the causes of weather and the roles that huge air masses play in their creation and expression.)

The invasion of France had to occur between June 5 and June 7 to take advantage of the right conditions of the moon and tidal levels in the ocean. Darkness was needed when the airborne troops landed, and moonlight was needed once they were on the ground. Spring low tide was necessary to ensure low sea level so that the landing craft could spot and avoid the thousands of obstacles that had been placed on the beaches. If this narrow time slot were missed, the invasion would have to be delayed for a considerable time, and the surprise element would be lost. The decision to invade on Tuesday, June 6, made late on Sunday night and finally confirmed early Monday morning, was based on a forecast of a short period of improved weather following Monday's rain and strong winds, a condition that had already given the invading forces an advantage. It had put the Germans off guard because Hitler was quite sure that the invasion would come after several days of good weather, and he had said so to his field commanders.

CHAPTER 4

The Dust Bowl of the 1930s

The worst drought in U.S. history, and the worst series of heat waves, swept across the Midwest in the 1930s, devastating agriculture and making living conditions unbearable. Dust clouds overwhelmed farms and homes, and this feature gave rise to the term "Dust Bowl," the enduring identity of the time. The dust clouds created darkness at noon. It was difficult, at times, to see another person clearly across a living room because the dust was everywhere, entering homes through cracks in windows and doors. Even the best-constructed homes were helpless against the repeated attacks of the dust storms. Breathing was painful, and fresh food was quickly ruined. Even in refrigerators there was no escape. A thin film of dust lay across the shelves. People experienced electric shocks every time they touched anything that was metal, just as happens today in dry hot locations.

Kansas experienced more damage than most states. From such states as Arkansas, Oklahoma, Missouri, and Kansas hundreds of thousands of people migrated westward in the wake of the destruction

A dust storm on the Great Plains overwhelms farmhouses during the Dust Bowl years of the 1930s. (NOAA) caused by the Dust Bowl. Farming had been their main source of livelihood, and their hopes for the future kept fading as they saw thousands of tons of topsoil being blown away day by day. Additionally, the early 1930s was the time of the Great Depression. Farm prices had dropped precipitously and stayed down all through the Dust Bowl years. Comparisons with earlier years illustrate the seriousness of the economic downturn: in the 1880s farmers in Oklahoma and Kansas made annual profits of 300 percent from wheat and dairy cattle farming. In the years immediately after World War One, in 1919 and 1920, profits were equally good, mainly from wheat and beef cattle. In the years 1933–1935 there was no wheat harvest, and there were major losses from all livestock sales.

Extreme drought is the result of temperatures that are too high and rainfall that is too low. Under these conditions the small amount of moisture soon evaporates. The surface of the ground cracks and disintegrates into tiny particles of soil that are easily picked up by the wind and carried away. The highest temperatures in Kansas are usually in the 80s. In 1934, 1935, and 1936, they hovered around 115 and sometimes reached over 120. Rainfall and snowfall were correspondingly far below normal. The movie *The Wizard of Oz* that appeared in 1939 captured the sense of hopelessness that the people of Kansas felt throughout the 1930s. The tornado that swept Dorothy from her farmland into the world of Oz was close to reality. It reflected the dreams of everyone at that time for a better life somewhere else. The big difference was that there was no magic alternative like Dorothy's for the real victims of the tornadoes and dust storms in Kansas.

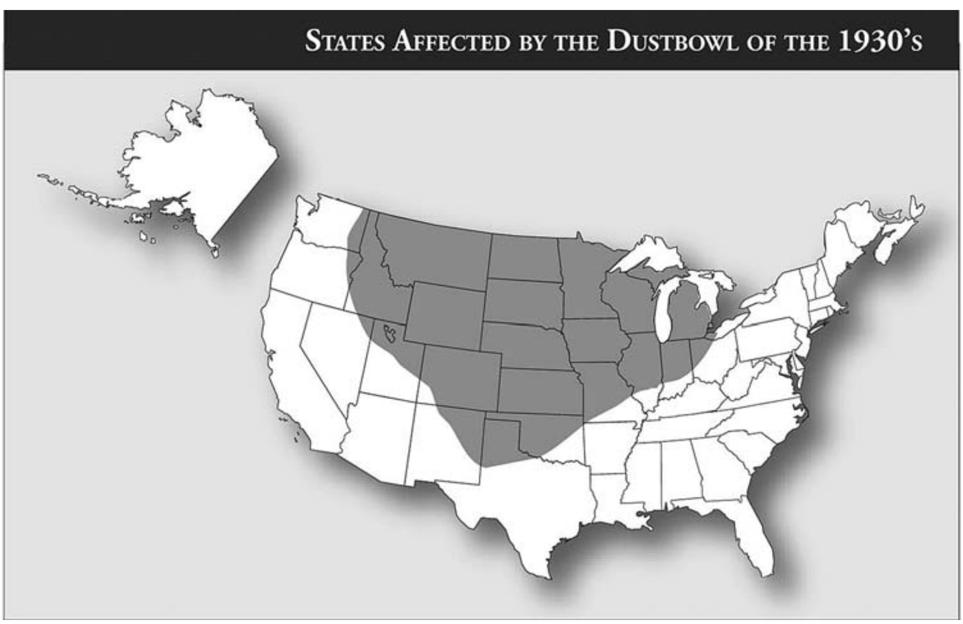


Figure 4-1 Map showing the area in the midwestern United States affected by repeated dust storms in the 1930s. (ABC-CLIO)

In the same year as *The Wizard of Oz* was produced, an author from California, John Steinbeck, wrote a novel about a poor family that had worked on farms in Oklahoma. Drought and poor sales for agricultural products drove them to a sense of hopelessness and they, like those from the Dust Bowl, migrated westward toward California in search of a better living. Steinback's novel was titled *The Grapes of Wrath,* a name taken from the lyrics of Julia Howe's "Battle Hymn of the Republic," written 70 years before the Dust Bowl era. There is one line in that hymn that contains Steinbeck's title, "He is tramping out the vintage where the grapes of wrath are stored." The stories in the novel seemed to be so close to the reality of the Dust Bowl experience that the book became the symbol of life in the Midwest in the 1930s. A very successful movie based on this book was produced and distributed in 1940.

The drought of the 1930s first appeared in the eastern part of the United States in 1931. Over the following three years it moved westward until, by 1934, it had transformed the Great Plains into a desert. Newspaper reports from places such as Oklahoma and Kansas carried one phrase that had been heard so often from farmers that it began to define the national tragedy that was unfolding. These words were the responses to reporters from local residents: "If it rains." The U.S. Soil Conservation Service used the term "Dust Bowl" on their maps of western Kansas, southeastern Colorado, the Oklahoma panhandle, the northern part of the Texas panhandle, and northeastern New Mexico. Altogether, a third of the Great Plains region, or about 100 million acres, was affected. It was a tragedy that was said to be due to natural causes that were beyond human control. Nevertheless, the human factor, as will be shown, had a lot to do with what happened.

LEARNING FROM DUST BOWL EXPERIENCES

The drought alone may not tell the whole story. Even though dry spells recur in the Great Plains region from time to time, generally three or four times every century, and even though the one that ravaged the area in the 1930s was unusually bad, the role played by humans must be considered. Hundreds of thousands of people settled in the Great Plains in the years leading up to 1930. They were mostly farmers, and their greatest profits came from wheat, sheep, and cattle. The type of grass that grows naturally in this region does not form a complete sod as it does in humid areas. Soil is exposed between the grass clumps, and if grazing is heavy the grass fails to hold the soil in place. Erosion becomes easy. It is a similar story when the land is plowed for wheat cultivation. There are techniques that can be employed to prevent soil loss in both of these aspects of farming, but, in the 1930s, these preventive measures were not understood and therefore not employed. Thousands of acres that were plowed should have been left fallow.

Beginning in 1935, federal conservation programs were created to rehabilitate the Dust Bowl even though farmers were at first reluctant to accept the proposed changes. The changes included seeding areas with grass, rotating crops, contour plowing, strip patterns in grain fields, and planting trees to serve as wind breaks. With some federal assistance, and with the evidence of greater productivity, there was a gradual and widespread acceptance of the changes. Farmers who had been considering leaving the area were persuaded to stay as they saw the financial gains from the new approaches. They began to understand that their optimism about their future in the Great Plains had led to a disregard of nature's limits and uncertainties. Over the years the farmlands that were devastated in the 1930s have recovered, and they prosper as farmers make use of the lessons learned from the Dust Bowl experiences. Nevertheless, the prospect of repeated droughts remains. Droughts recur in this area on average every nineteen years.

In the spring of 2008, farmers noted that it had been 20 years since the last drought hit the Midwest, and they were concerned that they might encounter another. The remnants of an El Niño episode had brought a lot of rain during the spring planting season, a condition that often leads to shallow roots, not a helpful situation given that La Niña was already active, bringing dry weather that would weaken the corn in the growing season. If this happened and the market cost of corn went from its usual price of \$6 a bushel to \$10, all kinds of effects would follow. In fact, due to the flood of 2008, in Iowa and surrounding areas, the price of corn rose to more than \$8 a bushel. (Farmers still use old measures such as bushel. It represents a volume equal to that of eight dry

A typical Iowa farm. (Dreamstime.com)

gallons.) The first and immediate effect of a rise in corn prices would be an increase in the cost of beef, because corn is a major food of livestock. This is not a very serious problem within the United States, but it is a very serious one in poorer countries. The United States exports more than two billion bushels of corn every year.

In the early months of 2008 food costs soared all over the world, largely due to huge increases in the price of oil and thus higher costs of bringing food to markets. In addition, the slowdown in the world's economy during 2008 raised the costs of most foods. In some of the world's poorest nations there were food riots in which people were killed and much damage was done to infrastructure. Alongside the impact of higher corn costs on food supplies worldwide, there was also, in 2008, a new concern over the use of ethanol, a corn-based biofuel that is used in automobiles with gasoline as one effort to slow down global warming. We will examine this subject in much greater detail in Volume Four of this set. One of the things we learn in tackling global warming is the interconnectedness of every attempt at slowing it down. In the case of ethanol, after years of use and mounting evidence of its value as one solution to global warming, Western governments in 2008 began to stop using it because of the demands it made on the available supplies of corn, a demand that raised world prices of corn to unacceptable levels.

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CHAPTER 5

Weather and Floods

When unexpected changes in weather cause widespread flooding, the effects are often the most destructive of all the weather and climate extremes that we experience. Although the arrival of rain is generally welcomed in the arid areas of the world, human memories tend to focus on events in humid places where life was completely disrupted by floods again and again. It is in such locations that we find the deadliest consequences of excessive rainfall. Worldwide in the course of the twentieth century, seven million people died, another million were injured, and 100 million lost their homes as a result of floods. China has suffered more than any other country from these recurring floods, so it will be examined first. Then we will take note of two other areas of the world, the United States and the Netherlands (also known as Holland), where unpredictable weather conditions have caused levels of rain and wind that led to devastating floods.

What Is Humidity?

There is always some water in the air in the form of water vapor. The amount at any given time is measured in terms of, or relative to, the maximum possible amount of water vapor that the air can hold. When the temperature increases, the relative amount of water vapor drops. When the temperature drops, the relative amount of water vapor rises. All of this is very important to our health and lifestyle. Too much or too little humidity can produce a host of difficulties. High humidity causes corrosion in electrical circuits and may cause short circuits. Low humidity causes static electricity, and this too may shut down electrical circuits. The ideal level of humidity, according to the U.S. Environmental Protection Agency, is about 45 percent, that is to say close to half the maximum amount the air can carry at a given temperature.

Measuring humidity is as simple as measuring temperature. The instrument we use is called a hygrometer. There are different types of hygrometers, the best of which, and the simplest to use, is the wet and dry bulb thermometer. Two ordinary thermometers are used, one of them having the bulb at the bottom covered continuously with a wet cloth. Air passing over this wet bulb evaporates some water and thereby cools the bulb and so lowers the temperature reading. A set of readings for the differences in temperature between the two thermometers gives the percentage of humidity. You can easily demonstrate the working of this instrument by putting water on your hand, then blowing on it and feeling the drop in temperature.

WEATHER CONDITIONS BEFORE 1887 FLOODING

Throughout its history, on both of its major rivers, flooding has always been a common experience in China. The Yellow River, locally known as the Huanghe, rises in the hot, desert regions of northwestern China where rain is infrequent and unpredictable. But when it does come, as is common in similar desert regions around the world, it arrives in bursts of precipitation. Ordinarily this small amount of water would not be a problem. However, this part of China has an unusual surface soil, known as loess. It is light and dry, a type of silt that was brought to the present site by wind in earlier centuries. It is widely distributed all over the region through which the Huanghe flows. It is easily eroded by water and is consistently carried downstream by the river. Over time some of the loess accumulates in the bed of the river, so people have erected dikes on either side of the stream to prevent silt-laden water from escaping and damaging the farmlands below.

As long as the amount of loess in the bed of the river is well below the height of the dikes, all is well, but no one knows when a sudden rainfall will arrive farther upstream, greatly increasing the flow of water in the Huanghe and the amount of loess it carries. As the river rushes eastward toward the sea, all that is needed to create a crisis is a small blockage in the bed of the stream, perhaps at one of the sharp bends, a common site for these. Under these circumstances the loess being carried by the river piles up at the blockage, and the water level rises. All of this can happen within a short time. A buildup of water level at a blocked point can rise to the top of the dikes within an hour or two, and the river then overtops the dikes. This has been a common occurrence through the centuries of Chinese history. Only in recent times have there been weather stations installed at critical points to inform the farmers about upstream precipitation.

In the long history of farming near the river, as loess accumulates in the bed of the river, the earthen dikes get raised higher and higher to prevent overtopping. Thus, over time, the river becomes an elevated stream, high above the farmland, and hence increasingly liable to cause extensive destruction as the effect of gravity adds to the damage when an overtopping occurs. In 1887 the farmers' worst fears were realized when the worst flood in Chinese history occurred in Henan Province, one of the richest farming regions of the country. The river was still hundreds of miles from the sea and flowed high above the farms. Five thousand square miles were inundated. Eleven large towns and hundreds of villages were destroyed. Nine hundred thousand people died, and two million were left homeless. "River of Sorrow" is a name that has often been given to the Huanghe, and the reason is easy to understand after reading about events like this one.

DAMAGE FROM 1887 FLOODING

The damage was enormous because of the height of the river. The speed of the water as it left the river enabled it to wash away large segments of the dikes. The overflow of water continued until it reached the lowest point in the broken dikes. It took some time for the water to drop to this level, so the total volume of water released was correspondingly great. The year 1887 was one of heavy rain right through the latter part of summer and into the month of September. It was near the end of September that this major collapse of dikes took place. Immediately after the break in the dikes the alarm was sounded, and a large number of people rushed quickly to the river in the hope of repairing the dikes. Before they could reach the river, the breaks had expanded upstream by more than two thousand feet. There was little they could do. Many of them ran or walked upstream in order to reach a level above that of the flooded area, but they were caught in the fast-moving volume of water and drowned.

Within an hour a lake as big as Lake Ontario had formed on the adjacent plain. People from the city attempted to reach as many victims as they could by rowing around in small boats. Some of the peasants were able to reach terraces that were slightly higher than the water level and there they waited for someone to reach them. Others desperately tried to stay alive by clinging to straw barrows. The overall temperature is quite low in this part of China by the end of September, and on the day of the tragedy there was a strong wind that added a wind chill factor, making everyone feel cold. It was slow work for the small boats as they tried to go from terrace to terrace and take people to safety. Often there would be as many as a hundred families on one of these terraces. Some homes were still erect though under water, and survivors stood on their roofs as long as they could before succumbing to either hunger or cold.

Here and there an old tall tree was standing, and people of all ages were seen clinging to branches in the hope that help would arrive. One family, knowing that it had no chance of surviving, placed a baby on top of a chest along with some food and a piece of paper with its name, and this chest stayed afloat long enough for the child to be rescued. There was very little organization or resources for the rescue work. Foreign missionary societies shared their meager food supplies with survivors, but the small amounts of food did little for so many. Efforts by individuals and government agencies continued unabated through the winter months. It took a lot of time because there was so little organization in China at that time for dealing with emergencies. When the water finally stopped, residents saw a plain on which lay a heap of loess mud about eight feet deep. As it dried out, the whole region looked like the Sahara Desert rather than the green fertile plain that had been there a year earlier.

People unfamiliar with life around the Huanghe wonder why peasants insist on living and working in such dangerous areas. The same people also wonder why peasants live and work very close to volcanoes. The answer in both instances is the same: it is there that the best soils for farming are found. The cleanup of the farm fields and the rebuilding of the dikes had to be undertaken immediately despite the approaching cold weather of winter. Farm work in this part of China is a year-round activity. Furthermore, the danger of a new flood would increase once the warmer weather of the following year came around. Every person was familiar with the routine for dike repair. Thousands of tons of earth had to be moved in wheelbarrows and, in the process of both removing the mud from their farms and rebuilding the dikes, almost all of it had to be passed from place to place by hand buckets. The stones needed for the work had to be carried in ox carts from places that were sometimes as far as a hundred miles away. Finally, in the early part of the year 1889, the dikes were closed.

WEATHER CONDITIONS BEFORE 1993 FLOODING

The sustained and very heavy rainfall in the Mississippi-Missouri river system from April to July of 1993 was the greatest that had been experienced since weather records began in 1875. Furthermore, the previous winter in this same area had the biggest snowfall of the previous 14 years. Various factors contributed to these unexpected weather conditions. Mount Pinatubo's powerful eruption in 1991 lowered global temperatures for two years and added huge amounts of dust particles to the atmosphere that interfered with normal weather. This dust caused heavy rain, the result of excess cloud condensation nuclei. Storms, persistent and repetitive in nature during the late spring and summer,

A flooded street in Davenport, Iowa, during the Mississippi flood of 1993. (AP/Wide World Photos) bombarded the upper Midwest with voluminous rainfall amounts. On top of these things, El Niño had been active in 1992 and 1993. Many locations in the nine-state area of the Mississippi-Missouri basin experienced rain on 20 days in July, compared to an average of nine days.

Kansas had 24 inches of rain between June and August, a rare phenomenon in this arid state. By June 1 streams and soils all over the upper Midwest were saturated with water, so all additional input of rain had nowhere to go but over the banks of streams onto neighboring land. The Great Flood of 1993 was dated as beginning in June of that year. Rainfall persisted all through the summer months, and by the end of August many multiyear records had been surpassed. Water levels of one-hundred-year recurrence intervals were common on several streams, and in some cases two-hundred-year levels were recorded; that is to say, the flooding that occurred was so severe that experts expected it to happen only once in a hundred years and in one or two places only once in two hundred years.

DAMAGE FROM 1993 FLOODING

The magnitude and severity of this flood event was overwhelming, and it ranks as one of the greatest natural disasters ever to hit the United States. It was the largest and most significant flood event in U.S. history. Six hundred places in the Mississippi-Missouri system that had been selected over previous years as markers that would indicate the approach of a flood were found to be above flood stage, all at the same time. Costs amounted to $15 billion, and the flooded area was 30,000 square miles. It was much worse than the 1927 flood in the same area, about which more will be said later.

Fifty lives were lost in the course of this flood and hundreds of levees failed. Thousands of people were evacuated, some for months. The flood was unusual in the magnitude of the crests, the number of record crests, the large area impacted, and the length of the time the flood persisted. The Mississippi River drainage basin, which includes the Missouri basin, is one of the largest in the world and the largest in North America. Floods have been a constant feature of it since historical records began to be kept, about two hundred years ago. In the early part of that period, perhaps because state's rights have always been a top priority in the political life of America, these floods were regarded as the responsibilities of the states affected despite the obvious fact that no state could control conditions upstream in other states.

HISTORY OF THE LEVEES AND FLOODWALLS

All of that tradition changed after 1927, when a massive flood occurred. It began when heavy rains pounded the central basin of the Mississippi in the summer of 1926. By September, the Mississippi's tributaries in Kansas and Iowa were swollen to capacity. On New

Year's Day 1927, the Cumberland River at Nashville topped at 56 feet. The Mississippi River broke out of its levee system in 145 places and flooded 27,000 square miles. The area was inundated up to a depth of 30 feet. The flood caused over $400 million in damage and killed 246 people. Arkansas, Illinois, Kentucky, Louisiana, Mississippi, and Tennessee were affected. Arkansas was hardest hit, with 14 percent of its territory covered by floodwaters. By May 1927 the Mississippi River below Memphis, Tennessee, had reached a width of 60 miles.

The Flood Control Act of 1928 brought the problem of Mississippi floods under joint federal and state control. About 1,800 miles of levees and floodwalls were built along the river's course, and floodways were provided to divert water into storage areas or into the Gulf of Mexico. For a time it seemed that these measures were a solution to the problem of repeated flooding, but subsequent floods proved that there was no single set of solutions. The flood of 1993 was far bigger and more destructive that the 1927 one. It was among the most costly and devastating floods ever experienced in the United States. As China had discovered over hundreds of years, the United States came to realize that weather is quite unpredictable and the levees constructed to cope with one major event may not be adequate for a subsequent one. The emerging concerns about global warming, which we will examine in Volume Four of this set, suggest that the future may surprise us even more than it did in 1993.

A flooded car on a street during the Mississippi flood of 1927. (NOAA)

WEATHER CONDITIONS BEFORE 1953 FLOODING

The Netherlands, or Holland, is a very different country in relation to floods than either China or the United States. The easiest way to understand this country is to think of New Orleans, a city that has most of its built-up area below sea level and most of the rest no higher than a foot above sea level. It is constantly dependent on levees to prevent the frequent storm surges of ocean water that rise to ten or more feet from destroying everything. America will never forget Hurricane Katrina of 2005, when the levees of New Orleans failed and the city was devastated. Holland has exactly the same problem. The whole country, like New Orleans, is close to or below sea level. For centuries Dutch people have been building and reinforcing levees to keep out seawater from the North Sea. Every time stormy weather sweeps across the country, and water rises high on the ocean side of the levees, Dutch people sleep lightly. They know a lot about past failures of these levees.

Around 6 PM on the evening of January 31, 1953, a regular mid-latitude storm of the kind we will study in Volume Two of this set began south of Iceland, traveled across northern Scotland, and then moved southward along the North Sea toward Holland. As it traveled southward, weather stations along the way noted that air pressure at the center of the storm was dropping very fast, by as much as 12 millibars between 6 PM on January 31 and noon on the following day. This represented a very serious increase in the speed of the winds that circled around the storm, speeds that reached hurricane strength by the time the storm was off the east coast of England. These are the winds that push up ocean waves and cause storm surges. Unfortunately, in 1953, there were no satellites or computers to make an accurate forecast, and there was no single body responsible for flood warnings, so the storm moved on southward toward Holland without forewarning, arriving there late in the evening after dark.

Just as we have seen in the cases of China and the United States, preparations against future disasters are based on what happened in the past. People feel confident if the levees are high enough to withstand the worst flood previously experienced. Holland was completely unprepared for this storm, despite the fact that it was already well acquainted with winter storms like this one and its levees had successfully resisted them. This time, however, the story was different. Not only was the storm as strong as any other the country had known, it arrived at the worst possible time, at high tide, when water levels in the ocean were already at their peak. The coincidence of a very strong storm and a high tide arriving at the same moment had never been experienced by Holland. The water level in the ocean rose 16 feet above normal. The levees were overwhelmed, and they collapsed. The extensive flooding that followed produced one of the worst floods in living memory in Holland. Other countries on either side of it also experienced flooding.

Aftermath of the 1953 flood in the Netherlands. (AP/Wide World Photos)

DAMAGE FROM 1953 FLOODING

Over 1,800 Dutch citizens were drowned, 72,000 were displaced, and 47,000 homes were either destroyed or seriously damaged. Some 800,000 acres of rich farmland were submerged for days in saltwater, and farmers lost 250,000 of their cattle, hogs, and poultry. The people of Holland had been warned of the poor condition of many of the dikes in reports dating back to 1928 and 1934, but little action had been taken, not because of indifference or unwillingness to do what was needed, but rather because of the aftermath of World War Two. Holland had suffered from two factors during the war, the exploitation of the country under years of occupation by Germany and the destruction of much of their levees by Allied bombers in their attacks against Germany. After the 1953 flood, just as the people of New Orleans discovered, they realized that it would have been far less costly to rebuild the levees before the disaster than face the enormous costs they incurred afterward.

The dikes had not been designed to withstand the pressure they experienced in 1953. In the design of the system of polders, there are several lines of dikes extending landward from the sea. The first line is made strongest because it has to withstand the first and biggest blow from the sea. The others are progressively less massive because it is assumed that the water reaching them will have less momentum than it had when closer to the sea. What happened in 1953 was not typical, and certainly not the conditions for which the Dutch engineers had planned. The wave of water that overtopped the first one or two lines of dikes was so powerful that it hollowed out the foundations of the weaker dikes farther inland so that they collapsed. It was almost an exact precursor to the way the levees collapsed in New Orleans. Thus, from an early stage of the tragedy, the cities and farms that should have suffered last became the earliest victims. They had no time to escape inland, and large numbers of people there lost their lives. Before the end of the day and long before anyone could put corrective measure in place, 89 dikes had been broken through.

Many woke up in the middle of the night as the water reached them. They quickly found themselves isolated, shut inside their homes. Many homes collapsed. A few people managed to hold on to floating debris until they were rescued. Most were drowned. Where homes remained in place, people climbed onto the roofs, hoping that they could stay above the final water level. All telephone and radio communications were cut off. By the morning of February 1 the tide had receded and the water level dropped. There were individual rescue operations taking place. Villagers in boats looked for victims and brought them to higher land. After the disaster a new and comprehensive plan was initiated to protect the areas of high-density population around the Rhine estuary. A network of barrier dams was built to seal off most of the large sea inlets. By so doing the exposed coastline of the country was reduced in length by more than 400 miles. The construction work on this new and very big project began in 1958, and the last part of it was finished in 1986.

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CHAPTER 6

The Kenyan Drought of 1998

Kenya's worst drought in living memory arrived late in 1998, mainly caused by exceptional damage from El Niño and La Niña: that year was their strongest showing in a hundred years. The worldwide influence of these special weather events will be described later in this chapter. Agriculture, the country's principal source of income, was devastated, as six of the eight provinces were damaged. It was rare for Kenyans to see so much of their country suffering from a drought. Kenya is familiar with tragedies of this kind. It experienced 20 of them in the course of the twentieth century, but the 1998 one was the worst of all because of the coincidence of a drought cycle and the arrival of El Niño and La Niña. El Niño brought heavy rainfall in 1997 and the first half of 1998, breaching embankments and carrying away huge quantities of soil. Water storage capacity was thus reduced. La Niña arrived in 1998 and stayed, providing low levels of rain that were inadequate to sustain agriculture.

Most Kenyans face starvation if agriculture is disrupted, so by the beginning of the year 2000 almost five million people became dependent on food aid from the central government and from various international aid agencies. The arid and semi-arid lands of the country suffered the most, with large numbers of deaths among livestock and wildlife. The loss of wildlife was particularly bad for the country's economy because these animals are the basis of the tourist industry. It is impossible to give a precise definition of drought because it means different things in different countries. It is usually understood as a drop in total precipitation over a period of time to a level where all the land resource production systems drop far below their average. An examination of the main elements of Kenya's climate explains why this African country experiences droughts of different intensities approximately every ten years.

Kenya straddles the equator, with most of the country lying within approximately four degrees on either side of it. Its climate therefore is dominated by the high levels of heat and moisture that are always found there, and these high levels move north and south with the seasons within what is technically known as the Inter-Tropical Convergence Zone (ITCZ). As the band of equatorial air moves north in the spring, the areas of Kenya that are mountainous and in the south experience the heaviest rainfall. In late fall when the band of equatorial air is at its southernmost location, these places have minimum rainfall. Other areas of the country have a lesser but similarly distributed pair of rainfall seasons. If these influences were the only factors determining the annual rainfall patterns, all would be well in Kenya, and droughts would be rare and far less destructive than they are. However, patterns of monsoon winds from both the Indian Ocean and the country's land neighbors to its west, in addition to El Niño and La Niña, constantly and unpredictably interfere with the moisture regimes that are brought from the ITCZ. As a result, there is rarely a year or a season of rain that might be called normal.

Kenya was poorly equipped to cope with the drought of 1998–2000. There was no organization to coordinate the responsibilities of different government departments. Every department of government acted independently, and the result was a lot of inefficiency through duplication of efforts. The shock of the drought led, in 1999, to the passing of a new law, the Environment Coordination and Management Act. This new act provided for the establishment of environmental action plans that would document and constantly update the natural resources of each of the eight provinces. In addition, it would coordinate all the environmental issues as well as the actions to be taken in all future droughts. A more detailed examination of El Niño and La Niña, Pacific Ocean phenomena that only in recent times have been adequately understood, will help us understand better why Kenya had such a challenging time in 1998.

EL NIÑO AND LA NIÑA

El Niño and its opposite weather event, La Niña, are caused by changes in the temperature of the Pacific Ocean off the coast of Peru. Because the Pacific Ocean is so big, these temperature changes influence weather all over the world. The story of these fluctuating temperatures goes back a long way in the history of South America, but only recently have their behaviors been understood. We can now identify the early stages of their development and thus predict which parts of the world are likely to be most affected by them. For hundreds of years, Peruvian fishermen conducted a profitable fishing business off the coast of Peru. This area is one of the most productive fisheries in the world, especially for anchovies, small fish that are popular worldwide. Cool water welling up from the depths of the ocean creates large quantities of plankton, a rich source of food for these fish. Around Christmas time every year this rich upwelling water becomes warmer. Warm water does not produce as much plankton as does cold water, and hence there is a decline in the number of fish available. This annual decline is not a serious disruption of the fishery, but every few years a major warming occurs, one that disrupts the temperature regime of the entire globe. The fishermen called it "El Niño," a Spanish phrase that means "The Christ Child" (although its simplest meaning is "little boy"), because of its association with the Christmas season.

This name has remained as the identifying term for these major increases in water temperature. La Niña, the Spanish term for "little girl," is the name given to an intensification of the cold upwelling water. It is the opposite of El Niño and frequently follows an El Niño event. Patterns of wind, ocean currents, and temperatures all across the Pacific Ocean from Peru to Australia are affected by El Niño and La Niña, as are many other locations around the globe. The effects of the famous 1997–1998 El Niño, the most powerful one of the twentieth century, were felt in both Peru and Indonesia—halfway around the world from one another. Add to that the northern and southern extensive coverage of the Pacific Ocean, and it is easy to see why every El Niño and every La Niña carries a global impact. Unfortunately, because the destructive effects of every El Niño are relatively sudden, we tend to focus on these effects rather than on the longer-term beneficial aspects.

The winter of 1997–1998 was the warmest of the twentieth century, a great benefit for northern U.S. states. During the same time there was flooding in California and southeast states and tornadoes in Florida. Alaska and the northern states of the contiguous United States gained greatly from the warmer weather, both economically and healthwise. The U.S. southern states were less fortunate. They were wetter and cooler than usual. Tornado outbreaks and floods in Florida cost $1 billion in damage and the loss of 132 lives.

An El Niño event brings warmth to southern China in winter. Millions of Chinese in 2007–2008 must have wished for that rather

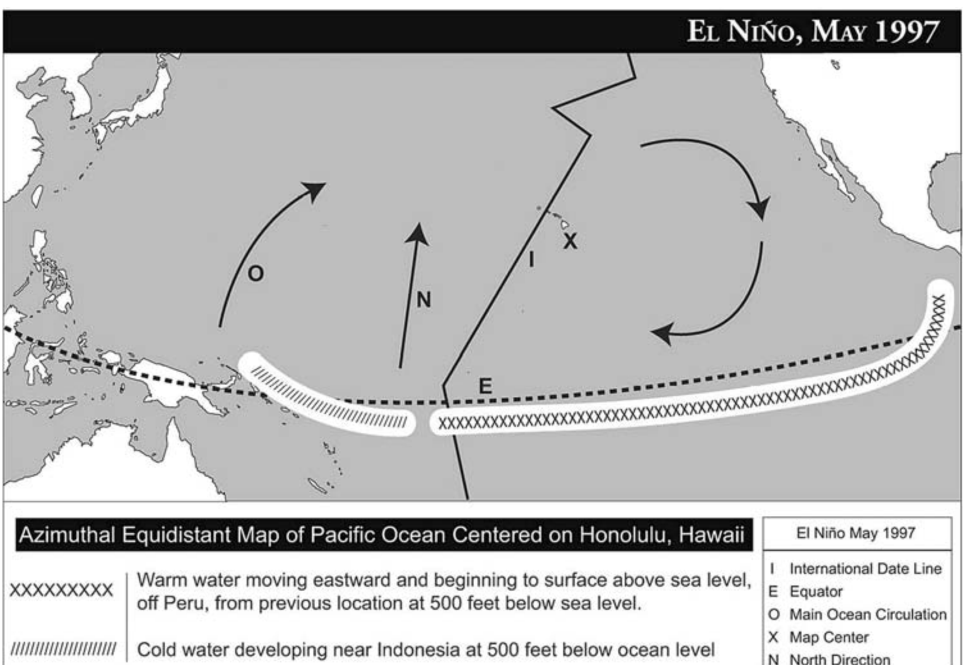


Figure 6-1 The disruptive global weather pattern known as El Niño is the warm phase of an irregular warm/cold fluctuation of the Pacific Ocean. (ABC-CLIO)

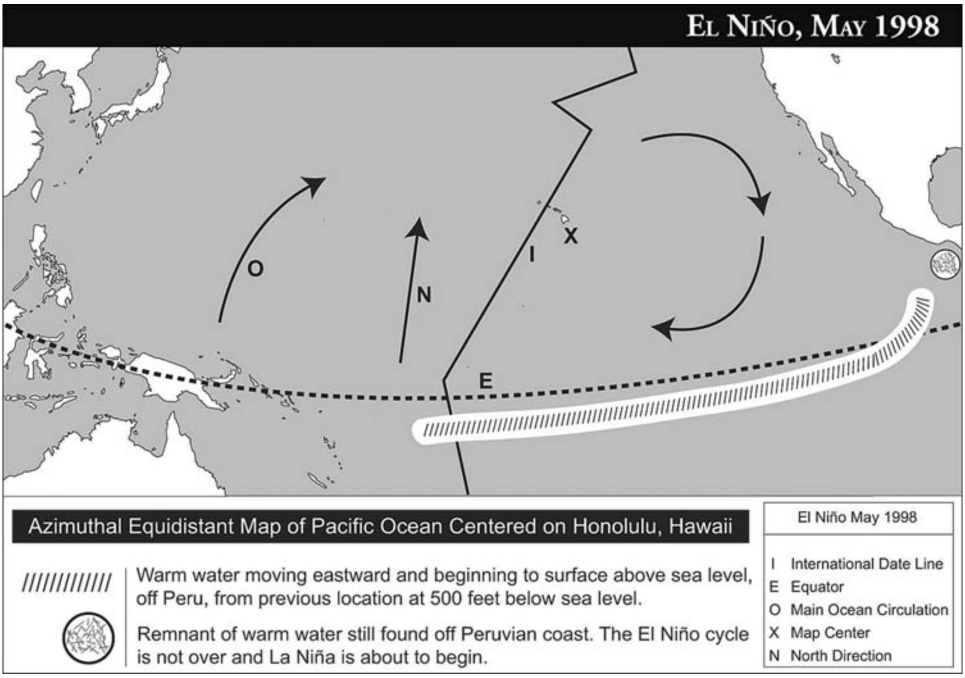


Figure 6-2 Eight to ten months in duration, El Niño is characterized by warmer-than-usual ocean temperatures and weakened trade winds, which together cause anomalies of temperature and precipitation that have consequences for the entire planet. (ABC-CLIO)

than the La Niña they were encountering at that time. Snowfall levels higher than any that had been known in the previous 50 years devastated the transportation system and cost billions of dollars of loss to the nation's economy. Farther south, in southeast Asia and in Australia, unlike southern China, El Niño represents costly and destructive weather conditions. Widespread fires in the fall of 1987 in northern Australia, Papua New Guinea, and Indonesia were reported because of the dry conditions. Satellite imagery from NASA showed a smoke haze from burning material that extended from Thailand to Indonesia. Near the locations where the fires were burning this haze was 30 times thicker than normal. In this same period of time Singapore registered a 30 percent increase in hospital admissions of people suffering from air pollution problems.

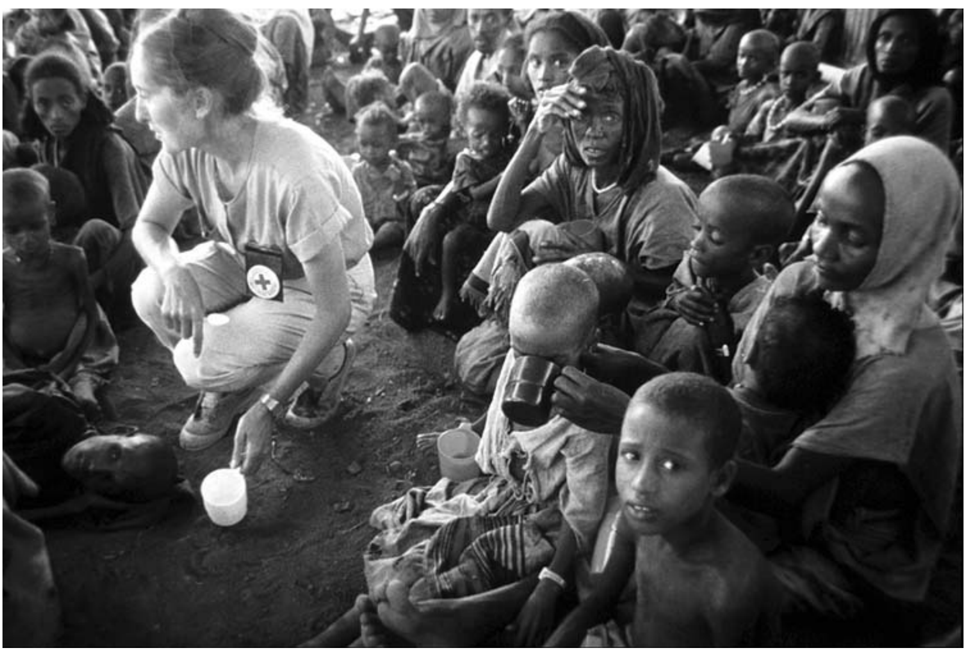
One billion dollars of damage was done to Indonesia's agriculture in 1997–1998. For all the countries of this area of southeast Asia total damage amounted to $4 billion. Worldwide, the total losses from storms, floods, droughts, and fires added up to $89 billion for all of 1998, almost 50 percent higher than the previous record of $60 billion in 1996. In addition to material losses, 32,000 lives were lost in 1998 and 300 million people were displaced from their homes. At the same time, the southern Caribbean and northern regions of South America experienced warm, dry weather during an El Niño summer, and these conditions provided an economic benefit for their tourism industry.

THE ETHIOPIAN DROUGHT OF 1984

The recurrence rates of El Niño episodes average four years, although the historical record varies from every two years to every seven. In the future, as global warming increases, we can expect to encounter surprises in the behavior of these two powerful determinants of weather patterns. The impact of El Niño and La Niña on Kenya, worsening the recurring droughts that hit that country, made the events of 1998 an exceptional story. However, droughts happen all over the world at different times and places, and most of them never reach the headlines of our newspapers or television screens unless some aspect happens to catch our attention. The Ethiopian drought and famine of 1984 was one crisis that the whole Western world heard about.

North of Kenya and stretching latitudinally across Africa south of the Sahara Desert, there is a large region known as the Sahel that is frequently hit with dry weather. Grazing land for cattle is destroyed by droughts, and the region takes years to recover from the famines that follow. The year 1969 was one of these dry-weather years. A drought swept across the Sahel and reached as far as Ethiopia. By 1973 this famine threatened the lives of hundreds of thousands of Ethiopians, and within a year 300,000 of them had died.

In 1974 a new dictatorial government also forcibly removed people from one part of the country to another, and the internal conflicts that arose from this added more violence to existing conflicts. Ethiopia had been involved for some time in a civil war and



Red Cross worker assisting victims during Ethiopia's drought of 1984–1985. (Corel) a territorial war with neighboring Somalia, and these showed no signs of easing. By 1980, 2.5 million Ethiopians had left their homes to search for food wherever they could find it. As famine conditions continued and extended to larger and larger numbers of people, observers around the world insisted that the crisis in Ethiopia had become the world's worst. Cries for international help became louder and louder. Many Western countries were reluctant to assist because they feared that the Marxist government would divert aid money into the purchase of weapons. Finally, in 1984, both the government of Ethiopia and aid agencies raised a new cry for help as five million faced starvation.

Televised images of starving Ethiopian children were circulated all over the world. By this time, the long period of famine had claimed a million lives. Live Aid, a 1985 fundraising effort headed by Bob Geldof, who had led the charity group Band Aid in its efforts to help during the previous year, caught the attention and interest of Western nations. Millions of dollars were donated for food relief. This television event increased awareness of Ethiopia's plight, and made this one area of famine, out of the world's thousands, the place that received the greatest help and attention. Live Aid was viewed by 1.5 billion people, the most widely viewed television broadcast in history. Sadly, the story did not end in 1985. Fifteen years later, in 2000, Western media were asking, why are the numbers facing starvation in Ethiopia greater than they were in 1985? Again, in the year 2007, the same media were asking a similar question: why are twice as many facing starvation in and around Ethiopia as there were in 1985?

CHAPTER 7

France in the Summer of 2003

For thousands of years changes in weather have been affecting human health, sometimes for the better and often for the worse. Sometimes even short-term changes can be very destructive, especially for the most vulnerable members of society, as will be evident in the experience of France in 2003. We tend to adjust to the weather that normally prevails where we live. When an extreme change occurs it takes some time for our bodies to adjust, and harm may come in that period of time. Furthermore, as weather returns to the previous norm, we have to adjust back to the previous regime. Seldom are we prepared for extreme changes in prevailing temperatures.

The summer of 2003 in France was by far the hottest in five hundred years. Temperatures peaked in the first two weeks of August and stayed high throughout these two weeks. All parts of the country were affected, including mountains and coasts. With almost no wind during the two-week period, night temperatures stayed high. In Paris there was also the impact of a high level of air pollution. All of Europe to some degree experienced this heat wave, but France was the most seriously affected. Tragically there were 15,000 more deaths than would have occurred in that timeframe on the basis of statistics for the previous two years. All but two hundred of the 15,000 died between August 1 and 20.

Detailed studies were conducted later on the ages, lifestyles, and medical conditions of those who died, and the first findings, all predictable ones, showed that the vast majority of those who died were age 70 or older. In terms of differences between male and female, a slight majority were female, something that would be expected because females generally live longer than males. Most deaths happened in health care facilities, mainly retirement homes, both public and private ones, as a result of heat strokes when body temperatures reached approximately 105°F. A majority of those who died from heat stroke had suffered from one or more of mental illness, heart trouble, and diabetes. Deaths were highest in Paris, the country's largest city, and proportionately high in other large cities.

Although the temperature extremes could not be anticipated by French authorities, the problems in the public health system that were exposed by the catastrophic events of August 2003 included a great lack of preparedness for emergencies of any kind. There was no system of communication between the different agencies that would be called

TABLE 7-1 Global Extremes of Temperature and Precipitation (NOAA)

Place	Date	Elevation in Feet	Temperature in °F
	Highest-Temperature Extremes		
El Azizia, Libya	1922	367	136
Death Valley, CA	1913	–178	134
Tirat Tsvi, Israel	1942	–722	129
Cloncurry, Australia	1889	622	128
Seville, Spain	1881	26	122
Rivadavia, Argentina	1905	676	120
Tuguegarao, Philippines	1912	72	108
Vanda Station, Antarctica	1974	49	59
	Lowest-Temperature Extremes		
Vostok, Antarctic	1983	11,200	–129
Oimekon, Russia	1933	2,625	–90
Northice, Greenland	1954	7,687	–87
Snag, Canada	1947	2,120	–81
Ustshchugor, Russia	1930	279	–67
Sarmiento, Argentina	1907	879	–27
Ifrane, Morocco	1935	5,364	–11
Charlotte Pass, Australia	1994	5,758	–9

Place	Number of Years	Elevation in Feet	Amount of Precipitation in Inches
	Highest Average Annual Precipitation Extremes		
Llovo, Colombia	29	520	524
Mawsynram, India	38	4,597	467
Mt. Waialeale, Hawaii	30	5,158	460
Debundscha, Cameroon	32	30	405
Quibdo, Colombia	16	120	354
Bellenden Ker, Australia	9	5,102	340
Henderson Lake, Canada	14	12	256
Crkvica, Bosnia	22	3,337	183
	Lowest Average Annual Precipitation Extremes		
Arica, Chile	59	95	0.03
Wadi Halfa, Sudan	39	410	0.1
Amundsen-Scott, Antarctica	10	9,186	0.8
Batagues, Mexico	14	16	1.2
Aden, Yemen	50	22	1.8
Mulka, Australia	42	160	4.05
Astrakhan, Russia	25	45	6.4
Puako, Hawaii	13	5	8.93

upon in a crisis. All of these agencies, especially the nursing homes, were understaffed at the time of the heat waves because August is a holiday month in France. There was already a shortage of cooling equipment in both care homes and hospitals. To take protective action on behalf of elderly people, some sort of warning system was needed that would alert staff when a critical temperature was reached. Nothing of that sort existed. Very few studies had ever been made before 2003 on the consequences of heat waves, yet high temperatures were frequently experienced in August. After the tragedy all of these deficiencies were faced in a coordinated way for the first time, at the highest levels of government, and plans for remedial action were set in motion.

ARCTIC OUTBURST IN JANUARY 1999

In the early part of 1999 a blast of Arctic air swept across the United States and northern areas of Scandinavia and Russia. Temperatures in many parts of the United States were lowered so much that a number of records from that year still stand. Most of the nation froze, and for the second time in history the Mississippi River carried ice into the Gulf of Mexico. The east coast was paralyzed for a time. The National Weather Service described the event as the "Mother of all cold waves." Several lives were lost, and the damage to livestock and crops was enormous. In the nation's capital, the temperature dropped to –15°F. It was even colder in nearby Virginia. Huge snowfalls fell all along the east coast, with the capital region receiving the most, about ten feet. In Chicago, because no snow had reached the city, the ground froze to a depth of five feet, seriously damaging water and gas service pipes. Tugs on Lake Michigan were trapped in the ice for several days.

In the Nordic region, all countries had very low temperatures, but the lowest of all occurred in northern Finland because of its proximity to the huge landmass of Russia. At a village in Lapland, the record low temperature for all of the twentieth century was broken in January 1999. The new low was –60°F. Fortunately, the thermometer in use at that place was an alcohol one. It does not freeze until the temperature is far below –60°F. Places with older thermometers, using mercury, were unlucky, because that substance freezes at –38°F. Under a regime of –60°F, cars are unable to move: brakes, steering, and suspension are all frozen. In addition, there was no electricity when temperatures dropped to the new low, so there were no plug-ins available to heat the engine blocks. With four layers of clothing Finns made every effort to stay warm. Russia's experience of January 1999 was the worst of all northern hemisphere countries. Even for a country with many records of extreme weather, it was the nation's coldest of the century. Furthermore, this deep chill lingered for days. In Russia's far north, in the Kola Peninsula, the temperature dropped to –69°F.

Antarctica is the coldest place on earth. Few who go there are prepared to cope with its low temperatures, especially if they happen to encounter extreme wind chill. Captain Scott, who reached the South Pole in 1912, lost his life along with his companions when they were caught in a zone of extremely low temperatures on the return journey. In January 1999, which is in Antarctica's summer, Peter Hillary, son of Sir Edmund Hillary, who conquered Mount Everest more than once, traveled to the South Pole in order to retrace the path taken by Captain Scott in 1912. While crossing the continent to his destination he passed through a part of Antarctica that had experienced a steady drop in temperature over the previous 15 years, a common event in that part of the world if the winds fade for an extended period of time. For Hillary, with all of his experience in challenging environments, this unexpected extreme temperature almost overwhelmed him. He was completely exhausted when he finally reached the South Pole.

Often, in events like those of early 1999, there are echoes of similar earlier happenings: for example, the weather patterns of 1850 were repeated close to 1900 and again in 1950. In the case of early 1999, there was an almost exact duplicate in early 1899. The National Weather Bureau noted that every state of the union had temperatures below zero in February of that year. It was the first and so far only time that that had occurred. It has already been observed that the Mississippi carried ice into the Gulf of Mexico in January 1999. It did this also in February 1899, the only other time when that took place. Some of the other happenings of early 1899 included –61°F in Montana, –59°F in Minnesota, and over a foot of ice in the upper Mississippi. Washington, D.C, registered –15°F on February 11, 1899, its coldest ever.

THE SUN'S HEAT REPRODUCED ON EARTH

It is only since the dawn of the atomic age that we have understood the enormous amount of energy and heat that the sun produces continually through the nuclear explosions that occur at its core. July 16, 1945, was the first time that a nuclear explosion was seen on earth, when scientists in New Mexico set off a test explosion in preparation for using this new power in a bomb in World War Two. Very little was known at that time about the amount of energy that would be released, or whether human life would be endangered by the radiation that came with the explosion. Scientists discovered that the amount of energy released was three times greater than had been anticipated, about the equivalent of 20,000 tons of TNT. The shock wave was felt over a hundred miles away in one location and at a distance of two hundred miles in another place. The mushroom cloud that rose into the air went as high as eight miles. The whole countryside was lit up many times brighter than was ever known from the light of the midday sun; every crevasse and every ridge in the nearby mountains was seen with a new clarity.

It was later, following the bombing of Hiroshima, that we discovered the harmful effects of radiation on humans. That discovery led to multiple investigations into the nature of the radiation that reaches the earth from the sun. Scientists already knew that something must have been protecting life on earth from full exposure to the sun's energy, because otherwise there would be no life anywhere on our planet. The protective element turned out to be the ozone layer in the highest part of our atmosphere. This layer, 30 miles above the earth in the stratosphere, is the key to the protection of life. It filters out most of the sun's biologically harmful ultraviolet radiation. However, human activities from industry and accidents of nature such as volcanic eruptions send aerosols into the ozone layer, reducing its effectiveness. It was 40 years after the first atomic bomb was dropped on Hiroshima in Japan that we discovered this danger in the atmosphere over Antarctica. Subsequently, international agreements were made to reduce the amounts of industrial products, such as chlorofluorocarbons, that could harm ozone.

Had we discovered all this before the first atomic bomb was dropped, the amount of human suffering might have been greatly reduced. The destruction unleashed on Hiroshima in August 1945 was total. Seventy percent of all buildings and 80,000 people were obliterated in an instant. It is a story that needs to be told many times because it is so closely related to our relationship to the sun, and also because it has affected so many events all over the world since 1945. Much of what was learned about the risks in the nuclear power accidents that have occurred since 1945 all over the world came from the experiences of people in Hiroshima. Why was the bomb dropped on Hiroshima? There are many answers to this question, because there were many people involved in the decision. The decision was made at that time as a military strategy. The United States wanted to force Japan's surrender as quickly as possible in order to reduce the large numbers of American casualties that the war continued to cause.

Several scientists, including Dr. Albert Einstein, opposed the use of nuclear weapons on ethical grounds, but they did not prevail. Dr. Edward Teller, one of the designers of the bomb, urged President Truman to drop the bomb high above Tokyo, where it would be less destructive, but where its power might be sufficiently strong to persuade the Japanese to surrender. That may have seemed like a good idea at the time, but even atomic scientists could not have foreseen then that such an event could have been worse than a direct hit. It was an example of the danger of accepting scientific opinion when evidence in support of the opinion is lacking. We know now that in such a plan the radiation would have been distributed all over the city of Tokyo and its surroundings, and the death toll would have been greater than from a direct hit. In fact, the choice to have the bomb explode high in the air over Hiroshima did cause more casualties than a direct hit might have.

The history of the bomb tells quite a lot about the harmful influences of dictatorships on scientific research. In the years before

World War Two, several of the world's scientists who knew the most about how to make an atomic bomb lived and worked in Germany and Italy. As these nations became dictatorships and began to single out Jews for persecution, many of the scientists who were Jews, fearing they might be targets for attacks by state officials, left their home countries and went to the United States. One of them, Dr. Leo Szilard, who emigrated to the United States, as did Einstein, in 1940, persuaded Einstein, at that time the most eminent scientist in the country, to write to President Roosevelt proposing a research project in order to develop an atomic bomb. President Roosevelt was not interested at that time. He saw no need for such a weapon, but he changed his mind quickly after the attack on Pearl Harbor in 1941. Szilard and Einstein were convinced that Adolf Hitler would attempt to develop an atomic bomb. Later, it was discovered that he was trying to do that, but by then he had lost his best scientists, and he failed.

After the successful test explosion in the United States, action followed quickly to plan for the dropping of an atomic bomb over Hiroshima. Individual parts of the second bomb, each encased in a lead container, were shipped one at a time to Tinian Island in the Mariana group of islands. From there the final flight would be made, a distance of about a thousand miles. In preparation for the flight with the bomb, the bomber crews involved had been doing extensive training and flying both at the base in Tinian and in flights over Japan. It was during this period that some uncertainty developed over how best to load the triggering device into the bomb. The pilot of the plane, after consulting with his crew, decided to do the loading while in flight. He reasoned that, if something went wrong, the loss of everything in flight would be better than totally destroying the island of Tinian. It was a bold decision. Fortunately for him and his crew the loading of the bomb in flight was successful, and they arrived over Hiroshima early on August 6, 1945. This city was selected because it was an isolated place, one that had not been bombed before, and because the terrain made it suitable for testing out the bomb's capability.

The bomb was dropped around 8 AM and timed to explode at a particular elevation above the ground. The plane, the Enola Gay, was nine miles away when the bomb went off, and they were able to look back at it from 30,000 feet up, using special protective goggles. On the next day President Truman broadcast news of the event in words like these: "We have captured the energy of the sun in a new and terrible bomb and one of these has already been dropped on Japan. If they do not now accept our demand for surrender, they may expect a rain of ruin from the air, the like of which has never before been seen on earth." At Hiroshima, everything below the bomb had been vaporized. The metal framework of one building was all that was left, and this became part of a museum that was built later in the center of the city. Beyond the vaporized zone the supersonic blast of air, releasing millions of degrees of heat, destroyed everything. People standing ten or more miles away were burned right through their skins. They died

One of the few buildings left standing after Hiroshima was hit by an atomic bomb in 1945. (Library of Congress)

either immediately or soon afterward. Iron, stone, and roof tiles were twisted out of shape. Clothing, railway ties, and trees instantly ignited.

At eight hundred miles an hour, the 9,000°F hot air created huge swirls of wind that circled back into the city to fill the vacuum initially created by the bomb. About 70,000 people had been killed. Four months later the death toll had doubled as a result of the radiation damage. Over the years since then, casualty numbers have continued to mount, but statistics are difficult to collect because of health complications other than those caused by radiation. The special atomic bomb museum that now stands in the center of the old city of Hiroshima carries a detailed, visual documentation of the horror that citizens endured on and after that day in 1945. Many thousands from all over the world visit this memorial annually. At the present time, the people who were put through the terrible events of August 1945, and their offspring, are more closely monitored than almost any other group of people in the world. This is the only place where the effects of radiation on the human body are clearly evident. It provides for researchers all over the world evidence for the vital importance of maintaining the quality of the ozone layer by preventing the production of industrial products that would harm it.

After World War Two, President Truman directed the U.S. Navy to investigate the effects of atomic bombs on U.S. warships. Bikini Atoll was chosen for this project for several reasons. It was located outside regular air and sea routes, had a good-sized lagoon, and there were a few large islands close by that could serve as observing stations. There was good access to the lagoon through wide channels, and a shallow area a few miles away provided a suitable site for anchoring the target ships. Bikini received a steady succession of bombs. The first two, each of the same power that had devastated the cities of Hiroshima and Nagasaki, were detonated in the air. Twenty others of the same strength were detonated at various elevations above the ground. In 1954 the new and vastly more dangerous hydrogen bomb, a thousand times more powerful than the one that destroyed Hiroshima, was detonated on the ground. On Bikini Island of the Atoll, millions of tons of sand, coral, plants, and sea life from Bikini's reef and the surrounding lagoon waters were sent high into the air.

The force of this explosion was far beyond the expectations of observing scientists. It was the most powerful bomb ever exploded. Fifty thousand square miles were contaminated and remained uninhabitable for the rest of the century. The native people had been moved to other islands during the tests. After decades of delays awaiting successful decontamination of their home areas, they were still unwilling to move back to their original homes. The sites, for the second half of the twentieth century, became a place for investigating the effects of atomic bomb radiation on land. Furthermore, what was learned at Hiroshima of the effects of radiation was not applied at Bikini. Hundreds of military personnel who were involved in the tests suffered from radiation diseases of various kinds. Today the dangers from radiation are well known and protective measures are in place. Bikini today is free from contamination and is a popular tourist destination. Former target ships, including the U.S.S. Saratoga, that still lie in the Bikini lagoon are popular sites for diving.

CHAPTER 8

Arctic Meltdown of Sea Ice

The most recent, and also the biggest, extreme of weather, is the melting of the Arctic sea ice. Whenever there is a 1°F change of temperature in the United States, the Arctic changes by 2°F. This is a common opinion, and it is largely correct due to the influence of global circulation patterns on areas north of the Arctic Circle. Since the mid-1990s there has been a marked shrinkage in Arctic ice cover. Average land temperatures, as a result, rose by as much as 5°F. There is also an additional accelerating influence. As long as the Arctic Sea is covered with ice, incoming radiation from the sun bounces off the bright surface. As soon as sea ice melts, the sun's radiation is partly absorbed by the water, raising its temperature. The higher temperature speeds up the melting process on the remaining sea ice areas. In 2008, an extremely rapid speed of melting was identified in the eastern Arctic island of Baffin, over an area of 3,000 square miles. Before the twenty-first century this area had remained frozen for more than 20,000 years, long after most of the ice on the rest of North America melted.

The confirmation of these changes comes from the three hundred researchers from eight nations who form the Arctic Climate Impact Assessment (ACIA) and who recently issued a statement following a four-year scientific assessment. Similar conclusions came from the climate change director of the World Wildlife Federation. The ACIA report's projections for the future show a two to three times higher warming rate for the Arctic than for the rest of the world, with potentially devastating consequences for the physical, ecological, and human systems of the region. If nothing is done in the intervening years to reduce carbon dioxide emissions, the Arctic will lose at least half of its ice distribution by 2100. Using data from the United Nations Intergovernmental Panel on Climate Change (IPCC) in its predictions, the ACIA estimates that sea level could rise by as much as three feet in this century.

IMPACT ON ARCTIC HUMAN LIFE AND WILDLIFE

The native people of the Arctic region, formerly known as Eskimo, now Inuit, depend on a hunting lifestyle to survive. Their survival is at stake because the wildlife on which they depend for their food may disappear. Species such as the polar bear, as well as thousands of others, will soon be listed as endangered. The Inuit self-governing territory of Nunavut became a reality at the beginning of the twenty-first century, and one of its first decisions was to allow half of its area to operate in the traditional hunting and gathering lifestyle. The scientific community says that these traditional lifestyles will disappear, and the Inuit must soon find alternatives. Warming also affects the infrastructure of the region. Roads, airports, and buildings of all kinds that traditionally relied on the support of the underlying frozen ground, known as permafrost, now have to be rebuilt on new foundations. At the same time, for some humans, there are advantages: an ice-free Arctic gives access to oil and gas resources. A quarter of the world's remaining reserves of these are in the Arctic.

On either side of the International Date Line, both the United States and Russia are eager to exploit the seabed oil and gas resources that have already been identified but that hitherto were inaccessible because of the ice. Will there be another concentration of energy resources in the north like the Alberta tar sands, a resource made economically viable by the high price of oil? The tar sands now constitute one of the world's greatest reserves of oil, surpassed only by Saudi Arabia. The possibility of another similar concentration of oil resources in the far north will certainly trigger intense competition for access to these resources among all the nations that border the Arctic. Already tensions are building over land and ocean rights: Canada and Denmark squabbled over the ownership of a tiny mid-ocean island

Polar bears range throughout the Arctic in areas where they can catch seals at open-water spots as they wait on ice floes. If all the floes disappear, the bears will be helpless. (Tersina/Dreamstime.com)

Gabriel Daniel Fahrenheit

Gabriel Daniel Fahrenheit, an instrument maker, made the first reliable thermometers in 1714. His name was given to the one he designed in 1724, at the age of 38. It is used today all over the United States. His early life had been a difficult one. Both of his parents died when he was 15 years old. There was no public system for school or university education at that time, so the only option open to him was to get a job and, at the same time, if possible, learn a trade. He worked for a time for a merchant in his hometown of Amsterdam, the Netherlands. While working for this merchant he acquired some ability in instrument making, and this gradually became his life's work.

Fahrenheit used alcohol as the liquid for the bulb in his first thermometers. Later he switched from alcohol to mercury. Very little was known in 1714 about the rate at which mercury expands under heat, nor had anyone accurately determined the temperature at which water boiled. As a result of his experiments Fahrenheit began to doubt that he could find any certainty in figures representing the freezing and boiling points of water. He began to search for alternative standards to represent the bottom and top of his scale. Finally he settled for a scale of 32 to 212, the same one we still use today, for his 1724 instrument. The zero represented the most intense level of cold that he was able to create artificially using a mixture of water, ice, and salt ammoniac or even sea salt. The figure of 32 then represented the temperature where water turned to ice. The top end of his scale, 212, was based on the temperature of boiling water. Fahrenheit's thermometer was well received everywhere for the two centuries that followed, until the demands of scientific terminology made many countries switch to a zero-to-100 scale, better known as the Celsius thermometer.

between Baffin Island and Greenland, the United States rejects Canada's claim to exclusive sovereignty over the vast stretch of ocean and land from Banks Island to Baffin Island to Ellesmere Island, and Russia also disagrees with Canada's claims.

IMPACT ON EASTERN NORTH AMERICA AND EUROPE

If the average winter temperatures of two places at latitude 60° north, one in North America and one in Britain, are compared, the difference is often as much as 45°F. Why is this? Shouldn't places at the same distance from the equator have similar temperature ranges? The answer is that other factors besides distance from the equator determine the temperature of a place. One of these factors is the ocean conveyor belt, a global two-way current of water that distributes warmth and salinity from place to place around the world. Because it is involved in the distribution of warmth and salinity it is technically known as the thermohaline circulation (THC), "thermo" for warmth and "haline" for salinity. In the North Atlantic this circulation is known as the Gulf Stream. It travels near the surface in a northeasterly direction, bringing warmth to coastal areas of the United States and northwest Europe. The return flow of water that completes the global circuit is a cold stream far below the ocean's surface.

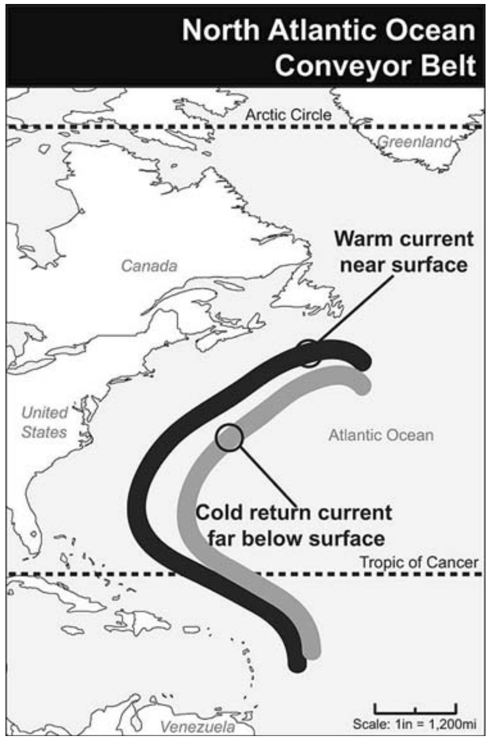


Figure 8-1 Gulf Stream portion of the ocean conveyor belt. (ABC-CLIO)

The rate of movement of the THC is very slow, but it carries a huge amount of heat toward the colder regions of the globe, as much as is conveyed by the total atmospheric circulation. The mechanics of the Gulf Stream branch of the THC is quite simple. As the water reaches its northernmost limit, two things happen: first, the water cools, and so it gets heavier and begins to sink. At the same time, because so much fresh water has been withdrawn to form icebergs and sea ice, the level of salinity in the Arctic Ocean increases, making it heavier, adding to the total weight of water. This double source of increased weight makes the Gulf Stream sink, thereby drawing water northward in its wake, and so keeping the circulation in motion. Consider, now, what would happen if the Gulf Stream became lighter at its northernmost extremity. How does the recent acceleration in the melting of Arctic ice relate to this possibility? Leading scientists are presently wondering if all this melting could provide enough freshwater to slow down and even stop the Gulf Stream.

The signs of such a change are already appearing. A report in 2004 from the National Aeronautic and Space Administration (NASA) satellite surveillance of the entire North Atlantic circulation system reveals that the Gulf Stream by the late 1990s had slowed down by a considerable amount since the 1970s. NASA's data is collected from direct measurements taken by instruments in satellites, from buoys anchored at sea, and from ship reports. In addition, NASA uses low-flying robot airplanes that can measure underwater conditions much more accurately than is possible from the higher elevation of satellites.

In Search of the Northwest Passage

The King of England, five years after Columbus had reached the Caribbean instead of Indonesia, decided to search for a sea route to Indonesia around northern Canada. His first explorer, John Cabot, was sent westward in search of this route. Canada as a country did not exist at this time, and very little was known about the climatic conditions and the distances that might have to be traversed. Cabot, like Columbus, only got as far as the east coast of North America, but in the 250 years that followed explorer after explorer from Britain and other European countries set out in search of the Northwest Passage. We know today that it was an immense challenge to sail across the north of Canada, at a time when some parts of the 900-mile route were covered by ice. Nevertheless, the prospect of success inspired many to search. A great deal of information about northern Canada had been acquired over the years, yet it still proved to be impossible to sail north around Canada, even for Sir John Franklin's 1845 expedition.

Many years later, on June 25, 1981, University of Alberta professor of anthropology Owen Beattie began the 1845–48 Franklin Expedition Project. He and his team of researchers and field assistants left from Edmonton for King William Island. They hoped to find artifacts and human remains so that they could use modern forensic methods to help them understand the fates of Franklin's lost men. Permission was obtained from descendants of Franklin's men to exhume the skeletons of bodies, and these, on their return to Edmonton, were sent to testing labs for trace element analysis. The lead content in their bones was ten times higher than normal, and it was concluded, after examining empty food cans, that the cause was the improper lead sealing of the cans in England in 1845. It was likely that a combination of bad weather, disease, poisoned food, and simple starvation had killed all the members of the Franklin Expedition.

If the trend that NASA documented were to continue to the point of stopping the Gulf Stream, the result would be disastrous for eastern areas of North America and all of northwest Europe. Both would experience climates like northern Russia. It has happened before, in the distant past, shortly after the end of the last ice age. Arctic temperatures dropped 27°F within a very short period of time and stayed at that low temperature for almost three thousand years.

THE NORTHWEST PASSAGE

The famous Northwest Passage is now navigable at certain times of the year. That means ships from the east and southeast areas of the United States, and from Europe and Russia, are able to sail to Japan and other parts of Asia in far less time and at far less cost than the present routes using the Panama Canal or the Suez Canal or the long routes around South America or South Africa. The Northwest Passage has for centuries captured the interest of Europeans, and the prospect of it being at last accessible is leading to international disputes. Canada says it has full rights over those parts of the Passage that pass through its territory, but this view is rejected by the United States and the European Union. They argue that it must be treated as an international strait, open to vessels of any nation.

During the centuries of the Little Ice Age Europe experienced very low levels of productivity in both agriculture and stock rearing. These conditions stimulated interest in gaining access to East Asia for pepper and other spices via a sea route through a Northwest Passage. The fodder grown for animals in the summer was frequently inadequate to feed them through the winter, so it was common for farmers to slaughter their pigs and cattle in the fall and store the meat as a food resource for the following winter and spring. There were no freezers or other modern methods of storage available at that time. As a result, the meat that had been stored was not very tasty, and often inedible, four or six months later. Spices such as pepper that grew in the islands of Indonesia proved to be one answer to this problem of bad meat. From the days of Marco Polo, who had traveled to China and Indonesia hundreds of years earlier, the sources of these spices were known, and a lively trade emerged for their purchase and transportation to Europe. For a time this trade was conducted on land, along such routes as the Silk Road through central Asia, but by the 1400s Europeans were denied access by land. They had to get to Indonesia by sea. Christopher Columbus, in 1492, was the first to sail westward in search of such a sea route.

CHAPTER 9

Kivalina

Kivalina, an island in northwest Alaska near the mouth of the river of the same name, has become world-famous as an example of the effects of global warming. Newspapers around North America wrote about it in 2007, and the United Nations Panel on Climate Change (which won the Nobel Peace Prize in 2007) defined it as a prime example of the problems that result from climate change. This subject will be dealt with in Volume 4 of this series, but it is appropriate to look at some aspects of it here because of the relevance of this island's experience. The settled area of Kivalina is half a mile long and less than 600 feet wide. The four hundred who live on the island belong to the Inupiat cultural group, an Inuit people. Most of the residents are under the age of 24. Only 20 are over the age of 65. Although the island is a sandspit, created by the Kivalina River over time and therefore not ideal material on which to build a permanent settlement, there have been homes and people living there for almost all of the twentieth century. People lived by hunting for salmon, seal, walrus, and caribou. Until the early years of the twenty-first century they caught humpback whales, but these mammals are now protected from hunters because they are an endangered species.

The weather in this part of North America can be very stormy, with high winds and high seas a common experience in fall and winter. Kivalina, despite its sandy composition, survived these assaults because the land and ocean froze, and waves and wind swept over the ice, leaving buildings and land as they had been before the stormy season. All of this changed in 2002 as the meltdown of Arctic ice reached Kivalina. Waves and wind swept onto the island, dislodging the sand and carrying it away. By the fall of 2006 it became necessary to place one-ton bags of sand around the settled area in order to slow down the erosion. This initial installation cost $3 million, but ever since the first sandbag was placed in position replacements became a frequent necessity as melt water from the land coupled with wave action from the sea kept undercutting the sandbags. The U.S. Army Corps of Engineers in Alaska estimated in 2007 that the foundations of the settled part of the village would be completely undermined by

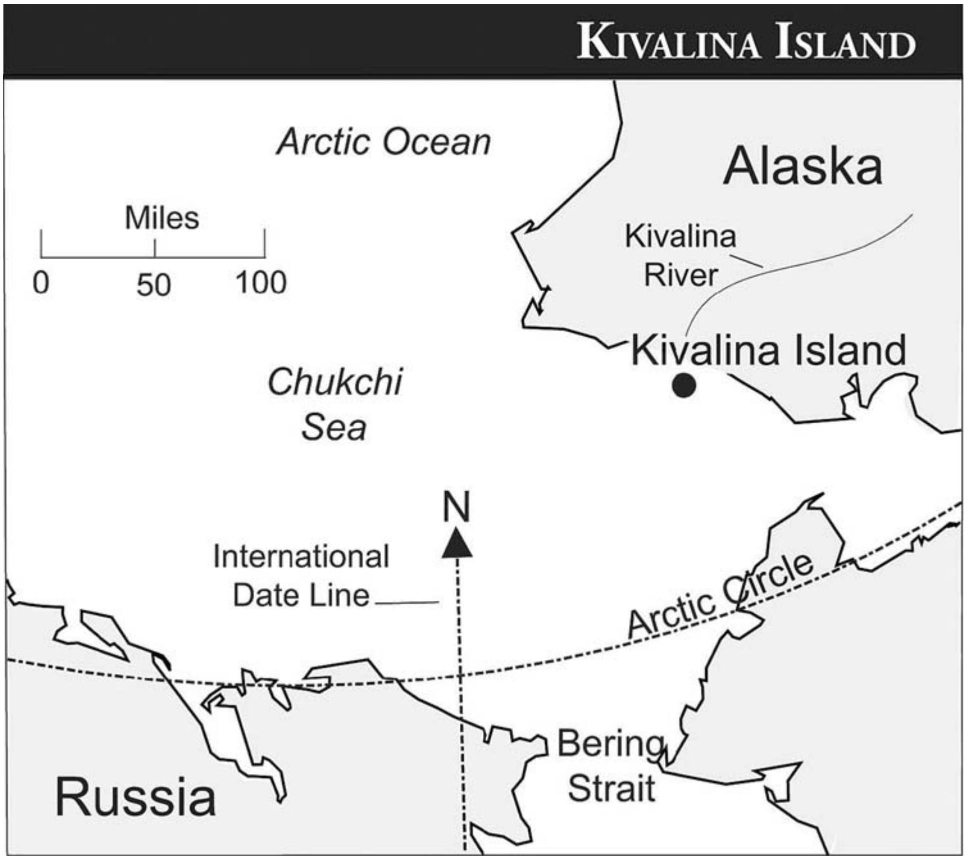


Figure 9-1 Kivalina is an Inupiat community on a barrier island located in the Chukchi Sea, at the mouth of the Kivalina River. (ABC-CLIO)

2022 if present rates of erosion continued. The Corps therefore recommended immediate planning for a complete evacuation of Kivalina before that date.

The people of Kivalina are largely enthusiastic about the prospect of a move to another place. They are well aware of much more than the erosion of their island: most homes have no running water, and the standard toilet in use is a five-gallon bucket. For much of its history, before it became a settled community, this island was a temporary location for hunters as they moved from place to place in search of food and furs. The homes from those times were never fully upgraded for permanent use because the economic base of the village does not provide sufficient income. There are very few jobs within Kivalina, and many of the residents have to supplement their incomes from hunting by traveling to work sites on land, either to a mine 45 miles away, or to Kotzebue, a comparatively large town 80 miles to the south. The unanswered question about relocating people to a new site is, "Who will pay for the move?" Discussions continue with local, state, and federal officials about who will pay the necessary $250 million for the move.

Erosion of Kivalina Island due to melting sea ice. (AP/Wide World Photos)

INVESTIGATING FUTURE TRENDS

The Web site discussed here comes from the country that is most affected by global warming in the Arctic, Canada. This Web site is part of a Canadian Internet atlas, available free to anyone as of 2009, and the site selected here deals with future possible levels of temperature and precipitation in places all over the world. This site can be found at http://atlas.nrcan.gc.ca/site/english/maps/climatechange. All of this information is based on findings from scholarly research, their predictions being based on what is likely to happen by the middle of the present century, or at its end, if nothing is done before then to remove some of the causes of global warming. Much is already being done to change present trends, and much more is likely to be done before we reach the dates listed on the site with these different predictions. We therefore need to understand that the actual future conditions are likely to be different from these predictions. As you open this Web site on your computer, follow the steps listed below:

1. Go to "Climate Change" on the left side of your screen, follow the arrow to "Climate Warming," and click on it. You may wish to read the introduction to the maps and also the section about the issue of climate change before clicking back to the page of maps and opening the first one on the list. It deals with

predicted annual changes for 2050. Where are the biggest temperature changes? Where are the second biggest? Notice the marked area above the map that is labled "zoom in to region." Place your cursor over it, come down to the words "North America," and click on them. This will give you a closer view of the United States. Which states are expected to have the greatest temperature changes in 2050? See Chapter Four on the Dust Bowl and identify the states that were most affected at that time. Are they the same as the ones in this map that show the highest levels of temperature? Was it temperature extremes that caused the tragedy of the Dust Bowl? To answer this last question, we need to check another map.

2. Click back to the list of maps under climate warming and click on the one dealing with predicted annual precipitation for 2050. Once again, read the information provided before tackling questions similar to the ones you examined for temperatures. Your answers this time relate to precipitation. Why are the data provided in percentages rather than actual numbers, as was the case with temperatures? As you move on to the North American map, identify the states that are expected to have the lowest amounts of precipitation. Are they the same states that were listed as having the highest temperatures? Check again in Chapter 4 to find out the conditions that were most destructive at the time of the Dust Bowl—high temperatures, low precipitation, or both? Is there likely to be another Dust Bowl tragedy in the future?

There are other future trends that will be described in later volumes. In particular, the problem of increasing amounts of carbon dioxide in the atmosphere, and the effects it is having on climates all over the world, is something that we must consider now as well as in the future. This subject will be the main emphasis in Volume 4, but a major aspect of it arises from what we have been noting about the Arctic. The rapid melting of Arctic ice means that a large amount of carbon dioxide will be released from the ground as it melts and added to what is already in the atmosphere. This additional Arctic carbon dioxide constitutes almost a third of the world's total. It is stored in frozen soils, and its release could add to our concerns over the damage that existing amounts of carbon dioxide are already doing.

CHAPTER 10

Volume One Review

This first volume of this set concentrates on extremes of weather in many places, covering a long stretch of time and many aspects of human activity. Some of the extremes go back in time beyond anything within our present experience, but, as is indicated in the early part of the book, these events could occur again in the future. Some past extremes of temperature and moisture, such as the Dust Bowl, repeat themselves within short timeframes, and they will therefore affect us much sooner. Extremes such as the Great Ice Age and the Dust Bowl represent very big changes from the normal. Others, such as the Little Ice Age, deal with small changes, often less than 5°F. They remind us that even small deviations can carry great influence when combined with other developments.

A number of the extremes that are described in other chapters represent, like the Little Ice Age, quite small changes in temperature or weather conditions, but they happen to have occurred among people who were under great stress at the time and who therefore could not cope with the change. The war experiences of Napoleon and Hitler, as they attempted to conquer Russia, are examples of this kind, and they illustrate the fact that wars and battles are not always won or lost on the basis of the military leaders' abilities. Another example of this same kind was the failure of the first settlement of Europeans in North America. Their lifestyle in Newfoundland was very precarious, and it only needed one small change in temperature to compel them to leave their new home.

IMPORTANT TERMS

Drought

Statistical average

Volcanic eruptions

Climate

L'Anse Aux Meadows

Northwest Passage

Global warming

El Niño

Tar sands

Gulf Stream

Guerilla-type attacks

Armada

Inuit

D-Day

Norwegian school of meteorology

Sahel

Air pollution

Alcohol thermometer

Mercury thermometer

Permafrost

QUESTIONS

What is meant by a hundred-year event in weather?

How does Arctic melting affect eastern areas of the United States?

How does Arctic melting affect the behavior of the Gulf Stream?

Why did Europeans want to get pepper from Indonesia?

What are sunspot cycles?

What is the volcanic explosivity index?

What was the Medieval Warm Period?

What did farmers learn from the Dust Bowl tragedy?

Why is loess an indirect cause of flooding in China?

Why do Chinese people live very close to rivers that often flood?

WEB SITES FOR FURTHER STUDY

The report from the Arctic Climate Impact Assessment Council describes its findings and its recommendations for the future, and is available on its Web site, http://amap.no/acia.

In addition, you can use the Web site listed in Chapter 9, which deals with global warming, http://atlas.nrcan.gc.ca/site/english/maps/climatechange.

Appendix A: Important Dates in Weather and Climate History

1238 The hottest and driest summer of the millennium in England.

1281 A North Sea storm surge hit the Netherlands in January, flooding large tracts of land and drowning 60,000 people.

1421 Worst North Sea storm surge hit the Netherlands in November, causing the deaths of 100,000 people.

1586 England's first colony in America, established on Roanoke in 1585, had to be abandoned because of severe weather.

1737 The second-deadliest Asian cyclone in recorded history killed 300,000.

1772 The biggest U.S. snowfall (before official records began) occurred in January, when three feet fell in the Washington-Baltimore area. It has been called the Washington-Jefferson snowstorm because it was recorded in both of their diaries.

1780 A hurricane traveled the length of the Windward Islands chain in the Caribbean in October, with St. Lucia and St. Vincent the worst affected, causing the deaths of 24,000 residents.

1791 Cuba was hit in June with a powerful hurricane that took three thousand lives.

1816 The year that was called "the year without a summer." In Savannah, Georgia, the Fourth of July had a high temperature of 46°F. Because it was so cold across the eastern United States, crops were ruined. Snow fell in June, heaviest in New England, with snow drifts of 18 inches. It was the same story in Canada and in Europe. These changes in weather were attributed to the 1815 eruption of Mount Tambora in Indonesia.

1824 In St. Petersburg, Russia, in November, a powerful storm from the Baltic Sea brought a storm surge into the Sea of Finland that swept inland, flooding the Imperial Capital and its palace and drowning 570.

1831 The Caribbean island of Barbados experienced its worst hurricane, which destroyed thousands of buildings and killed 1,500, representing 2 percent of the island's total population

1840 The second-deadliest tornado in U.S. history, Natchez, killed 317.

1870 U.S. Weather Bureau was founded and placed under the office of the Secretary of War.

1881 The third-deadliest Asian cyclone of all time, the Haiphong Typhoon in Vietnam, killed 300,000.

1887 San Francisco's greatest snowfall came in February, with a total of four inches in the downtown area.

1888 The Blizzard of 1888 affected the eastern United States in March. Over four feet of snow fell in the Albany and Troy areas of northeastern New

York state. More than 400 people lost their lives, mainly due to exposure to strong winds and cold temperatures.

1896 The third-deadliest tornado in U.S. history, St. Louis, killed 255.

1899 In February a cold wave caused a massive east coast blizzard and induced bitter cold temperatures across two-thirds of the United States. It was the only occasion that saw true blizzard conditions in the state of Florida.

1900 The second-deadliest Atlantic cyclone in U.S. history, Galveston, hit in September, killing 12,000.

1913 The highest U.S. temperature on record was recorded in Death Valley, California, on July 10, at 134°F.

1913 Several tornadoes hit southwest England and central Wales on October 27.

1921 On September 10, Thrall, Texas, experienced the greatest U.S. 24-hour rainfall on record up to that date. The total was 38.2 inches.

1922 A community in Libya, Africa, on September 13, claimed the world record for the highest temperature of 136.4°F.

1925 The deadliest tornado in U.S. history, Tri-State, killed 689.

1934 On April 12, Mount Washington, New Hampshire, experienced a gust of wind at 231 mph, accepted as the U.S. record for the highest wind speed.

1936 The fourth-deadliest tornado in U.S. history, Tupelo, killed 216.

1940 The U.S. Weather Bureau moved to the U.S. Department of Commerce.

1947 At Snag in the Yukon Territory of Canada, on February 3, the temperature was –81.4°F. This is the lowest on record for all of North America.

1949 In October Guatemala experienced a week of heavy rain from a stalled tropical cyclone. The results were flash floods and mudslides and a death toll of 40,000.

1952 From December 2 to December 6, London, England, experienced its deadliest weather disaster, the great smog that paralyzed the city, stopping all traffic and almost all pedestrian movements, and killed 6,000.

1953 The worst North Sea storm surge of modern times hit the Netherlands and southeastern England on January 31, killing more than 2,000.

1954 In Qazvin, Iran, a violent thunderstorm over the Elburz mountains triggered a flash flood over this city, killing 10,000.

1959 Due to an unusually wet summer monsoon season the Yellow River in northern China overflowed its banks and caused the deaths of an estimated two million people, the highest death toll ever for a meteorological disaster.

1963 The third-deadliest Atlantic cyclone in U.S. history, Flora, hit Haiti and Cuba in October, killing 8,000.

1964 At Oymyakon, Siberia, Russia, in February, the lowest temperature for the northern hemisphere was registered at –96°F

1964 Karachi, Pakistan, in December, experienced a major tropical cyclone that took the lives of 10,000.

1970 The deadliest Asian cyclone of all time, the Great Bhola of Bangladesh, killed 550,000.

1974 A tropical cyclone hit Darwin, Australia, on December 25, killing 65.

1975 The eighth-deadliest Asian cyclone of all time, the Super Typhoon Nina, hit China, killing 170,000.

1983 In Vostok, Antarctica, on July 12, the world's lowest temperature of –138.6°F was recorded.

1992 Hurricane Andrew, the United States' costliest meteorological disaster, swept across Dade County in August with devastating results.

1993 Missouri–Mississippi flooding, greatest U.S. flood of the century.

2005 Hurricane Katrina, costliest storm in U.S. history.

2008 The tenth-deadliest Asian cyclone of all time, Nargis, hit Myanmar, killing 140,000.

U.S. WEATHER AND CLIMATE FROM AD 1000 TO 2000

There are no written records for the first half of this millennium, so there are no details of actual weather conditions. However, there is a huge amount of archeological, botanical, and zoological evidence available, and we can construct from them a picture of the prevailing conditions at different periods of time. At the beginning of the last millennium, both in the United States and throughout Europe, warm weather was widespread, and this continued for the first two centuries, from 1000 to 1200.

The overall regime of warmth was accompanied with abundant, reliable rainfall across the Great Plains, giving rise to extensive wooded areas, the kind of landscape that remained unique to this time period of 1000 to 1200. This was also the time when a large population could be sustained in heartland America. One place in southern Illinois had 50,000 inhabitants between 1100 and 1200. All of this changed in the early years of the thirteenth century; by its first decade, what is now the United States became much colder and drier. The warm and moist air masses from the Gulf Stream were replaced by a strengthening that developed in the westerly flow across the continent. Within the following 40 years the woodlands had retreated from the U.S. Interior, and the Great Plains became grasslands, the habitat of the buffalo that would become, at a later time, so familiar to early European explorers.

Native American populations declined as a result of the change in climate. Settlements were abandoned, and people migrated westward and southward. It was a similar story farther to the north, where the first Europeans had settled for a long time during the warm period on the island of Newfoundland in Canada. By the fourteenth century, they had to abandon their North American settlement as well as those they had founded in Greenland and Iceland. Most of the United States remained cold for the long period that came to be known as the Little Ice Age. The first English colony that was established on an island off the coast ofVirginia had to be abandoned within a year due to low temperatures. An overall warming trend, one that affected all of the United States, began to arrive toward the end of the nineteenth century, but it did not become a settled pattern until the second half of the twentieth century.

EVOLUTION OF CLIMATE CHANGE CONCERNS

1970s For much of this decade, mainly because evidence of global cooling had been experienced over the previous three decades, scientific interests and publications focused on the prospect of a return to ice-age conditions.

1980 A report to the president of the United States from the Federal Council on Environmental Quality pointed out that human-caused climate change as a result of greenhouse gas emissions would probably be evident to all within the following 20 years.

1988 The World Meteorological Organization and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC).

1993 The scientific journal *Nature* published the findings of the scientists who had extracted a two-mile ice core from the Greenland ice sheet in order to identify climatic conditions 12,000 years ago. These scientists were astonished at both the rapidity and extent of the climate changes they identified, in particular the 1,300-year cold snap that appeared relatively suddenly. This period of time is often called the Younger Dryas after an Arctic flower.

1997 The scientific journal *Science* published an article that identified the slowdown in recent years of the Gulf Stream as a development that closely resembles the rapid changes in the Younger Dryas time.

2005 The Kyoto Protocol, a set of obligations related to the IPCC, came into force in February, and many developed countries agreed to follow its prescriptions. These related to reductions in levels of greenhouse gases by a specific date.

2007 The Norwegian Nobel Committee awarded the Nobel Peace Prize in two equal parts, to the IPCC and Albert Arnold (Al) Gore Jr., for their efforts to build up and disseminate greater knowledge about manmade climate change and to lay the foundations for the measures that are needed to counteract such change.

APPENDIX B: SOME EXTREME GLOBAL WEATHER EVENTS

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as well as Appendix C, which focuses specifically on U.S. extremes, is to provide a larger context to which the individual references can be linked. When it comes to global extremes, the nations of Asia still dominate. Again and again, even after a century of improved methods of protection from tropical cyclones and interior floods, weather events are far more severe in Asia than we are accustomed to in North America. Numbers of casualties and the extent of environmental damage are often huge. One reason for this is the high terrain that borders nations such as Bangladesh and Vietnam; another is that the Pacific Ocean is much bigger than the Atlantic, and storms reach the Asian mainland with huge volumes of moisture after moving across great stretches of water.

The two biggest nations of Asia in terms of population are China and India, and they epitomize two extremes of weather: flooding in China and drought in India. The extremes of flooding in China are described in Volumes 1 and 2, and the drought problems of India are explained in some detail in Volume 3. The China flood of 1931, described next, was by far the most extreme in centuries, and the drought that hit India in 1900, along with the accompanying famine and starvation, was the worst of the entire twentieth century. Extremes of tropical cyclones, just like floods and droughts, are usually greatest in Asian countries, but occasionally other parts of the world experience exceptional storms. The two examples included here are of this character, Hurricane Mitch of Central America and Cyclone Wanda of Australia. The fifth extreme event included here took place in the Sahel of Africa, selected because it is an area that experienced so many droughts in the twentieth century that the United Nations set up a special task force to study the problem and identify the causes.

CHINA FLOOD, 1931

In the United States it is easy to think of hurricanes and tornadoes as the causes of more deaths than other weather events. In fact, in the United States, and to a far greater extent in Asia, floods cause far more deaths. In China, in particular, there is a tragic history associated with flooding, and Chapter 5 of Volume 1 shows this in the tragic story of

the great 1887 flood. The 1931 flood went far beyond the 1887 one in terms of deaths and damage. Nothing equal to it had happened in China in centuries of experiences of flooding. It began during the summer months, and the worst flooding occurred on the Yangtze River, although the heavy rains and rapid snow melt affected many other rivers in central China at the same time. About 51 million people were affected, representing a quarter of the nation's population at that time.

The U.S. National Oceanic and Atmospheric Association (NOAA) considered this 1931 event the most extreme weather-related disaster of the twentieth century, possibly the deadliest natural disaster ever recorded. The number of deaths was approximately four million, not all due to drowning. In 1931 China was still predominantly a rural society, and people earned their livelihood from agriculture. There was no national organization that could provide emergency food supplies, so, as water destroyed their food crops, mostly rice, people had nothing to eat beyond the supplies they might have saved from previous crops. Thus many died from hunger. Many others became infected with deadly diseases from polluted water. The causal factors that led up to this tragedy were a combination of extended droughts, from 1928 to 1930, followed by an equally protracted period of heavy rain. In winter much of the precipitation fell as snow, and in the following spring, the thaw added quantities of water to the rainfall, greatly increasing the volume of water in the rivers.

Rainfall persisted throughout the summer months and, in July alone, the area on the Yangtze River near the capital of that time, Nanjing, was hit with seven tropical cyclones, each of which added substantially to the amount of water in the rivers. Normally this part of China experiences about two tropical cyclones a year. By July of 1931, Nanjing had become an island in a massive flooded area. The high-water mark on the Yangtze reached 53 feet above normal by the middle of August. The immediate cause of flooding in China is nearly always a result of failure of the levees. Historically these are built of sods, so they offer little resistance to a sudden rise in the level of the river, especially if the rise in river flow occurs on a downward slope. These levees get built up over time to compensate for the rise in elevation of the riverbed, as more and more silt is deposited in it, so the river runs at an elevation above the surrounding plain.

Thus, as soon as a breach occurs in a levee, the rapid flow of water through the opening quickly expands the opening and increases the volume of water escaping into the lower land below. Toward the end of August the water flowing through the Grand Canal near the mouth of the Yangtze washed away the supporting dikes and drowned 200,000 people. In modern China the ancient forms of levees and dikes have been replaced in critical areas of the country by protective walls of concrete so that the enormous tragedies of the past will not be repeated. Additionally, hydroelectricity is being produced in many locations on rivers, and the dams serve as control points to prevent overtopping during sudden increases in river flows. The huge undertaking to dam the Yangtze River in order to secure much greater amounts of hydroelectricity provides protection from flooding all along the river.

HURRICANE MITCH, 1998

Deadly tropical cyclones frequently strike coastal areas along the Bay of Bengal, causing enormous loss of life and extensive environmental destruction. The Bangladesh cyclone of 1970 that is described in Volume Three of this series was the nation's greatest disaster of the twentieth century. Winds coupled with a storm surge killed between 300,000 and 500,000 people. The tropical cyclones we experience in North America, which we call hurricanes, do not generally reach these levels of destruction, but occasionally there are extreme examples of deadly hurricanes. Hurricane Mitch of 1998 was one of these. It was a late-season arrival, forming in the western Caribbean in October and moving westward over the mountainous areas of Central America. This storm weakened as it reached Honduras. Perhaps because it arrived late in the season, it did not have the strength to continue westward after reaching Honduras so it stalled over that country.

Hurricanes that travel across the warm waters of the Caribbean carry large amounts of water, and this volume of moisture is usually spread over an extensive area of land when precipitation takes place and the storm moves along. It is a very different story when a hurricane operating in the warm waters of latitude 15° north stalls over land, and especially when it stalls over mountainous land, as Mitch did. It unleashed precipitation amounts estimated as high as 75 inches. The resulting floods devastated the entire infrastructure of Honduras and also severely impacted other countries in the Central American region. The final estimated death toll was 11,000, the greatest loss of life from a tropical system in the western hemisphere since 1780. The fact that this was an estimated death toll tells us a lot about the level of development, and preparedness for hurricanes, in the countries affected.

Extensive wind damage and devastating floods occurred all over Honduras, particularly on the northern seaboard and in the Bay Islands that are located off the northern coast. Approximately 1.4 million persons were left homeless, more than 92 bridges were damaged or destroyed, and nearly 70 percent of crops were lost. The U.S. Geological Survey was called to help assess and map the damage and to provide technical help with landslide mitigation. Fortunately, the recent date of this hurricane makes possible the use of techniques to accurately assess the extent of the damage and provide expert help in recovery.

INDIAN DROUGHT, 1900

In contrast to the famines that occur in China due to the country's frequent floods, the Indian famines are caused by the absence of rain. The monsoon is the name given to the annual arrival of massive amounts of rain that reach land after traveling thousands of miles across the warm waters of the Indian Ocean. It is the greatest weather event in the world for two reasons: it travels over an area of water greater than

that of any other weather system, and it affects a bigger population than is ever affected by another single series of rainfalls. This main weather event of the year begins with rain arriving in early summer in the south of the country and often continuing unabated for weeks before dying down. It is common for rivers to overflow and communities to be flooded, but no one objects because this summer rain is the lifeblood of the whole nation. Even today, most of India is still a rural, agricultural society. In 1900 everyone depended on what could be grown in order to survive and, in this hot tropical climate, every crop depended on rain.

India has a second monsoon that arrives in the fall of each year. It is quite different from the summer one because it travels south over dry land and so carries much less moisture. If we think of India together with the large mass of continental land that lies north of it in the Himalayas, China, and Siberia, the enormity of these two annual events can be visualized. In summer, because land heats up much quicker than water, the air that had been circulating over long stretches of warm ocean water, and that therefore carries large quantities of moisture, is attracted toward the low-pressure areas over land. As it rises over higher ground water is precipitated, and the summer rains begin. People talk about it as rain, rain, and rain again; clothes damp, bed linen damp, walls damp, food damp, everything damp. Rain hammers a tattoo on corrugated iron roofs, tears up roads, and smashes down vegetation. The opposite movement of air happens in the fall as the land cools below sea temperatures, and a reverse flow of air takes place. It is the summer rains that are always the focus of interest. They sustain crops, especially rice, for the hundreds of millions of Indians. Billions of rice seedlings are in the fertilized, prepared plots of land in May or early in June awaiting the arrival of the monsoon.

What happens if it fails to arrive at the time the weather forecasters gave? In 1900 forecasting the exact date of arrival involved quite a bit of guesswork. There were few weather stations serving the land areas, and nothing on the ocean except reports from passing ships. A primitive form of statistical prediction operated. That is to say, forecasters knew that, on average, the monsoon would arrive within ten days of the middle of June, so they used whatever data they had to fix a date within that timeframe. However, even if the statistical average proved to be true for 30 years, the elders in Indian communities knew that occasionally there were huge exceptions. They knew of the terrible years of 1768, 1769, and 1770, when inadequate rain arrived and ten million people died. Somehow these anomalies had been forgotten in the year 1900. There had been exceptionally low amounts of rain in 1899 and again in 1900. Because of the possibilities of weak monsoons, farmers had been in the habit of storing some grain each year as a kind of insurance against a famine, but for some reason this had not been done before 1899 and 1900.

Severe shortages of rice were reported all over southern India in 1899 and over the rest of the country a year later. Unlike modern times

in India, in which food reserves are on hand to cope with disasters like this one of 1900, there was nothing that could be done for the farmers who had inadequate amounts of rice. A certain amount of sharing was done within communities, but the overall picture deteriorated into widespread famine by the fall of 1900. Disease and a breakdown in social order followed. There were many deaths. Subsequently it was discovered that there had been low levels of rain in the monsoons of 1896 and 1897, and these conditions led to the inability of farmers to put some grain aside as a reserve for emergencies. The British colonial authorities of the time paid no attention to these failures in the monsoons. They were only concerned with securing their quota of rice in order to satisfy their superiors. The final tally of deaths from famine and disease ranged from two million to ten million. The uncertainty about the numbers is a sad commentary on the failure of the colonial power to look after the people over whom they ruled.

AUSTRALIAN CYCLONE WANDA, 1974

Australia is quite well acquainted with extremes of climate. It has a very large desert area, and its location in a tropical zone means it gets the full effect of the unexpected heavy rains and high temperatures that are commonplace in that part of the world. During the summer of 1974 there happened to be one of the wettest seasons that Australia had ever known. The climatic variation called La Niina had been one of the most extreme of the entire twentieth century. As result of both of these conditions, rainfall was torrential and continuous through most of January 1974, as the inter-tropical zone settled over northern Australia. On January 25 of the same year, Cyclone Wanda moved over the interior of Queensland and New South Wales, dumping more than 12 inches of rain in 24 hours over a very wide area. As a result, because the summer rains had completely saturated the ground, massive flooding occurred on all the nearby river systems.

The city of Brisbane was the worst hit. It had not experienced a major flood for more than 70 years, and few suspected that anything like this would ever happen. After the last occasion when a major flood had hit the city, in 1893, very strict regulations were established for building on areas below a certain elevation. These restrictions were laid out for the parts of the city that would be at risk in the event of a major flood. Sadly, these regulations were not maintained for one reason or another, and subdivisions were allowed to develop on the areas on which no homes or other buildings were to be built. It is a story that is similar to what we have seen in the aftermath of the San Francisco earthquake, where areas that should never have been built on were once again rebuilt. Throughout Brisbane on January 25 there was a general failure of disaster warnings. There was no central authority that was able to receive details on the amount of flooding that occurred in different areas, so that local flooding in key areas was never reported to the authorities. About 70 percent of the

residents who were questioned afterward about the flood said that they had received no official warning.

January 25, 1974, the peak of the damage caused by Wanda, will be remembered as the worst floods in Australian history. Flooding covered an area slightly larger than the entire drainage basin of the Mississippi River. It reached from the dry interior at Alice Springs all the way to the Pacific Ocean, and from the extreme north of the country to the areas around Sydney, including the Murray River system. Military airplanes had to be used to supply isolated towns that were cut off by the floodwaters with emergency food for both humans and animals. In Brisbane, all bridges across the Brisbane River were damaged or destroyed, and 35 people drowned. At its height, the river broke its banks and ran through the central business district of the city. Water levels peaked at 20 feet by January 29. In one of the subdivisions 1,200 homes were destroyed. Overall, 20,000 people were left homeless. There was no adequate relief organization at this time, and about half of the victims depended on church contacts and a large number of volunteers for the help they did receive. By the end of January much of Australia, normally the dry continent, was submerged in water. Crops were destroyed, and there were outbreaks of disease.

Major flooding like this is so rare in Australia that the disasters of January 1974 are unique in the history of the country. In the aftermath, thoughts were concentrated on appropriate action that would prevent future disasters. Almost immediately the Queensland Government introduced a series of flood mitigation measures that expanded earlier ones. The experience was a wake-up call for Australia.

SAHELIAN DROUGHTS

This region, which stretches for three thousand miles across Africa south of the Sahara Desert, from Senegal at the Atlantic Ocean to Eritrea at the Red Sea, is a focus for all the world in the study of drought. It is an extreme example of aridity because of the extent and persistence of the droughts that overwhelm it. From 1968 to 1973 most of the region suffered from lack of rain, and the Sahelian Office at the United Nations created a special unit in 1973 to investigate the causes and recommend ways of coping with droughts. Occasionally the whole world becomes aware of the deadly nature of these times of aridity when international aid efforts are launched. One of these efforts is described in Chapter Six of Volume One: half a billion dollars was raised by Live Aid to help Ethiopia cope with a famine that had already taken the lives of 300,000 people. Overall, in the Sahel as a whole, between the 1960s and 1980s, famines took the lives of a million people, and many millions more were affected.

The 50 million people of the Sahel pursue different livelihoods. These include agriculture, livestock herding, fishing, and short- and

long-distance trading. Farming is almost entirely reliant on three months of summer rainfall, except for places that happen to be near a major river such as the Niger. Researchers from The United Nations, as they examine the region's economic fragility, recognize that the vast majority of the population is dependent on some form of rain-fed agriculture, including pastures for animal production. Three major droughts have occurred this century, in 1910–16, 1941–45, and a long period of below average rainfall that began in the late 1960s and continued, with some interruptions, into the 1980s. Absolute minimum rainfall levels were recorded at many stations in 1983 and 1984. The period of poor rainfall in the 1970s was particularly hard for many Sahelian farmers and pastoralists. An estimated 100,000 died from it.

Sahelian droughts and their effects have been studied extensively since the 1970s as part of the international response to this environmental emergency. It is only since 2000, however, that the long-term impacts of the famines of the 1970s have become evident. Those events provoked a rethinking of the links between population growth, drought, and sociopolitical change, and also helped to refocus development policy away from expensive and unsuccessful interventions toward more considerate strategies targeted at boosting local capacities. A complicating factor was increases in migration and international trade. Food distribution in famine situations by donors and governments has not been successful, despite the establishment of national cereals boards in most Sahelian nations, and the construction of roads into more remote rural areas. Rural residents still have to pay for government grain, and not all households are able to pay.

Originally it was believed that the problems in the Sahel were caused by humans overusing natural resources through overgrazing, deforestation, and poor land management. The expansion of farming and herding into marginal areas was said to have produced a spiral of changes, in which reduced vegetation caused reduced rainfall, producing further decreases in vegetation and thence a further reduction in rainfall. The series of Sahelian studies and climate modeling carried out by an agency of the NOAA over some years, and published in 2005, present a very different story: the problems are caused by changing sea surface temperatures that, in turn, were created by greenhouse gases and atmospheric aerosols from volcanic eruptions. In other words, global warming and climate change are the primary villains. The NOAA studies also point out that these human-induced changes in sea temperature could lead to a substantial reduction in the Sahel's rainfall in the course of this century.

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Appendix C: Some Extreme U.S. Weather Events

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as with Appendix B, is to provide a larger context to which the individual references can be linked. This list of U.S. extremes begins with two volcanic eruptions, one from Alaska, the biggest that occurred anywhere on earth during the twentieth century, and one from Washington State, the biggest ever within the contiguous United States. They are reminders of the unpredictable element brought by volcanic eruptions to the ongoing changes occurring in our atmosphere. Volume 1 describes the role of volcanic eruptions in considerable detail, with regard to their influences both now and in the future.

The other three extreme events included in this appendix are two extremes of temperature, cold and hot, and one of the most violent hurricanes of modern times, Camille of 1969. The extreme of heat is interesting because it arrived in the midst of widespread talk about global warming and climate change and is a reminder that the addition of carbon dioxide to the atmosphere has different effects in different places. In this instance, the high heat of the year 2006 is almost identical to that of the year 1936, the time of the Dust Bowl. The years 2006 and 1936 were the two hottest of the twentieth century.

MOUNT KATMAI, ALASKA, 1912

Katmai was the biggest eruption of the twentieth century anywhere on earth. A volume of volcanic ash greater than the amount from all other volcanic eruptions in Alaska was ejected, and it devastated every place within miles of the source. It created the Katmai Caldera and the Valley of Ten Thousand Smokes. Volcanic ash devastated areas hundreds of miles away. Within four hours of the initial eruption, ash had reached Kodiak, lying one hundred miles to the southeast, and by the end of the event, both Vancouver, British Columbia, and Seattle, Washington, were showered with sulfurous ash. The cloud produced by the eruption had reached Virginia by June 7. Ten days later, it had reached North Africa.

Kodiak suffered greatly during the three-day eruption. Ash and sulfurous smoke caused a slew of health problems ranging from respiratory illness to sore eyes. Additionally, the eruption rendered Kodiak's water

supply undrinkable, disrupted radio communications, and destroyed many buildings, some of which burned and others of which collapsed under the weight of mountains of ash.

As a result of the Katmai disaster, several villages were abandoned forever. Additionally, the eruption caused untold environmental havoc, and many animals, ranging from bears to birds, died of starvation. Aquatic organisms were also affected where waters were shallow and became choked with ash. This devastated local salmon fisheries for years.

Despite the fact that the eruption was so close to the continental United States and comparable in magnitude to that of Krakatau of 1883, it was hardly known at the time because Mount Katmai was so remote from the world's main population centers.

Almost a hundred years after it happened, researchers are still paying attention to Katmai because it is near the Arctic Circle, and its impact on global climate appears to be quite different from that of volcanoes in lower latitudes. Unlike eruptions in the tropics, the aerosols emitted by Arctic volcanoes tend to stay at high latitudes, because the stratosphere's average circulation is poleward from the equator. As a result, these particles remain effectively "bottled up" in the Arctic, dispersing into the rest of the earth's atmosphere only very gradually. Professor Alan Robock of Rutgers University has argued that this trapping of aerosols in the Arctic has an unexpected side effect: the weakening of the Indian monsoon. Robock reached these conclusions using complex calculations; however, the basic concept is that cooling in the northern hemisphere caused by the Katmai eruption set in motion a chain of events ultimately affecting air flow over the Himalayas and thus rainfall in south Asia.

To check his results, Robock and colleagues have been examining weather and river flow data from Asia, India, and Africa from 1913, the year after Katmai. They have also investigated the consequences of other high-latitude eruptions in the last few centuries. The fact that the stratosphere in high latitudes is shallower than at the tropics means that even small eruptions near the North Pole may deposit more aerosols than bigger events in the tropics. Furthermore, they would remain in circulation longer, as happened with Katmai. Indians will need to keep an eye on future Arctic eruptions.

It is unlikely that another eruption on the scale of Katmai will occur in the same region in the foreseeable future. However, volcanologists have confirmed that at least seven Katmai-scale eruptions have occurred over the last four millenia within a five-hundred-mile radius of the city of Anchorage, Alaska, so such a recurrence is far from outside the realm of possibility.

MOUNT ST. HELENS, WASHINGTON, 1980

The eruption of Mount St. Helens was the largest ever in the history of the contiguous United States. It had a VEI of 5. Mount St. Helens is the

youngest of the Cascades' volcanic peaks, and the explosion of 1980 is just the most recent of the many intermittent eruptions that took place over the past 40,000 years. Pumice and ash from these past events now cover large areas of the Pacific Northwest. From the 1950s onward, the mountain was intensively monitored, perhaps to a greater degree than any other. Days before the fateful event of Sunday May 18, 1980, there were many signs of impending danger, but no one was quite prepared for what finally happened. It all seemed to take place in seconds. Seattle's air traffic control tower tracked the mass of ash and rocks hurtling out of the mountain and concluded that it was traveling at close to 300 mph. The earthquake that triggered the explosion measured 5.1 on the Richter scale, but the energy released might be more accurately defined as the equivalent of thousands of Hiroshima-size bombs.

An avalanche of mud, rock, and ice roared down the mountainside, and the ash cloud rose as high as 54,000 feet. What had moments before been a beautiful 9,000-foot-high peak was reduced to a 7,500-foot decapitated mountain. Ash high in the atmosphere drifted eastward across the country, covering the ground everywhere it went with a layer of ash and blocking out sunlight in several communities near the mountain. Two hundred square miles of forest was flattened. Mudflows rushed westward down river valleys toward the Columbia River, blocking the navigation channel for ships with logs and mud for a distance of ten miles. It was estimated that 57 people lost their lives on that first day.

A Boeing 737 jet flying from Reno, Nevada, to Vancouver, Canada, at six thousand feet, was 40 miles south of Mount St. Helens when the mountain exploded. The pilot saw the explosion and swung away from his course, a path that would have taken him directly over the eruption, escaping in so doing a dirty gray cloud that was rising quickly to meet him. His 737 rocked in the air from the shock of the explosion as if it were a ship at sea. Fortunately his flight had been delayed for 30 minutes at Reno, or all 122 passengers plus crew would have been added to the list of deaths for May 18. The earthquake that triggered the event was not an unusual event in a region that experiences frequent earthquakes of this strength and stronger ones, but the scale of the eruption was a very different matter. It was a rare event even in historical time. Volcanic eruptions are identified by a volcanic eruption index number (VEI) based on the volume and speed of the rock and ash that is ejected. The index is numbered similarly to the Richter scale, each number representing ten times the volume of the one immediately below it, and one tenth that of the next number above it.

For this event of VEI 5, a volume of eruption greater than any other in the contiguous United States, one has to go back into earlier times to find a meaningful comparison. Vesuvius in the year 79 or Krakatau in 1883 each had VEIs of 6, or they were ten times more powerful than Mount St. Helens. Volcanoes in the Cascade Range are fairly new in geological time. A few date back several million years. Mount St. Helens is one of the youngest. Much of its visible cone was

formed within the last thousand years. It was frequently active during that time, and because of that geologists were convinced that a major eruption would occur sometime in the twentieth century. Further evidence in support of that expectation came more recently when it was found that the mountain had been more active and more violent over the past few thousand years than any other volcanic mountain in the contiguous United States. From the evidence in ash deposits across the western Cordillera, it is clear that some of these older eruptions must have had VEIs of 6.

The most recent well-documented eruption, prior to 1980, occurred in 1842. Eyewitness accounts from that time described seeing vast columns of smoke and fire. Ash from that time was subsequently located at The Dalles in Oregon, about 65 miles away. Fireworks continued intermittently over a 15-year period. Then came a three-year lull followed by a lot of activity in the year 1857. After that date the volcano seemed to have slept for the 123 years before 1980. The moment of eruption on May 18 of that year was indelibly etched in many memories. David Johnston, the expert geologist from the U.S. Geological Service who was monitoring the mountain on the morning of the explosion, talked to news reporters early on that day. He described Mount St. Helens as a keg of dynamite with a lit fuse whose length you do not know. He was well aware of the risks of being so close to the summit, but he stayed there right up to the moment of the eruption. He told the reporters that it was extremely dangerous to stand where they were at that time. "If the mountain explodes," he told them before they left, "we would all die." Soon afterward they heard his final words as he yelled into his radio, "Vancouver, Vancouver, this is it!"

A family watched their dream $100,000 home smashed and washed down the chocolate-brown Toutle River. A couple on a camping and fishing trip on the same river tried to grab their camping gear when they heard the explosion, but quickly saw there was no time to escape in their car. They were thrown into the water and carried along in a mass of mud, logs, and rocks, grimly clinging to one log. They were lucky. The log was shunted sideways out of the main stream. Some time later, a helicopter picked them up. A television cameraman a kilometer and a half from the base of the mountain filming the event saw the mass of mud and debris heading for him. He dropped everything, got into his car, and drove madly to keep ahead of destruction. He was able to stay ahead of it.

Farther east, travelers were stranded in numerous small communities, altogether 10,000 of them in three states. One couple driving west from Spokane saw the black oncoming cloud. Soon they could only inch along the highway at less than eight kilometers per hour. They abandoned their car and joined the other stranded ones. Everywhere around, trains, buses, airplanes, and cars came to a stop. Walking was the only thing that worked. Digging out from under the ash was yet another hazard. It proved to be as hard as getting around it. For some time people wore masks of whatever material they could find for fear of toxic fumes.

As is common in volcanic eruptions, the magma that had risen and caused the explosion left the inner chamber empty for a time until new magma moved up from below. The interior dome then began to grow until pressure rose to a level that caused another eruption. Several of these subsequent eruptions came in May, June, July, August, and October of 1980. By 1983 the dome had grown to six hundred feet and the crater in which it sat was two miles in diameter, waiting for the moment of the next event, and meanwhile continuing to grow.

How can volcanic eruptions and earthquakes be predicted? The answer remains elusive, but experience from Mount St. Helens shows us some of the things that can be done. As mentioned earlier in this chapter, this mountain received more monitoring since the 1950s than almost any other, and the small number of people who were killed is largely due to this, as well as to the actions that were taken in the months before May 18, 1980. The first earthquake in Mount St. Helens struck on March 20, 1980, and immediately afterward seismologists met with local authorities to warn of the danger ahead and make some preliminary plans.

One week later steam and ash exploded from the summit of the volcano, and this was followed by several minor eruptions over the following weeks. As these eruptions became more frequent, public authorities closed off the area around the mountain, causing heated opposition from the general public. Later they lowered the water level in the Swift Dam reservoir to minimize damage from mudflows. Still closer to the time of the eruption, the governor of Washington declared a state of emergency in order to use the National Guard to staff the roadways. So angry were some over the closure that they found ways of circumventing the law by using little-known roads and footpaths to gain access. Some, including Harry Truman, a veteran resident of the mountain, refused to leave their homes on the north side and died.

ARCTIC OUTBREAK, 1989

America's coldest spell of the century arrived in December 1989. In the South, New Orleans experienced 64 consecutive hours at or below 32°F and a total of 81 out of 82 hours below freezing. A total of 15 hours were below 15°F, with the lowest reading of 11°F on the morning of December 23. A low of 8°F was recorded at Baton Rouge. Snow and sleet paralyzed transportation systems in New Orleans, and there were a hundred fires in the city, a result of inadequate heating systems. The greatest impact was on breakage of water pipes in homes and businesses. Five weather-related deaths occurred in the area during this rare Arctic outbreak.

The story was similar in the Midwest: it was the coldest day of the season for south central Nebraska and north central Kansas, and most locations experienced subzero temperatures. This Arctic outbreak peaked around December 15 and continued for about ten days. Low temperature records were broken throughout the United States. Nothing comparable

is found in weather records until we go back to 1899, when a similar chill occurred. The events in both of these years were quite similar: both were fast-moving, very powerful Arctic outbreaks that stretched across most of the United States and reached into Mexico and Florida.

GREAT HEAT WAVE, 2006

In 2006, from June 1 to August 31, as summer is defined by the National Climatic Data Center, the United States experienced its greatest heat wave in 70 years. The average temperature across the country was 74.5°F, based on readings from hundreds of weather stations. It was the second-hottest summer temperature since the government started to keep records in 1895. The only comparable heat wave was in 1936. At the 2006 peak, temperatures greater than 100°F covered the Great Plains, Midwest, South, and much of the Northeast. The year 1936 is a reminder of the Dust Bowl years that are described in Volume One.

With air conditioning being quite limited in its coverage in 1936, many people were forced to sleep in their yards or in parks. The death toll was high, estimated at about 50,000 total. The heat was especially deadly in large Midwestern cities such as St. Louis, Minneapolis, and Detroit. The total number of deaths from a heat wave is rarely given out by media for various reasons: deaths from heat are silent killers, they do not cause visible destruction where they occur, and causes of deaths are difficult to identify.

HURRICANE CAMILLE, 1969

Camille was one of only three hurricanes in the history of the United States to make landfall as a Category 5. It was an extreme hurricane, one of the most violent storms of the twentieth century. It arrived from western Cuba on August 14 and entered the warm waters of the Gulf, reaching Bay St. Louis on the evening of August 17 with sustained wind speeds of 190 mph. It almost totally destroyed the Mississippi coast. Before it left the mainland United States it had caused the deaths of more than 250 people and injured 8,900, and destroyed 6,000 homes and damaged 14,000. The total costs of the destruction it caused were in excess of a billion dollars. Millions of Gulf coast residents were made aware of the strength of the storm before nightfall on August 17. Before the storm reached Bay St. Louis, about 200,000 residents had fled the coastal areas into sheltered places.

As the storm moved across the coast in darkness, homes, motels, apartments, restaurants, and other buildings were swept off their foundations and deposited in mountains of rubble. It was the same for almost everything movable and for much, such as trees, that was not. Camille maintained its hurricane strength for ten hours. On the morning after

the storm, thousands searched among the wreckage for anything that might have been left. There was no semblance of normal life in the region around New Orleans for days, but fortunately the levees around the city were not affected because the storm was centered a few miles to the east. About 15,000 people were left homeless. There was no water, food, or fuel. The storm had wiped out all means of communication, and roads, bridges, airports, and even railways were impassable or destroyed. Gulfport Hospital had closed down and evacuated all of its patients to hospitals farther inland.

Adding to the devastated landscape was a serious vermin problem. There were thousands of dead animals of all kinds, and insects and rodents had quickly overrun the stricken area to feed on these and on the rotting food. Rattlesnakes, fire ants, and rats bit dozens of victims who were sifting through the rubble. In an attempt to control the ants, low-flying planes roared up and down the Mississippi coast, dropping quantities of mirex. At the time of Camille this product was not considered dangerous to humans, but eight years later the U.S. Environmental Protection Agency banned it as a possible carcinogen. President Nixon sent a thousand troops to help, and the state governor declared a state of emergency in order to control crime. Using federal troops and state police, all roads leading into the area where the eye had crossed the coast were sealed off. Military and local police imposed a curfew. The first problem to overcome was the thousands of dead farm animals, pets, and wildlife. Camille's incredible 25-foot storm surge had drowned thousands of animals. Heavy equipment was brought in to bury these thousands of animals.

The National Hurricane Center took note of Camille's weather data because of the unusual ferocity of this storm. The lowest barometric pressure recorded on land during the evening of August 17 was 26.85 inches. That was at Bay Saint Louis. This was the second-lowest barometric pressure ever measured in the United States. Only the 1935 Labor Day hurricane produced a lower pressure in the middle keys. That figure was 26.35 inches. The highest tidal surge ever recorded in the United States belongs to Camille. It was officially recorded as 22.6 feet above mean sea level, but high-water marks on buildings, still clearly visible long after the storm had passed, showed water heights of 25 feet. Camille moved inland and then gradually weakened to a tropical depression over northern Mississippi on August 19. It had picked up a lot of moisture over the Gulf of Mexico, and this led to torrential rain over the mountains of Virginia. In eight hours, 28 inches of rain fell on Nelson County, an amount that more than tripled the state's 24-hour record, which had been set in 1942 and has not been broken since. In other parts of the state, 14 inches came down during the night. Afterward, Camille turned eastward to emerge into the Atlantic near Virginia Beach on August 20.

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Appendix D: Measuring Weather and Climate Events

MEASUREMENT CONVERSIONS

1 inch equals 2.54 centimeters

1 centimeter equals 0.39 inches

1 meter equals 3.28 feet

1 kilometer equals 0.62 miles

1 square meter equals 10.76 square feet

1 square kilometer equals 0.39 square miles

1 hectare equals 2.47 acres

1 cubic meter equals 35.31 cubic feet

1 cubic kilometer equals 0.24 cubic miles

1 degree Fahrenheit equals 9/5 degree Celsius plus 32

1 degree Celsius equals 5/9 degree Fahrenheit minus 32

FUJITA F AND EF SCALES FOR TORNADOES

The F scale was created by Japanese American meteorologist Tetsuya Fujita in 1951 to classify tornadoes.

F0 40–72 mph (light)

F1 73–112 mph (moderate)

F2 113–157 mph (significant)

F3 158–206 mph (severe)

F4 207–260 mph (devastating)

F5 261–318 mph (incredible)

Half of all tornadoes worldwide are F1 or less. Only 1 percent of all are F5.

Over the years, the F scale has revealed weaknesses: (1) too much reliance on the estimated wind speeds, and (2) oversimplification of the

damage description. Fujita recognized that improvement was necessary. When the committee met to develop the enhanced Fujita scale, one point was made very clear: it must continue to support and maintain the original tornado database; in other words, there must be some conformity to the F scale that is listed in the database.

F Scale

F0 40–72 mph

F1 73–112 mph

F2 113–157 mph

F3 158–207 mph

F4 208–260 mph

F5 261–318 mph

EF Scale

EF0 65–85 mph

EF1 86–110 mph

EF2 111–135 mph

EF3 136–165 mph

EF4 166–200 mph

EF5 Over 200 mph

SAFFIR-SIMPSON SCALE FOR HURRICANES

Developed in the later 1960s by Herbert Saffir to quantify potential wind damage from hurricanes, and expanded in the early 1970s by Robert Simpson, director of the National Hurricane Center, the Saffir-Simpson scale is used to measure hurricane strength. Wind speed is the determining factor in the scale, but storm surges caused by wind are highly dependent on the slope of the continental shelf and the shape of the coastline.

Category 1 74–95 mph (minimal)

Category 2 96–110 mph (moderate)

Category 3 111–130 mph (extensive)

Category 4 131–155 mph (extreme)

Category 5 155 mph or more (catastrophic)

VOLCANIC EXPLOSIVITY INDEX (VEI)

To compare the magnitudes of volcanic eruptions, scientists have developed a volcanic explosivity index (VEI) in which each level is ten times as powerful as the previous level. The index measures eruptions on a scale of 0 to 8. The VEI of any eruption is based on the volume of rocks and ash that is emitted. A VEI of 1 could represent a Hawaiian eruption, a gentle oozing of lava with no violent activity; a VEI of 8, a very rare event, would apply to Toba, an Indonesian eruption of gigantic proportions that occurred 74,000 years ago. Krakatau of 1883 had a VEI of 6. Mount St. Helens of 1980 had a VEI of 5.

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GLOSSARY

absorption of radiation. Transfer of electromagnetic energy into heat energy.

adiabatic process. Temperature change in a gas or in air due to compression or expansion. No heat is gained or lost from the outside in the process.

advection fog. A fog that develops when condensation occurs within moist air close to the earth's surface.

acid rain. The presence of acidic elements in rain that tend to destroy plants and trees.

aerosols. Tiny substances in the atmosphere, so small that the slightest movement of air keeps them aloft.

air. The mixture of gases that make up our atmosphere.

air mass. A large body of air that has defined temperature and humidity characteristics. It may extend over thousands of square miles and be miles in depth.

air pollution. A harmful substance put into the atmosphere from the earth

albedo. The amount of solar radiation that is reflected by a part of the earth's surface, usually expressed as a percentage.

alcohol thermometer. *See* thermometer.

anemometer. An instrument for showing wind speed.

Antarctic Circle. The parallel of latitude at 66.5° south.

anthropogenic. Caused by human activities.

anticyclone. High pressure mass of air with winds circulating clockwise in the northern hemisphere or counterclockwise in the southern hemisphere.

Arctic Circle. The parallel of latitude at 66.5° north.

Arctic front. The zone of interaction between polar and Arctic air masses.

armada. A Spanish word meaning a very large group of warships.

Asian cyclone. A tropical cyclone or typhoon that occurs in Asia. *See* typhoon.

atmosphere. The gaseous envelope surrounding the earth, mostly consisting of nitrogen and oxygen, concentrated within an area 30 miles above the earth.

atmospheric pressure. The force exerted by the weight of the atmosphere on an area.

aurora borealis. Lights visible near the North Pole, caused by interaction between the sun's radiation and molecules in the earth's atmosphere.

automatic weather stations. Weather stations, often at sea, that record and transmit data to a central location for weather forecasting.

barometer. An instrument for measuring atmospheric pressure.

biosphere. The part of the earth system that contains all living things, in or on the land, in the atmosphere, and in or on the oceans.

blizzard. Violent winter storm that lasts for several hours or longer.

caldera. A steep-sided circular depression in the ground, the end result of a volcanic eruption.

carbon dioxide. Gas that is a byproduct of burning fossil fuels or biomass. It also occurs naturally.

Celsius scale. A temperature scale in which the freezing point of water is zero degrees and the boiling point is one hundred degrees.

Chinook wind. A very dry wind that flows down the eastern side of the Rocky Mountains.

chlorofluorocarbons (CFCs). Compounds used in refrigerators, aerosol products, and solvents. Now banned in many products because of their harmful influence on the earth's ozone layer.

climate. The average pattern of weather in a given area over a long period of time.

climate classification. Division of the earth's climates into a system of regions, each defined by specific climatic elements.

climograph. A graph that shows the monthly totals for two climatic variables such as temperature and precipitation.

cirrus cloud. A high-level cloud, stringy and layered.

cloud. A suspended concentration of water or ice particles.

cloud base. The lowest elevation where cloud particles such as water droplets or ice crystals can be observed.

cold front. At the boundary between two air masses of different temperatures and humidities, the cold front is the heavier of the two, so it pushes the warm air mass upward.

colony. A territory owned and administered by a colonial power, usually a European power.

condensation. A physical process in which water vapor is changed into a liquid, that may take the form of a cloud, fog, or dew.

condensation nucleus. A tiny substance in the atmosphere on which water vapor condenses to form a drop of water.

convection. Transference of heat in a gas or liquid by upward movement of the heated and therefore less dense part.

Coriolis effect. A force caused by the earth's rotation that turns air movements to the right in the northern hemisphere and to the left in the southern hemisphere.

cumulonimbus. A heavy and dense cloud with a substantial vertical component.

cumulus cloud. A cloud made up of a rising mass of air that can be found at any level in the lower atmosphere.

cyclone. An area of low atmospheric pressure with inwardly rotating winds.

D-Day. The day selected to launch a massive attack by sea from Britain to France near the end of World War Two.

depression. An area of the atmosphere in which sea-level pressures are lower than those of the surrounding region, often the early stage of a middle-latitude cyclone.

desert. An ecosystem with less than four inches of rain a year.

dew. Water that has condensed on things near the ground.

dew point temperature. The temperature at which a mass of air holds its maximum amount of water vapor.

diurnal. Daily.

doldrums. A belt of calm seas near the equator.

doppler radio. A radar tracking system that enables a meteorologist to determine the speed of a moving object.

downburst. Violent and damaging downdraft associated with a severe thunderstorm.

drought. When an area experiences rainfall levels significantly below normal.

dust storm. A heavy mass of dust in a disturbed air mass.

El Niño. The fluctuating warm temperatures of the equatorial Pacific Ocean that affect global circulation of air.

energy balance. Globally, the total energy input from the sun equals the total energy output.

equator. The parallel of latitude that is midway between the North and South Poles.

equinox. The moment in time when the sun is directly overhead at the equator.

evaporation. The change of a liquid into a gas.

eye of tropical cyclone. The clear and calm area inside the rotating wall of convective clouds.

Fahrenheit scale. A temperature scale where the freezing point of water is 32 degrees and the boiling point is 212 degrees.

fall equinox. When the sun is overhead at the equator in autumn. It occurs around September 23.

fertilizers. Substances added to soil to make it more fertile.

flash flood. A flood caused by heavy rainfall within a short period of time.

flood. A stream that overtops its banks and covers the surrounding area.

flood stage. A particular level on a stream at which flooding occurs.

fog. A cloud at ground level.

forecast. A prediction about future weather conditions.

frost. Small ice crystals that form on or near the ground when temperatures are below freezing.

Fujita scale. The method used for calculating the strength of tornadoes.

global energy balance. The balancing of solar short-wave incoming energy with outgoing long-wave energy from the earth

global warming. An overall increase in the earth's average surface temperature.

greenhouse effect. Absorption of long-wave radiation, especially by water vapor and carbon dioxide, and reflection of heat back to earth to raise ground level temperatures.

greenhouse gases. Atmospheric gases that absorb and reflect long-wave radiation, causing the greenhouse effect. The two most important gases of this type are water vapor and carbon dioxide.

green revolution. The use of new quick-ripening, high-yield plants for use in developing countries.

guerilla-type attacks. The use of individual soldiers or small groups of soldiers to carry out raids on enemy positions.

Gulf Stream. The warm ocean current that flows northward along the east coast of the United States.

hailstorm. Pellets of ice falling from thunderclouds.

heat island. An area within an urban zone that has higher temperatures than those of the surrounding areas.

Himalayas. A mountain chain on the border between India and China.

humidity. The amount of water vapor in an air mass, measured as a percentage of the maximum that it could carry.

hurricane. A North Atlantic or Caribbean tropical cyclone.

ice age. A geological period in which ice sheets covered much of North America.

iceberg. A mass of floating ice.

Indian monsoon. *See* monsoon.

insolation. The technical term for the energy that reaches the earth from the sun.

irrigation. Water that is taken to fields from ponds or streams.

isobar. A line on a weather map connecting places that have the same atmospheric pressure.

jet streams. High-speed air flows about 15 miles above the earth, usually running from west to east.

L'Anse Aux Meadows. A Heritage site on the island of Newfoundland where the first Europeans to reach North America lived.

La Niña. The fluctuating cold temperatures of the equatorial Pacific Ocean that affect global circulation of air.

latent heat. Energy being absorbed from the air during changes from water to water vapor and released to the surrounding air during changes back from water vapor to water.

levees. Embankments to prevent rivers from flooding.

mercury thermometer. *See* thermometer.

meteorologist. A person who understands, studies, and predicts weather conditions.

microburst. A very narrow downburst.

monsoon. A persistent seasonal wind with a change in direction from season to season, usually associated with the wind patterns to and from the Asian interior in relation to the Indian Ocean.

NOAA. U.S. National Oceanic and Atmospheric Administration.

nor'easter. An extra-tropical storm along the coasts of Atlantic Canada and from Maine to New York, frequently referred to by this name because its winds come from the northeast.

Norwegian school of meteorology. The group of meteorologists who discovered and used air mass theory in forecasting the weather.

Northwest Passage. The north shore of Canada, the shortest sea route to Asia from Europe, now no longer permanently covered by ice.

ocean conveyor belt. Another name for the thermohaline-driven global ocean current.

ozone. A gas in the higher reaches of the atmosphere, created both naturally and through photochemical reactions, that absorbs ultraviolet radiation from the sun, an activity that is vital to the preservation of life on earth.

ozone layer. A region of the stratosphere stretching from about eight miles to 25 miles above the earth that contains large concentrations of naturally occurring ozone.

permafrost. Permanently frozen areas of the earth's surface.

pesticides. Chemical substances used to destroy insects or other organisms that are harmful to growing crops.

photosynthesis. The process by which plants take carbon dioxide from the air and release oxygen into the air.

polar front. The front between cold polar air masses and warm tropical air masses.

precipitation. A general term for different forms of water that may either be falling from or held in suspension in the air. Included in this term are rain, drizzle, snow, hail, and ice pellets.

rain gauge. Instrument for measuring the amount of rain that has fallen.

relative humidity. *See* humidity.

Rossby waves. Planetary waves in the atmospheric westerly circulation, characterized by great length and amplitude.

Sahel. The dry southern part of the Sahara Desert.

Santa Ana winds. Hot and dry winds that come from the interior desert regions of California and pass over the coast mountains to reach the Pacific Ocean.

sensible heat. Heat that can be measured by a thermometer.

sleet. A mixture of snow and rain.

smog. Fog combined with smoke, a common problem in large cities.

solar constant. The intensity of solar radiation on one unit of area when it is at right angles to the incoming sun's rays.

spring equinox. When the sun is overhead at the equator in the spring. It occurs around March 21.

statistical average. A calculation made by adding a collection of numbers and then dividing the answer by the total number of individual items in the collection.

Stevenson screen. A shelter for housing such weather measuring instruments as thermometers.

storm surge. The temporary increase in the height of the sea at a particular location due to a hurricane or a strong wind.

stratosphere. The part of the atmosphere above the troposphere, from about eight to 30 miles above the earth.

sublimation. The change of ice directly to water vapor or vice versa without passing through the liquid phase.

subsolar point. A place where the sun's rays are perpendicular to the earth's surface.

summer monsoon. Inflow of air from the Indian Ocean toward the continental Asian low-pressure center.

summer solstice. When the sun is overhead at 23.5° north, at the Tropic of Cancer. It occurs around September 23.

tar sands. The rich oil-bearing sands of northern Alberta, Canada.

thermometer. An instrument that measures temperature by using the properties of either alcohol or mercury as they respond to heating.

thunderstorm. Sudden electrical discharges, usually from convective clouds such as cumulonimbus, followed by lightning, thunder, and rain.

Tibetan Plateau. The highest extensive elevation of land north of the Himalayas.

tornado. A violent rotating storm of small diameter, a twister, usually appearing as a funnel cloud extending from the base of a cumulonimbus to the ground.

tornado F5. The most destructive type of tornado.

tornado outbreak. A succession of powerful tornadoes occurring within a short period of time.

trade winds. Winds that blow from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.

tropopause. The boundary between the troposphere and the stratosphere.

troposphere. The lowest part of the atmosphere, extending upward from the earth for about seven miles.

trough. A layer of the atmosphere with low pressure.

typhoon. A tropical cyclone occurring in the western Pacific Ocean.

urban heat island. An area at the center of a city where temperatures are higher than they are in the surrounding areas.

volcanic eruptions. The ejections of masses of lava and other material from a volcano.

warm front. The transition zone between warm and cold air masses. The warm front is the lighter of the two, so it is pushed upward by the cold air mass.

water vapor. Water when it is in gaseous form.

wave cyclone. A mid-latitude cyclone, usually originating at the polar front.

westerlies. Winds from the west between the latitudes 35° north and 65° south.

wind chill. A temperature based on actual temperature and wind strength. It indicates the cooling effect of wind on exposed parts of the body.

winter monsoon. Outflow of continental air from the Siberian high to southeast Asia and the Indian Ocean.

winter solstice. When the sun is overhead at 23.5° south, at the Tropic of Capricorn. It occurs around December 22.

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A Student Guide to

Climate and Weather

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Air Masses and Weather Patterns

VOLUME 2

Angus M. Gunn

GREENWOOD

AN IMPRINT OF ABC-CLIO, LLC
Santa Barbara, California • Denver, Colorado • Oxford, England

Library of Congress Cataloging-in-Publication Data
Gunn, Angus M. (Angus Macleod), 1920-
A student guide to climate and weather / Angus M. Gunn.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-313-35568-4 (set: hardcover: alk. paper) — ISBN 978-0-313-35569-1 (set: ebook: alk. paper) — ISBN 978-0-313-35570-7 (v. 1: hardcover: alk paper) — ISBN 978-0-313-35571-4 (v. 1: ebook) — ISBN 978-0-313-35572-1 (v. 2: hardcover: alk paper) — ISBN 978-0-313-35573-8 (v. 2: ebook) — ISBN 978-0-313-35574-5 (v. 3: hardcover: alk paper) — ISBN 978-0-313-35575-2 (v. 3: ebook) — ISBN 978-0-313-35576-9 (v. 4: hardcover: alk paper) — ISBN 978-0-313-35577-6 (v. 4: ebook) — ISBN 978-0-313-35578-3 (v. 5: hardcover: alk paper) — ISBN 978-0-313-35579-0 (v. 5: ebook)
1. Climatology. 2. Meteorology. 3. Climatic changes—Effect of human beings on. I. Title.
QC861.3.G86 2010
551.5—dc22 2009042256

14 13 12 11 10 1 2 3 4 5

This book is also available on the World Wide Web as an eBook.
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Manufactured in the United States of America

Contents

Introduction

This is Volume Two of a set of five books on weather and climate designed for schools and universities. These books are intended to provide two kinds of information: an understanding of the scientific processes at work in weather and climate, and an analysis of the ways in which weather and climate impact human life and the places where we live. The second of these goals is the more important of the two, as there is a number of books in print dealing with the scientific processes involved in weather and climate but few on how weather influences our lives. Beginning in the first volume with aspects of the subject that impinge on us daily, such as the unpredictable nature of weather, we go on in the second and third volumes to deal with characteristic global weather patterns, before moving, in the last two books, into more general themes such as global warming and earth-sun relationships. A list of reference materials will appear at the end of each book to assist in linking together the different aspects dealt with in individual volumes.

The subject matter of this book, Volume Two of the set, is the everyday weather patterns we encounter. Although the focus of this book is mainly U.S. weather patterns, other parts of the world are included because of the global interactions that we discover when we examine the weather at one location. The first chapter introduces this global perspective by describing what we call the global energy balance: the incoming energy from the sun is balanced by the outgoing energy from the earth and its atmosphere. The incoming energy is not sensible heat, heat that can be felt. That only happens when solar radiation is absorbed by material things, either in the atmosphere or on the ground. One very important law concerning energy is illustrated in this balancing act: energy cannot be lost; it can only be changed from one form to another. After this introduction to the earth's one and only source of energy in Chapter One, the rest of the book deals with the great variety of weather conditions across the United States, what causes them, and why they vary so much in the course of a year.

Chapters Two, Three, Four, and Five focus on the different patterns of weather within the United States, ranging from the light rain and overcast sky that are familiar to people living around the Great Lakes,

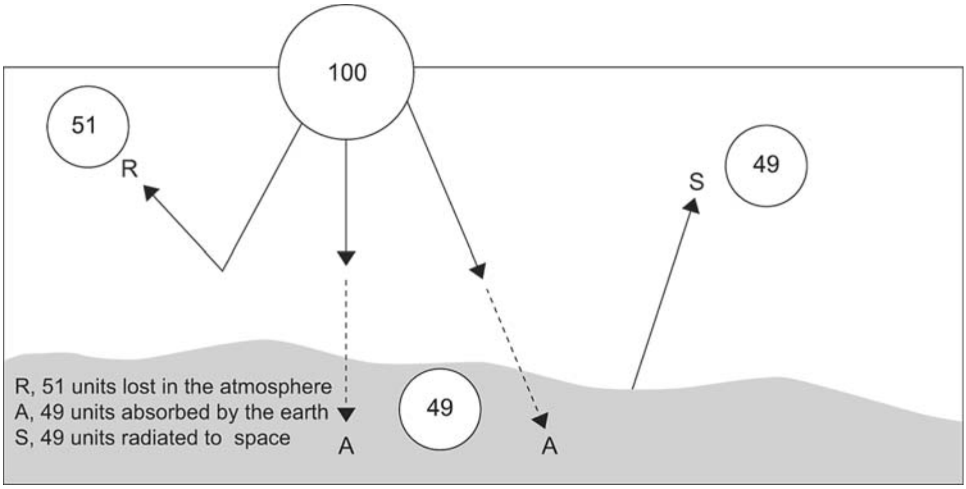

Figure 1 Incoming short-wave solar energy equals outgoing long-wave energy, ensuring energy balance. (ABC-CLIO)

to the more violent thunderstorms common farther south. Central to all of these is the concept of air masses and air mass fronts. As warm air circulates globally from the equator, it encounters Arctic air, in an area that varies seasonally from southern Canada to the northern United States. This forms the polar front as pressure changes and the Coriolis effect stabilize the migration of air. At the same time, the universal global distribution of warm air is changed as it passes over the North American continent. The differential rate of heating and cooling of land, compared with the ocean, causes the air over land to form masses instead of bands of air. Each mass of air takes its character from the ground beneath it, so we get polar and continental air masses, as well as maritime and tropical air masses. The polar front is the place where the polar air mass meets—and often collides with—the tropical air mass.

The chapters dealing with these weather patterns take up about half of this book. Thereafter, three more specialized subjects are examined in Chapters Six, Seven, and Eight. Chapter Six explains how the fundamental changes in the way we forecast weather today, compared with traditional methods, both ensure greater safety for human life and help us understand better why tragedies like the 1900 destruction of Galveston occurred. Chapter Seven outlines the vital role of the ozone layer, high in the atmosphere, why it is absolutely essential for human survival, and why it is threatened at the present time. The final chapter details the changes that are happening in cities all over the world, and why these changes are important in the study of weather. Not only are cities growing faster than the general world population, but their unusual weather conditions demand more attention than they have traditionally received because they now constitute the majority of the population in every country.

ABSORBING AND DISTRIBUTING SOLAR ENERGY

The solar energy that reaches the earth is in a very-short-wave electromagnetic form. It has negligible heat properties, and warmth comes to the earth only when these solar short waves are absorbed at the earth's surface and transformed into long-wave heat waves. The amount of warmth that any part of the earth's surface experiences depends on the angle of the sun's rays that reach it rather than the length of time it is exposed to the sun. We know this from conditions above the Arctic Circle in summer. Many places have 24 hours of sunlight but remain very cold. Why? Because the sun's rays reach them at a low angle, and so the rays get spread over a much bigger area than would be the case at or near the equator, where the incoming radiation strikes the ground almost at a right angle. There is a certain amount of natural generosity in the way the earth shares the huge volume of heat it collects from the sun near the equator. This is the story that is explained in Chapter One.

One of the laws of physics regarding air is that air expands when it is warmed and thus gets lighter. Because it is lighter, warmer air rises up into the atmosphere until it reaches a level where the surrounding air has the same (lower) density. Colder air moves into the empty spaces left by the rising air, and, as it gets warmed, it too rises up into the atmosphere and pushes away the air that rose before it. This initiates a set of circular motions in which the warm air rises up at the equator,

Photo taken at midnight in northern Norway. Average temperatures here during July, the warmest month, rarely exceed 70°F. (Mettesd/Dreamstime.com)

What Causes a Rainbow?

The breakup of the sun's rays into seven bands of color as they pass through raindrops or ice crystals explains the colorful picture of the rainbow. In most of North America, a rainbow is usually seen in the late afternoon or evening when there is a rain shower reflecting the rays of the sun that are coming from the west. The clearness of the reflection is best in the part of he rainbow that is close to the ground. The reason for this difference relates to the various shapes of raindrops and the distortions they cause if the angle of reflection is more vertical than horizontal. A second rainbow is common when reflection occurs more than once in different raindrops.

and is pushed away to the north and south by new warm air. This brings warm air to places that did not have much warmth because they were too far from the equator. Two additional things happen as the warm air moves away from the equator. First, because the earth is spinning on its axis all the time, the warm air gets twisted to the right in areas north of the equator. We call this the Coriolis effect. Second, air cools as it moves farther away from the equator, and so it gets heavier and sinks.

If we now put these two additional things together, this is what we get: the warm air gets close to ground level and, at the same time, changes direction and travels from west to east. There are two places where this happens, at 30° north and 60° north, and it is at these places that we see how the circulation of warm air is completed all over the world. It is possible to think about the circular motions of air from the equator as one complete, continuous circle of movement: warm air rises from the equator, moves north as far as 30° latitude, sinks close to the ground, and pushes the air that is there back to the equator to complete the circle of activity. A similar circle of activity happens when warmer air moves from 30° north and sinks down at 60°north to form another continuous circle of activity. All of this sharing of warmth all over the globe sets the stage for the next events, this time around the places where the cooling air sinks down, at the 30° and 60° north latitudes.

INTERACTIONS AT AIR MASS FRONTS

For most of America, it is what happens around 60° north that matters more than what occurs at 30° north. The reason is that air north of 60° north is much colder than air on the south side. One came from the Arctic and the other from the tropics. Inevitably, when warm and cold air lie close together, as they do here, a slight ripple can form and grow into a major front, which is an area in which the two different packages of air start circling around each other. Chapter Two explains developments at this stage, including the action of the front of cold air as it moves beneath the warm front, forcing it upward because it is the warmer and therefore lighter air. As the lighter air rises, it cools and releases moisture. There is a wide range of outcomes in this phase, depending on the difference in temperatures and the level of moisture in the area. A number of examples of specific events are described in Chapters Two and Three. The name that is given to interactions of this kind is "cyclone."

Because the interaction around 60° north is so much less than cyclones in the tropics, the name "mid-latitude cyclone" or "wave cyclone" is given to the ones that occur north of the tropics. In a later chapter, when the tropical cyclones we know as hurricanes or the more violent cyclones of the Bay of Bengal are examined, other aspects of cyclones will be described. As far as Chapters Two and Three are concerned, the only other aspect of cyclones that needs to be mentioned is the northern hemisphere jet stream. Up to this point, discussions about temperature differences and air mass fronts have dealt only with conditions near the ground. At the higher elevations, six or more miles above the earth, air pressure differences can be just as great as on the ground, but there is no friction, so air currents can move much faster. At this elevation, we find the northern jet stream. It runs from west to east at speeds of 200 mph and more, above the location of the front between polar air and tropical air. Because of its position directly above the polar front, and because of its speed and strength, it acts as a guide to the cyclones that develop on this front, drawing them from west to east.

Thunderstorm activity is found all over the United States, but is most serious in the south because of the greater contrasts that occur there when Arctic air reaches as far south as Texas. In Volume Three, we will see the close relationship between major thunderstorms and tornadoes. For the most part, thunderstorms triggered at the polar front give rise to wave cyclones, but from time to time, the temperature and moisture content in the places where they originate lead to floods and hailstorms. Both of these types of events are very serious, often causing death and substantial property damage. Several historical examples of these weather conditions are described in Chapter Four. The most intriguing aspect of thunderstorms is the microburst, an extreme action of wind close to the ground, regarded as the cause of many airplane crashes. Why and how this happens is explained in Chapter Four. The microburst was discovered and named by Tetsuya Fujita, who came to the United States from Japan. More will be said about him in Chapter Six.

Because east coast is the most densely populated part of the United States, a chapter is devoted to the nor'easters, unusual and very destructive cyclones that affect the New England states and some areas farther west. They are most severe in winter. The name comes from the direction of the wind, the northeast, where cold Arctic air masses and warm air masses from the Gulf Stream collide, and where fronts form, creating cyclones. These were the storms that made it impossible for the Vikings to remain in North America after the Little Ice Age came along. That Little Ice Age was still there at the time of the Revolutionary War. When George Washington crossed the Delaware with his troops on that fateful Christmas Day in 1776, he had to contend with an unusually strong nor'easter. Meteorologists in modern times assembled the records from 1776 and concluded that the severity of the storm General Washington faced was worse than similar storms of today because the Little Ice Age was active at that time and place. The details of Washington's journey are included in Chapter Five.

FLASH FLOODS AND STORM SURGES

Within the broad category of flooding, there are two types of floods that need to be singled out from flooding in general because they do not fit our general understanding of places being inundated. One type originates from a stagnant condition in the atmosphere above a place when precipitation is exceptionally high. The other arises from very high wind pressure acting on a coastline. The first type is well illustrated in the Big Thompson Canyon Flood, one of the most deadly in recent times in the United States, which is explained in detail in Chapter Four. It led to campaigns for limiting human construction near such places, and also for installing warning systems to alert people to likely future events of this kind. Chapter Four will also describe some devastating flash floods, as well as the tragic storm surge associated with the 1938 New England hurricane. Other examples of both types of flood are included here in this introduction.

In June 1972, Rapid City, South Dakota, experienced a flash flood that took the lives of more than two hundred people. The immediate weather conditions included a stalled interaction between a northward-moving moist air mass and a southward-moving cold air mass from the north. Torrential rains flooded the area with as much as 15 inches falling within a six–hour period. Twenty years before this event, a dam had been built above the settled area, ensuring freedom from periodic flooding, and encouraging considerable increase in home construction on or near the floodplain. That was a bad move. Too many places around the world did similar things and, in time, saw their floodplains devastated. In the 1972 event, the dam's spillway was clogged, and a huge wave of water crushed many homes and killed more than two hundred residents. Subsequently, the community decided that the floodplain should no longer be used as a residential area. It was converted into a golf course and park.

In the small town of Heppner, Oregon, in June 1903, Willow Creek, a small seasonal stream that meandered through the town, suddenly became a foaming wall of water, about 40 feet in height, that destroyed the entire community. A cloudburst had released huge volumes of rain. Everyone in the town was taken by surprise. Nothing like this had ever been known before, yet the meteorological setting of this and similar places along the western sides of the Cascade Mountains

Result of a flash flood in Rapid City, South Dakota, in 1972. (NOAA)

were regularly subject to strong offshore air masses getting stalled as they reached the mountains. A monument stands today near the cemetery, inscribed with the names of 250 people, the victims of the 1903 tragedy.

If we turn now to storm surge events, the causes are very different, but the outcomes are the same: massive volumes of water suddenly hit settled areas, with deadly results. Cyclones from the Bay of Bengal reaching Bangladesh are among the world's worst cases. In 2007, for instance, a cyclone that had 150-mph winds, peaking at 160 mph, crashed into the world's largest mangrove forest with a storm surge of 15 feet. Three thousand villagers were killed instantly.

WEATHER FORECASTING UNDER CHANGING ENVIRONMENTS

For most of its history the U.S. Weather Bureau relied on information from various ground stations around the country in making forecasts about weather. This data included the prevailing temperature, wind direction, air pressure, and cloud patterns for each location. We know today that weather is very much affected by conditions high in the atmosphere, such as the northern jet stream and the activities of air masses described earlier. These air masses often extend thousands of feet above the earth. Before the middle of the twentieth century, little attention was paid to information about the air at these elevations. The destruction of Galveston, Texas, by a hurricane in 1900 illustrates the problem of relying on ground data and past experience. U.S. Weather Bureau forecasters were convinced that the hurricane would veer to the east after it entered the Gulf of Mexico, because that was what had happened on previous occasions. As a result, they sent warnings of an approaching hurricane to east coast weather stations. They ignored the reports that told of a major storm moving west and approaching Galveston.

Chapter Six describes the changes that took place in weather forecasting in the second half of the twentieth century. The use of computers, new high-altitude air measurements from aircraft, satellites, and balloons, as well as calculating next day's weather as a statistical probability rather than a prediction, revolutionized weather forecasting. All of this increase in knowledge of the upper atmosphere, especially of the very high atmosphere where the ozone layer is, has proved to be extremely valuable. Changes have been occurring in the ozone layer, a protective shield without which life on earth would not be possible. Over time, it has done its work well, but during the past 20 to 30 years, gases from equipment developed and employed by humans have been released into the high atmosphere, causing serious damage to the ozone layer. So much damage has been done to this protective layer that international conferences and agreements have taken place, and decisions have been made to abolish emissions that would damage the ozone.

The Ozone Layer

High above the clouds, ranging from 10 to 30 miles above us, there is a layer of gas called ozone, which is formed by the interaction of the ultraviolet portion of the sun's rays with the natural supply of oxygen molecules in the air. It's a very important layer, described by scientists as being responsible for life on earth as we know it, because it absorbs the ultraviolet portion of the sun's rays. If it were not absorbed by ozone, this ultraviolet radiation could do a lot of damage, causing various types of skin cancer and cataracts in humans, and harming crops and marine life. Scientists have established records that list normal ozone levels during natural cycles. In recent years, however, there is evidence that this important ozone shield is being depleted beyond the changes that occur from natural cycles. Both human activities and weather are responsible for these changes. The first kind of human activity that caused concern was our use of chlorofluorocarbons (CFCs).

These substances were in widespread use before the damage they were doing to the ozone layer was detected. They were used in refrigerators and as foam-blowing agents. Because they do not break down easily, they were ending up in the higher reaches of the atmosphere, where they released chlorine as they eventually broke down under the influence of ultraviolet radiation. When CFCs break down, they release chlorine atoms. The chlorine destroy ozone molecules. In the 1970s and 1980s, the increasing use of CFCs, including new applications of them, was shown to be depleting the ozone layer. This became so serious that the nations of the world agreed in 1987 to stop using CFCs entirely. It took some time before they could be eliminated because of the many uses to which they had been put. Within two years of this agreement, the rate of ozone loss began to slow down, but the complete restoration of the ozone layer to its historic norms will not be achieved for many more years.

In the final chapter, the weather environment of big cities is described in some detail, for two reasons: first, they are different from those of rural areas; and second, something is happening in the distribution and size of big cities that calls for new attention. An examination of the table of city sizes in Chapter Eight shows that they are growing much faster than the general world population. In fact, since the year 2005, for the first time in human history, there are more people living in cities than in rural areas, and this will be true for almost all the countries of the world. It is therefore essential to give priority to the unique features of weather conditions in big cities, because this will be the environment of most people in most countries. Additionally, in all of the bigger cities of the Western world, and in several developing countries, the prevalence of fog or smog is as damaging to weather and therefore to human health and welfare as are the volcanic eruptions we have already examined in Volume One.

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CHAPTER 1

Keeping Earth Suitable for Humans

All living things on planet earth, including humans, are dependent on energy from the sun. Unlike other planets in our solar system, the earth receives enough energy to maintain an average temperature that sustains life as we know it, one that is substantially higher than the freezing point of water and lower than its boiling point. The earth's distance from the sun makes this possible. This distance varies a little in the course of a year as the earth moves around the sun along an elliptical path. The amount of the sun's energy that reaches the earth varied quite a lot in the past, and may do so again in the future, as was noted in Volume One. The important aspect for us to understand at the present time is this: what happens when the sun's rays of energy enter our atmosphere and the land and water areas below it? The sun's rays carry almost no warmth, and heat appears only when these rays are absorbed by substances either in the atmosphere or on the surface of the earth.

Some substances absorb more of the sun's energy than others. That's why we wear white clothing in hot weather. It absorbs less of the sun's energy than does black clothing. For the opposite reason we prefer black clothing in cold weather. The present crisis over global warming is caused mainly by one substance, carbon dioxide, absorbing too much solar radiation. We will study this problem in Volume Four, but the way it works is easily understood if we remember that it is described as a greenhouse gas. A greenhouse is a small garden shed made mostly of glass. It allows the sun's rays to enter easily, because glass absorbs very little of the incoming energy. These rays then are absorbed by the soil and floor, and the heat energy generated is reradiated. Glass absorbs this energy and sends it back into the interior of the garden shed. The interior gets warmer and warmer. We see a great principle of science here: energy can never be destroyed; it can only be changed from one form into another.

SHARING ENERGY WEALTH

Because most of the warmth we experience is generated at the surface of the earth and radiates upward, we need to give priority to ground-level temperatures. It is there that our maximum temperature is found. Above that level, with rare exceptions, the atmosphere gets progressively colder. The lower part of the atmosphere behaves like a protective blanket to maintain the warmth that we enjoy. On cloudy days, it reflects back to earth some of the long-wave energy output from the earth. We are all familiar with the cold that is experienced on a clear, cloudless day when this heat from the ground is not being returned. Clouds and water are a very special aspect of weather and climate, and they will be analyzed in much more detail later. For the present, we should note the interesting role of latent heat in water. Latent heat is heat that is absorbed and stored in water vapor when evaporation takes place. When water vapor, a gas, changes to clouds or rain, this latent heat is released. It becomes an important factor in thunderstorms.

The fact that the temperature of air gets colder and colder as we move vertically away from ground level has a parallel in the changes that occur as we move away from the equator toward the North and South Poles. In both of these situations, even though the reasons are different, there is a steady reduction in temperature with distance from the origin. Vertical variations of temperature will be a major theme in Volume Three when we examine tornadoes and tropical cyclones and the wind systems they generate. They will be easier to understand if we first consider the ways in which natural forces act to distribute horizontal levels of warmth more equitably. Air follows the same physical laws as other substances, such as water, that have weight: one of these is that the heavier air tends to move toward the lighter. If we conduct a simple experiment with water, because it is easier to observe than air, we can see how this law works to distribute warmth around the world: heat the bottom of one side of a container of water with a small flame, and then introduce some dye to the other side. The water with dye sinks to the bottom of the container and moves along the bottom to the spot that was heated. This is called convection.

Now let us apply this same method of convection to a far bigger setting, the flow of heat from its greatest level, at or near the equator, depending on the season of the year, to the rest of the earth. The intensity of the heat generated in the region of the equator is due to its position relative to the sun's rays, which hit this region at a vertical angle. The exact latitude where the suns rays are perfectly vertical moves north and south over the course of a year as the earth moves around the sun, but it is always within 23.5° of latitude from the equator. The heat generated at the equator, as that location absorbs the input from the sun, warms the air above it. As it gets warmer, the air gets lighter, and hence rises higher and higher in the atmosphere. Cooler air moves in, in accordance with the convective principle of denser air moving toward lighter air. A new element now enters this description of convection: as we move farther away from the equator, the impact of solar radiation gets weaker, because the sun's rays are no longer meeting the earth vertically. The farther we move from the equator, the farther the sun's rays move away from being vertical.

Why Is the Sky Blue?

The sky is blue because of the action of the sun's rays. Energy from the sun consists of a wide spectrum of electromagnetic radiation of many different wavelengths. Some, such as x-rays and radio waves, are invisible. Others, such as light, are visible. The wavelengths of visible light, which are the one we are most aware of, are usually thought of as a mixture of the wavelengths of red, orange, yellow, green, blue, indigo, and violet. If any one of these encounters a particle as it passes through the atmosphere, and the diameter of this particle is smaller than the ray's wavelength, that light from the sun is scattered in all directions. A substance such as a nitrogen or oxygen molecule could have this effect, because the diameter of either is smaller than any one of the light wavelengths. It so happens that the energy from the sun, within the visible spectrum, peaks at blue and decreases with the relatively longer wavelengths of green, yellow, orange, and red. Thus we see the dominant blue as the color of the sky, because the wavelengths of blue are scattered.

GLOBAL WIND AND PRESSURE PATTERNS

In order to visualize the flow of air from the equator to the North and South Poles, it helps if we first ignore the presence of continents, but keep in mind that the earth is rotating on its axis. At a later time, once we understand the main features of this global airflow, we can add the presence of continents and see how they affect the grand convection. The reason for keeping in mind that the earth is always rotating on its axis relates to a very important series of winds, the trade winds. They were named a long time ago because they were essential to trade between continents, when sailing ships plied the waters of the Atlantic from Europe to the Americas. These winds blow from the northeast to the southwest north of the equator, and from the southeast to the northwest south of the equator. Think of colder winds from the north moving toward the equator to fill the spaces left by hot rising air. As they travel southward, the earth is turning on its axis, and this is why wind directions get changed from what you might expect. A simple experiment will illustrate what is happening: draw a line toward some nearby object on a sheet of paper while moving the paper slowly in a circle. Instead of getting a straight line, you end up with a curved one.

Now consider the convective flow of warm air from high above the equator to the north. As it travels into cooler air, it loses much of its warmth, becoming heavier as a result. By the time it reaches the latitude of 30° north, it has sunk close to the ground. It has also turned toward the east because the earth is rotating. This accumulation of cold air, and therefore heavier air, forms a belt of high pressure all around the world, the subtropical high-pressure belt. Some of the equatorial air continues northward, where it encounters additional cold air, cools, and sinks to form the polar front. If now we add to the convection the effect of the continents of the world, the belts of high pressure become masses of air, affected by the land beneath them. Both the subtropical

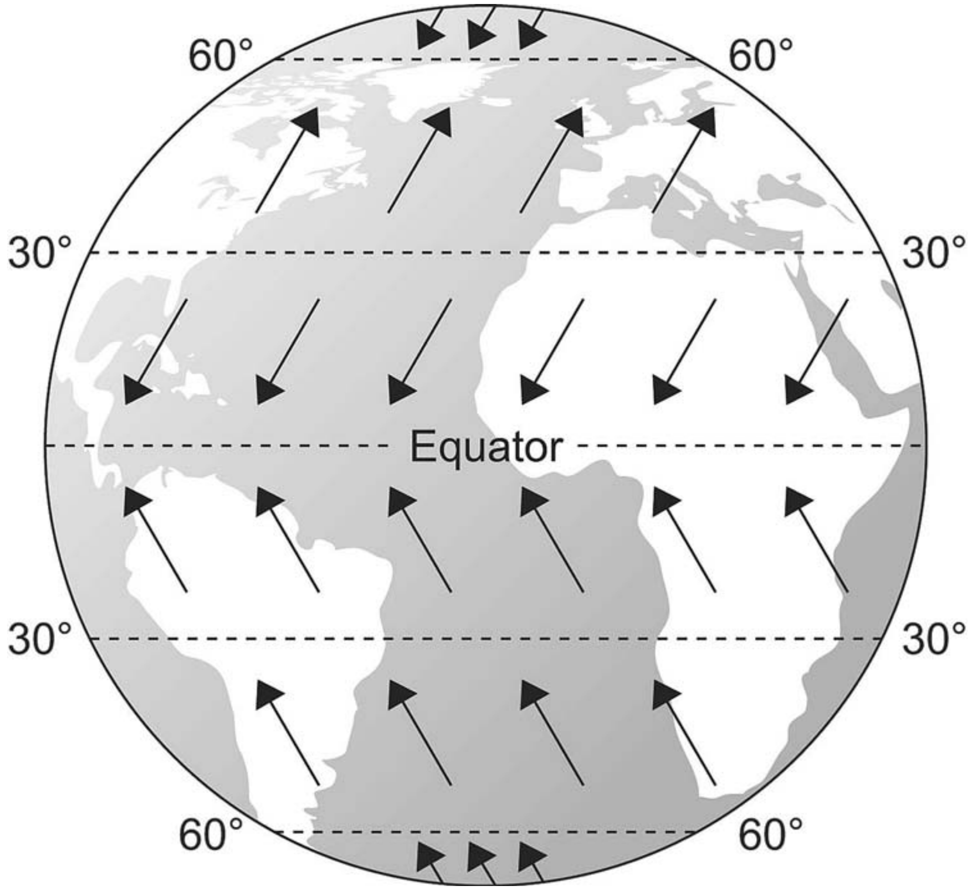

Figure 1-1 Global wind systems under the influence of the Coriolis effect. (ABC-CLIO)

high-pressure belt and the polar front are made up of masses of air, each with its own characteristics of temperature and moisture. It is easy to visualize these convectional flows if we think of a beach on a hot day. During the daytime, the land is more quickly heated than the ocean, so air rises and is replaced by airflows to the land from the sea. The opposite happens at night, because the land cools quickly after sunset and becomes colder than the sea surface, so the wind then travels from land to sea.

So far, most of this chapter has been about temperature, wind, and air pressure. Although much of the weather we experience is due to these, the biggest challenges come when water is involved. Weather patterns are affected by water in all three of its forms, solid, liquid, and gas. Think about the behavior of water in the same way as we considered temperature, as convection: it is constantly evaporating from the ocean, and from lakes, rivers, and even from what looks like dry ground. It rises as invisible water vapor into the atmosphere, because it is lighter than the air around it. Somewhere in the atmosphere, the water vapor cools enough to change into a cloud, that is to say, into a liquid. Later, as temperatures fall further, the water falls to the earth as rain or other precipitation, rejoining the ocean or lake to begin the cycle all over again. The hidden heat that we call latent heat is absorbed into water vapor during evaporation, and later released to warm the surrounding atmosphere when water vapor turns to rain. It is this latent heat that creates powerful cyclones in hot climates. The higher the overall temperature in a place, the greater the amount of water vapor that can be evaporated. When water vapor turns to rain in such areas, huge volumes of water are released.

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CHAPTER 2

Air Masses and Wave Cyclones

In Chapter One, we noted that the effect of the presence of continents was to change the belts of high pressure into masses of air. It is these air masses that give rise to our daily weather, especially the type of weather that is dominant over North America most of the time, the quiet storms that we know as wave cyclones. (Though it needs to be added that they are not *always* quiet.) In Chapter One, the role of moisture in the air was also introduced. This element, because of its powerful influence in weather conditions all over the world, needs to be examined further before we come to consider the role of wave cyclones. It is the presence of large volumes of water in the storms that make the Asian cyclones the most destructive on earth. Whenever water changes to a gas—that is, to water vapor—it needs energy to make the transformation. The presence of latent heat provides the needed energy. Later, during condensation, the same latent heat becomes sensible heat. This is the energy released when the water vapor changes back to a liquid. You can experience the reality of latent heat if you pour a small amount of alcohol into your hand. Because it evaporates at room temperature, it quickly disappears. Your hand feels cool because heat has been taken from it and stored as latent heat in the evaporated alcohol.

WATER AS LIQUID OR GAS

How much water can the air absorb? That becomes a very important question in places that experience sudden downpours. The answer is that it depends on the prevailing temperature. The higher the temperature, the greater the volume of water vapor that the atmosphere can carry. For this reason, violent rainstorms frequently occur in hot climates. The amount of water vapor in the air at a given time is measured as a percentage of the total amount that the air can carry. Thus, in a cold climate, this figure will be small in terms of the total amount of water vapor in the air, but the percentage may be as large as anywhere else, because it reflects how much of the maximum amount is in the air at a given time. Every weather report indicates the relative humidity (RH) for the time and place of the report, so that people can understand if there is a likelihood of rain. In addition, if the RH is near 100 percent, even in very cold climates, we feel the effect as a buildup of perspiration on our skin. This is due to the atmosphere reaching its limit and being unable to accept more water vapor. RH can therefore be thought of as a measure of personal comfort, This applies to both the outdoors and to the insides of our homes. Wherever we are, healthy living requires an adequate amount of humidity in the air we breathe.

As soon as RH reaches 100 percent, water vapor changes back to a liquid again. This happens everywhere in the world, independent of the climate. The cooling that raises the RH may be caused by a mass of air either rising higher or moving into an area of low pressure; both events cause lowering of temperature. However, water vapor needs a solid surface in order to change back to a liquid. Tiny particles of matter are always present in the atmosphere. These include dust, smoke particles, and sea salt from ocean evaporation. If the particles on which condensation occurred are very small, the liquid on it may be light enough to stay in the air as part of a cloud. The roles of low and high pressures to cool and heat a gas can be seen in a bicycle tire: if air is released from the tire, it feels cool as it escapes, because the pressure under which it had been placed has been removed. If air is pumped into the tire, you can feel the pump getting hot as pressure builds up within the tire. The Chinook wind of southern Alberta, Canada, illustrates the effects of differential air pressures: westerly moisture-laden winds rise up the slopes of the Rockies, cooled by the low pressure they lose their moisture. As dry winds, they descend into Alberta on the eastern slopes of the Rockies, and, as they do, their temperatures increase in the high-pressure areas of the lower elevations.

Clouds are vital aspects of the air masses that collide and form fronts where warm and cold masses meet. Both water vapor and clouds affect the amount of solar radiation that reaches the earth or returns back from the earth in the form of long-wave radiation. Both of these aspects of water make it a greenhouse gas, just like carbon dioxide, and we will examine them again in Volume Four when we consider climate change and global warming. Because most evaporation comes from the ocean, and because we now know that the average temperature of the ocean has

What Are Chinook Winds?

The name of this type of wind is taken from a native Indian word meaning "snow eater." It was first used for the warm winds that sweep down from the Rocky Mountains in Canada into Calgary and surrounding areas. There are similar winds all over the world, and they include the Santa Ana winds of California. This high-energy wind spills out of the Great Basin and is pulled by gravity into the surrounding lowlands. The air circulating around the high-pressure area brings winds from the east and northeast to southern California.

The Santa Ana winds usually form during fall and early spring, when the desert is relatively cold. The air heats up while being compressed during its descent. The air is then forced down the mountain slopes out toward the Pacific coast. Additional heating occurs as it drops in altitude before reaching the Los Angeles Basin. The southern California coastal region gets some of its hottest weather of the year while the Santa Ana winds are blowing.

been increasing over recent decades, it is likely that wave cyclones will bring higher rainfall in the future. Clouds are usually named according to their height above the earth and their overall shape. Thus we have altocumulus clouds high in the air, looking like a bundle of clouds in a small space; the name is taken from a Latin word for heap. Nearer the earth, there are stratus clouds; this name comes from a Latin word for layer, and these are the ones we are most familiar with, the kinds that suggest an overcast day. It often happens that a cloud is heated in one or two parts of the cloud due to the earth being differentially heated and sending convective cells upward into the cloud. This creates an unstable air mass. Small shoots rise above the main mass of the cloud because they are warmer and therefore lighter. As they encounter cooler air, they tend to release their moisture, but the presence of latent heat keeps them warm, so they continue to rise, until finally there is a sudden downpour of rain.

AIR MASSES AND POLAR FRONT

From the study of the atmosphere's global circulation, we saw that warm and cold air masses encounter each other at the polar front. This is usually located above the part of North America north and south of the Great Lakes, stretching all across the continent. The map of air masses shows the different kinds that are involved at different times of

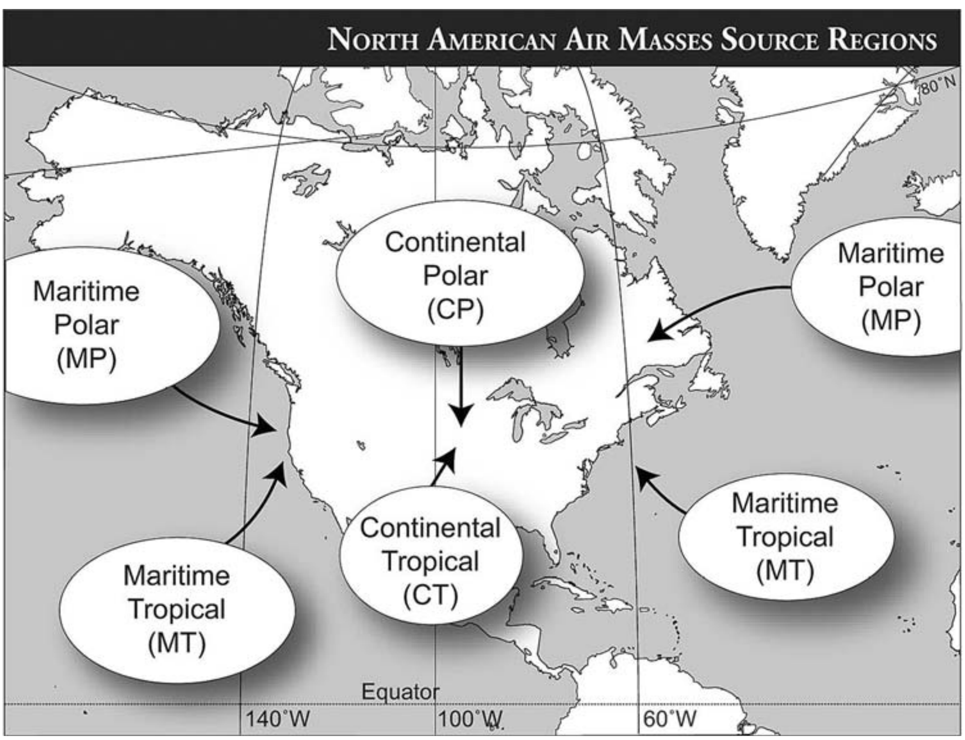

Figure 2-1 Map depicting air masses over North America. These large bodies of air have uniform temperature and humidity. (ABC-CLIO)

the year. Each one of these takes its character from the ground over which it is located over time. For this reason, each is known as a source region air mass, and has specific levels of moisture and temperature. One may have great quantities of water vapor with potential for causing heavy rainfalls, and another may be quite dry. Many of these extend over hundreds of thousands of square miles, so their interactions with other air masses affect correspondingly large parts of the United States. Continents may be hot source regions in summer and cold ones in winter. Ocean areas serve as source regions for high-humidity air masses. The greatest contrasts exist between tropical air masses and polar ones, so we would expect to see the biggest and sometimes most violent outcomes where these air masses interact. Tornadoes originate in such interactions, as we will see in Volume Three. Most wave cyclones are not violent.

A typical wave cyclone begins as a slight disturbance between two air masses, one that creates a ripple along the front between them. The colder air, always heavier than the warmer air, pushes against the warm air as a natural action of gravity. The interface between the two masses of air is vertical as well as horizontal. The warm air gradually gets trapped

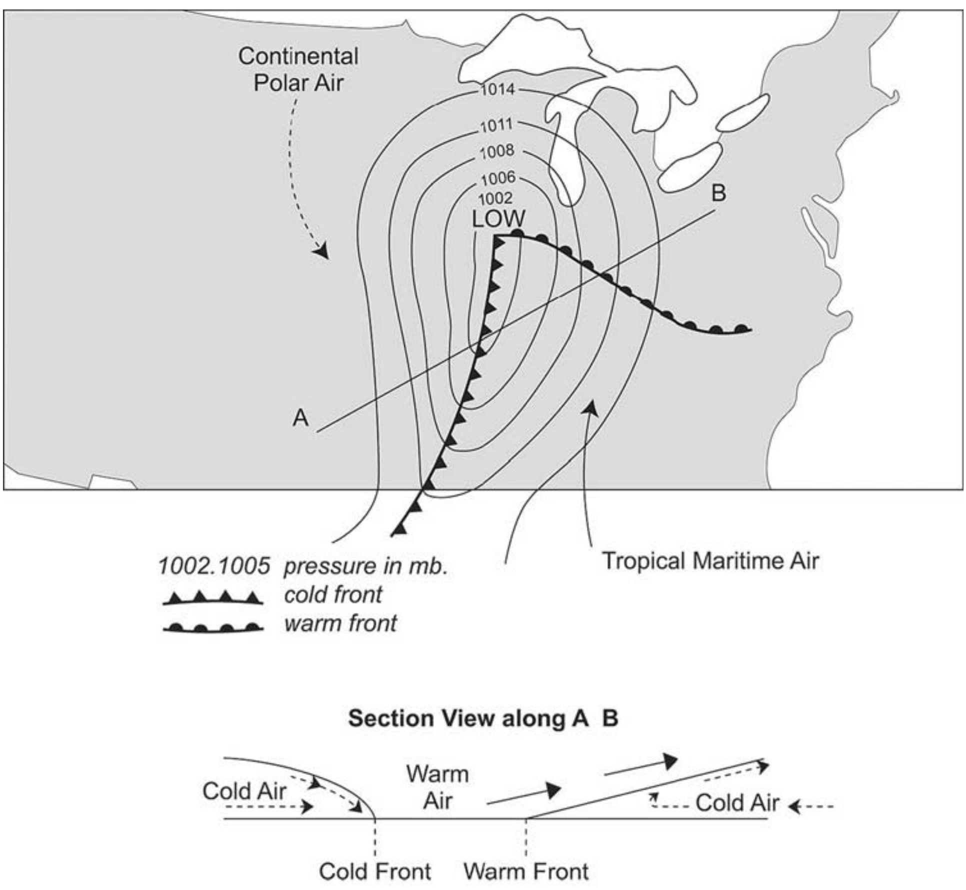

Figure 2-2 The formation of a mid-latitude cyclone. (ABC-CLIO)

in the wave that develops from the initial ripple, and as it is pushed further and further by the cold air, it moves in the only direction possible, that is, vertically. As warm air rises, it cools, and precipitation follows, either as a drizzle or a cloudburst, depending on the amount of water vapor in the air mass. The advance of the cold air continues until the warm air is completely replaced by the cold air and the cycle ends. As all of this is happening, the entire cyclone is being steered across the continent by the jet stream, a high-altitude westerly wind.

THE MID-LATITUDE JET STREAM

The high-speed wind of the northern jet stream, found near the top of the troposphere, plays a major role in guiding and sometimes triggering wave cyclones. Many factors, including the earth's rotation and the sun's uneven heating of earth's surface, contribute to the formation of this powerful eastward flow of air, which circles the earth in a narrow path, often as fast as 250 miles per hour. If you think back to the global movement of warm air from the equator described in Chapter One, the development of the mid-latitude jet stream is easier to understand. The first thing that happens to the equatorial air is cooling, and as it cools, it descends to the earth's surface because it becomes heavier. That happens around 30° north. As it moved from the equator toward 30° north, it was gradually turned to the right by the force of the Coriolis effect, so it became a west-to-east flow. The movement of warmer air toward the colder air of the north continued from this point, so the same events that occurred at 30° north were repeated at the cold polar front in the mid-latitudes. The sharp contrasts in temperature at this point are so great that the easterly flow in the upper atmosphere is correspondingly a high-speed one.

This stream of air generally runs parallel to the polar front and runs from west to east, but the polar front is not always in the same place. It can swing southward into the southern states of the United States, and it is often at such times that the more violent wave cyclones are triggered. This is due to the extreme contrasts between polar and tropical air masses. The average location of this jet stream in the winter is over the southern United States. In the summer, it is near the U.S.-Canadian border. Because the north-south temperature gradients are greater during winter than during summer, the winds of the jet stream are faster in winter than in summer. Pilots flying from North America to Europe or vice versa take careful note of the jet stream, either to avoid it if it slows them down or to join it when it might shorten the time of their flights and save fuel. There is another jet stream in the southern hemisphere, because the movement of air southward from the equator is similar to the northward one, different in outcomes only because the sizes and shapes of landforms in the two hemispheres are not identical. Both of these jet streams exercise a considerable influence on human affairs everywhere.

We hear about the jet streams every day in weather forecasts. Weather forecasters need detailed knowledge of them, their locations, altitudes, and strengths, for predicting the weather conditions as well as for providing safe and efficient routing of aircraft. In the previous paragraph, the differences in the form and size of the southern hemisphere's land areas compared with those of the northern hemisphere were mentioned. Land greatly modifies temperature regimes because it heats and cools at a dramatically different rate than the oceans do. The topography of the land also influences a jet stream's location. Mountain ranges and plains will always affect the distribution of atmospheric temperatures. Because of the increasing concerns over global warming, many scientists are now investigating the possibilities of securing nonpolluting energy from these jet streams. Because of the absence of ground friction, the wind at high elevations is a hundred times more powerful than the wind near the ground. So, in theory, high-flying generators could generate electricity at costs that are less than those available from any other source. Many aspects of maintenance, repair, and ways of transmitting energy to the ground have yet to be worked out.

CHAPTER 3

Impacts of Different Energy Inputs

In the introduction to wave cyclones in Chapter Two, it was mentioned that these mid-latitude storms are, on the whole, quiet when compared with the ferocious and fatal storms we will examine in Volume Three of this set, the tornadoes and Asian cyclones. However, for various reasons, they are not always quiet. When the jet stream, the high-elevation, fast-moving wind that determines the paths of wave cyclones, happens to swing farther south, the wave cyclones that emerge carry high winds and deposit copious amounts of rainfall. There are also factors other than the location of the jet stream that affect the formation and movement of these storms. If we look at the factors that influence the amount of energy received from the sun at particular places and times, a picture soon emerges of a very varied temperature regime, even within one locality. The accompanying illustrations help to show the different temperatures and thereby demonstrate the unpredictability of both the strength and the rainfall we might experience from a particular wave cyclone.

The first variable in the amount of energy, or insolation, to use the technical term for energy from the sun, is location. If a U.S. place is on the side of a hill or mountain and happens to face east or south, it gets more insolation than a similar place on level ground. A second advantage or disadvantage of location is related to latitude. Other things being equal, a place that is closer to the equator gets more insolation than one that is

What Is Albedo?

Different areas of the earth's surface reflect or absorb solar radiation differently. For example, a stretch of blacktop absorbs almost all of the incoming energy from the sun, but an ice sheet on a glacier reflects back into space almost all of the incoming energy. We use the term albedo to define the amount of incoming energy that is reflected back to space. Thus, a place that reflects half of the incoming radiation is given an albedo rating of 0.5. If an area has a very low albedo, it will reflect back into the atmosphere most of the energy it receives, in the form of long-wave radiation, or sensible heat, and people living there will enjoy the prevailing warmth. We might therefore be inclined to think that the lower the albedo, the better for us. That may be true for some parts of the world, but we saw in Volume One how a low albedo is causing enormous hardship among wildlife in the Arctic Ocean. There, when the ice covering on the ocean melts due to global warming, the high albedo of ice is replaced by the much lower albedo of water. The temperature of the atmosphere above the water is raised as a result of this change, and the melting of ice increases, further worsening the environment for wildlife.

farther away. An additional factor in the amount of warmth a place receives is the albedo of the surrounding area; a dark surface will get more warmth than a bright one. Time of day and time of year are other factors affecting the insolation, and therefore the temperature, of a place. In the case of a place on a hillside, the angle of the sun's rays are more perpendicular than they are for a location on level ground. In a similar way, in all places the amount of energy received from the sun is greatest around the middle of the day and least in the morning or evening. A situation almost identical to the daily variation occurs with the seasons of the year as the angle of the sun's radiation waxes and wanes during the year.

As we will see later in this chapter, all of these variables make for surprises in the kinds of wave cyclones that occur. Additionally, there are influences from both the surface of the earth and the atmosphere above it that greatly affect the behavior of both mid-latitude cyclones in North America and various climatic conditions in other places. For example, in June 1991, Mount Pinatubo, in the Philippines, erupted and released volcanic products that made a large impact on the atmosphere all over the world. Over a period of nine hours, a cubic mile of volcanic debris and more than 18 million tons of sulfur dioxide were sent skyward into the highest parts of the atmosphere. It was the second-largest eruption of the twentieth century, and it soon began to affect temperatures and rainfall regimes everywhere. There were decreases in the amount of solar radiation that reached the earth's surface, causing a cooling of the northern hemisphere by about 2°F. This persisted for two years, and we have already noted its influence in Chapter Five of Volume One; the extreme rainfall and lower temperatures contributed to the massive 1993 flood.

Volcanic eruptions can have dramatic effects on weather and climate all over the earth, disrupting the environment and creating hazards for human settlements. Beyond its influence in North America, the Mount Pinatubo eruption increased the amount of sulfur dioxide aerosols in Antarctica for three years, from 1991 to 1994. These aerosols added to a weakening that appears from time to time in the ozone layer high above Antarctica, something that is always a major concern for humans everywhere. More will be said about this in Chapter Seven. In another part of the world that frequently suffers from rainfall shortages, the Sahel region of central Africa, the recurrent droughts of the 1990s were partly attributed to Mount Pinatubo's eruption. These Sahel droughts have already been examined in Chapter Six of Volume One. The following three examples of mid-latitude cyclones illustrate the differences in outcomes when the conditions at their sources are different.

THE THANKSGIVING SNOWSTORM OF 1950

This storm hit the eastern part of the United States, killing 160 and causing millions of dollars in damage. Some named it the "Appalachian Storm" because it dumped record amounts of snow in the Appalachians. It originated over North Carolina just before Thanksgiving and quickly moved north, striking western Pennsylvania, eastern Ohio, and West Virginia. These areas were blanketed with several feet of snow for several days, making travel almost impossible. Pittsburgh received 30 inches of snow in one snowstorm. An accompanying windstorm disrupted a much wider area; there was a 94-mph wind gust in New York City, a 140-mph wind gust just north of New York City, and hurricane-force winds throughout most of New England. High tides and wind-driven surf battered the coastline. Record low temperatures were recorded in Tennessee and North Carolina, and in one location in North Carolina, Mount Mitchell, the thermometer reading dropped to 26°F. A Weather Channel expert described that this storm was almost unique in its large range of weather elements.

This was the biggest snowstorm in Ohio's history, with the entire state covered in 10 inches of snow and most communities in the eastern half receiving 20 to 30 inches of snow. A severe cold wave swept over the state on Friday, November 24, bringing temperatures close to 0°F. The greatest concerns, however, centered on a long-awaited football game that was scheduled for Saturday afternoon in Columbus. Ohio State was to play Michigan, and the stakes were the Big Ten championship and a trip for the winner to the Rose Bowl in California. The Saturday morning temperature was 26°F, and there was a 40-mph wind. Few U.S. college football games had ever been played in worse weather. The contest had been sold out by August—82,300 tickets sold for the 78,413-seat stadium. Intermittent snow continued all day Friday. With the forecast of 15°F and gale-force winds for game time on Saturday, officials expected attendance to drop to 70,000. Thousands of early arrivers trudged into Columbus looking like refugees. During the night, a blast of frigid air swept over Ohio, paralyzing the region with heavy snow, gale-force winds, and near-zero temperatures.

At the stadium, the hardy souls who attended were wrapped in an odd assortment of blankets and other gear, sitting on their snow-covered seats. Some had cardboard cartons over their heads with peepholes cut out for vision. Many tried to build fires under the stands. Stadium officials warned that all toilets in the top of the stadium were frozen. Assisted by several hundred Boy Scouts, undergraduates, and spectators, the ground crew cut the tarp from the frozen field, rolled the segments to the sidelines, and watched as new snow quickly obliterated all the field stripes. The Ohio State band could not play because it was impossible to put lips to frozen mouthpieces. The officials and team captains met for the coin toss, recognizing that the game would, at best, be composed of short bursts into the line. The turf was too treacherous for deception or fancy footwork. The game started with the temperature at 10°F and a 28-mph wind whipping into the open end of the horseshoe-shaped stadium, blowing the five inches of snow into six-foot drifts. The first quarter ended with Ohio State leading 3 to 2. Michigan's longest run had been eight yards, and Ohio State had a similar run. Each team had punted seven times. Rushing statistics were Michigan seven yards, Ohio State minus two yards.

What Is Wind Chill?

There is a thermal boundary layer of air on our skin, the result of body warmth modifying the temperature of the surrounding atmosphere. It is less than half an inch in depth, and it protects us from sudden changes in temperature. When it is cold and the wind is blowing, the temperature of the air feels colder than it does when it is calm because this layer of warmer air is blown away. The term "wind chill" is used to describe this change in felt temperature. The stronger the wind, the more of the thermal boundary is blown away. Hence the effect of wind chill on our bodies is increased or decreased as wind increases or decreases. Wind chill always feels colder than calm air, as can be seen in tables that predict the felt value of wind chill under different conditions. With a temperature of 30°F, for example, and wind of speed 10 mph, wind chill is 16°F. If the wind speed is 50 mph at the same temperature, wind chill drops to –7°F.

Special care needs to be taken in places where the temperature is normally very low and winds are high, as in the Arctic and the Antarctic. Many people make decisions as to how they will dress for outdoor activity, or whether they will take part in outdoor activity, based on the wind chill rather than the actual temperature. Wind chill has a potential economic impact on ski operators and other outdoor recreation areas. Schools use the wind chill forecast to decide whether to let students outside for recess or lunch in cold weather. Heart patients pay attention to the wind chill, to estimate the stress the weather might place on their circulatory systems. Military agencies often modify their training exercises when wind chill reaches dangerous levels.

During halftime, Ohio State changed from cleats to tennis shoes in hopes of gaining better traction, but everyone agreed at the end of the game that they had been of little help. The second half began in a snowstorm with the snow so heavy that visibility was near zero. The game continued in punts plus a few desperate passes. The *Columbus Dispatch* labeled the game "the Blizzard Bowl." Comments after the game were brief: "It was a nightmare," said one of the coaches. A player said, "My hands were numb and blue. I had no feeling in them and I could not hold onto the ice-covered ball." The fans who braved the blizzard were divided in their views on the whole day. Michigan had won without making a single first down. Their total offense for 46 plays was 27 yards, all of them rushing. Kick returns added 29 yards to the total Ohio State managed, 41 yards of offense on 58 plays with only 16 by rushing. Three passes had been completed out of 18 attempts with two interceptions. Travel for players after the game brought additional frustrations. Roads remained impassable throughout Ohio, and many travelers had to find temporary accommodation in Columbus.

COLUMBUS DAY STORM OF 1962

The Columbus Day Storm of 1962 was an extra-tropical wave cyclone. It was ranked among the most intense to strike the United States Pacific Northwest in half a century. It was unmatched in terms of wind velocity, and only hurricanes of category 3 or more had comparable

Damage from the Columbus Day storm, Oregon, 1962. (National Weather Service, Portland)

wind power. As tropical storm Freda, this storm formed far out in the Pacific and, later, became an extra-tropical cyclone as it moved into colder waters and interacted with the jet stream. Freda redeveloped explosively off the northern California coast due to favorable upper-level atmospheric conditions, producing record rainfalls in the San Francisco Bay area. The rain delayed the 1962 World Series between the San Francisco Giants and the New York Yankees. When the winds are from the west, as in this case, they are stronger on the coast than in the interior valleys due to the north-south orientation of the Coast Range and the Cascades. Winds are reflected northward, parallel to the mountain ranges.

Freda was a classic example of what came to be known as a south windstorm, moving northward toward the Oregon coast. Atmospheric pressure fell rapidly ahead of the storm center and rose back up again just as rapidly once the storm center passed, creating very sharp pressure differences. The storm continued in a northeastward direction and then swung straight north as it neared southwest Oregon, maintaining a forward speed of 40 mph with the center just 50 miles off the Pacific Coast. There was little central pressure change until the cyclone passed the latitude of Astoria, Oregon. From there it passed over Washington and ended on Vancouver Island, British Columbia, Canada. Peak winds were felt as the storm passed close to Oregon's Cape Blanco, where an anemometer that lost one of its cups registered wind gusts in excess of 145 mph. Many anemometers, official and unofficial, within the heavily stricken area of northwestern Oregon and southwestern Washington were destroyed before winds attained their maximum velocity.

In less than 12 hours, more than 11 billion board feet of timber were blown down in northern California, Oregon, and Washington combined. This amounted to more than the annual timber harvest for Oregon and Washington combined. In central and northern California, all-time rain records were passed, particularly in the San Francisco Bay area. The destruction of barns and other structures threatened livelihoods, and many farm animals died inside collapsed buildings. Additionally, the local power distribution system was utterly decimated and had to be rebuilt from scratch.

Many of the area's backcountry roads, used today by hunters and hikers, are a visible legacy of the Columbus Day storm. These rough roads were made following the storm for timber salvage as part of the rebuilding effort. The storm caused at least 46 deaths, hundreds of injuries, and $235 million in property damage. It is remembered today as the greatest storm emergency in the Pacific Northwest in living memory. The memory is vivid for those who lived through it more than four decades after the event.

RED RIVER FLOOD OF 1997

The Red River Flood of 1997 affected both the United States and Canada. It was a major flood that occurred in May 1997 in North Dakota, Minnesota, and southern Manitoba. It was the most severe flood of the river since 1826, causing extensive flooding and destruction on both sides of the border and damaging almost $3 billion worth of property. This international waterway annually faces some risk of flooding because of the several variables that affect water levels in both countries. The Red River originates in Minnesota and flows northward through a large glacial lake basin, that of Lake Agassiz, the largest of the glacial lakes that were formed at the close of the last ice age. The glacier covered an area of half a million square miles and left in its wake a low-lying landscape, almost completely flat in places. The Red River overflows its banks in most years, and the low elevation of the surrounding terrain ensures that water covers a large area when that happens.

The flatness of the river basin is evident in the gradient as the river flows northward, an average slope of six inches per mile for the whole

Flood water covering the Sorlie Bridge, Grand Forks, North Dakota, during the Red River Flood of 1997. (U.S. Geological Survey)

500 miles of its length. Natural levees, 5 feet in height, rise on either side of the river. The events of 1997 were far worse than anything previously experienced. The river reached the cities of Grand Forks and East Grand Forks, where floodwaters stretched outward from the river for three miles, inundating virtually everything in these two cities. The situation was similar in Canada.

Floods are notoriously unpredictable, as the Chinese discovered over the centuries of their history, and as the United States discovered with the Mississippi River. In fact, our inability to distinguish between weather and climate in our preoccupation with the advancing global warming has tended to make us attribute every daily change in temperature or precipitation to global warming. Media commentators are the worst culprits here. The last time that Winnipeg had a flood like the 1997 one was 1826, and Canadian meteorologists predicted that it would not repeat for another 500 years. It happened again in about 170 years.

There was some sense of imminent threat in Grand Forks, but the National Weather Service (NWS) had a long-standing forecast for the river to crest at 49 feet, the river's highest level during the 1979 flood, so people felt secure. The cities had been able to get their dikes to this level, but the river continued to rise past it in 1997, to the astonishment of the NWS, which had failed to upgrade its forecast until April 16, 1997, the day the river actually reached 49 feet. The dikes in the Grand Forks and East Grand Forks area all were overtopped on that day, flooding thousands of homes, and necessitating the evacuation of all of East Grand Forks and 75 percent of Grand Forks. School was canceled in both cities for the remainder of the term, as were classes at the University of North Dakota.

Because all transportation was cut off between the two cities, East Grand Forks residents were evacuated to nearby Crookston, Minnesota, namely to the University of Minnesota campus there, while residents of Grand Forks went to the Grand Forks Air Force Base. Many residents also evacuated to motels and homes in neighboring communities. The river crested at 54.35 feet on April 21, 1997, and the river level would not fall below 49 feet until April 26. Because water drained so slowly out of the most low-lying areas, some homeowners couldn't visit their damaged property until May. All told, there was $2 billion in damage to Grand Forks and East Grand Forks. Grand Forks lost 3 percent of its population from 1997 to 2000, but it didn't fare as badly as its sister city, which lost nearly 17 percent of its residents. The five-foot discrepancy between the actual crest and that which the NWS had predicted led to widespread anger among locals, especially because the citizens of both cities reached and even slightly surpassed the NWS's predicted level of needed protection through weeks of hard work raising the level of the dikes.

The province of Manitoba completed the Red River Floodway in 1968 after six years of excavation, put up permanent dikes in eight towns south of Winnipeg, and built clay dikes and diversion dams in the Winnipeg area. However, even with these flood protection measures, the province was not prepared for the 1997 event, known as "the flood of the century." At the flood's peak in Canada on May 4, the Red River occupied an area of nine hundred square miles with more than a thousand additional square miles of land under water, appropriately dubbed "the red sea." There were 75,000 people who had to abandon their homes. Damage costs were $450 million. The U.S.-Canadian Mission that looked after the Red River Waterway immediately began to plan for better protection against floods.

In retrospect, there were five main factors that contributed to the flood's severity: (1) rainstorms in autumn of 1996 had saturated the ground, so it could not absorb much water; (2) there was overabundant snowfall during the 1996–1997 winter; (3) an abnormally cold temperature regime plagued the upper Midwest during this same winter; (4) between November 7, 1996, and March 18, 1997, the air temperature reached 40°F for only three days, so there was very little melting of the snow; and (5) a freak blizzard dumped a large amount of snow on the area on the weekend of April 5, 1997.

CHAPTER 4

Thunderstorms, Flash Floods, and Hailstorms

Thunderstorms come in all shapes, sizes, and speeds, and in the course of their lifetimes they give rise to a variety of associated weather phenomena. Masses of water vapor get lifted up into the atmosphere when the ground is heated or when moving air travels over mountainous terrain. The water vapor cools rapidly into liquid form, the familiar cumulus cloud appears, and the cloud continues to rise as it is heated by the release of latent heat. This updraft is followed by a downdraft as the cloud reaches its maximum height and discharges its accumulated water in the form of light rain, ice pellets, or flash flooding, depending on conditions at a particular time. Sometimes there is a microburst, which is an intense wind close to the ground that can destroy a low-flying plane. The details of these many aspects of thunderstorm activity will be described in the following accounts of a thunderstorm, a flash flood, a hailstorm, and a microburst.

An average thunderstorm is 15 miles in diameter and lasts an average of 30 minutes. At any given moment, there are thousands of them in different places around the world. Some, mainly in the

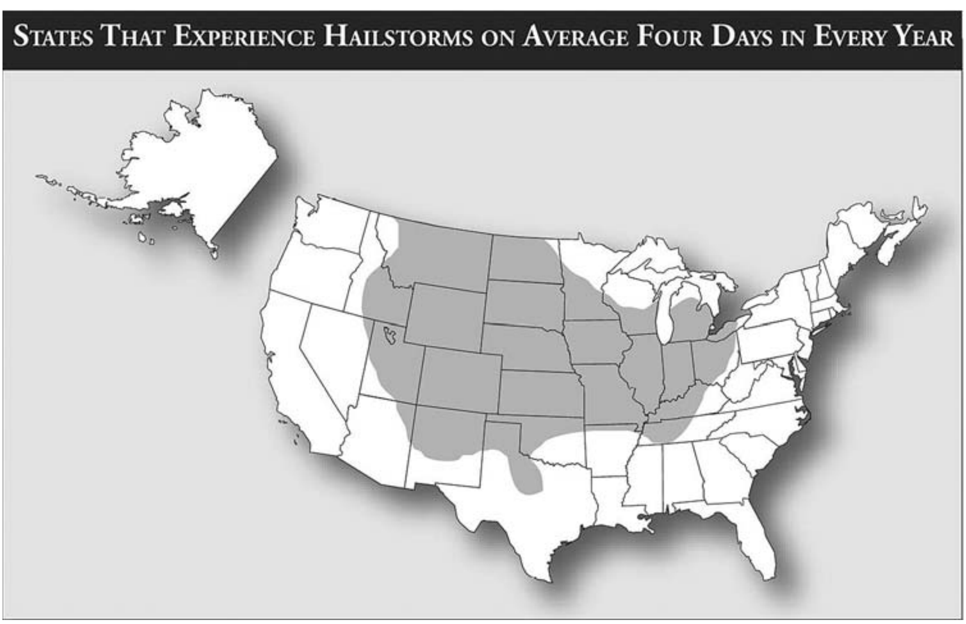

Figure 4-1 Hailstorms are most common in the interior of continents at mid-latitudes. (ABC-CLIO)

United States, will develop into multi-cell spiraling clouds that end as tornadoes. We will examine these in Volume Three of this series of books. For the vast majority of thunderstorms, their life cycles are simple and they make little impact on life or location. They begin when areas of the earth are heated and, as a result, the warmer and therefore lighter air rises into the atmosphere. It continues to rise higher and higher as long as it is warmer than the surrounding air. The only direction it can go when its temperature is the same as its surroundings is horizontally. Thereafter, depending on the amount of heat from the earth pushing the air higher, this horizontal mass of air continues until it reaches its condensation point, what we call its dew point, and water vapor changes into a liquid. Additional latent heat is released at that point, raising the temperature of the air and thus pushing it farther into the upper atmosphere.

The cloud that was formed as condensation took place continues to rise higher if the updraft pressure from below is strong enough, until, as a huge cumulus cloud, it reaches its limit, and the large quantities of water stored in the whole cloud begin to condense. Water vapor has been turning into liquid throughout this period, some of it having become ice because of the high rate of vertical advance. Collisions of particles in the clouds lead to ice particles having positive charges and water droplets having negative charges. As a result, there is a buildup of static electricity in the air mass, and as this electricity is discharged, we see it as lightning and hear it as thunder. Eventually, the accumulation of water in the thunderstorm triggers a downdraft, the release of large quantities of water in different forms. They water may fall as ice pellets, hail, or heavy rain. The damage on the ground caused by lightning can be as violent as that from downdrafts of rain or hail. Deaths and injuries to animals, thousands of forest and brush fires, and millions of dollars in damage to buildings and electrical systems can result from lightning strikes. NASA is very much aware of the risk of accidents from lightning strikes. One major incident occurred during the 1969 launch of the Apollo 12 mission, when lightning knocked out vital communications. Fortunately, the astronauts regained control.

THE BIG THOMPSON CANYON FLOOD OF 1976

The Big Thompson River Canyon flood occurred July 31, 1976. The walls of the canyon through which the river flows are almost vertical, with little soil or vegetation to absorb water. This river starts high in the Rocky Mountains near Estes Park and flows eastward through canyons before exiting into the rolling, forested plains west of Loveland. On July 31, a weak, moist, easterly flow of air developed on the east side of the Rockies and quickly rose up the mountain slopes to become a thunderstorm. Normally, the strong winds that are always present at the crests of mountains push thunderstorms like

Big Thompson Canyon flood, Colorado, 1976. (AP/Wide World Photos)

this one away from the valley areas below. Things were different on July 31, however, because the upper winds were extremely weak, quite incapable of pushing the thunderstorm away from the Big Thompson valley.

Instead, the storm remained virtually stationary for more than three hours and dumped a foot of rain into the canyon. At one stage, eight inches of rain fell within one hour. In Colorado's dry climate, and with steep canyon walls that had no vegetation cover, this amount of rain created a raging torrent that swept down the valley of the river at an enormous speed. This speed was increased because the elevation of the area that experienced the downpour was far above sea level. Cars, campers, and buildings in the path of the water had no chance of survival. The wall of water moved so fast that even if Highway 34 had not been washed out, the only avenue of escape was up the canyon walls. Vehicles and buildings became death traps for unsuspecting campers.

In two hours, the Big Thompson Canyon flood killed 145 people (including six who were never found), destroyed 418 houses and damaged another 138, destroyed 152 businesses, and caused more than $40 million in damage. One outcome was the adoption of new regulations limiting construction of any kind along the Big Thompson River. These regulations were extended to similar situations across the United States. In addition, a major drive was initiated for the creation of early warning systems for flash floods in mountain cities and recreation areas.

JOHNSTOWN FLASH FLOOD OF 1889

On May 31, 1889, the town of Johnstown, Pennsylvania, with a population of thirty thousand, was devastated by the worst flood in the nation's history. More than 2,200 people died, and many others were left homeless. A small lake, about four hundred feet higher than the elevation of Johnstown, that had once been used to supply the old Pennsylvania canals, had been purchased by a private group, The Hunting and Fishing Club, and they had enlarged it, raising its dam to a height of one hundred feet. This club failed to give attention to the old sluiceways at the bottom of the dam, so that, as heavy rain raised the water level in the lake, the only escape route for water was over the top. The dam had never been designed to restrain the weight of water at that level. On May 31, 1889, unusually heavy rains that had persisted for days raised the lake level to the top of the dam. Leaks began to appear in several places, and within a short time the whole dam collapsed. The waters of the entire three-square-mile lake thundered down the valley to Johnstown.

Johnstown in 1889 was a steel-company town. It was a growing and industrious community known for the quality of its steel. It had been founded in 1794, had prospered with the building of the Pennsylvania Mainline Canal in 1834, and had grown still more with the arrival of the Pennsylvania Railroad and the chartering of the Cambria Iron Company in the 1850s. There was one drawback to living in the city. Johnstown had been built on a flood plain at the fork of the Conemaugh River and Stony Creek. Because the growing city

The Johnstown Flood of 1889, in western Pennsylvania, destroyed the town of Johnstown. (Library of Congress) had narrowed the river to gain building space, heavy rainfall quickly raised its water level, frequently flooding parts of the town. Fourteen miles up the Conemaugh River, Lake Conemaugh, at an elevation of four hundred feet above Johnstown, had a poorly maintained dam. This was a constant source of concern to the people farther down the valley. Every spring, as heavier rain arrived, there was talk that it might not hold back the water, especially if its level rose very high.

At 4:00 PM on the wet afternoon of May 31, 1889, the inhabitants heard a low rumble that grew to a roar like thunder. Some knew immediately what had happened. After one more day of heavy rain, the South Fork Dam had finally broken, sending 16 million tons of water crashing down the narrow valley. Brimming with huge chunks of debris, the wall of floodwater grew at times to 60 feet high, tearing downhill at 40 miles per hour, leveling everything in its path. Thousands of people desperately tried to escape the wave. Those caught by it were swept up in a torrent of oily, muddy water, surrounded by tons of grinding debris, which crushed some while providing rafts for others. Many became helplessly entangled in miles of barbed wire. There were no telephones or anything similar beyond the telegraph stations at different locations to warn the people of Johnstown of the approaching deluge.

A young civil engineer who was the first to see the impending break in the South Fork Dam rode his horse as fast as he could down the valley shouting, "the dam is breaking, run for your lives." At South Fork Station, he stopped to send a telegraph message to Johnstown, ten miles down the valley. Some paid attention to his cry, but most ignored him. He lost his life as he crossed a railway bridge below Johnstown and was caught in a wall of water and debris as the bridge collapsed. It was all over in 10 minutes, but for some the worst was still yet to come. When darkness fell, thousands were huddled in attics, others were floating on the debris, and many more had been swept downstream to the old Stone Bridge at the junction of the rivers. Piled up against the arches, much of the debris caught fire, entrapping forever 80 people who had survived the initial flood wave.

Floods are familiar events in most parts of the world, and they most frequently occur when humans compete for the use of floodplains. The natural function of a floodplain is to carry away excess water when there is a flood. Our failure to recognize this fundamental fact has led to extensive development on floodplains, without adequate attention being paid to the risk of flash floods, and hence an increase in flooding that affects populated areas. Because these places are ideal locations for agriculture, there are good reasons for using them. In the introduction to this volume, there is an example of human use of floodplains and also the disastrous consequences of inadequate planning in time of flood. Another example is given in Chapter Five of Volume One in this set: China's terrible experience of a flood on the Yellow River in 1887. In that event, heavy rains raised the water level in the river so high that the levees were overtopped, then partly destroyed, and so the floodplain became a deep lake. Close to a million people lost their lives. Although this example involved huge numbers of people and a large amount of land, the cause of the tragedy was exactly the same as the Johnstown one. There had not been sufficient strength in the methods used to hold back the water, neither in the levees in China nor in the dam above Johnstown.

The outstanding example of floodplain problems is the Mississippi River basin. It is the largest floodplain in the world, and it occupies almost half of the total surface area of the coterminous United States. Floods have been a constant feature of this river from the beginning of historical records. For most of this period of time the Mississippi's floods were considered to be local responsibilities. When the flood of 1927 occurred, killing 246 people, flooding 137,000 buildings, and leaving 700,000 people homeless, it became clear to all that national action was essential if the ravages of flood damage were to be effectively minimized. At the mouth of the Mississippi, human activity of various kinds is destroying the wetlands that would normally develop if the river were free to deposit its silt naturally. Sixty square miles of wetlands are lost annually in this area, a higher percentage than occurs on any other U.S. coastal area. Yet we know now, in the aftermath of Hurricane Katrina, that these wetlands provide the first line of defense against deadly hurricanes, by both limiting the storms' access to the warm ocean water that drives them and by creating a physical barrier to the floodwaters that they generate.

Johnstown is not the only example in the United States of flash floods leading to a dam failure. There are numerous other examples, large and small, of similar failures. One of them, Buffalo Creek, will be described in the next section of this chapter. It is very similar to the Johnstown tragedy, the failure of a dam in a community that was dominated by a single company, in the case of Buffalo Creek, a coal-mining company. As so often happens when a single owner has complete control of the economic life of a community, there is a temptation to minimize safety precautions and maximize profits. In the case of Johnstown, there had been ample warning by various officials that the dam posed a great risk to the whole community, and that external, objective advice was needed to assess that risk. In spite of these recommendations, the company decided to accept the risk. Its conclusion was that the dam was safe. No one seemed to be able to insist on a second opinion.

Once the dam had collapsed and the wall of water and debris started moving down the valley toward Johnstown, there was little that anyone could do to save lives. The only communications possible were shouts of warning. Within 20 minutes of the dam's collapse, it was all over. Men, women, and children had been carried along to their deaths in a tornado of water and debris, frantically shrieking for help. The speed of the flow of water and materials made it impossible to rescue anyone. The aftermath was painful in every way. Recriminations soon appeared. Why was the water level in the dam allowed to rise so high? Even as late as May 30, action could have been taken to release large quantities of water. The most urgent task was the burial of bodies, large numbers of them unidentified. A mass funeral and mass burial was arranged. There were no pallbearers. Ox teams and carts, each cart carrying six boxes, brought the bodies to a mass grave. Memories of the final day were recounted many times, stories of heroes and of villains, as is always the case in such situations.

In the offices of the Cambria Iron Company south of Johnstown, an assistant cashier noticed that the water had reached as far as the second floor, where he was and where the money for the workers was kept in a safe. The dam had not yet collapsed, but the numerous leaks had already turned the river into a torrent that was steadily rising higher. He took the money from the safe. It was in packages of bills, altogether amounting to $12 thousand. He climbed to the next floor and within a short time went on to the roof, the only place that was still above water. Moments later, the entire office building disintegrated, and he jumped onto a house that was floating past. This temporary spot carried him downstream, and, fortunately, it got stuck for a time against a bank. He managed to clamber his way onto land, then found his way into the woods, where he hid for the night in order to safeguard the money. There were other memories too from the days immediately following the tragedy, memories that people would have liked to forget but could not. Some young men came from Pittsburgh, 50 miles away, to observe the scene, found some barrels of whiskey, and in a state of intoxication began to rifle the dead bodies. They stole rings, clothing, jewelry, and anything else that might have value.

The telegraph line was the only form of communication with other places, so the telegraph operator was always a vital part of efforts at saving people. Some telegraph lines had been swept away by the flood and later partly reconnected by volunteers who strung wires across trees wherever they could. As had happened elsewhere in similar situations, the telegraph connection was so important that operators often stayed there until it was too late to escape. That was the story of the lady who had been telegraph operator for the Western Union Telegraph Office. She sent messages to every place that might be affected, but waited too long to save her own life. In the days and weeks that followed, aid money and help of all kinds poured in from governments, businesses, and people in all walks of life. President Benjamin Harrison, who had been sworn in as president in the same year as the flood, convened a meeting of eminent citizens to plan relief. He also sent a gift of money as a personal contribution to the community.

BUFFALO CREEK FLASH FLOOD OF 1972

After almost three days of heavy rain, an earthen dam holding back 15 acres of drainage water carrying the waste from strip mines broke in the morning of February 26, 1972. Water black with accumulated coal dust poured into Buffalo Creek. In the days immediately before this event, heavy rain had fallen almost continuously, although experts later claimed that this was typical for late-winter weather in the area. Buffalo Mining officials, concerned about the condition of the highest dam, measured water levels every two hours during the night of February 25. Although an official with the Pittston Coal Company—parent company of Buffalo Mining—was alerted to the increasing danger, the residents of the hollow were not informed. The company even dispensed with two deputy sheriffs who had been dispatched to help. The flood unleashed approximately 132 million gallons of muddy water, cresting at over 30 feet in 16 hamlets in Buffalo Creek Hollow. Out of a population of 5,000 people, 125 were killed, 1,121 were injured, and more than 4,000 were left homeless. In addition, 507 houses were destroyed, along with 44 mobile homes and 30 business premises.

Buffalo Creek encompasses three separate branches. As early as 1957, the Buffalo Mining Company began dumping tailings from its strip-mining operations into the creek's Middle Fork. Between 1960 and 1972, the company erected three dams to impound the polluted water, which transformed Buffalo Creek's Middle Fork into a series of black cesspools. Minor dam breaks occurred in 1967 and 1971, but little actual flooding took place in either incident. Although the state cited Pittston Coal for safety violations, it did not conduct follow-up inspections.

Just prior to 8 AM on February 26, 1972, heavy-equipment operator Denny Gibson discovered that the water had risen to the crest of the impoundment. Minutes later, the dam collapsed. The water obliterated the other two impoundments, and approximately 132 million gallons of black, muddy water rushed through the narrow Buffalo Creek hollow. Mountaintop-removal mining is a departure from both underground and flat land surface mining. It dates from shortly after World War Two, and is employed in West Virginia as well as in some other locations where the territory is mountainous. It is a fairly destructive form of coal mining. The topography and ecosystems are fundamentally changed, and environmentalists constantly oppose it. As much as three million pounds of explosives are used daily in many locations to blast the top seven hundred feet off the tops of densely forested, steep-sided mountains in order to reach the coal seam deep below the surface.

All the rock, soil, trees, and vegetation above the coal seam are removed and dumped in adjacent hollows such as mountain streams. Once a mountainside area has had its coal removed, the company is required by law to restore the land surface to some type of green pasture. Quick-growing, non-native grasses, planted to quickly provide vegetation on a site, are often the only type of restoration used. Even when some trees are planted, the young seedlings, as is regularly pointed out by environmentalists, will not serve as carbon sinks to slow down global warming for many years, as the trees that were removed did. Furthermore, these seedlings always have difficulty establishing root systems in the kind of surface left by the mining companies. The

U.S. Environmental Protection Agency (EPA) pointed out that between 1985 and 2001, 724 miles of Appalachian streams were destroyed by mine waste.

Furthermore, as was pointed out by EPA, blasting at a mountaintop-removal mine expels coal dust and tiny fragments of rock into the air, and these materials can then disturb, or settle on, nearby private property. This dust contains sulfur compounds, which corrode structures and are a health hazard. Many of the Buffalo Creek survivors left the area permanently, but the majority, because of local ties and the opportunities for work, stayed on. They were able to build new homes with the modest amount of financial aid given by the coal company. Many victims, feeling that the aid they had been offered was too small, decided to launch a legal challenge in federal court. They secured the services of a major law firm in Washington, D.C. In the course of the legal proceedings, previous lethal accidents at the Pittston Coal Company were discovered, and this greatly strengthened the claims from the people at Buffalo Creek. As a result, each of the six hundred claimants received $13,000, a sum far in excess of the amount that had been offered by the mining company and already accepted by some.

NEW ENGLAND HURRICANE AND STORM SURGE OF 1938

On the afternoon of Wednesday, September 21, 1938, a hurricane slammed into Long Island at 150 miles an hour, bringing in its wake a storm surge of more than 30 feet. On Long Island's southern beach, as residents tried to cope with the storm by putting up shutters and fastening windows, they suddenly found their homes swamped by 30 feet of water. Some homes just exploded. In Rhode Island, the city of Providence, unprotected from the wind because of its location east of Long Island, fared worse than most places. It is located 30 miles from the ocean at the head of a funnel-shaped sea inlet. The storm surge, trapped by the narrowing passage, rose far beyond the 30 feet that was experienced elsewhere and destroyed everything in it path. About half of the six hundred deaths from the storm happened in Rhode Island. There would not be a deadlier U.S. natural disaster until the arrival of Hurricane Katrina in 2005.

The hurricane was born in the Caribbean as a tropical storm four days earlier. It traveled westward, and forecasters warned Floridians to expect its arrival three days later. On its way through warm waters it gathered strength, arriving off the southeast coast of Florida on the morning of September 20 as a category 5 hurricane, the strongest possible. It stretched across five hundred miles of ocean, and its 150-mph winds had already torn up coconut palms in the Bahamas. As it neared the coast of Florida, weather forecasters observed the telltale signs of the storm curving northward, the path taken by so many storms before, and they gave a sigh of relief. Predictions now indicated that there would be no landfall either in Florida or anywhere else along the coast before the storm veered out to sea and faded away in the colder water of the northern Atlantic. In 1938, all weather decisions affecting Florida were made in Jacksonville, and, on this occasion, forecasters at the weather bureau there decided that this storm would behave like most of its predecessors that took similar paths. Little attention was paid to weather conditions farther north along the coast, a risky omission, because this hurricane was a category 5, the most powerful type.

Weather forecasting skills in the United States were far below those of Europe at this time, particularly those of Norwegians, who had developed a system of air mass analysis for predicting weather conditions. In the United States, predictions were based on measurements on the ground at each place, including temperature, wind speed, air pressure, and so on. Norwegian scholars had discovered that the atmosphere is not a single undifferentiated mass of air, but rather consists of different masses of air, each defined by specific humidity and temperature levels, some extending as far as six hundred miles from side to side. It's the interactions between these different air masses that create all of our weather patterns. Any hurricane approaching a high-pressure air mass will move away from it, because hurricanes are low-pressure zones. Low-pressure air masses will attract hurricanes. Had U.S. weather forecasters taken account of these things, the devastation could have been avoided, as can be seen today by examining the environment of September 21, 1938, in and around New York.

There were thunderstorms over New York and muggy conditions over Long Island. Heavy rain had been falling in Connecticut and Massachusetts, and there was a risk of flooding there. A low-pressure system covered the area from New England to the Carolinas. A warning had been received from a ship off the coast of Florida that air pressure within the hurricane was lower than had ever previously been known in the Atlantic at that time of year. One additional anomaly was the surprising location of the Bermuda high air mass. It had migrated to a position 10° latitude father north than its usual position. The combination of the Bermuda high air mass preventing the hurricane from moving out into the Atlantic and the attractiveness of the low that had covered the New England area for days alerted one young forecaster to issue a warning, but he was overruled by a senior staff member who insisted that hurricanes rarely reach New England and that there was only a 1-percent chance of one coming at that time. It is true that the last time a hurricane hit this area was in 1815, but the United States has sometimes seen places with a 1-percent chance of being hit by a hurricane be hit twice within one month of the same year.

The observations of the young staff member at the Washington, D.C., branch of the Weather Bureau, the agency that took over from the branch at Jacksonville as the storm moved north, were the ones that should have been heeded. The general conditions all along the coast were very different from the usual pattern. The low-pressure area extended all the way from east of the Great Lakes southward as far as

Cape Hatteras, and it was stationary in that extended location on September 20 as the hurricane began to move northward from the coast of Florida. The winds circulating in this area of low pressure were strong because of the extent of the low pressure, and they were warm as they swept air along with the hurricane from within the warm Gulf Stream. By midnight on September 20, two developments had occurred, both of which were probably not observed by the Weather Office in Washington, D.C. Had they been aware of them, warnings would have been issued long before the late morning of September 21. The two developments that accelerated the hurricane to a speed of 60 mph and also pulled it toward the northern coast were the attraction of the big low-pressure area and the "extra push" from the warm air that circulated northward around this low-pressure area.

At 2:30 PM on September 21, the hurricane made landfall on Long Island. It had traveled from the Carolinas at 60 miles an hour, and, unknown to the forecasters, the positions of the main air masses ensured that it would travel northward in a straight line and be drawn onto shore by the low-pressure air mass that lay over all of New England. Within a short time of its arrival, community after community across Long Island, Connecticut, and Rhode Island were knocked out. All power was lost, and there was no way by which any one location could share its experiences with another. Conditions were made worse by a general indifference to any possibility of a hurricane reaching this part of the country. They had heard of the hurricane throughout the previous day, and assumed that what the forecasters had predicted was going to happen. Even when a radio

View of Island Park, Rhode Island, destroyed by a storm surge of more than 30 feet during the New England Hurricane of 1938. (NOAA) warning of an approaching hurricane suddenly came with the afternoon weather forecast of September 21, people ignored it till tragedy struck. In some places winds reached more than 180 mph, and in others more than 230 mph.

The city of Providence was hardest hit because its physical location raised storm water levels very high, and also because it was more exposed to open sea. Cape Cod also experienced extensive damage and a number of deaths because of its exposure to open sea, but other areas of both Massachusetts and Connecticut had some protection from storms because of the shelter provided by Long Island. Nevertheless, a shoreline city like New London, Connecticut, was no match for the fury of the hurricane. Winds and floods combined to leave it in ruins. In and around Jamestown and Newport in Rhode Island, marinas, beach pavilions, and buildings of all kinds were demolished. Farther north in Providence, yet another unusual feature of this city was the source of trouble: its arcade, an old indoor shopping mall that became a wind tunnel for the hurricane. Many people were seriously hurt by flying pieces of glass.

In summary, thousands of boats, cars, and buildings were destroyed in the short three-hour rampage of the storm, and virtually all telephone lines were knocked out of service. Some creative individuals were able to make use of the cables linking New York and Boston with the cities of Europe, so these two U.S. cities were able to send messages to each other. Recovery of something approaching pre-storm conditions was long and difficult. Not only were thousands of homes washed away or damaged beyond repair, but entire shorelines and other land areas had been washed away, making rebuilding impossible and property titles meaningless. In one or two locations in Rhode Island, there was one redeeming feature: a barrier beach had been opened up in several places, a change that local people had long hoped for because it would ease access for small craft. The final assessment of damage included 680 deaths, 2,000 injured, 4,500 homes destroyed, an additional 15,000 damaged, and 60,000 people left homeless. Total value of damage was estimated at $400 million in 1938 currency.

A HAILSTORM IN TEXAS

Fort Worth, Texas, experienced a hailstorm on May 6, 1995. Hail as big as softballs hit the city, accompanied by high winds and flash flooding. A number of people were killed, and a larger number of others were injured. The source of this event was a super-cell, which is a powerful thunderstorm of the kind that usually is associated with tornadoes. On this occasion, there was an updraft of moisture and heat that rose into the atmosphere at quite a high speed and returned in the downdraft at a similar rate. It was the third major hailstorm that Fort Worth had experienced in 1995, and it cost the insurance industry a billion dollars. Earlier hailstorms brought hail that measured three inches and four inches in diameter.

As the hail began to fall at 80 mph, approximately ten thousand people were in an open area of the city enjoying the May Fest activities. Their encounter with the hail left three-inch welts in the skin before most escaped by getting into their cars. However, this was no escape. The hail shattered the windows and showered them with both glass and hail. Those without cars just tried to cover their heads. Damage to buildings was extensive in both the downtown and outlying areas: homes, offices, vehicles, and communications suffered. About 55,000 homes were without power for a day. Strong winds ripped roofs off some buildings and completely destroyed others. Numerous trees were uprooted.

In the wake of the hail, there was heavy flooding and a dense fog. By the time the rain ended, the streets of Fort Worth were waist-deep in water. Twelve people lost their lives from flash flooding and one from lightning. Five drowned when rain runoff swept their vehicle into a creek, two were killed when the weight of the rain collapsed a roof at a clothing plant, and three drowned when they were caught in a powerful current of water and were sucked down into a storm drain that had lost its manhole cover.

MICROBURSTS

Updrafts and downdrafts are some of the main causes of in-flight turbulence in planes, and are one reason for airlines trying to avoid regions of bad weather. Extreme cases, known as downbursts and microbursts, are responsible for many airplane crashes. The crash of Delta Air Lines Flight 191 on its final approach before landing in 1985 was presumably caused by a microburst. This incident prompted the Federal Aviation Administration to research and deploy new storm-detection radar stations at some of the major airports. Downbursts can cause extensive localized damage, similar to that caused by tornadoes, except that the resulting destruction is circular, radiating away from the center. Tornadoes, as we will see in Volume Three of this set, radiate inward toward the center.

A microburst is a special aspect of a downburst, a phenomenon that until recently was not fully understood. Tetsuya Fujita, the Japanese American tornado expert, showed how a microburst could destroy a low-flying airplane. Fujita defined it as an extreme form of wind shear because it can affect much larger areas. It consists of a fast-moving segment of a downburst, in speed and power similar to a tornado, but different in its behavior in that it produces diverging as well as straight-line winds very close to the ground. Fujita coined the term microburst for this aspect of downburst behavior. He helped authorities identify the cause of the 1985 Delta Air Lines crash.

Microbursts are now recognized as capable of generating wind speeds higher than 168 mph. In a $2 million research project at Denver's Stapleton International Airport, a dense network of ground stations linked to six specially equipped aircraft is being used by scientists to measure wind behavior close to the ground in order to get a better understanding of microbursts and thus avoid accidents like the 1985 one. Having detected and recognized many wind patterns that fit Fujita's definition of a microburst, the scientists at Stapleton have extended their research into the atmospheric conditions that were precursors of the winds they had already identified as microbursts. In every instance, the precursors related to thunderstorms, so the extended research included installing instruments in aircraft that would measure, over time, the whole thunderstorm environment.

As a result of their work at Stapleton, scientists investigated aircraft disasters from earlier times for which there was no satisfactory explanation. The July 9, 1982, disaster at New Orleans was studied, and it proved to have been caused by a microburst combined with a wind shear. All 146 people on board and at least eight on the ground lost their lives. Pan Am Flight 759, a Boeing 727-235, was a regularly scheduled passenger flight from Miami to Las Vegas, with an en-route stop at New Orleans. On July 9, 1982, just after 4 PM, this flight began its takeoff from runway 10 at the New Orleans International Airport, now known as Louis Armstrong International. At the time of takeoff, there were thunderstorms over the east end of the airport, and the winds were strong.

Flight 759 lifted off the runway, climbed to an altitude of about 120 feet, and then began to come back down. At half a mile beyond the end of the runway and at an elevation of 50 feet, it struck a line of trees, then continued to descend until it crashed into a residential area

Wreckage of Pan Am Flight 727, New Orleans, 1972. (Bettmann/Corbis) beyond the trees, exploded on impact, and caught fire. The conclusion of the National Transportation Safety Board was that the disaster was caused by a microburst-induced wind shear during the liftoff, a set of conditions that the pilot could not have anticipated and would have been unable to recognize. A microburst, as defined with new precision by the National Center for Atmospheric Research, is a localized downdraft of great intensity. It may be only a few hundred yards wide and last only a few minutes, and thus it can be missed by weather detection systems.

At least four wind shear alerts were broadcast by the control tower at New Orleans International Airport before the crash there. While preparing for takeoff, the crew apparently debated whether to wait. About 60 airports, including New Orleans, have warning systems based on five or six wind-recording devices placed at the runway approaches. Under normal conditions all the devices show similar readings, but if one indicates a sudden, local change of 15 mph or more in wind, an alarm sounds. Specialists say, however, that because there are so many false alarms, flight crews often disregard the warnings. In addition, the system can only detect wind conditions at ground level. Both with regard to this New Orleans tragedy and many other earlier ones, Tetsuya Fujita has been the pioneer in understanding microbursts and in proposing ways of avoiding their destructive potential.

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CHAPTER 5

Nor'easters

Nor'easters are winter storms that reach the northeastern United States between October and April when moisture and cold air are plentiful. They are known for dumping heavy amounts of rain and snow, producing hurricanes, and creating high ocean waves that cause beach erosion and coastal flooding. A nor'easter is so named because its winds usually blow in from the northeast and over the warm waters of the Gulf Stream, often meeting up with storms that move up the coast from warmer tropical water. The strongest storms occur when a low-pressure system moving up the coast, guided by the jet stream, collides with an Arctic high-pressure system moving south off the coast of New England. The difference between a nor'easter and a hurricane is that a hurricane forms in the tropics and has a warm core. A nor'easter forms in the middle latitudes and has a cold core. Its strongest winds are not near the surface and not near the core of the storm. The storms described in this chapter illustrate the many variations that exist within the general category of nor'easter.

These storms often stretch across an area of a thousand miles, and they move slowly. America first discovered their power and pain at Christmastime in 1776, when George Washington, against the advice of other leaders and in the face of an unusually strong nor'easter, decided to cross the Delaware by night in order to reach and take by surprise the English garrison at Trenton. It was a time of low morale among the revolutionary soldiers. There had been too many setbacks, and survival depended on gaining a success that would revive the hopes of all. George Washington saw his opportunity and seized it, refusing to be discouraged by the extremely bad weather and the state of exhaustion among many of his small army. On Christmas night 1776, as a howling blizzard struck the Delaware Valley, he led his men across the river and attacked the garrison at Trenton, killing or capturing nearly a thousand men. They were taken by surprise because they had been convinced that weather conditions would prevent anyone from trying to cross the river.

In modern times, meteorologists examined records from that historic event in order to reconstruct what they suspected must have been a severe nor'easter. This was their summary of what happened: a nor'easter came sweeping into the Delaware Valley from the northeast and struck with great violence as the revolutionary soldiers were preparing to cross the river. It was a combination of snow, hail, and rain. Ice was widespread on the river, and this was an important detail of history because the Delaware has rarely been frozen over the past century. The year 1776 was still within the very cold period described in Volume One, the Little Ice Age. Nor'easters are still serious storms, but not as serious as they were in the 1700s. The best way to understand their forms since 1776 is to follow the accounts of the particular events described in this chapter.

THE BLIZZARD OF 1888

The worst blizzard in history to hit the eastern United States occurred in March 1888. This storm caused destruction from Maine to New Jersey, with some areas receiving 50 inches of snow. The greatest snow accumulation was in central New England, and the greatest dislocation of life was borne by New York City. About four hundred people tragically lost their lives. The storm quickly became known as The Blizzard of 1888 or The Great White Hurricane. Sustained winds of over 45 miles per hour produced snow drifts in excess of 50 feet. Railroads were shut down, and people were confined to their homes for a week. Some tried to go to work for fear of losing their jobs, and, in New York City, 30 of them froze to death on their way home after

Blizzard of 1888, New York City. (Library of Congress) they found there was no electricity. All telegraph connections from Washington to Maine were cut off for several days. People in rural areas had to stay in their homes for two weeks.

New York City was shut down by the blizzard. Telegraph lines collapsed due to the weight of ice. Communication was knocked out internally, as well as the long distance lines from Boston to Philadelphia. Food and fuel were scarce. There was little refrigeration in 1888, so fresh food was brought into the city every day. Transportation of needed food supplies was impossible for several days. People wandered the streets searching for shops that might still have coal so they could heat their homes. About 35 inches of snow fell throughout New York City. Seven-foot drifts were common, and in many locations there were drifts of 30 feet or more that completely covered homes. In a few places, three-story buildings disappeared under snow. New York's Central Park Observatory reported a minimum temperature of 6°F and a maximum of 9°F on March 13.

The weather preceding the blizzard was unseasonably mild, with heavy rains that turned to snow as temperatures rapidly dropped. The storm began in earnest shortly after midnight on March 12, and continued unabated for a day and a half. Weather forecasting was not very accurate in 1888, so there was no warning of the blizzard. People went about their daily activities and were caught by surprise. Rain quickly turned to sleet and then to heavy snow. Trains loaded with passengers were stranded on the tracks. It took a week to clear away the snow drift that had stopped the New York, New Haven and Hartford Railroad. From Chesapeake Bay through the New England area two hundred ships were either grounded or wrecked, resulting in the deaths of at least one hundred seamen. Power lines were downed due to heavy snow and strong winds, and all communications between major cities was cut off. Many residents who were unable to receive delivery of coal or wood were forced to burn their furniture to stay warm.

Railway and road travel was at a standstill because the routes were impassable. Fire trucks were unable to respond to emergencies, so there were many fires that burned out of control. The elevated railroad in New York City was barely moving. The rails were slippery, and it was difficult for the trains to stop at stations or climb steep grades. Visibility was poor, and rail cars had to be dug out of the drifts in the overnight storage area. Property loss from fire alone was estimated at $25 million. Severe flooding occurred after the storm due to melting snow, especially in Brooklyn, where serious flooding had occurred because of its low elevation. Efforts were made to try pushing the snow into the ocean. No one knew at the time if massive snowfalls were about to be regular visitors in coming years, so thought was given, immediately after the blizzard, to ways and means of safeguarding essential communications systems in any future blizzard.

In the years that followed, telegraph and telephone lines were buried underground and the first steps were taken to construct the now-famous Boston and New York subway transportation systems.

Other systems soon followed. They included electrical power cables and fire alarms. Marietta Moskin wrote a fictional children's book, *The Day of the Blizzard*, based on all that had happened, and this book became a popular reader for schools.

NORTHEAST HURRICANE OF 1944

The Northeast Hurricane of 1944 devastated the U.S. east coast all the way from North Carolina to Cape Cod. It was popularly named the Great Atlantic Hurricane because of the extent of its deadly and costly damage along the coast. It caused 390 deaths as it traveled up the east coast, sweeping the beaches, sinking ships, and throwing wave watchers into the sea. The entire coastline was raked with hurricane-force winds. Damages from the storm amounted to $100 million plus the losses of ships. All of this happened during World War Two, so there were many naval vessels involved. This large and powerful hurricane was first detected northeast of the Leeward Islands on September 9. It moved west-northwest through September 12, then turned northward on a track that brought it near Cape Hatteras, North Carolina, two days later.

At that time it was a category 3 storm that extended over an area of six hundred miles. It made an initial landfall at Cape Hatteras, but quickly moved offshore toward the northeast. At that stage it was moving at 16 mph, but as it moved northward it accelerated to 40 mph. This is not a common pattern. Storms that move into higher latitudes and, therefore, colder waters, tend to slow down both in internal wind speed and in rate of movement. However, this storm had many of the features of the very destructive 1938 one that caused so much damage in the New England area. Two warm air masses, one from the Gulf and one from the Bahamas, were moving north as the Great Atlantic Hurricane left Cape Hatteras. At the same time, the Bermuda high air mass had greatly strengthened, and another high over the Appalachians began to weaken. The warm waters raised the intensity and forward speed of the hurricane, and the Bermuda high made sure that it stayed close to the coastal areas.

Along the Virginia coast, the storm measured sustained winds of 134 mph and gusts of 150 mph. Covering a huge expanse of ocean, hurricane-force winds from the storm were reported elsewhere along the track from North Carolina to Massachusetts with a maximum reported gust of 109 mph at Hartford, Connecticut. Rainfall totals of 6 to 11 inches accompanied the storm for most of its time along the U.S. east coast. There were 344 deaths of naval personnel when five ships were sunk. They included a destroyer, a minesweeper, two Coast Guard cutters, and a light vessel. This storm went virtually undetected until September 9, 1944, despite the introduction of air reconnaissance in 1943. This happened even though it was of hurricane strength when first detected several hundred miles northeast of the Windward Islands. One of the very important differences from the hurricane of 1938 is that there was plenty of advance warning.

This was due to the better understanding in 1944 compared with 1938 of air masses and their role in transforming and guiding hurricanes. Thus, weather stations were able to predict their paths once they knew the conditions in the prevailing lows and highs. Hurricanes, because they are centers of low pressure, are attracted to lows, and they move away from highs. The media were kept informed, and the civil defense officials always knew of the storm's current position. As the hurricane moved northward, its intensity and destructive power were reported along the way. Tremendous damage occurred all along the coast from North Carolina to New England, including major damage to 41,000 buildings. In Maine, 40 percent of the total apple crop in one county was destroyed. Elsewhere in the same state, trees were uprooted, limbs torn down, and electric and telephone service cut off. The storm, by September 15, had accelerated across eastern New England and into Canada. It became extratropical over Canada, and finally merged with a larger low near Greenland on September 16.

ASH WEDNESDAY STORM OF 1962

This storm began on March 6, 1962, along the mid-Atlantic coast, in an area accustomed to hurricanes as well as the periodic nor'easters, but the Ash Wednesday Storm of 1962 was unlike anything anyone could recall. The U.S. Geological Survey considered it to be the most destructive storm ever to hit the mid-Atlantic states and placed it on the list of the ten worst storms in the United States for all of the twentieth century. It stayed where it had originated for three days, killing 40 people, injuring more than a thousand, and causing hundreds of millions of dollars of property damage over a wide area. The combination of heavy rain, high winds, and exceptionally high tides helped to make it particularly devastating.

Homes, hotels, motels, and resort businesses were destroyed along North Carolina's Outer Banks from Cape Hatteras northward as far as Virginia Beach, at which terminus the waves had broken the concrete boardwalk and sea wall. Further inland, Norfolk and Hampton Roads were overwhelmed with high water. Construction work underway on the new Chesapeake Bay Bridge was dealt a severe blow, and a major piece of custom-built construction equipment was destroyed. At the Town of Chincoteague on Virginia's eastern shore near the border with Maryland, six feet of water covered parts of Main Street, and most of the island was flooded to various depths. On adjacent Assateague Island, the Chincoteague Fire Company lost a portion of its herd of wild Chincoteague Ponies.

Further north, 60-mph winds and 25-foot waves struck Ocean City, Maryland, and 40-foot waves swept over Rehoboth Beach, Delaware, destroying the boardwalk and beachfront homes. Sand dunes were flattened along the entire length of Delaware's ocean coastline. In New Jersey, the storm ripped away part of the Steel Pier in Atlantic

City. Long Beach Island was cut through in several places. In New Jersey alone, an estimated 45,000 homes were destroyed or greatly damaged, and, in New York, on Long Island, one hundred homes were destroyed. In summary, the coastal areas from North Carolina to New York were battered and changed forever by the wind, waves, and record high tides.

The U.S. Weather Bureau took the unusual step of giving this storm a name: the Great Atlantic Storm. Perhaps a fitting memorial to what was lost in the storm was the naming, in 1965, of Assateague Island as a National Seashore, a unit of the National Park Service. In the 1950s, some five thousand private lots comprising what is now National Park Service land were zoned and sold for resort development. The Ash Wednesday Storm halted these plans for development because it destroyed the few existing structures on the island and ripped the roads apart.

THE GROUNDHOG DAY GALE OF 1976

This was a severe winter storm that hit the northeastern United States and southeastern Canada on February 2, 1976, the day widely recognized as Groundhog Day, the occasion that celebrates non-scientific predictions about weather. A storm was stationary on January 28 across the U.S. Southwest, and another storm from Canada's midwest was moving toward the southeast. They merged on February 2 over New England, then moved northward through southern Canada into Davis Strait. With sustained winds of 102 mph and gusts of 116 mph, the coastal areas of New England experienced severe damage before the storm swept across eastern Canada, hitting and severely damaging the province of New Brunswick as it moved northward. Maine recorded its lowest pressure on record, with a reading of 28.26 inches, accompanied by blizzard conditions for several hours. Boston had a comparably low record, its second-lowest ever at 28.48 inches.

It was a true nor'easter, causing extensive damage in many areas. In Bangor, Maine, there was a 12-foot storm surge that blew down many trees. Many more were destroyed by the quantities of seawater that were blown inland. Fishing vessels had trouble all the way from Boston to Portland, with many of them breaking loose and drifting out to sea. There were no reports of deaths as a result of the storm surge, but about two hundred cars were submerged, and office workers were stranded as the tidal surge reached Portland, Maine. Damages added up to $2 million. On the Canadian side, where most of the destruction took place, there was one fatality from the storm, a 30-year-old man who lost his life when his fishing shack was blown across the ice on the Kennebecasis River in the province of New Brunswick. The city of Saint John on the coast of that same province in the Bay of Fundy was flooded by a six-foot storm surge. Wharves, buildings, and boats of all kind were destroyed, and lines of communication were cut off.

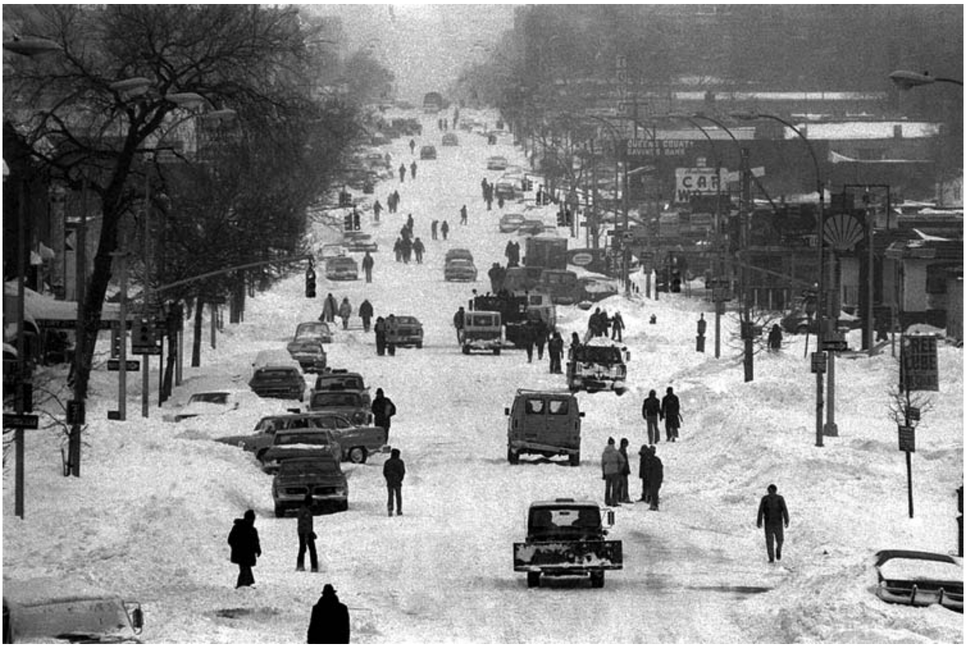
Swells of 40 feet were reported offshore from the provinces of New Brunswick and Nova Scotia. New Brunswick's lighthouse at Fish Fluke Point was destroyed and subsequently abandoned. The overall damage to this part of Canada amounted to $5 million, and the storm's aftermath was worsened by a severe cold snap that followed. The residents of Saint John remember the gale as if it were yesterday. Almost everyone old and young can recall exactly where he or she was when the storm hit. Nobody saw it coming, but it brought hurricane-force winds that hammered the city and knocked out power. Some parts of the city were in the dark for seven days. A picture published in the newspaper the next day shows telephone poles blown nearly horizontal, hanging from their sagging wires. Salt spray from the Bay of Fundy was identified on homes that were more than six miles inland.

Tourists were warned by local authorities in Saint John, describing the storm and its aftermath in words like the following: with the high wind, power poles snapped like matchsticks and roofs were torn off. In a new high-rise building that was being constructed on King Street, sheets of plywood used to cover the window spaces were ripped off. They flew through the air and slammed into cars and buildings causing considerable damage. The wind pushed saltwater from both the harbor and Courtenay Bay all over low-lying areas throughout the city. Both the Courtenay Bay Causeway and the Marsh Creek Bridge were in danger of being washed away from the pounding of the waves. A large barge in Courtenay Bay broke from its moorings and was driven against the bank of the causeway. The Saint John Expressway, still under construction, was opened for traffic as it was the only available exit from the city on its eastern side.

NEW ENGLAND BLIZZARD OF 1978

In February 1978, a disastrous snowstorm swept over New England, leaving people with no power, no transportation, and no heat for homes. There was an early accumulation of three feet of snow, so, when people had to get out of their homes, the only exits were through windows. The blizzard lasted for 24 hours and was sustained by high winds throughout that time. The storm originated in a low-pressure center that had stalled off the southern New England coast, causing substantial damage to properties near the water. Even as winds began to abate and the snow stopped, most of New England remained paralyzed for a week.

People were trapped in all kinds of situations: some were unable to leave their place of employment, some were stuck inside their cars because they were trying to get home, and many were stuck in their homes. There was no mail delivered, or even sorted, and no schools or colleges opened for more than a week. Later analysis showed that there had been a buildup of an enormous pressure area before the storm. It stretched from the upper Midwest to New England, and it brought temperatures all across the southern areas of New England to freezing



The New England blizzard of 1978 paralyzed all aspects of life throughout the city of New York. (Bettmann/Corbis)

levels. At the same time, a small storm had moved southeastward toward Pennsylvania, bringing colder air from central Canada.

One of the major problems with the blizzard of 1978 was the lack of knowledge about the storm's severity. Weather forecasting in New England was difficult, and meteorologists had developed a reputation for being inaccurate. Forecasting techniques and technology had improved dramatically in the 1970s, but the public was still quite skeptical. Snow failed to arrive in the predawn hours as predicted, and many locals suspected that it was another failed forecast, so they went to work and school as normal. Because of this, people did not have enough time or will to prepare properly for the blizzard. The state of Massachusetts had a system in place for notifying major employers to send employees home early in the event of heavy storms. Thousands of employees were sent home starting in the early afternoon, but thousands more were still caught by the storm. Some did not make it home for several days.

Snow is no stranger to the residents of New England. From the northernmost areas at the Canadian border to the west of New Jersey snow arrives in quantity every winter. It's hard to know how big a snowstorm is going to be at any given time. The whole area is jammed in between three unpredictable air masses: cold Arctic, warm tropical, and offshore Atlantic. All that is needed for a disaster to happen is for a close-in, offshore, moisture-laden air mass to stall. Under these circumstances, the boundary between the two other air masses becomes a heavy snow front, and it continues to flood the area as long as the offshore air keeps pumping moisture over the land. It's rare for this eventuality to occur, but, when it does, everyone is caught off guard. The last one and its aftermath have usually been forgotten, and chaos accompanies the new one. This was what happened in the winter of 1978. New York and its surrounding area had been hit with what the National Weather Service called perhaps the worst winter storm ever to hit this part of the nation. For 32 hours, the snow continued to fall, blanketing every location with snow drifts under the pressure of 80-mph winds, some high enough to rise above the heights of the houses. Many individuals were seen trying to exit their homes through windows. All snow records were broken. Thousands of students and office workers, unable to reach home even though released from work and school in the early afternoon, had to be accommodated in emergency shelters. Within a short period of time, basic services of electricity, food deliveries, and water all failed, and they remained unavailable for a week in most places. More than 50 lives were lost, and more than two thousand homes were either destroyed or seriously damaged. Troops were flown into Boston to assist the U.S. National Guard both to maintain order and to help clear the streets.

The governors of Connecticut and Massachusetts ordered the closure of all roads coming into or leaving their states, and they held this condition for three days. Clearing the streets was not an easy task, because many cars were left beneath snow drifts, and they had to be removed before the snow could be tackled. In Boston, some clearing was achieved by dumping snow dumping in the harbor. The coastal areas, under constant pressure for more than a day with 80-mph winds, high waves, and heavy rain, were severely damaged. Shores were eroded, and many coastal installations from Boston to northern Virginia were destroyed. Throughout the region, innovation was the order of the day: sleds, riding on the snow, were seen in use for purposes from getting an elderly person to a hospital to ferrying groceries to those in need.

This blizzard of February 1978 caused $500 million in damage in the state of Massachusetts, mainly as a result of losses among coastal properties. This damage was caused by both the severity of the storm and the accompanying storm surge. In addition, there was a very high tide. The tide could have been anticipated, but the many variables causing the snowstorm would only have been known two or three days in advance. There is never enough time in such circumstances to make arrangements for coping with days of heavy snow. The blizzard of 1978 will never be forgotten. Many still call it the worst that New England has ever experienced.

THE HALLOWEEN PERFECT STORM OF 1991

The 1991 Halloween nor'easter is the event that gave rise to the name "The Perfect Storm," as it was called by one of the meteorologists from the National Weather Service. He gave it this name because of the

Coastal home in Scituate, Massachusetts, destroyed by a 1991 Nor'easter storm; the owner is recovering the remains of his home. (AP/Wide World Photos)

unusual coincidence of three weather-related events arriving at the same place at the same time: warm air from a low-pressure system coming from one direction; cool, dry, air from a high-pressure system coming from another direction; and tropical moisture arriving at the same time as the other two via Hurricane Grace. These coincidences gave rise, at a later date, to the use of the name for a book, *The Perfect Storm,* and still later to a movie with the same title. Other storms were more powerful than this one, but it was the convergence of the three events that made this a special type of nor'easter, one that would be remembered for these reasons as well as for its association with the book and movie that became linked to its title.

October and November of each year are times when weather conditions around the northeast United States are in transition. Air masses from Canada move south and southeast in these months, the Atlantic Ocean loses its warm water temperature very slowly, and this time of year includes the hurricane season. The temperature contrasts that ensue often result in two very dissimilar air masses appearing in massive storms just offshore of the northeast United States. These storms in the Atlantic states have, in the past, sunk many ocean vessels, and this storm was as likely as any one from the past to do the same. As we examine the meteorological history of this storm we need to keep in mind that nor'easters are not always caused by just two storms. Altogether, the northeast region of the United States can be the destination of weather events that converge here from four distant source regions.

These four distant regions include Canadian high-pressure systems that characteristically travel southeastward, tropical hurricanes or other low-pressure systems that are carried northward by the jet stream, Atlantic storms that are attracted by the Gulf Stream or pushed westward by the Bermuda high that often appears in early October, and, finally, the wave cyclones that move from west to east across the northern United States. The perfect storm began on October 28 as an extratropical, low-pressure storm on a northeastern cold front. It deepened at a rapid rate and became the main storm of the northwestern Atlantic. Hurricane Grace, which had formed from a pre-existing tropical storm on October 27 and was moving northwestward, was attracted to the low-pressure systems already in place. The resultant huge low-pressure system continued to deepen and generate 15-foot swells. By October 30, it reached the New England coast north and south of Boston, westward of which was a strong high-pressure system.

Because of the size of the low-pressure offshore system and the equally strong high-pressure system westward of it, the strength and the extent of the damage it caused were unusually large. As described by the NOAA:

> North Carolina's coast was lashed with occasional winds of 35 to 45 mph for five consecutive days. In New England on October 30–31, wind gusts of above hurricane force pounded the Massachusetts coastline. Representative peak gusts included: 78 mph at Chatham NWS, 74 mph at Thatcher Island, 68 mph at Marblehead, 64 mph at Blue Hill Observatory (all in Massachusetts) and 63 mph at Newport, RI. Even more damaging were the heavy surf and coastal flooding caused by the tremendous seas and high tides caused by the long overwater fetch length and duration of the storm. Waves 10 to 30 feet high were common from North Carolina to Nova Scotia. . . .
>
> A state by state damage summary reveals the widespread and extensive damage caused by the storm and accompanying seas. Beach erosion and coastal flooding was severe and widespread, even causing damage to lighthouses. Hundreds of homes and businesses were either knocked from their foundations or simply disappeared. Sea walls, boardwalks, bulkheads, and piers were reduced to rubble over a wide area. Numerous small boats were sunk at their berths and thousands of lobster traps were destroyed. Flooding was extensive invading homes and closing roads and airports. Former President Bush's home in Kennebunkport, ME suffered damage as windows were blown out, water flooded the building, and some structural damage also occurred. Even inland areas suffered major damage. The Hudson, Hackensack, and Passaic Rivers all experienced tidal flooding, and high winds brought down utility poles, lines, tree limbs, and signs in several states.
>
> The most extensive damage occurred in New England where federal disaster areas were declared for seven counties in Massachusetts, five in Maine, and one in New Hampshire. Off Staten

> Island, two men were drowned when their boat capsized. Other fatalities occurred when a man fishing from a bridge was either blown or swept off in New York and a fisherman was swept off the rocks at Narrangansett, RI by heavy surf. Offshore, six lives were lost when the Andrea Gail, a swordfishing boat, sank. Total damage in the Halloween Storm, as it came to be known because of its date, was in the hundreds of millions of dollars.

Forecasters had trouble predicting the Halloween storm's course. One unusual aspect of the system was its retrograde motion toward coastal New England rather than away from it. Meteorologists estimate that a storm like the Halloween storm has a statistical probability of occurring only once in a hundred years.

SUPERSTORM, MARCH 1993

This storm gets its name from the recognition given to it by NOAA, namely, it was called the strongest storm to hit the east coast in all of the twentieth century. It began as a low-pressure system that moved out of the Rockies to the Gulf, where it grew rapidly. It should have been followed more carefully, because most of its movements were predictable from its early days. A huge low- pressure area had moved southward as far as Cuba, bringing cold air much farther south than is ever normally experienced. It triggered tornadoes in both Cuba and Mexico. On its western side, it was responsible for snowfalls, even in Alabama, where it created a new record of more than a foot of snow. The storm, now much stronger, moved up the east coast, bringing snow to northern Florida and southern Georgia.

In its wake, cold air was moving south along with very strong winds. Snow began to pile up in the Appalachians. Asheville, North Carolina, recorded a 24-hour snow record of more than 16 inches. Higher elevations had much more: Mount Mitchell had 50 inches and Mount Le Conte 56 inches. The sharp differences in temperature, due to the path this storm had taken, were reflected in near-hurricane storms along the east coast and new levels of snow in many locations. Blizzard-like conditions shut down the bigger airports all the way from Atlanta to Boston. Highways and interstates were closed even in New England because of the heavy snow. Passenger trains stopped running from Washington to Florida and from Washington to Chicago. The inland track of the storm resulted in corresponding snowfalls in interior cities: Pittsburgh received 25 inches, Syracuse 43 inches, and Snowshoe, West Virginia, 44 inches. All in all, 270 people were killed in this storm, and 48 were missing at sea.

The weight of record snows collapsed many factory roofs in the South, and snow drifts on the windward sides of buildings caused a few decks with substandard anchors to fall from homes. Though the storm was forecast to strike the snow-prone Appalachian Mountains, hundreds of people were nonetheless rescued from the Appalachians, many caught completely off guard on the Appalachian Trail, or visiting cabins and lodges in remote locations. Drifts up to 14 feet were observed at Mount Mitchell. Snowfall totals of between two and three feet were widespread across northwestern North Carolina. Boone, North Carolina, in a high-elevation area accustomed to heavy snowfalls, was nonetheless caught off guard by 24 hours of below-zero temperatures along with storm winds that gusted as high as 110 miles per hour. Electricity was not restored to many isolated rural areas for a week or more, with power outages occurring all over the east. Nearly 60,000 lightning strikes were recorded as the storm swept over the country for a total of three days.

The 1993 storm marked a milestone in U.S. weather forecasting. By March 8 (and by some accounts even earlier), several operational numerical weather prediction models and medium-range forecasters at the U.S. National Weather Service recognized the threat of a significant snowstorm. After reviewing the data, the National Weather Service was convinced that a serious threat loomed. This marked the first time that National Weather Service meteorologists were able to accurately predict a system's severity five days in advance. Official blizzard warnings were issued two days before the storm arrived, as shorter-range models began to confirm the predictions. Forecasters were finally confident enough in the computer-forecast models to support decisions by several northeastern states to declare a state of emergency before the snow even started to fall.

In the South, temperatures in the days prior to the storm were typical for early March. Although large fluctuations in temperature are not unusual in that region, many residents doubted that freezing temperatures could return so rapidly, nor that snow was likely due to the rarity of significant snowfall later than February. Many local news stations were reluctant to even broadcast the forecast models, due to the extreme numbers being predicted by the computers, but the models turned out to be right. During Friday, March 12, temperatures over much of the eastern United States began to fall quickly. The area of low pressure rapidly intensified during the day on Friday and moved into northwest Florida by early Saturday morning. As this happened, snow began to spread over the eastern United States, and a large squall line moved from over the Gulf of Mexico into Florida and Cuba. The low tracked up the east coast during the day on Saturday and into Canada by early Monday morning.

Temperatures accompanying the storm were unseasonably cold for early spring: average daily maximum temperatures, in mid-March, are around 46°F in Boston, 51°F in Philadelphia, and 65°F in Atlanta. During the 1993 storm, these places were all near or below freezing, and parts of New England saw daily maximum temperatures as low as 14°F. Record low temperatures for March were recorded in much of the southern United States. Farther to the south, numerous supercells developed over the state of Florida, spawning 11 tornadoes and killing seven people. Cities that usually receive little snowfall, such as Chattanooga, Tennessee, received anywhere from two to four feet of snow, causing some municipalities to adopt at least an emergency winter-weather plan for the future where one might not have existed before.

Birmingham, Alabama, which normally receives one inch of snow in a year, received 17 inches, shattering the records for most snow in a single storm, a single month, and even a single season. The psychological impact in the southern states, where average high temperatures in March tend to run into the 60s, was magnified by the fact that the storm struck a week before spring. Two NASCAR weekends had to be canceled, one at Atlanta Motor Speedway, where the Motorcraft 500 Winston Cup round and the Slick 50 300 Busch Grand National Series event were postponed for eight months. At Martinsville Speedway, the Miller 500 Classic weekend for the Busch Grand National cars and Late Models was postponed for two months because of the aftereffects of the storm, namely, soggy grounds.

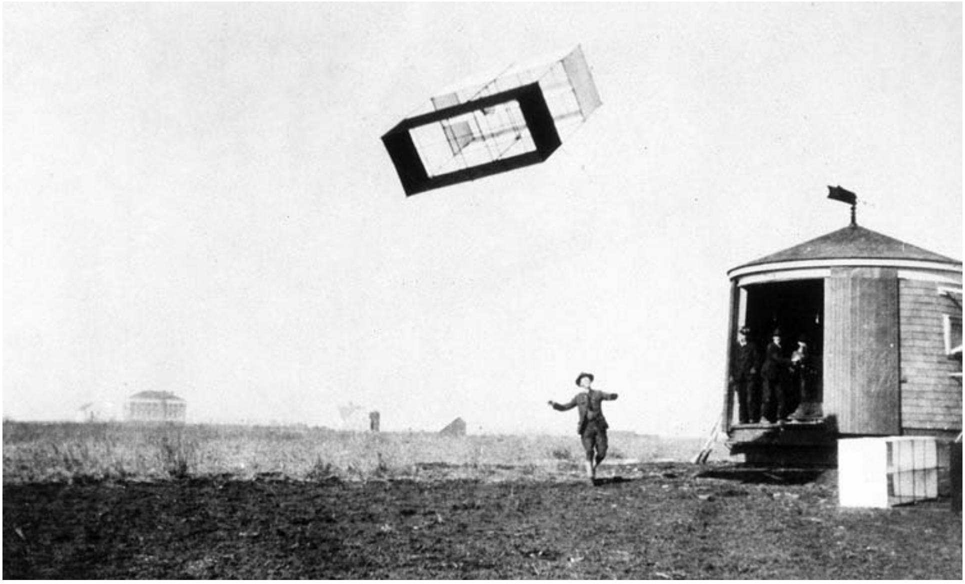
CHAPTER 6

Forecasting Weather, Traditional and Modern

In earlier times, and today in less developed areas of the world, people remembered things about weather for long periods of time because there were no instruments available to help them and no weather forecasts from government agencies. They had to depend on what they had observed for predicting the future. If their stories, which we call folklore, happened to be arranged in rhyming couplets, they were much easier to remember. Here is one that is often quoted in North America: "Red sky at night, sailor's delight. Red sky in the morning, sailor's warning." This one has been around for a long time and is based on some words of Jesus as recorded in the biblical passage from Matthew 16:1-3: "When evening comes, you say, it will be fair weather, for the sky is red, and in the morning, today it will be stormy for the sky is red." People looked to plants and to animal behavior to help them. They noticed that just before a rainfall, cows lie down and ants move to higher round. The couplet "Clear moon, frost soon" is easy to understand. If there is no cloud cover, the heat that the ground absorbed during the day will be radiated back into space at night, and frost will form.

The U.S. Weather Bureau, founded on February 9, 1870, through a joint congressional resolution, and signed into being by President Ulysses S. Grant, was the beginning of U.S. government action for weather forecasting. The mission of the Weather Bureau was to take meteorological observations at the military stations in the interior of the country and report on the approach and force of storms. This new agency was placed in the office of the Secretary of War in the belief that military discipline would probably secure the greatest promptness, regularity, and accuracy in the required observations. The new agency was called the Division of Telegrams and Reports for the Benefit of Commerce. Twenty years later, in 1890, it became a civilian enterprise, part of the Department of Agriculture. From 1891 to 1940, the Weather Bureau was part of the Department of Agriculture, and in 1940, President Franklin D. Roosevelt transferred it to the Department of Commerce, where it remains today.

The first wireless weather report was received from a ship at sea in 1905. Two years later, the daily exchange of weather observations with Russia and eastern Asia was inaugurated. In 1910, the Weather Bureau began issuing weekly outlooks to aid agricultural planning. In 1913, the first fire-weather forecast was issued. Throughout this whole period of



Early attempts, in 1900, by the U.S. Weather Bureau, at measuring upper air conditions by means of kites. (NOAA)

time, forecasting efforts at any given site depended solely on observations that could be made at that site. Observations of sky, wind, and temperature conditions, along with some knowledge of local climate history, permitted a limited amount of predictability. Synoptic weather charts appeared, the predecessors of those in use today. The physical bases of atmospheric motions were not yet understood, however, so prediction depended on various empirical rules. The most basic of these was that weather systems are always changing and that precipitation is associated with regions of low atmospheric pressure.

The years 1900 to 1920 saw a great deal of improvement and expansion in weather forecasting, culminating in the establishment of the American Association of Meteorologists in 1920. Throughout this period of time, a new and revolutionary approach to weather forecasting was emerging. Visitors from the Bergen School of Meteorology in Norway from time to time lectured in the United States, bringing new perspectives from work that had been going on there for a long time. Their views were not readily accepted because they represented a revolutionary approach to the science of forecasting, using the modern scientific methodology of theory and models, especially as they related to the activities within air masses high above the earth's surface.

For more than a hundred years, Norwegian meteorologists have been developing a more scientific approach to weather forecasting, in particular a focus on air mass behavior at their points of collision with each other. The Bergen School of Meteorology became the best-known center of these developments, and many of their scientists visited the United States, some staying for years and greatly influencing the thinking of U.S. scientists. Until the Bergen people applied modern scientific

Sverre Petterssen (1898–1974)

Weather forecasting in the United States was revolutionized in the 1920s by the work of a group of Norwegian scientists from the Bergen School of Meteorology. By far the most influential of the members of this school was Sverre Petterssen, if only for his contribution to the famous D-Day forecast see Chapter Six). He introduced to America the polar-front theory to account for the large-scale movement of air masses. His group provided a consistent and empirically based description of atmospheric circulation systems such as cyclones and anticyclones, and of the formation of precipitation. Petterssen came to the United States in 1935, lecturing on Norwegian meteorological theories to the U.S. Navy and at Caltech. In 1939 he was hired by MIT as head of the meteorology department and he wrote two important books there: *Weather Analysis and Forecasting* (1940) and *Introduction to Meteorology* (1941). When Germany invaded his home country, Norway, in 1941, he could not return there. He accepted a position with the British Meteorological Office and served there for the remainder of World War II.

thinking and measurement to atmospheric data, long-term forecasting was very difficult. Their work is often referred to as air mass frontal theory. It is based on a three-dimensional pattern of measurement and analysis. The founder of the Bergen School came to the United States in 1905, where his lectures at the Massachusetts Institute of Technology were enthusiastically welcomed. There is one very important member of the Bergen School, Sverre Petterssen. He will always be remembered in the United States because of the central role he played in what has been called "the most important weather forecast in history."

THE MOST IMPORTANT WEATHER FORECAST IN HISTORY

What has been called the most important weather forecast in history was the one that determined the date and time for the massive 1944 sea invasion of France by Allied forces in World War Two. A brief mention of it was made in Volume One of this set. It was called Operation Overlord, the invasion of Normandy, France, in June 1944, and it constituted the Western Allies' greatest operation of the war. Only the United States and the British could have successfully undertaken this largest and most dangerous amphibious assault in history. It was so complicated that General George C. Marshall described it as something that defies description. The Allies assembled hundreds of thousands of numerous nationalities, nearly five thousand ships, and 11,000 aircraft, without the Germans knowing where or when the invasion would take place.

The sea invasion had been planned down to the last detail, or rather down to the last detail but one, the weather. Britain's weather in the summer months is notoriously unreliable, yet everyone involved in the invasion knew that an accurate forecast was vital. The decision to go ahead would come down to the most important weather forecast ever made. London was at the heart of all the planning activities. The crucial weather advice, based on which General Eisenhower would decide when to invade occupied France, came from the main Allied forecasting centers, which were all close to London. The invasion would use Allied air, naval, and land forces. Because it would be a truly combined operation, the decision was made that the weather forecast for D-Day, the day to launch the sea invasion, would be a combined effort as well. The man given the job of getting consensus among the weather experts and presenting the forecast to the Allied commanders was meteorologist James Stagg.

He took note of the military needs and was told that, ideally, there should be two low tides during daylight hours, and the night before should be moonlit. Stagg was then informed that the generals wanted several days advance notice of weather conditions. His response, knowing the unpredictability of British summer weather, was that if several days of what was called quiet weather was needed, the invasion might not occur for another hundred years. To him, forecasting the weather more than 24 hours ahead in the 1940s was generally regarded as being impossible. He then added his own question: what are the least favorable weather conditions? The whole British team was convinced that it was not possible to make regular forecasts extending several days ahead. Sverre Petterssen, who was attached to the British team at that time, believed that some degree of extended forecasting was possible by using details of what was happening high up in the atmosphere.

The British weather had been particularly bad all through the previous month, and nothing in the critical days leading up to the invasion had been very much different, yet there were several quite specific requirements that General Eisenhower had laid down as fundamental to initial success. They included, first, visibility during the night before the invasion, at least moonlight, so that aircraft pilots could see enough of the surface to do their advance bombing. The second requirement was a high tide to enable the landing crafts to get as far onto the beach as possible; that automatically limited the whole venture to one day within a few days. To add to the challenge of weather forecasting, there was a big difference between the U.S. meteorologists and the British. The former used past history for forecasting; the latter used existing high-level air masses. Yet both teams had to agree on the weather forecast, or at least one team had to accept the recommendation of the other. This was for added certainty about the weather as well as for support of the principle of a joint operation.

Meanwhile, as the planned day for the invasion approached, the two teams of meteorologists were in disagreement about the forecast for that day. The American team, comparing present with past conditions, were overly optimistic about allowing the invasion to proceed on June 5, the day that Eisenhower had tentatively chosen some time earlier. The British Admiralty and the British meteorological teams, being significantly influenced by Sverre Petterssen, urged delay. Everyone knew that the lives of every soldier, sailor, and airman were at stake, yet the operation could not be postponed for much longer. Too many men were revved up to go. A serious postponement would do dreadful things to that most crucial of military variables, morale. Finally, there was an agreement among the meteorologists that there should be a delay of one more day. Then came a moment of inspiration: James Stagg, late in the evening of June 5, discerned a calmness in the middle of the weather system that was causing all the headaches, and he was able to predict a high-pressure ridge that would maintain calm weather for the morning of June 6. As everyone eagerly watched the evolution of the high-pressure ridge, confidence in Stagg's prediction mounted, and Eisenhower gave the order for the invasion to proceed on June 6.

As it turned out, the weather was perfect, and all the more perfect for having seemed to be so imperfect. If Eisenhower had waited for the next combination of moonlight and tide, a couple of weeks later, the invasion would have been a disaster, because the English Channel was hit from June13 onward by one of the worst summer storms in 20 years.

FORECASTING IN THE TWENTIETH CENTURY

The first Weather Bureau radiosonde was launched in Massachusetts in 1937. This mode of date collection went on to replace all routine aircraft observation within two years. The Weather Bureau was renamed the National Weather Service (NWS) in 1967, as part of the Environmental Science Services Administration, which became the National Oceanic and Atmospheric Administration (NOAA) three years later with the enactment of the National Environmental Policy Act. Upper air weather

An early launch of a radiosonde by the U.S. Bureau of Standards. (NOAA) data is essential for weather forecasting and research. The NWS operates 92 radiosonde locations in North America and ten sites in the Caribbean. A small, expendable instrument package is suspended below a six-foot-wide balloon filled with hydrogen or helium that is released daily. Sensors on the radiosonde measure profiles of pressure, temperature, and relative humidity. These sensors are linked to a battery-powered radio transmitter that sends the measurements to a ground receiver.

At the time of the Galveston hurricane of 1900, forecasters relied on ship reports, tidal measurements, barometric readings, and the color of the sky as warnings of impending tropical storms. It was known that a hurricane was nearby in the Gulf of Mexico, but forecasters lacked the ability to track storms. Hurricane Camille in 1969 was the first major hurricane whose approach was followed closely by geostationary satellite images. Hurricane Andrew (1992) provided one of the most accurate hurricane forecasts up to that time, thanks to computer models that predicted the initial landfall south of Miami, and the subsequent landfall near New Orleans, three days in advance.

CREATING A WEATHER FORECAST TODAY

The announcer on Canada's TV Weather Channel often introduces the program in words similar to these: Every morning millions of people ask themselves the same question, What is the weather going to be

Stevenson Screen on a mountain in Switzerland. (Pyewackett/Dreamstime.com)

U.S. Temperature Highs and Lows for Each Day of December 2007

Day of Month	Highest Temperature	State	Lowest Temperature	State
1	89	Texas	–29	Alaska
2	92	Texas	–29	Alaska
3	90	Florida	–44	Alaska
4	87	California	–46	Alaska
5	88	Texas	–27	Alaska
6	86	Texas	–31	Alaska
7	89	Texas	–22	Alaska
8	90	Texas	–29	Minnesota
9	89	Texas	–32	Minnesota
10	88	Texas	–23	Minnesota
11	91	Texas	–17	Wyoming
12	87	Hawaii	–21	Wyoming
13	86	Florida	–29	Alaska
14	86	Florida	–35	Alaska
15	86	Florida	–27	Wyoming
16	83	Hawaii	–34	Alaska
17	82	Hawaii	–38	Alaska
18	82	Texas	–44	Alaska
19	87	Texas	–51	Alaska
20	89	Texas	–54	Alaska
21	90	Texas	–51	Alaska
22	82	Hawaii	–47	Alaska
23	83	Hawaii	–33	Alaska
24	83	Hawaii	–28	Alaska
25	82	Hawaii	–33	Alaska
26	82	Hawaii	–36	Alaska
27	85	Florida	–42	Alaska
28	85	Florida	–29	Alaska
29	85	Florida	–29	Alaska
30	86	Florida	–35	Alaska
31	88	Texas	–30	Alaska

Questions:

1. What is the average for the month for both highs and lows?
2. What is the range of temperature for each? Find the lowest and the highest, and subtract the lower value from the higher one.

today? What should I wear? Will I need an umbrella? The daily weather forecast makes your life easier and more comfortable. It also helps to make it safer. What information is needed to make an accurate daily weather forecast? The first requirement is the collection of specific information from the thousands of sites across the country that regularly record data such as temperatures and air movements.

A Stevenson screen is used to collect this data. It is a wooden box in which barometers, thermometers, cellometers (used to measure cloud height), anemometers, and other instruments are all shielded from direct sunlight. The Stevenson screen has been in use for a very long time, and the data it provides is now augmented with information from satellites and special balloons. All of this information is fed into computers, where it is compared with models of weather systems so that staff meteorologists can assess the features that will become the keys to forecasts, things like areas of high air pressure, lines of contrasting temperatures and other characteristics typical of fronts between air masses, and wind directions and their speeds.

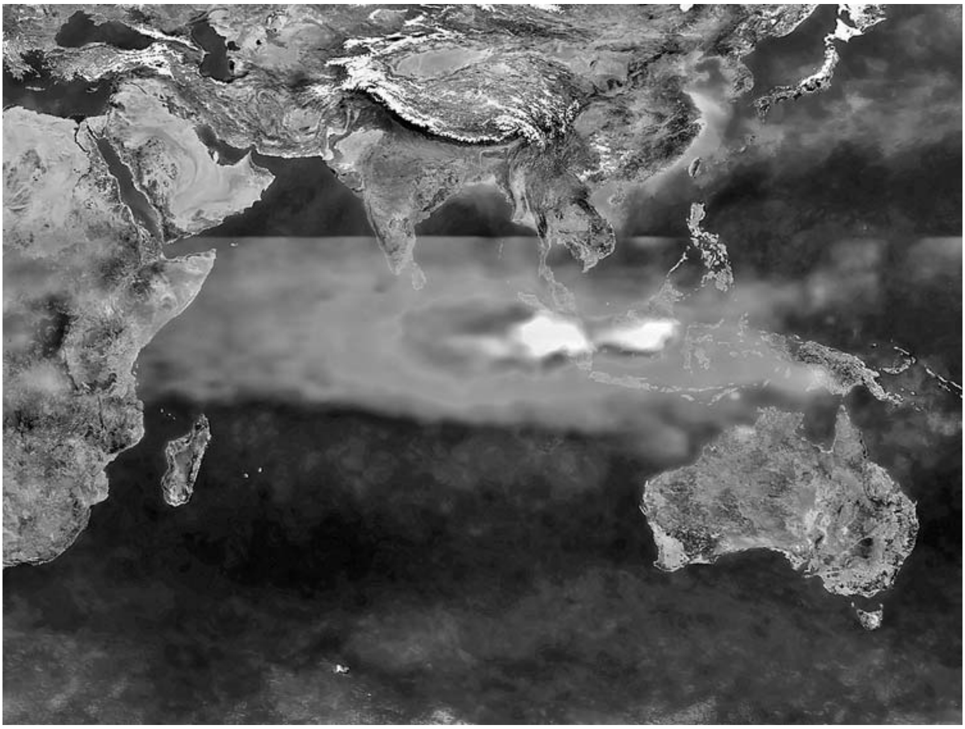
CHAPTER 7

Air Pollution, Rural and Urban

Air pollution is a major global problem, a human-induced one, and like volcanic eruptions it can disrupt atmospheric conditions and change weather patterns. An Indonesian smog cloud of 1997 destroyed more than 17,000 square miles of forest land on the islands of Borneo and Sumatra. Emissions from fires caused air pollution problems through all the countries of southeast Asia, especially Singapore, Indonesia, and Malaysia. A glance at a map will show why these countries were the worst affected. They are the closest to the sources of pollution. Tiny pieces of the carbon remnants from the fires proved to be the most damaging pollutants. They caused acute respiratory diseases such as bronchitis and asthma, and often caused death. Secondary effects of this kind of solid matter in the air were poor visibility and disruption of transportation systems. Flights were delayed, and transportation on land and sea was slowed down. Construction work was stopped for fear of damaging the health of workers. Tourists stayed away.

The fires were the result of bush clearance practices. These were carried out by business enterprises that wanted to make way for the development of new palm oil plantations. The first of these practices, often known as slash and burn, is widely condemned by environmentalists all over the world. It is an ancient mode of agriculture, once acceptable in remote areas of jungle among small groups of people, but too destructive when conducted on a large scale. Plantation planning is on a much bigger scale. About a tenth of the world's remaining tropical rainforest is in Indonesia, and these are the forests that are exceptionally rich in biodiversity. For this reason alone, these forests of Indonesia are a valuable area that needs to be preserved for the sake of humanity as a whole. One problem in trying to take action is that our knowledge of the resources of this country is not accurate. It is not known, for instance, how much of the forest is being cut down each year. Some estimates go as high as two million acres.

Satellite imagery from the National Aeronautics and Space Administration (NASA) identified a smoke haze extending over more than a million square miles from Indonesia to Thailand in 1997. NASA also noted that the level of pollution was far above normal air quality standards for that region and was, in fact, 30 times higher in places close to the fires. Visibility in the islands where burning was taking place dropped to half a mile and at times to less than three



NASA image of smog over south and southeast Asia, due to the removal and burning of trees from forested lands, especially in Indonesia. (NASA)

hundred feet. The urban centers of southeast Asia are already overcrowded, and their services are inadequate to cope with the steady influx from rural areas. Air quality is always poor, so any sudden increase like the 1997 one raises pollution to dangerous levels. In Singapore, all through the latter part of 1997, there was a 30 percent increase in hospital admissions duo to illnesses related to the haze. Estimated damages for the smog cloud of 1997 were one billion dollars in Indonesia alone. For Malaysia and Singapore combined it was half a billion dollars, and for the whole of the Association of Southeast Nations, about four and a half billion dollars.

Air pollution is a source of environmental damage to forests, soils, air, and acid-sensitive aquatic organisms. All these impacts add significant economic costs. As this becomes widely known, pollution abatement policies are given higher priority. Direct regulation is one way of responding. Taxation and private litigation are other approaches. Contamination of the atmosphere is a longstanding side effect of industrialization. The severity of the problem and the public awareness of it, however, are relatively new. We know what happened to weather in the United States when the air was filled with ash and smoke from the 1991 volcanic eruption of Mount Pinatubo in the Philippines. Rainfall increased greatly in the Mississippi Valley, and the greatest flood that ever happened on that river, up to that time, was the result. Other

What Causes a Flood?

In Chapter Four, flash floods and storm surges are described, and several U.S. examples of these kinds of floods are included to help us better understand what causes them and how they affect human lives. There are, however, many other kinds of floods, and their causes and consequences also need to be understood. The one we know best, and the one that causes the greatest hardship for people, is river flooding, when too much water flows in a river and the river overflows its banks, flooding the surrounding area. The terrible Mississippi floods of 1927 and 1993 that are described in other volumes were of this kind. There are other kinds of floods that are not described in the books of this set. They are still interesting and important. I will includes their names, and you see if you can find out all you can about their causes and consequences in human life: (1) ice-jam floods, which occur when ice blocks the flow of a river; (2) dam floods, which occur when the supporting front of a dam gives way and all the stored water spills out; and (3) mud flows, which occur when a volcanic eruption occurs and the ice cap is melted, such as in the Alaskan mountains.

places around the world were also affected, and the consequences were equally tragic. A major drought in Africa was one of the things that Mount Pinatubo's eruption triggered.

CITIES AND WEATHER

Weather in big cities is a very different event than weather in rural areas. There is very little vegetation in cities: blacktop, houses, and large public buildings dominate, and, because their albedos (measures of diffuse reflectivity) are lower than those of a field of grass or trees, there is a large amount of heat generated. This in turn raises the level of warmth within the city. Fuel consumption and waste heat adds to the buildup of

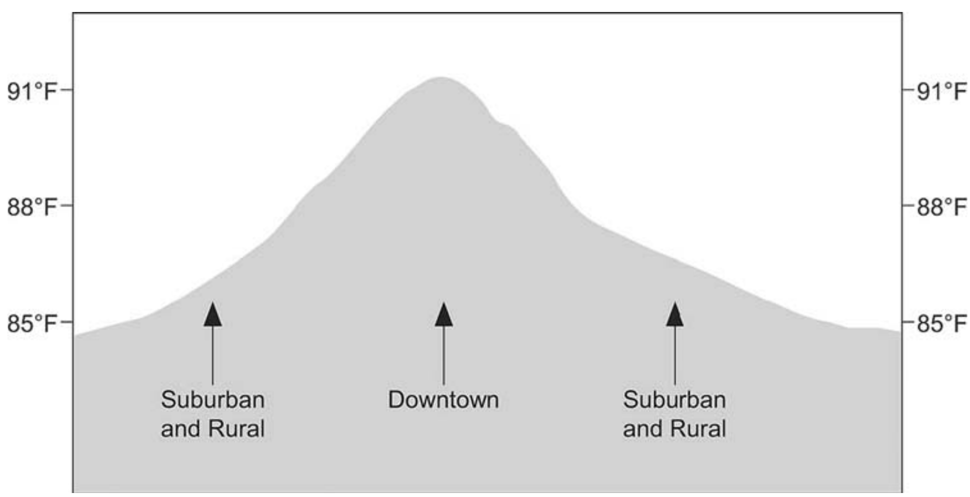


Figure 7-1 Temperatures in downtown areas of cities are often 15° higher than in surrounding locations. (ABC-CLIO)

heat, especially in summer, when air conditioners are active. Both the fuel that drives the air conditioners and the heat that they pump out of the buildings add to the total amount of heat. Although developed countries are able to compensate somewhat for the additional heat by planting trees and creating city parks, less developed nations cannot afford such luxuries in the face of an accelerated migration of people from rural areas to the downtown centers of the big cities.

The main reason why we must give more attention to urban weather and climate relates to their numbers. In the year 2005, for the first time in human history, more of the world's people were living in cities than in the rural areas. Although there may still be places where this is not true, the overall situation is clear when we take the total world population and compare it with the total numbers of people in the biggest cities. The migrations from rural areas to cities, particularly in developing countries, usually focus on the biggest urban areas in their countries. Mumbai, in India, as can be seen in Table 7.1, grew from 14 million to 23 million within 10 years, an extremely rare rate of increase. The rate of growth of the biggest cities is outstripping the growth rate of the world's population as a whole. From all the above, it is clear that we need to give high priority to weather and climate conditions in cities, because it is in such places that most of the world's people both now live and will increasingly live in the future.

TABLE 7-1 Populations of the World's 15 Biggest Cities, in Millions

City	2005 Population	Estimated 2015 Population
Tokyo, Japan	33	36
Seoul, South Korea	18	25
New York, United States	18	23
Sao Paulo, Brazil	18	20
Mexico City, Mexico	17	21
Manila, Philippines	15	17
Mumbai, India	14	23
Jakarta, Indonesia	14	18
Calcutta, India	13	17
Lagos, Nigeria	13	17
Delhi, India	12	21
Los Angeles, United States	12	18
Dhaka, Bangladesh	11	18
Buenos Aires, Argentina	11	15
Karachi, Pakistan	10	16
Total world population	**6,0007,000**	

A LONDON PEA-SOUPER

London, England, experienced an attack of smog that closed down the entire city for four days, beginning on December 5, 1952. The city's nine million residents were almost totally immobilized for four days. The thick smog smothered the city and killed four thousand people. A mass of dry, cold air settled over the city, strong enough to prevent any upward movement of the air on the ground. Above this strong layer of very cold air, there was a layer of warm air, the opposite of what one would expect. This is often referred to as a temperature inversion. In this situation, pollutants get trapped at ground level. Because there was no wind on this occasion, pollutants stayed within the areas of highest population density. The air became a blinding, suffocating cloud of gas, creating the worst smog in living memory. Breathing passages were clogged and eyes hurt. Within a few hours, people were breathing foul and very dangerous gases. Before cleaner air returned a few days later, four thousand people had died and many thousands more were seriously ill.

London's history of fogs is well-known. Novelists often refer to it, and many of them conjure up pictures of a dark, damp, foggy atmosphere to enrich their stories, especially if they are murder mysteries. The tons of sulfur dioxide and other pollutants that came from coal-burning fires and furnaces were the causes of this unhealthy atmosphere, however, so smog might indeed be a better word than fog to describe it. Locally the preferred term is "pea soup." From the earliest days of the Industrial Revolution, coal was the choice of almost everyone for heating and cooking, so, over the past two centuries, huge population centers such as London had a growing problem that came from coal fumes. Long before 1952, there were complaints that the outsides of heritage buildings were decaying from coal smoke. By the middle of the nineteenth century, the problem was acute. Novelists made reference to London's half million coal fires mingling with the surrounding air, being modified by inadequate drainage, and causing a black, unhealthy atmosphere.

It is hard to imagine a metropolitan area of nine million people coming to a complete standstill, but that is exactly what happened. Every aspect of city life was crippled, and, perhaps for the first time, most of its residents discovered how interconnected and interdependent all the parts really were. All transportation except the underground railway system was stopped. Even the underground trains had trouble when they emerged above ground. In streets everywhere, visibility dropped to a point where nothing could be seen beyond a couple of feet. Drivers who tried to move were confronted with barricades of abandoned cars. One ambulance attendant walked 25 miles holding an open-flame torch to guide his driver. Heathrow airport was closed, and planes were told to use Bournemouth, a seaside town 150 miles southwest of London. Ships unloading food and other essentials had to stop their work because of fears that people as well as goods might fall into the water and no one would know.

Polluted air poured through windows and under doorways. The city became a place of lost and troubled people. Fleets of ambulances were called in from surrounding communities to help with the masses of people of all ages who just could not cope with the attacks on their lungs. They were of little use because visibility made it almost impossible for them to get to where they were needed. Doctors were unable to reach hospitals or individuals at home and resorted to telephone calling to diagnose as well as recommend treatment. Fires broke out, but nothing could be done. In one location, the fire station was only four hundred yards away from a building that caught fire, yet firefighters could not get to it. The building was totally destroyed.

Pregnant women were unable to reach hospitals and had to deliver babies in all kinds of places. Electric power was cut off for large sections of the city when staff failed to turn up for duty at the control stations. The story was similar at the main studios of the British Broadcasting Corporation. Both radio and television programs were curtailed. At a cattle auction, animals were dying as they inhaled the poisonous fumes. Some were kept alive by one enterprising worker who covered the animals' noses with cloths that were moistened with whiskey.

For the fearless who decided to attend movie theaters, the usual tactic was to form a crocodile—that is, a line of people with each person holding onto the next ahead as they tried to find their destination. If they succeeded, they had to sit near the front. The movie was barely visible from the back seats. On one of the four evenings of the disaster, the opera *La Traviata* was canceled after the first act because of the intensity of the fog. Birds crashed into buildings and plummeted onto streets. Two of the very few positive outcomes were the increases in business by dry cleaners and beauty shops. If a person went outside for an hour, clothing and hair were soon covered with a black unpleasant coating. The saddest aspect of all, though predictable, was the crime rate. It rose very high because police were powerless to do anything about it.

After several days, stagnant air gave way to winds, and the smog began to lift. An investigation was launched into the cause of the disaster. Within the millions of tons of sulfur were huge volumes of acid, and it was this that caused the greatest damage. It combined with metal, stones, and clothing to weaken and destroy them. As a result of this disaster, the Clean Air Act of 1956 was introduced. Stricter regulations were placed on coal-burning furnaces, and anti-pollution laws were strongly enforced, but it took time for change to occur. Six years after the passing of the act, a smog attack killed 60 people within three days. A newspaper reported that, on that day, smoke levels were 10 percent above normal and sulfur dioxide 14 times higher. Gradually, the switch to low-sulfur fuels such as natural gas changed the city's air. London's pea soups now belong to history. Coal is no longer in widespread use. Where it is still used in electricity-generating stations, there are scrubbers in place to minimize the amounts of pollutants released into the atmosphere.

Sunset over Beijing obscured by smog. (iStockPhoto.com)

From time to time across the United States, there are problems of air pollution that change weather patterns and endanger health. In Donora, Pennsylvania, in October 1948, a temperature inversion occurred, very similar to London's. Donora was the site of a steel mill and other industrial plants. Normally, the smoke and fumes from them posed little danger to health. This time, because of a mass of cold air, pollutants were concentrated in one area for three days. Twenty people died, and thousands became ill. Of the fatalities, two had active pulmonary tuberculosis. The others were known to have had chronic heart disease or asthma. All were between 52 and 85 years of age. People in the area had complained for years abut the industrial pollution that "takes the paint off your houses and prevents fish from living in the river." A subsequent investigation, supervised by the director of the state government's Bureau of Industrial Hygiene, revealed an extraordinarily high level of sulfur dioxide in the air at the time of the tragedy.

In the summer of 1955, Los Angeles experienced a week of temperatures that stayed above 100°F and led to a smog emergency. A deadly dark haze filled the air as the sun's rays interacted with the exhaust fumes of cars. Large numbers of people complained of painful eye irritation and difficulty breathing. Los Angeles has been aware for a long time of this kind of eventuality because of its climate and its extensive use of cars. Years ago it mandated low emissions for all cars, and this has helped reduce the frequency of serious smog emergencies. Additional action has been taken since that time to curb the amounts of smog, but the problem is not yet eliminated. Smog is far from being eliminated in some of the biggest countries of the world. Today, in the capitals of India and China, conditions approximating those of London in 1952 are common. In 2008, in preparation for the Summer Olympics, Chinese authorities had to make extraordinary efforts to clean up the air over Beijing to bring it to acceptable levels for the games. Sources of problems like this one are the same as London's, the burning of fossil fuels and the failure to remove the harmful gases that escape from these fuels into the atmosphere.

CHAPTER 8

Volume Two Review

Volume Two of this series covers the daily weather of the area around the polar front, the border between warm topical air masses and cold Arctic air masses. It is at this front that the vast majority of our weather events occur, more particularly the wave cyclones, the quiet, extensive, and slow-moving storms that give rise to gray skies and light rain. It is also at this front that some very powerful storms originate. They are the ones that appear when the polar front happens to be drawn by the jet stream southward as far as Louisiana or Florida. Major thunderstorms, some of which become tornadoes, frequently originate there.

The global energy balance and the circulatory movements of warm tropical energy from the equator to the poles are also covered in this volume. The paths they follow and the shifts in direction because of the Coriolis effect give rise to both the mid-latitude high-pressure global belt and the polar front. All air movements that are close to the earth are slowed down by the action of friction between them and the earth. This friction is absent at higher elevations within the atmosphere, and it is at these higher elevations that pressure differences give rise to high-speed jet streams. In the northern hemisphere, it is these jet streams that guide cyclones across the country.

IMPORTANT TERMS

Global energy balance

Air mass

Wave cyclone

Polar front

Coriolis effect

Arctic Circle

Air pollution

Nor'easter

Relative humidity

Jet stream

Global warming

Greenhouse gas

Water vapor

Latent heat

Flash flood

Hailstorm

Urban heat island

Stevenson screen

Anemometer

Sensible heat

QUESTIONS

What is folklore weather forecasting?

What causes air pollution?

In which states would you expect to experience a nor'easter?

What discoveries were made by Norwegian meteorologists?

What happens when solar radiation is absorbed by the earth?

Why is the ozone layer important?

What is a microburst? Is it important?

Why does the air get colder as we go higher in the atmosphere?

How do volcanic eruptions change the weather?

What is the value of knowing the albedo of a surface?

WEB SITE FOR FURTHER STUDY

The Franklin Institute of Philadelphia, named after Benjamin Franklin, has programs on its web site (http://www.fi.edu/learn) to encourage scientific thinking and planning about weather.

Appendix A: Important Dates in Weather and Climate History

1238 The hottest and driest summer of the millennium in England.

1281 A North Sea storm surge hit the Netherlands in January, flooding large tracts of land and drowning 60,000 people.

1421 Worst North Sea storm surge hit the Netherlands in November, causing the deaths of 100,000 people.

1586 England's first colony in America, established on Roanoke in 1585, had to be abandoned because of severe weather.

1737 The second-deadliest Asian cyclone in recorded history killed 300,000.

1772 The biggest U.S. snowfall (before official records began) occurred in January, when three feet fell in the Washington-Baltimore area. It has been called the Washington-Jefferson snowstorm because it was recorded in both of their diaries.

1780 A hurricane traveled the length of the Windward Islands chain in the Caribbean in October, with St. Lucia and St. Vincent the worst affected, causing the deaths of 24,000 residents.

1791 Cuba was hit in June with a powerful hurricane that took three thousand lives.

1816 The year that was called "the year without a summer." In Savannah, Georgia, the Fourth of July had a high temperature of 46°F. Because it was so cold across the eastern United States, crops were ruined. Snow fell in June, heaviest in New England, with snow drifts of 18 inches. It was the same story in Canada and in Europe. These changes in weather were attributed to the 1815 eruption of Mount Tambora in Indonesia.

1824 In St. Petersburg, Russia, in November, a powerful storm from the Baltic Sea brought a storm surge into the Sea of Finland that swept inland, flooding the Imperial Capital and its palace and drowning 570.

1831 The Caribbean island of Barbados experienced its worst hurricane, which destroyed thousands of buildings and killed 1,500, representing 2 percent of the island's total population

1840 The second-deadliest tornado in U.S. history, Natchez, killed 317.

1870 U.S. Weather Bureau was founded and placed under the office of the Secretary of War.

1881 The third-deadliest Asian cyclone of all time, the Haiphong Typhoon in Vietnam, killed 300,000.

1887 San Francisco's greatest snowfall came in February, with a total of four inches in the downtown area.

1888 The Blizzard of 1888 affected the eastern United States in March. Over four feet of snow fell in the Albany and Troy areas of northeastern New

York state. More than 400 people lost their lives, mainly due to exposure to strong winds and cold temperatures.

1896 The third-deadliest tornado in U.S. history, St. Louis, killed 255.

1899 In February a cold wave caused a massive east coast blizzard and induced bitter cold temperatures across two-thirds of the United States. It was the only occasion that saw true blizzard conditions in the state of Florida.

1900 The second-deadliest Atlantic cyclone in U.S. history, Galveston, hit in September, killing 12,000.

1913 The highest U.S. temperature on record was recorded in Death Valley, California, on July 10, at 134°F.

1913 Several tornadoes hit southwest England and central Wales on October 27.

1921 On September 10, Thrall, Texas, experienced the greatest U.S. 24-hour rainfall on record up to that date. The total was 38.2 inches.

1922 A community in Libya, Africa, on September 13, claimed the world record for the highest temperature of 136.4°F.

1925 The deadliest tornado in U.S. history, Tri-State, killed 689.

1934 On April 12, Mount Washington, New Hampshire, experienced a gust of wind at 231 mph, accepted as the U.S. record for the highest wind speed.

1936 The fourth-deadliest tornado in U.S. history, Tupelo, killed 216.

1940 The U.S. Weather Bureau moved to the U.S. Department of Commerce.

1947 At Snag in the Yukon Territory of Canada, on February 3, the temperature was –81.4°F. This is the lowest on record for all of North America.

1949 In October Guatemala experienced a week of heavy rain from a stalled tropical cyclone. The results were flash floods and mudslides and a death toll of 40,000.

1952 From December 2 to December 6, London, England, experienced its deadliest weather disaster, the great smog that paralyzed the city, stopping all traffic and almost all pedestrian movements, and killed 6,000.

1953 The worst North Sea storm surge of modern times hit the Netherlands and southeastern England on January 31, killing more than 2,000.

1954 In Qazvin, Iran, a violent thunderstorm over the Elburz mountains triggered a flash flood over this city, killing 10,000.

1959 Due to an unusually wet summer monsoon season the Yellow River in northern China overflowed its banks and caused the deaths of an estimated two million people, the highest death toll ever for a meteorological disaster.

1963 The third-deadliest Atlantic cyclone in U.S. history, Flora, hit Haiti and Cuba in October, killing 8,000.

1964 At Oymyakon, Siberia, Russia, in February, the lowest temperature for the northern hemisphere was registered at –96°F

1964 Karachi, Pakistan, in December, experienced a major tropical cyclone that took the lives of 10,000.

1970 The deadliest Asian cyclone of all time, the Great Bhola of Bangladesh, killed 550,000.

1974 A tropical cyclone hit Darwin, Australia, on December 25, killing 65.

1975 The eighth-deadliest Asian cyclone of all time, the Super Typhoon Nina, hit China, killing 170,000.

1983 In Vostok, Antarctica, on July 12, the world's lowest temperature of –138.6°F was recorded.

1992 Hurricane Andrew, the United States' costliest meteorological disaster, swept across Dade County in August with devastating results.

1993 Missouri–Mississippi flooding, greatest U.S. flood of the century.

2005 Hurricane Katrina, costliest storm in U.S. history.

2008 The tenth-deadliest Asian cyclone of all time, Nargis, hit Myanmar, killing 140,000.

U.S. WEATHER AND CLIMATE FROM AD 1000 TO 2000

There are no written records for the first half of this millennium, so there are no details of actual weather conditions. However, there is a huge amount of archeological, botanical, and zoological evidence available, and we can construct from them a picture of the prevailing conditions at different periods of time. At the beginning of the last millennium, both in the United States and throughout Europe, warm weather was widespread, and this continued for the first two centuries, from 1000 to 1200.

The overall regime of warmth was accompanied with abundant, reliable rainfall across the Great Plains, giving rise to extensive wooded areas, the kind of landscape that remained unique to this time period of 1000 to 1200. This was also the time when a large population could be sustained in heartland America. One place in southern Illinois had 50,000 inhabitants between 1100 and 1200. All of this changed in the early years of the thirteenth century; by its first decade, what is now the United States became much colder and drier. The warm and moist air masses from the Gulf Stream were replaced by a strengthening that developed in the westerly flow across the continent. Within the following 40 years the woodlands had retreated from the U.S. Interior, and the Great Plains became grasslands, the habitat of the buffalo that would become, at a later time, so familiar to early European explorers.

Native American populations declined as a result of the change in climate. Settlements were abandoned, and people migrated westward and southward. It was a similar story farther to the north, where the first Europeans had settled for a long time during the warm period on the island of Newfoundland in Canada. By the fourteenth century, they had to abandon their North American settlement as well as those they had founded in Greenland and Iceland. Most of the United States remained cold for the long period that came to be known as the Little Ice Age. The first English colony that was established on an island off the coast ofVirginia had to be abandoned within a year due to low temperatures. An overall warming trend, one that affected all of the United States, began to arrive toward the end of the nineteenth century, but it did not become a settled pattern until the second half of the twentieth century.

EVOLUTION OF CLIMATE CHANGE CONCERNS

1970s For much of this decade, mainly because evidence of global cooling had been experienced over the previous three decades, scientific interests and publications focused on the prospect of a return to ice-age conditions.

1980 A report to the president of the United States from the Federal Council on Environmental Quality pointed out that human-caused climate change as a result of greenhouse gas emissions would probably be evident to all within the following 20 years.

1988 The World Meteorological Organization and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC).

1993 The scientific journal *Nature* published the findings of the scientists who had extracted a two-mile ice core from the Greenland ice sheet in order to identify climatic conditions 12,000 years ago. These scientists were astonished at both the rapidity and extent of the climate changes they identified, in particular the 1,300-year cold snap that appeared relatively suddenly. This period of time is often called the Younger Dryas after an Arctic flower.

1997 The scientific journal *Science* published an article that identified the slowdown in recent years of the Gulf Stream as a development that closely resembles the rapid changes in the Younger Dryas time.

2005 The Kyoto Protocol, a set of obligations related to the IPCC, came into force in February, and many developed countries agreed to follow its prescriptions. These related to reductions in levels of greenhouse gases by a specific date.

2007 The Norwegian Nobel Committee awarded the Nobel Peace Prize in two equal parts, to the IPCC and Albert Arnold (Al) Gore Jr., for their efforts to build up and disseminate greater knowledge about manmade climate change and to lay the foundations for the measures that are needed to counteract such change.

APPENDIX B: SOME EXTREME GLOBAL WEATHER EVENTS

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as well as Appendix C, which focuses specifically on U.S. extremes, is to provide a larger context to which the individual references can be linked. When it comes to global extremes, the nations of Asia still dominate. Again and again, even after a century of improved methods of protection from tropical cyclones and interior floods, weather events are far more severe in Asia than we are accustomed to in North America. Numbers of casualties and the extent of environmental damage are often huge. One reason for this is the high terrain that borders nations such as Bangladesh and Vietnam; another is that the Pacific Ocean is much bigger than the Atlantic, and storms reach the Asian mainland with huge volumes of moisture after moving across great stretches of water.

The two biggest nations of Asia in terms of population are China and India, and they epitomize two extremes of weather: flooding in China and drought in India. The extremes of flooding in China are described in Volumes 1 and 2, and the drought problems of India are explained in some detail in Volume 3. The China flood of 1931, described next, was by far the most extreme in centuries, and the drought that hit India in 1900, along with the accompanying famine and starvation, was the worst of the entire twentieth century. Extremes of tropical cyclones, just like floods and droughts, are usually greatest in Asian countries, but occasionally other parts of the world experience exceptional storms. The two examples included here are of this character, Hurricane Mitch of Central America and Cyclone Wanda of Australia. The fifth extreme event included here took place in the Sahel of Africa, selected because it is an area that experienced so many droughts in the twentieth century that the United Nations set up a special task force to study the problem and identify the causes.

CHINA FLOOD, 1931

In the United States it is easy to think of hurricanes and tornadoes as the causes of more deaths than other weather events. In fact, in the United States, and to a far greater extent in Asia, floods cause far more deaths. In China, in particular, there is a tragic history associated with flooding, and Chapter 5 of Volume 1 shows this in the tragic story of

the great 1887 flood. The 1931 flood went far beyond the 1887 one in terms of deaths and damage. Nothing equal to it had happened in China in centuries of experiences of flooding. It began during the summer months, and the worst flooding occurred on the Yangtze River, although the heavy rains and rapid snow melt affected many other rivers in central China at the same time. About 51 million people were affected, representing a quarter of the nation's population at that time.

The U.S. National Oceanic and Atmospheric Association (NOAA) considered this 1931 event the most extreme weather-related disaster of the twentieth century, possibly the deadliest natural disaster ever recorded. The number of deaths was approximately four million, not all due to drowning. In 1931 China was still predominantly a rural society, and people earned their livelihood from agriculture. There was no national organization that could provide emergency food supplies, so, as water destroyed their food crops, mostly rice, people had nothing to eat beyond the supplies they might have saved from previous crops. Thus many died from hunger. Many others became infected with deadly diseases from polluted water. The causal factors that led up to this tragedy were a combination of extended droughts, from 1928 to 1930, followed by an equally protracted period of heavy rain. In winter much of the precipitation fell as snow, and in the following spring, the thaw added quantities of water to the rainfall, greatly increasing the volume of water in the rivers.

Rainfall persisted throughout the summer months and, in July alone, the area on the Yangtze River near the capital of that time, Nanjing, was hit with seven tropical cyclones, each of which added substantially to the amount of water in the rivers. Normally this part of China experiences about two tropical cyclones a year. By July of 1931, Nanjing had become an island in a massive flooded area. The high-water mark on the Yangtze reached 53 feet above normal by the middle of August. The immediate cause of flooding in China is nearly always a result of failure of the levees. Historically these are built of sods, so they offer little resistance to a sudden rise in the level of the river, especially if the rise in river flow occurs on a downward slope. These levees get built up over time to compensate for the rise in elevation of the riverbed, as more and more silt is deposited in it, so the river runs at an elevation above the surrounding plain.

Thus, as soon as a breach occurs in a levee, the rapid flow of water through the opening quickly expands the opening and increases the volume of water escaping into the lower land below. Toward the end of August the water flowing through the Grand Canal near the mouth of the Yangtze washed away the supporting dikes and drowned 200,000 people. In modern China the ancient forms of levees and dikes have been replaced in critical areas of the country by protective walls of concrete so that the enormous tragedies of the past will not be repeated. Additionally, hydroelectricity is being produced in many locations on rivers, and the dams serve as control points to prevent overtopping during sudden increases in river flows. The huge undertaking to dam the Yangtze River in order to secure much greater amounts of hydroelectricity provides protection from flooding all along the river.

HURRICANE MITCH, 1998

Deadly tropical cyclones frequently strike coastal areas along the Bay of Bengal, causing enormous loss of life and extensive environmental destruction. The Bangladesh cyclone of 1970 that is described in Volume Three of this series was the nation's greatest disaster of the twentieth century. Winds coupled with a storm surge killed between 300,000 and 500,000 people. The tropical cyclones we experience in North America, which we call hurricanes, do not generally reach these levels of destruction, but occasionally there are extreme examples of deadly hurricanes. Hurricane Mitch of 1998 was one of these. It was a late-season arrival, forming in the western Caribbean in October and moving westward over the mountainous areas of Central America. This storm weakened as it reached Honduras. Perhaps because it arrived late in the season, it did not have the strength to continue westward after reaching Honduras so it stalled over that country.

Hurricanes that travel across the warm waters of the Caribbean carry large amounts of water, and this volume of moisture is usually spread over an extensive area of land when precipitation takes place and the storm moves along. It is a very different story when a hurricane operating in the warm waters of latitude 15° north stalls over land, and especially when it stalls over mountainous land, as Mitch did. It unleashed precipitation amounts estimated as high as 75 inches. The resulting floods devastated the entire infrastructure of Honduras and also severely impacted other countries in the Central American region. The final estimated death toll was 11,000, the greatest loss of life from a tropical system in the western hemisphere since 1780. The fact that this was an estimated death toll tells us a lot about the level of development, and preparedness for hurricanes, in the countries affected.

Extensive wind damage and devastating floods occurred all over Honduras, particularly on the northern seaboard and in the Bay Islands that are located off the northern coast. Approximately 1.4 million persons were left homeless, more than 92 bridges were damaged or destroyed, and nearly 70 percent of crops were lost. The U.S. Geological Survey was called to help assess and map the damage and to provide technical help with landslide mitigation. Fortunately, the recent date of this hurricane makes possible the use of techniques to accurately assess the extent of the damage and provide expert help in recovery.

INDIAN DROUGHT, 1900

In contrast to the famines that occur in China due to the country's frequent floods, the Indian famines are caused by the absence of rain. The monsoon is the name given to the annual arrival of massive amounts of rain that reach land after traveling thousands of miles across the warm waters of the Indian Ocean. It is the greatest weather event in the world for two reasons: it travels over an area of water greater than

that of any other weather system, and it affects a bigger population than is ever affected by another single series of rainfalls. This main weather event of the year begins with rain arriving in early summer in the south of the country and often continuing unabated for weeks before dying down. It is common for rivers to overflow and communities to be flooded, but no one objects because this summer rain is the lifeblood of the whole nation. Even today, most of India is still a rural, agricultural society. In 1900 everyone depended on what could be grown in order to survive and, in this hot tropical climate, every crop depended on rain.

India has a second monsoon that arrives in the fall of each year. It is quite different from the summer one because it travels south over dry land and so carries much less moisture. If we think of India together with the large mass of continental land that lies north of it in the Himalayas, China, and Siberia, the enormity of these two annual events can be visualized. In summer, because land heats up much quicker than water, the air that had been circulating over long stretches of warm ocean water, and that therefore carries large quantities of moisture, is attracted toward the low-pressure areas over land. As it rises over higher ground water is precipitated, and the summer rains begin. People talk about it as rain, rain, and rain again; clothes damp, bed linen damp, walls damp, food damp, everything damp. Rain hammers a tattoo on corrugated iron roofs, tears up roads, and smashes down vegetation. The opposite movement of air happens in the fall as the land cools below sea temperatures, and a reverse flow of air takes place. It is the summer rains that are always the focus of interest. They sustain crops, especially rice, for the hundreds of millions of Indians. Billions of rice seedlings are in the fertilized, prepared plots of land in May or early in June awaiting the arrival of the monsoon.

What happens if it fails to arrive at the time the weather forecasters gave? In 1900 forecasting the exact date of arrival involved quite a bit of guesswork. There were few weather stations serving the land areas, and nothing on the ocean except reports from passing ships. A primitive form of statistical prediction operated. That is to say, forecasters knew that, on average, the monsoon would arrive within ten days of the middle of June, so they used whatever data they had to fix a date within that timeframe. However, even if the statistical average proved to be true for 30 years, the elders in Indian communities knew that occasionally there were huge exceptions. They knew of the terrible years of 1768, 1769, and 1770, when inadequate rain arrived and ten million people died. Somehow these anomalies had been forgotten in the year 1900. There had been exceptionally low amounts of rain in 1899 and again in 1900. Because of the possibilities of weak monsoons, farmers had been in the habit of storing some grain each year as a kind of insurance against a famine, but for some reason this had not been done before 1899 and 1900.

Severe shortages of rice were reported all over southern India in 1899 and over the rest of the country a year later. Unlike modern times

in India, in which food reserves are on hand to cope with disasters like this one of 1900, there was nothing that could be done for the farmers who had inadequate amounts of rice. A certain amount of sharing was done within communities, but the overall picture deteriorated into widespread famine by the fall of 1900. Disease and a breakdown in social order followed. There were many deaths. Subsequently it was discovered that there had been low levels of rain in the monsoons of 1896 and 1897, and these conditions led to the inability of farmers to put some grain aside as a reserve for emergencies. The British colonial authorities of the time paid no attention to these failures in the monsoons. They were only concerned with securing their quota of rice in order to satisfy their superiors. The final tally of deaths from famine and disease ranged from two million to ten million. The uncertainty about the numbers is a sad commentary on the failure of the colonial power to look after the people over whom they ruled.

AUSTRALIAN CYCLONE WANDA, 1974

Australia is quite well acquainted with extremes of climate. It has a very large desert area, and its location in a tropical zone means it gets the full effect of the unexpected heavy rains and high temperatures that are commonplace in that part of the world. During the summer of 1974 there happened to be one of the wettest seasons that Australia had ever known. The climatic variation called La Niina had been one of the most extreme of the entire twentieth century. As result of both of these conditions, rainfall was torrential and continuous through most of January 1974, as the inter-tropical zone settled over northern Australia. On January 25 of the same year, Cyclone Wanda moved over the interior of Queensland and New South Wales, dumping more than 12 inches of rain in 24 hours over a very wide area. As a result, because the summer rains had completely saturated the ground, massive flooding occurred on all the nearby river systems.

The city of Brisbane was the worst hit. It had not experienced a major flood for more than 70 years, and few suspected that anything like this would ever happen. After the last occasion when a major flood had hit the city, in 1893, very strict regulations were established for building on areas below a certain elevation. These restrictions were laid out for the parts of the city that would be at risk in the event of a major flood. Sadly, these regulations were not maintained for one reason or another, and subdivisions were allowed to develop on the areas on which no homes or other buildings were to be built. It is a story that is similar to what we have seen in the aftermath of the San Francisco earthquake, where areas that should never have been built on were once again rebuilt. Throughout Brisbane on January 25 there was a general failure of disaster warnings. There was no central authority that was able to receive details on the amount of flooding that occurred in different areas, so that local flooding in key areas was never reported to the authorities. About 70 percent of the

residents who were questioned afterward about the flood said that they had received no official warning.

January 25, 1974, the peak of the damage caused by Wanda, will be remembered as the worst floods in Australian history. Flooding covered an area slightly larger than the entire drainage basin of the Mississippi River. It reached from the dry interior at Alice Springs all the way to the Pacific Ocean, and from the extreme north of the country to the areas around Sydney, including the Murray River system. Military airplanes had to be used to supply isolated towns that were cut off by the floodwaters with emergency food for both humans and animals. In Brisbane, all bridges across the Brisbane River were damaged or destroyed, and 35 people drowned. At its height, the river broke its banks and ran through the central business district of the city. Water levels peaked at 20 feet by January 29. In one of the subdivisions 1,200 homes were destroyed. Overall, 20,000 people were left homeless. There was no adequate relief organization at this time, and about half of the victims depended on church contacts and a large number of volunteers for the help they did receive. By the end of January much of Australia, normally the dry continent, was submerged in water. Crops were destroyed, and there were outbreaks of disease.

Major flooding like this is so rare in Australia that the disasters of January 1974 are unique in the history of the country. In the aftermath, thoughts were concentrated on appropriate action that would prevent future disasters. Almost immediately the Queensland Government introduced a series of flood mitigation measures that expanded earlier ones. The experience was a wake-up call for Australia.

SAHELIAN DROUGHTS

This region, which stretches for three thousand miles across Africa south of the Sahara Desert, from Senegal at the Atlantic Ocean to Eritrea at the Red Sea, is a focus for all the world in the study of drought. It is an extreme example of aridity because of the extent and persistence of the droughts that overwhelm it. From 1968 to 1973 most of the region suffered from lack of rain, and the Sahelian Office at the United Nations created a special unit in 1973 to investigate the causes and recommend ways of coping with droughts. Occasionally the whole world becomes aware of the deadly nature of these times of aridity when international aid efforts are launched. One of these efforts is described in Chapter Six of Volume One: half a billion dollars was raised by Live Aid to help Ethiopia cope with a famine that had already taken the lives of 300,000 people. Overall, in the Sahel as a whole, between the 1960s and 1980s, famines took the lives of a million people, and many millions more were affected.

The 50 million people of the Sahel pursue different livelihoods. These include agriculture, livestock herding, fishing, and short- and

long-distance trading. Farming is almost entirely reliant on three months of summer rainfall, except for places that happen to be near a major river such as the Niger. Researchers from The United Nations, as they examine the region's economic fragility, recognize that the vast majority of the population is dependent on some form of rain-fed agriculture, including pastures for animal production. Three major droughts have occurred this century, in 1910–16, 1941–45, and a long period of below average rainfall that began in the late 1960s and continued, with some interruptions, into the 1980s. Absolute minimum rainfall levels were recorded at many stations in 1983 and 1984. The period of poor rainfall in the 1970s was particularly hard for many Sahelian farmers and pastoralists. An estimated 100,000 died from it.

Sahelian droughts and their effects have been studied extensively since the 1970s as part of the international response to this environmental emergency. It is only since 2000, however, that the long-term impacts of the famines of the 1970s have become evident. Those events provoked a rethinking of the links between population growth, drought, and sociopolitical change, and also helped to refocus development policy away from expensive and unsuccessful interventions toward more considerate strategies targeted at boosting local capacities. A complicating factor was increases in migration and international trade. Food distribution in famine situations by donors and governments has not been successful, despite the establishment of national cereals boards in most Sahelian nations, and the construction of roads into more remote rural areas. Rural residents still have to pay for government grain, and not all households are able to pay.

Originally it was believed that the problems in the Sahel were caused by humans overusing natural resources through overgrazing, deforestation, and poor land management. The expansion of farming and herding into marginal areas was said to have produced a spiral of changes, in which reduced vegetation caused reduced rainfall, producing further decreases in vegetation and thence a further reduction in rainfall. The series of Sahelian studies and climate modeling carried out by an agency of the NOAA over some years, and published in 2005, present a very different story: the problems are caused by changing sea surface temperatures that, in turn, were created by greenhouse gases and atmospheric aerosols from volcanic eruptions. In other words, global warming and climate change are the primary villains. The NOAA studies also point out that these human-induced changes in sea temperature could lead to a substantial reduction in the Sahel's rainfall in the course of this century.

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Appendix C: Some Extreme U.S. Weather Events

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as with Appendix B, is to provide a larger context to which the individual references can be linked. This list of U.S. extremes begins with two volcanic eruptions, one from Alaska, the biggest that occurred anywhere on earth during the twentieth century, and one from Washington State, the biggest ever within the contiguous United States. They are reminders of the unpredictable element brought by volcanic eruptions to the ongoing changes occurring in our atmosphere. Volume 1 describes the role of volcanic eruptions in considerable detail, with regard to their influences both now and in the future.

The other three extreme events included in this appendix are two extremes of temperature, cold and hot, and one of the most violent hurricanes of modern times, Camille of 1969. The extreme of heat is interesting because it arrived in the midst of widespread talk about global warming and climate change and is a reminder that the addition of carbon dioxide to the atmosphere has different effects in different places. In this instance, the high heat of the year 2006 is almost identical to that of the year 1936, the time of the Dust Bowl. The years 2006 and 1936 were the two hottest of the twentieth century.

MOUNT KATMAI, ALASKA, 1912

Katmai was the biggest eruption of the twentieth century anywhere on earth. A volume of volcanic ash greater than the amount from all other volcanic eruptions in Alaska was ejected, and it devastated every place within miles of the source. It created the Katmai Caldera and the Valley of Ten Thousand Smokes. Volcanic ash devastated areas hundreds of miles away. Within four hours of the initial eruption, ash had reached Kodiak, lying one hundred miles to the southeast, and by the end of the event, both Vancouver, British Columbia, and Seattle, Washington, were showered with sulfurous ash. The cloud produced by the eruption had reached Virginia by June 7. Ten days later, it had reached North Africa.

Kodiak suffered greatly during the three-day eruption. Ash and sulfurous smoke caused a slew of health problems ranging from respiratory illness to sore eyes. Additionally, the eruption rendered Kodiak's water

supply undrinkable, disrupted radio communications, and destroyed many buildings, some of which burned and others of which collapsed under the weight of mountains of ash.

As a result of the Katmai disaster, several villages were abandoned forever. Additionally, the eruption caused untold environmental havoc, and many animals, ranging from bears to birds, died of starvation. Aquatic organisms were also affected where waters were shallow and became choked with ash. This devastated local salmon fisheries for years.

Despite the fact that the eruption was so close to the continental United States and comparable in magnitude to that of Krakatau of 1883, it was hardly known at the time because Mount Katmai was so remote from the world's main population centers.

Almost a hundred years after it happened, researchers are still paying attention to Katmai because it is near the Arctic Circle, and its impact on global climate appears to be quite different from that of volcanoes in lower latitudes. Unlike eruptions in the tropics, the aerosols emitted by Arctic volcanoes tend to stay at high latitudes, because the stratosphere's average circulation is poleward from the equator. As a result, these particles remain effectively "bottled up" in the Arctic, dispersing into the rest of the earth's atmosphere only very gradually. Professor Alan Robock of Rutgers University has argued that this trapping of aerosols in the Arctic has an unexpected side effect: the weakening of the Indian monsoon. Robock reached these conclusions using complex calculations; however, the basic concept is that cooling in the northern hemisphere caused by the Katmai eruption set in motion a chain of events ultimately affecting air flow over the Himalayas and thus rainfall in south Asia.

To check his results, Robock and colleagues have been examining weather and river flow data from Asia, India, and Africa from 1913, the year after Katmai. They have also investigated the consequences of other high-latitude eruptions in the last few centuries. The fact that the stratosphere in high latitudes is shallower than at the tropics means that even small eruptions near the North Pole may deposit more aerosols than bigger events in the tropics. Furthermore, they would remain in circulation longer, as happened with Katmai. Indians will need to keep an eye on future Arctic eruptions.

It is unlikely that another eruption on the scale of Katmai will occur in the same region in the foreseeable future. However, volcanologists have confirmed that at least seven Katmai-scale eruptions have occurred over the last four millenia within a five-hundred-mile radius of the city of Anchorage, Alaska, so such a recurrence is far from outside the realm of possibility.

MOUNT ST. HELENS, WASHINGTON, 1980

The eruption of Mount St. Helens was the largest ever in the history of the contiguous United States. It had a VEI of 5. Mount St. Helens is the

youngest of the Cascades' volcanic peaks, and the explosion of 1980 is just the most recent of the many intermittent eruptions that took place over the past 40,000 years. Pumice and ash from these past events now cover large areas of the Pacific Northwest. From the 1950s onward, the mountain was intensively monitored, perhaps to a greater degree than any other. Days before the fateful event of Sunday May 18, 1980, there were many signs of impending danger, but no one was quite prepared for what finally happened. It all seemed to take place in seconds. Seattle's air traffic control tower tracked the mass of ash and rocks hurtling out of the mountain and concluded that it was traveling at close to 300 mph. The earthquake that triggered the explosion measured 5.1 on the Richter scale, but the energy released might be more accurately defined as the equivalent of thousands of Hiroshima-size bombs.

An avalanche of mud, rock, and ice roared down the mountainside, and the ash cloud rose as high as 54,000 feet. What had moments before been a beautiful 9,000-foot-high peak was reduced to a 7,500-foot decapitated mountain. Ash high in the atmosphere drifted eastward across the country, covering the ground everywhere it went with a layer of ash and blocking out sunlight in several communities near the mountain. Two hundred square miles of forest was flattened. Mudflows rushed westward down river valleys toward the Columbia River, blocking the navigation channel for ships with logs and mud for a distance of ten miles. It was estimated that 57 people lost their lives on that first day.

A Boeing 737 jet flying from Reno, Nevada, to Vancouver, Canada, at six thousand feet, was 40 miles south of Mount St. Helens when the mountain exploded. The pilot saw the explosion and swung away from his course, a path that would have taken him directly over the eruption, escaping in so doing a dirty gray cloud that was rising quickly to meet him. His 737 rocked in the air from the shock of the explosion as if it were a ship at sea. Fortunately his flight had been delayed for 30 minutes at Reno, or all 122 passengers plus crew would have been added to the list of deaths for May 18. The earthquake that triggered the event was not an unusual event in a region that experiences frequent earthquakes of this strength and stronger ones, but the scale of the eruption was a very different matter. It was a rare event even in historical time. Volcanic eruptions are identified by a volcanic eruption index number (VEI) based on the volume and speed of the rock and ash that is ejected. The index is numbered similarly to the Richter scale, each number representing ten times the volume of the one immediately below it, and one tenth that of the next number above it.

For this event of VEI 5, a volume of eruption greater than any other in the contiguous United States, one has to go back into earlier times to find a meaningful comparison. Vesuvius in the year 79 or Krakatau in 1883 each had VEIs of 6, or they were ten times more powerful than Mount St. Helens. Volcanoes in the Cascade Range are fairly new in geological time. A few date back several million years. Mount St. Helens is one of the youngest. Much of its visible cone was

formed within the last thousand years. It was frequently active during that time, and because of that geologists were convinced that a major eruption would occur sometime in the twentieth century. Further evidence in support of that expectation came more recently when it was found that the mountain had been more active and more violent over the past few thousand years than any other volcanic mountain in the contiguous United States. From the evidence in ash deposits across the western Cordillera, it is clear that some of these older eruptions must have had VEIs of 6.

The most recent well-documented eruption, prior to 1980, occurred in 1842. Eyewitness accounts from that time described seeing vast columns of smoke and fire. Ash from that time was subsequently located at The Dalles in Oregon, about 65 miles away. Fireworks continued intermittently over a 15-year period. Then came a three-year lull followed by a lot of activity in the year 1857. After that date the volcano seemed to have slept for the 123 years before 1980. The moment of eruption on May 18 of that year was indelibly etched in many memories. David Johnston, the expert geologist from the U.S. Geological Service who was monitoring the mountain on the morning of the explosion, talked to news reporters early on that day. He described Mount St. Helens as a keg of dynamite with a lit fuse whose length you do not know. He was well aware of the risks of being so close to the summit, but he stayed there right up to the moment of the eruption. He told the reporters that it was extremely dangerous to stand where they were at that time. "If the mountain explodes," he told them before they left, "we would all die." Soon afterward they heard his final words as he yelled into his radio, "Vancouver, Vancouver, this is it!"

A family watched their dream $100,000 home smashed and washed down the chocolate-brown Toutle River. A couple on a camping and fishing trip on the same river tried to grab their camping gear when they heard the explosion, but quickly saw there was no time to escape in their car. They were thrown into the water and carried along in a mass of mud, logs, and rocks, grimly clinging to one log. They were lucky. The log was shunted sideways out of the main stream. Some time later, a helicopter picked them up. A television cameraman a kilometer and a half from the base of the mountain filming the event saw the mass of mud and debris heading for him. He dropped everything, got into his car, and drove madly to keep ahead of destruction. He was able to stay ahead of it.

Farther east, travelers were stranded in numerous small communities, altogether 10,000 of them in three states. One couple driving west from Spokane saw the black oncoming cloud. Soon they could only inch along the highway at less than eight kilometers per hour. They abandoned their car and joined the other stranded ones. Everywhere around, trains, buses, airplanes, and cars came to a stop. Walking was the only thing that worked. Digging out from under the ash was yet another hazard. It proved to be as hard as getting around it. For some time people wore masks of whatever material they could find for fear of toxic fumes.

As is common in volcanic eruptions, the magma that had risen and caused the explosion left the inner chamber empty for a time until new magma moved up from below. The interior dome then began to grow until pressure rose to a level that caused another eruption. Several of these subsequent eruptions came in May, June, July, August, and October of 1980. By 1983 the dome had grown to six hundred feet and the crater in which it sat was two miles in diameter, waiting for the moment of the next event, and meanwhile continuing to grow.

How can volcanic eruptions and earthquakes be predicted? The answer remains elusive, but experience from Mount St. Helens shows us some of the things that can be done. As mentioned earlier in this chapter, this mountain received more monitoring since the 1950s than almost any other, and the small number of people who were killed is largely due to this, as well as to the actions that were taken in the months before May 18, 1980. The first earthquake in Mount St. Helens struck on March 20, 1980, and immediately afterward seismologists met with local authorities to warn of the danger ahead and make some preliminary plans.

One week later steam and ash exploded from the summit of the volcano, and this was followed by several minor eruptions over the following weeks. As these eruptions became more frequent, public authorities closed off the area around the mountain, causing heated opposition from the general public. Later they lowered the water level in the Swift Dam reservoir to minimize damage from mudflows. Still closer to the time of the eruption, the governor of Washington declared a state of emergency in order to use the National Guard to staff the roadways. So angry were some over the closure that they found ways of circumventing the law by using little-known roads and footpaths to gain access. Some, including Harry Truman, a veteran resident of the mountain, refused to leave their homes on the north side and died.

ARCTIC OUTBREAK, 1989

America's coldest spell of the century arrived in December 1989. In the South, New Orleans experienced 64 consecutive hours at or below 32°F and a total of 81 out of 82 hours below freezing. A total of 15 hours were below 15°F, with the lowest reading of 11°F on the morning of December 23. A low of 8°F was recorded at Baton Rouge. Snow and sleet paralyzed transportation systems in New Orleans, and there were a hundred fires in the city, a result of inadequate heating systems. The greatest impact was on breakage of water pipes in homes and businesses. Five weather-related deaths occurred in the area during this rare Arctic outbreak.

The story was similar in the Midwest: it was the coldest day of the season for south central Nebraska and north central Kansas, and most locations experienced subzero temperatures. This Arctic outbreak peaked around December 15 and continued for about ten days. Low temperature records were broken throughout the United States. Nothing comparable

is found in weather records until we go back to 1899, when a similar chill occurred. The events in both of these years were quite similar: both were fast-moving, very powerful Arctic outbreaks that stretched across most of the United States and reached into Mexico and Florida.

GREAT HEAT WAVE, 2006

In 2006, from June 1 to August 31, as summer is defined by the National Climatic Data Center, the United States experienced its greatest heat wave in 70 years. The average temperature across the country was 74.5°F, based on readings from hundreds of weather stations. It was the second-hottest summer temperature since the government started to keep records in 1895. The only comparable heat wave was in 1936. At the 2006 peak, temperatures greater than 100°F covered the Great Plains, Midwest, South, and much of the Northeast. The year 1936 is a reminder of the Dust Bowl years that are described in Volume One.

With air conditioning being quite limited in its coverage in 1936, many people were forced to sleep in their yards or in parks. The death toll was high, estimated at about 50,000 total. The heat was especially deadly in large Midwestern cities such as St. Louis, Minneapolis, and Detroit. The total number of deaths from a heat wave is rarely given out by media for various reasons: deaths from heat are silent killers, they do not cause visible destruction where they occur, and causes of deaths are difficult to identify.

HURRICANE CAMILLE, 1969

Camille was one of only three hurricanes in the history of the United States to make landfall as a Category 5. It was an extreme hurricane, one of the most violent storms of the twentieth century. It arrived from western Cuba on August 14 and entered the warm waters of the Gulf, reaching Bay St. Louis on the evening of August 17 with sustained wind speeds of 190 mph. It almost totally destroyed the Mississippi coast. Before it left the mainland United States it had caused the deaths of more than 250 people and injured 8,900, and destroyed 6,000 homes and damaged 14,000. The total costs of the destruction it caused were in excess of a billion dollars. Millions of Gulf coast residents were made aware of the strength of the storm before nightfall on August 17. Before the storm reached Bay St. Louis, about 200,000 residents had fled the coastal areas into sheltered places.

As the storm moved across the coast in darkness, homes, motels, apartments, restaurants, and other buildings were swept off their foundations and deposited in mountains of rubble. It was the same for almost everything movable and for much, such as trees, that was not. Camille maintained its hurricane strength for ten hours. On the morning after

the storm, thousands searched among the wreckage for anything that might have been left. There was no semblance of normal life in the region around New Orleans for days, but fortunately the levees around the city were not affected because the storm was centered a few miles to the east. About 15,000 people were left homeless. There was no water, food, or fuel. The storm had wiped out all means of communication, and roads, bridges, airports, and even railways were impassable or destroyed. Gulfport Hospital had closed down and evacuated all of its patients to hospitals farther inland.

Adding to the devastated landscape was a serious vermin problem. There were thousands of dead animals of all kinds, and insects and rodents had quickly overrun the stricken area to feed on these and on the rotting food. Rattlesnakes, fire ants, and rats bit dozens of victims who were sifting through the rubble. In an attempt to control the ants, low-flying planes roared up and down the Mississippi coast, dropping quantities of mirex. At the time of Camille this product was not considered dangerous to humans, but eight years later the U.S. Environmental Protection Agency banned it as a possible carcinogen. President Nixon sent a thousand troops to help, and the state governor declared a state of emergency in order to control crime. Using federal troops and state police, all roads leading into the area where the eye had crossed the coast were sealed off. Military and local police imposed a curfew. The first problem to overcome was the thousands of dead farm animals, pets, and wildlife. Camille's incredible 25-foot storm surge had drowned thousands of animals. Heavy equipment was brought in to bury these thousands of animals.

The National Hurricane Center took note of Camille's weather data because of the unusual ferocity of this storm. The lowest barometric pressure recorded on land during the evening of August 17 was 26.85 inches. That was at Bay Saint Louis. This was the second-lowest barometric pressure ever measured in the United States. Only the 1935 Labor Day hurricane produced a lower pressure in the middle keys. That figure was 26.35 inches. The highest tidal surge ever recorded in the United States belongs to Camille. It was officially recorded as 22.6 feet above mean sea level, but high-water marks on buildings, still clearly visible long after the storm had passed, showed water heights of 25 feet. Camille moved inland and then gradually weakened to a tropical depression over northern Mississippi on August 19. It had picked up a lot of moisture over the Gulf of Mexico, and this led to torrential rain over the mountains of Virginia. In eight hours, 28 inches of rain fell on Nelson County, an amount that more than tripled the state's 24-hour record, which had been set in 1942 and has not been broken since. In other parts of the state, 14 inches came down during the night. Afterward, Camille turned eastward to emerge into the Atlantic near Virginia Beach on August 20.

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APPENDIX D: MEASURING WEATHER AND CLIMATE EVENTS

MEASUREMENT CONVERSIONS

1 inch equals 2.54 centimeters

1 centimeter equals 0.39 inches

1 meter equals 3.28 feet

1 kilometer equals 0.62 miles

1 square meter equals 10.76 square feet

1 square kilometer equals 0.39 square miles

1 hectare equals 2.47 acres

1 cubic meter equals 35.31 cubic feet

1 cubic kilometer equals 0.24 cubic miles

1 degree Fahrenheit equals 9/5 degree Celsius plus 32

1 degree Celsius equals 5/9 degree Fahrenheit minus 32

FUJITA F AND EF SCALES FOR TORNADOES

The F scale was created by Japanese American meteorologist Tetsuya Fujita in 1951 to classify tornadoes.

F0 40–72 mph (light)

F1 73–112 mph (moderate)

F2 113–157 mph (significant)

F3 158–206 mph (severe)

F4 207–260 mph (devastating)

F5 261–318 mph (incredible)

Half of all tornadoes worldwide are F1 or less. Only 1 percent of all are F5.

Over the years, the F scale has revealed weaknesses: (1) too much reliance on the estimated wind speeds, and (2) oversimplification of the

damage description. Fujita recognized that improvement was necessary. When the committee met to develop the enhanced Fujita scale, one point was made very clear: it must continue to support and maintain the original tornado database; in other words, there must be some conformity to the F scale that is listed in the database.

F Scale

F0 40–72 mph

F1 73–112 mph

F2 113–157 mph

F3 158–207 mph

F4 208–260 mph

F5 261–318 mph

EF Scale

EF0 65–85 mph

EF1 86–110 mph

EF2 111–135 mph

EF3 136–165 mph

EF4 166–200 mph

EF5 Over 200 mph

SAFFIR-SIMPSON SCALE FOR HURRICANES

Developed in the later 1960s by Herbert Saffir to quantify potential wind damage from hurricanes, and expanded in the early 1970s by Robert Simpson, director of the National Hurricane Center, the Saffir-Simpson scale is used to measure hurricane strength. Wind speed is the determining factor in the scale, but storm surges caused by wind are highly dependent on the slope of the continental shelf and the shape of the coastline.

Category 1 74–95 mph (minimal)

Category 2 96–110 mph (moderate)

Category 3 111–130 mph (extensive)

Category 4 131–155 mph (extreme)

Category 5 155 mph or more (catastrophic)

VOLCANIC EXPLOSIVITY INDEX (VEI)

To compare the magnitudes of volcanic eruptions, scientists have developed a volcanic explosivity index (VEI) in which each level is ten times as powerful as the previous level. The index measures eruptions on a scale of 0 to 8. The VEI of any eruption is based on the volume of rocks and ash that is emitted. A VEI of 1 could represent a Hawaiian eruption, a gentle oozing of lava with no violent activity; a VEI of 8, a very rare event, would apply to Toba, an Indonesian eruption of gigantic proportions that occurred 74,000 years ago. Krakatau of 1883 had a VEI of 6. Mount St. Helens of 1980 had a VEI of 5.

Glossary

absorption of radiation. Transfer of electromagnetic energy into heat energy.

adiabatic process. Temperature change in a gas or in air due to compression or expansion. No heat is gained or lost from the outside in the process.

advection fog. A fog that develops when condensation occurs within moist air close to the earth's surface.

acid rain. The presence of acidic elements in rain that tend to destroy plants and trees.

aerosols. Tiny substances in the atmosphere, so small that the slightest movement of air keeps them aloft.

air. The mixture of gases that make up our atmosphere.

air mass. A large body of air that has defined temperature and humidity characteristics. It may extend over thousands of square miles and be miles in depth.

air pollution. A harmful substance put into the atmosphere from the earth

albedo. The amount of solar radiation that is reflected by a part of the earth's surface, usually expressed as a percentage.

alcohol thermometer. *See* thermometer.

anemometer. An instrument for showing wind speed.

Antarctic Circle. The parallel of latitude at 66.5° south.

anthropogenic. Caused by human activities.

anticyclone. High pressure mass of air with winds circulating clockwise in the northern hemisphere or counterclockwise in the southern hemisphere.

Arctic Circle. The parallel of latitude at 66.5° north.

Arctic front. The zone of interaction between polar and Arctic air masses.

armada. A Spanish word meaning a very large group of warships.

Asian cyclone. A tropical cyclone or typhoon that occurs in Asia. *See* typhoon.

atmosphere. The gaseous envelope surrounding the earth, mostly consisting of nitrogen and oxygen, concentrated within an area 30 miles above the earth.

atmospheric pressure. The force exerted by the weight of the atmosphere on an area.

aurora borealis. Lights visible near the North Pole, caused by interaction between the sun's radiation and molecules in the earth's atmosphere.

automatic weather stations. Weather stations, often at sea, that record and transmit data to a central location for weather forecasting.

barometer. An instrument for measuring atmospheric pressure.

biosphere. The part of the earth system that contains all living things, in or on the land, in the atmosphere, and in or on the oceans.

blizzard. Violent winter storm that lasts for several hours or longer.

caldera. A steep-sided circular depression in the ground, the end result of a volcanic eruption.

carbon dioxide. Gas that is a byproduct of burning fossil fuels or biomass. It also occurs naturally.

Celsius scale. A temperature scale in which the freezing point of water is zero degrees and the boiling point is one hundred degrees.

Chinook wind. A very dry wind that flows down the eastern side of the Rocky Mountains.

chlorofluorocarbons (CFCs). Compounds used in refrigerators, aerosol products, and solvents. Now banned in many products because of their harmful influence on the earth's ozone layer.

climate. The average pattern of weather in a given area over a long period of time.

climate classification. Division of the earth's climates into a system of regions, each defined by specific climatic elements.

climograph. A graph that shows the monthly totals for two climatic variables such as temperature and precipitation.

cirrus cloud. A high-level cloud, stringy and layered.

cloud. A suspended concentration of water or ice particles.

cloud base. The lowest elevation where cloud particles such as water droplets or ice crystals can be observed.

cold front. At the boundary between two air masses of different temperatures and humidities, the cold front is the heavier of the two, so it pushes the warm air mass upward.

colony. A territory owned and administered by a colonial power, usually a European power.

condensation. A physical process in which water vapor is changed into a liquid, that may take the form of a cloud, fog, or dew.

condensation nucleus. A tiny substance in the atmosphere on which water vapor condenses to form a drop of water.

convection. Transference of heat in a gas or liquid by upward movement of the heated and therefore less dense part.

Coriolis effect. A force caused by the earth's rotation that turns air movements to the right in the northern hemisphere and to the left in the southern hemisphere.

cumulonimbus. A heavy and dense cloud with a substantial vertical component.

cumulus cloud. A cloud made up of a rising mass of air that can be found at any level in the lower atmosphere.

cyclone. An area of low atmospheric pressure with inwardly rotating winds.

D-Day. The day selected to launch a massive attack by sea from Britain to France near the end of World War Two.

depression. An area of the atmosphere in which sea-level pressures are lower than those of the surrounding region, often the early stage of a middle-latitude cyclone.

desert. An ecosystem with less than four inches of rain a year.

dew. Water that has condensed on things near the ground.

dew point temperature. The temperature at which a mass of air holds its maximum amount of water vapor.

diurnal. Daily.

doldrums. A belt of calm seas near the equator.

doppler radio. A radar tracking system that enables a meteorologist to determine the speed of a moving object.

downburst. Violent and damaging downdraft associated with a severe thunderstorm.

drought. When an area experiences rainfall levels significantly below normal.

dust storm. A heavy mass of dust in a disturbed air mass.

El Niño. The fluctuating warm temperatures of the equatorial Pacific Ocean that affect global circulation of air.

energy balance. Globally, the total energy input from the sun equals the total energy output.

equator. The parallel of latitude that is midway between the North and South Poles.

equinox. The moment in time when the sun is directly overhead at the equator.

evaporation. The change of a liquid into a gas.

eye of tropical cyclone. The clear and calm area inside the rotating wall of convective clouds.

Fahrenheit scale. A temperature scale where the freezing point of water is 32 degrees and the boiling point is 212 degrees.

fall equinox. When the sun is overhead at the equator in autumn. It occurs around September 23.

fertilizers. Substances added to soil to make it more fertile.

flash flood. A flood caused by heavy rainfall within a short period of time.

flood. A stream that overtops its banks and covers the surrounding area.

flood stage. A particular level on a stream at which flooding occurs.

fog. A cloud at ground level.

forecast. A prediction about future weather conditions.

frost. Small ice crystals that form on or near the ground when temperatures are below freezing.

Fujita scale. The method used for calculating the strength of tornadoes.

global energy balance. The balancing of solar short-wave incoming energy with outgoing long-wave energy from the earth

global warming. An overall increase in the earth's average surface temperature.

greenhouse effect. Absorption of long-wave radiation, especially by water vapor and carbon dioxide, and reflection of heat back to earth to raise ground level temperatures.

greenhouse gases. Atmospheric gases that absorb and reflect long-wave radiation, causing the greenhouse effect. The two most important gases of this type are water vapor and carbon dioxide.

green revolution. The use of new quick-ripening, high-yield plants for use in developing countries.

guerilla-type attacks. The use of individual soldiers or small groups of soldiers to carry out raids on enemy positions.

Gulf Stream. The warm ocean current that flows northward along the east coast of the United States.

hailstorm. Pellets of ice falling from thunderclouds.

heat island. An area within an urban zone that has higher temperatures than those of the surrounding areas.

Himalayas. A mountain chain on the border between India and China.

humidity. The amount of water vapor in an air mass, measured as a percentage of the maximum that it could carry.

hurricane. A North Atlantic or Caribbean tropical cyclone.

ice age. A geological period in which ice sheets covered much of North America.

iceberg. A mass of floating ice.

Indian monsoon. *See* monsoon.

insolation. The technical term for the energy that reaches the earth from the sun.

irrigation. Water that is taken to fields from ponds or streams.

isobar. A line on a weather map connecting places that have the same atmospheric pressure.

jet streams. High-speed air flows about 15 miles above the earth, usually running from west to east.

L'Anse Aux Meadows. A Heritage site on the island of Newfoundland where the first Europeans to reach North America lived.

La Niña. The fluctuating cold temperatures of the equatorial Pacific Ocean that affect global circulation of air.

latent heat. Energy being absorbed from the air during changes from water to water vapor and released to the surrounding air during changes back from water vapor to water.

levees. Embankments to prevent rivers from flooding.

mercury thermometer. *See* thermometer.

meteorologist. A person who understands, studies, and predicts weather conditions.

microburst. A very narrow downburst.

monsoon. A persistent seasonal wind with a change in direction from season to season, usually associated with the wind patterns to and from the Asian interior in relation to the Indian Ocean.

NOAA. U.S. National Oceanic and Atmospheric Administration.

nor'easter. An extra-tropical storm along the coasts of Atlantic Canada and from Maine to New York, frequently referred to by this name because its winds come from the northeast.

Norwegian school of meteorology. The group of meteorologists who discovered and used air mass theory in forecasting the weather.

Northwest Passage. The north shore of Canada, the shortest sea route to Asia from Europe, now no longer permanently covered by ice.

ocean conveyor belt. Another name for the thermohaline-driven global ocean current.

ozone. A gas in the higher reaches of the atmosphere, created both naturally and through photochemical reactions, that absorbs ultraviolet radiation from the sun, an activity that is vital to the preservation of life on earth.

ozone layer. A region of the stratosphere stretching from about eight miles to 25 miles above the earth that contains large concentrations of naturally occurring ozone.

permafrost. Permanently frozen areas of the earth's surface.

pesticides. Chemical substances used to destroy insects or other organisms that are harmful to growing crops.

photosynthesis. The process by which plants take carbon dioxide from the air and release oxygen into the air.

polar front. The front between cold polar air masses and warm tropical air masses.

precipitation. A general term for different forms of water that may either be falling from or held in suspension in the air. Included in this term are rain, drizzle, snow, hail, and ice pellets.

rain gauge. Instrument for measuring the amount of rain that has fallen.

relative humidity. *See* humidity.

Rossby waves. Planetary waves in the atmospheric westerly circulation, characterized by great length and amplitude.

Sahel. The dry southern part of the Sahara Desert.

Santa Ana winds. Hot and dry winds that come from the interior desert regions of California and pass over the coast mountains to reach the Pacific Ocean.

sensible heat. Heat that can be measured by a thermometer.

sleet. A mixture of snow and rain.

smog. Fog combined with smoke, a common problem in large cities.

solar constant. The intensity of solar radiation on one unit of area when it is at right angles to the incoming sun's rays.

spring equinox. When the sun is overhead at the equator in the spring. It occurs around March 21.

statistical average. A calculation made by adding a collection of numbers and then dividing the answer by the total number of individual items in the collection.

Stevenson screen. A shelter for housing such weather measuring instruments as thermometers.

storm surge. The temporary increase in the height of the sea at a particular location due to a hurricane or a strong wind.

stratosphere. The part of the atmosphere above the troposphere, from about eight to 30 miles above the earth.

sublimation. The change of ice directly to water vapor or vice versa without passing through the liquid phase.

subsolar point. A place where the sun's rays are perpendicular to the earth's surface.

summer monsoon. Inflow of air from the Indian Ocean toward the continental Asian low-pressure center.

summer solstice. When the sun is overhead at 23.5° north, at the Tropic of Cancer. It occurs around September 23.

tar sands. The rich oil-bearing sands of northern Alberta, Canada.

thermometer. An instrument that measures temperature by using the properties of either alcohol or mercury as they respond to heating.

thunderstorm. Sudden electrical discharges, usually from convective clouds such as cumulonimbus, followed by lightning, thunder, and rain.

Tibetan Plateau. The highest extensive elevation of land north of the Himalayas.

tornado. A violent rotating storm of small diameter, a twister, usually appearing as a funnel cloud extending from the base of a cumulonimbus to the ground.

tornado F5. The most destructive type of tornado.

tornado outbreak. A succession of powerful tornadoes occurring within a short period of time.

trade winds. Winds that blow from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.

tropopause. The boundary between the troposphere and the stratosphere.

troposphere. The lowest part of the atmosphere, extending upward from the earth for about seven miles.

trough. A layer of the atmosphere with low pressure.

typhoon. A tropical cyclone occurring in the western Pacific Ocean.

urban heat island. An area at the center of a city where temperatures are higher than they are in the surrounding areas.

volcanic eruptions. The ejections of masses of lava and other material from a volcano.

warm front. The transition zone between warm and cold air masses. The warm front is the lighter of the two, so it is pushed upward by the cold air mass.

water vapor. Water when it is in gaseous form.

wave cyclone. A mid-latitude cyclone, usually originating at the polar front.

westerlies. Winds from the west between the latitudes 35° north and 65° south.

wind chill. A temperature based on actual temperature and wind strength. It indicates the cooling effect of wind on exposed parts of the body.

winter monsoon. Outflow of continental air from the Siberian high to southeast Asia and the Indian Ocean.

winter solstice. When the sun is overhead at 23.5° south, at the Tropic of Capricorn. It occurs around December 22.

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A Student Guide to

Climate and Weather

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A Student Guide to

Climate and Weather

Cyclones, Hurricanes, and Tornadoes

VOLUME 3

Angus M. Gunn

GREENWOOD

AN IMPRINT OF ABC-CLIO, LLC
Santa Barbara, California • Denver, Colorado • Oxford, England

Library of Congress Cataloging-in-Publication Data
Gunn, Angus M. (Angus Macleod), 1920-
A student guide to climate and weather / Angus M. Gunn.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-313-35568-4 (set: hardcover: alk. paper) — ISBN 978-0-313-35569-1 (set: ebook: alk. paper) — ISBN 978-0-313-35570-7 (v. 1: hardcover: alk paper) — ISBN 978-0-313-35571-4 (v. 1: ebook) — ISBN 978-0-313-35572-1 (v. 2: hardcover: alk paper) — ISBN 978-0-313-35573-8 (v. 2: ebook) — ISBN 978-0-313-35574-5 (v. 3: hardcover: alk paper) — ISBN 978-0-313-35575-2 (v. 3: ebook) — ISBN 978-0-313-35576-9 (v. 4: hardcover: alk paper) — ISBN 978-0-313-35577-6 (v. 4: ebook) — ISBN 978-0-313-35578-3 (v. 5: hardcover: alk paper) — ISBN 978-0-313-35579-0 (v. 5: ebook)
1. Climatology. 2. Meteorology. 3. Climatic changes—Effect of human beings on. I. Title.
QC861.3.G86 2010
551.5—dc22 2009042256

14 13 12 11 10 1 2 3 4 5

This book is also available on the World Wide Web as an eBook.
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ABC-CLIO, LLC
130 Cremona Drive, P.O. Box 1911
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This book is printed on acid-free paper ∞

Manufactured in the United States of America

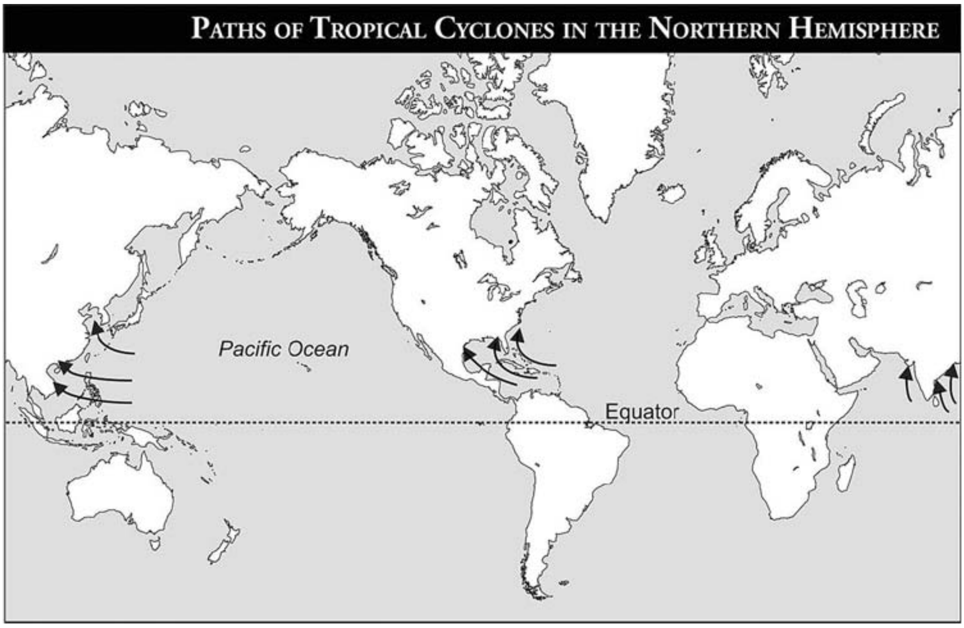
Contents

Introduction

This is Volume Three of a set of five books on weather and climate designed for schools and universities. These books are intended to provide two kinds of information, an understanding of the scientific processes at work in weather and climate, and an analysis of the ways in which weather and climate impact human life and the places where we live. The second of these goals is the more important of the two as there are a number of books in print dealing with the scientific processes involved in weather and climate but few on how weather influences our lives. Beginning in the first volume with aspects of the subject that impinge on us daily, such as the unpredictable nature of weather, we go on in the second and third volumes to deal with characteristic global weather patterns, before moving, in the last two books, into more general themes such as global warming and earth-sun relationships. A list of reference materials will appear at the end of each book to assist in linking together the different aspects dealt with in individual volumes.

Volume Three is all about the world's most violent and most destructive storms: tornadoes and hurricanes in the United States, cyclones and typhoons in Asia. Tornadoes and super outbreak tornadoes are a primarily U.S. feature, and they will be discussed later in relation to Chapters Six and Seven. This introduction begins with Asia, where storms take on proportions that go beyond anything we have known in North America from Atlantic storms. There are two reasons for the huge differences between the two places. The first is that many Asian storms, especially those in the Bay of Bengal, make landfall at a latitude of approximately 20° north instead of near the cooler waters of 30° north, at which storms make landfall in the southeastern United States. The second reason is the size of the land and ocean areas involved with Asian cyclones and typhoons, particularly the land close to the sea where millions of people live. Dominating both of these causal factors is the Indian monsoon, massive movements of air from sea to land in summer and in the reverse direction in winter.

By making landfall at 20° north, where temperatures are higher, the storms that reach land in Asia are carrying huge volumes of moisture. (The capacity of air to hold moisture increases with the temperature of the air.) Another factor is the influence of the area from which the



Tropical cyclones produce torrential rains and storm surges, often resulting in severe flooding and loss of life. (ABC-CLIO)

wind has picked up the moisture, which is nothing less than most of the Pacific Ocean and all of the Indian Ocean, together a stretch of sea that far exceeds the whole of the Atlantic Ocean. Eurasia (that is, Europe and Asia), because it is such a large area of land, controls the worldwide circulation of air. The air currents that traverse these oceans arrive at the shores of India heavily laden with moisture. The land is hot in the summer and fall seasons when the storms arrive, so the cooling and deposition of moisture does not happen until the air gets some distance inland. The result of all these factors makes for multiple tragedies, as will be seen in Chapters Two and Three, because it is in these areas close to the coast that the majority of south Asia's millions live and work. The storm tides, the winds, and the rain combine to cause enormous numbers of deaths. In addition there are both the advantages and risks of the Indian monsoon that usually arrives in southwest India in the month of June.

The Indian monsoon is described in detail in Chapter One. It is in every way the lifeline for most of India and its neighboring countries, because this part of the world is mainly an agricultural one. It is easy for people in the Western world, where most people earn their living in ways other than agriculture, to forget this. In India and in other Asian nations, if the summer rains do not arrive on time, or if there is too much rain, there can be either starvation because there is no rice harvest (unless governments provide emergency assistance) or floods. Floods have sometimes been due to natural causes (e.g., too much rain), but they have also come because governments have failed to do all they could to protect their people. The accounts of famine and flooding in Chapter Two illustrate both of these causal factors. Even China, the world's biggest country in terms of population, is mainly agricultural. We often fail to recognize this because of its huge level of manufacturing activity. Almost everywhere in our homes we see the words "made in China." However, only about a quarter of the people of China work in manufacturing industries.

TROPICAL CYCLONES IN ASIA AND THE UNITED STATES

The typhoons described in Chapter Four, which ravaged many parts of east Asia, reveal a mix of natural and human causal factors. It is the same story that is found in Chapter Five in the accounts of U.S. hurricanes, and it highlights a very serious problem, namely that tropical cyclones, whether cyclones, typhoons, or hurricanes, are becoming more costly each year. The reasons for this include that more and more people are moving to coastal areas or homes and that other buildings are being added to these areas. This is certainly true along the south and southeast coast of the United States, and it is equally true for many coastal locations in south and east Asia. Typhoon Linda did more damage to Vietnam than did any other storm within the previous 90 years. For a long time, in the United States, hurricanes were treated as natural events about which little could be done, and concerted efforts to minimize damage in future events of the same kind were not attempted. As is explained in Chapter Five, this kind of thinking changed when Hurricane Andrew struck Florida. It changed even more dramatically when Hurricane Katrina came, even though the main culprit in that disaster was the failure of the storm levees.

Hurricane Katrina was so destructive and so costly that it became the point of reference for every environmentalist and every leader who wanted the government to take new and adequate precautions to prevent future hurricane damage. Those advocates were convinced that future hurricanes would be increasingly more violent and more costly than the ones we have experienced. One research report that was published in *Nature* in 2007, however, does not support their view. Neither does meteorologist Dr. William Gray, one of the world's best-known hurricane experts. In a 2005 interview, this is what he said when asked if his prediction that there would be an increase in the number of Atlantic hurricanes over the next few years was based on global warming: "I am very confident that it's not. We have global warming. That's not in question. The globe has warmed over the last 30 years, and the last 10 years in particular, and it is true that there has been an increase in the number of Atlantic basin major storms." He went on to point out the following in support of his position:

> In an earlier period, such as from 1970 through 1995, even though the globe was warming, the number of major Atlantic storms was down, quite a bit down. Compare this with the other global storm

Costs of Hurricane Katrina

The significance of Hurricane Katrina in the history of the United States may best be seen when it is compared, see table below, with the deadliest and costliest U.S. natural disasters since 1900. It remains the costliest even when that list is expanded to include the costs of the September 11, 2001, terrorist attacks.

Top Disasters	Estimated Deaths	Estimated Damage (in billions of dollars)
Galveston hurricane, 1900	8,000	1
San Francisco earthquake, 1906	5,000	6
Atlantic-Gulf hurricane, 1919	600	1
Mississippi floods, 1927	246	2
Hurricane San Felipe, 1928	2,750	1
New England hurricane, 1938	600	4
Northeast hurricane, 1944	390	1
Hurricane Diane, 1955	184	5
Hurricane Audrey, 1957	390	1
Hurricane Betsy, 1965	75	7
Hurricane Camille, 1969	335	6
Hurricane Agnes, 1972	122	8
Hurricane Hugo, 1989	86	11
Hurricane Andrew, 1992	61	33
East coast blizzard, 1993	270	4
9/11 terrorist attacks, 2001	2,981	18
Hurricanes Charley, Frances, Ivan, and Jeanne, 2004	167	46
Hurricane Katrina, 2005	1,330	96

basins: over the last ten years their numbers have gone down and they always have had a far greater proportion of global storms that the Atlantic. In these other basins both in frequency and strength of storms their numbers have not changed. They have in fact gone down a little. Thus, if these factors related to global warming they should show similar changes everywhere. If I were to ask four or five of my colleagues who were around for some time they would all agree with me that global warming is not the cause when frequency of storms increase. I have to add that the people who disagree with me about this position turn out to be people who know very little about hurricanes; I would almost defend an equation like this: those who believe frequency of hurricanes is due to global warming are directly proportional to those who know little about hurricanes.

THE SPECIAL PROBLEM OF BANGLADESH

Bangladesh, whose deadly cyclones are described in Chapter Three, is a nation in the Bay of Bengal that present a unique meteorological situation and distinctive climate and weather problems. It experiences more destructive cyclones than any other Asian nation. Its physical location is the main cause of its troubles. Unlike all the other countries around it, Bangladesh has only a very small portion of its territory elevated significantly higher than sea level. Almost all of the country lies no more than one hundred feet above sea level, and extensive stretches of that low-lying land are less than 30 feet above the sea surface. On maps of Asia that show land elevation, Bangladesh is colored bright green, the color usually employed to show low-lying land. The reason for this low elevation comes from the country's position at the mouths of two great Asian rivers, the Ganges and the Brahmaputra. Their deposits of sand and soil over time created accessible areas of land, ideal for buildings and close to rich fishing grounds. These are deadly locations when cyclones strike.

In addition to the low elevation, there is the overall shape of the Bay of Bengal. It is a triangle, and its flows, whether water or wind, converge on the area of lowest elevation, the corner that is the coast of Bangladesh. Furthermore, as is the case with large river deltas all over the world, the water is shallow for some distance from shore, the result of accumulations of river deposits. Thus, with every cyclone that

Because Bangladesh is such a low-lying country, it is frequently overwhelmed by storm surges from the sea, causing destruction and death. (Department of Defense) arrives, even the weaker ones, the storm surge that may not have seemed higher than a few feet in deeper water rises in height as it nears the shore, and water crashes onto miles of low-lying land. Should a storm arrive at a time of high tide, large areas of land up to 40 feet high are quickly overwhelmed with saltwater.

Added to its physical elements is the fact that Bangladesh has been a very poor country for a very long time compared with its neighbors. It is a mainly agricultural nation whose residents live close to the sea in homes made from local materials. These homes cannot withstand the onslaught of cyclones with their powerful storm surges, yet people choose to live in these locations because they provide fertile soils for farming and ready access to the sea for fishing. It took a long time for international agencies to recognize the necessity of building shelters in low-lying areas so that lives could be saved even when their fields are destroyed. A glance at the significant reduction in casualties from cyclones following the provision of shelters, as noted in Chapter Three, will confirm the value of this action. There is one other feature of life in Bangladesh that subsequently became a model for poor countries worldwide. It is the World Bank's "bank for poor people." This institution was launched by a private foundation, then picked up by the World Bank because of its success. Small loans, the equivalent of $100, are made to individuals, enabling them to purchase materials for fabricating baskets and other craft-type products. As these things are sold, the loan is paid back. The repayment level has been so high that the model is now used elsewhere.

TORNADOES IN THE UNITED STATES

Chapters Six and Seven of this book are devoted to tornadoes because of their unique place in U.S. history as well as their profound and permanent impact on the lives of those who encounter them and are able to survive them. No other country in the world has anything comparable to the thousand or more tornadoes that hit the ground in the United States every year. Fortunately, the number of people who encounter a tornado is few, partly because these storms are concentrated in certain parts of the country and, even where they do occur, they affect a small area and do not last for a long time. Tornadoes are still deadly, in spite of the great advances that have been made in forecasting them. Greensburg, Kansas, was hit by an F5 tornado in 2007, and, though the town had a series of timed warnings of the approach of the storm, these were insufficient to prevent the deaths that occurred. A particularly tragic number of deaths occurred in 2008 when a scout camp in Ohio was hit by a tornado and several young people lost their lives. Both the camp's location and low visibility prevented them from receiving any warning signals.

The three tornadoes described in Chapter Six provide an overview of the U.S. experience with these storms from pre–Civil-War days right up to the present time. Improvements in forecasting and in warning systems are reflected in the great reductions in deaths over time. There is also a glimpse, not altogether a pleasant one, of life in the United States in the early 1800s. The Natchez 1840 tornado struck a flourishing town in the heyday of cotton plantations and heavy traffic on the lower Mississippi River. There were few warnings of an approaching tornado at that time until the noise and visible signs of it demanded immediate action to take whatever cover was available. This particular tornado is listed as the second most deadly in the recorded history of these storms, but historians are still trying to confirm or correct the given totals for the number of deaths. A different total may yet emerge, and Natchez may become the number one most deadly tornado ever when the total number of slaves who died is added. In 1840, slaves were recorded as property, not humans, and there is little doubt that many were employed around Natchez at the time of the tornado. There were some free blacks living in Natchez at the time of the tornado, and they would have been included in the given total of deaths.

Chapter Seven deals with tornado outbreaks. These are occasions when substantial numbers of strong tornadoes touch down in different places within a short period of time and within a particular weather system. This chapter includes information about the biggest outbreaks of the twentieth century, as defined by the tornado experts in Norman, Oklahoma. By far the biggest of all these was the super tornado outbreak of April 3–4, 1974. It included 148 twisters that touched down in 13 states. Before it was over, 330 people were dead and 5,484 had been injured along the 2,500-mile path the tornadoes had traveled. Xenia, Ohio, a town of about 25,000 people, suffered more than any other place from the super outbreak. It was shredded in less than ten minutes by a direct hit from a 300-mph twister. National records of this catastrophic event would never have been acquired were it not for the enthusiasm and hard work of Tetsuya Fujita, the Japanese American scientist who revolutionized our understanding of tornadoes, and who, by his discovery of the effects of microbursts, solved the mysteries of the planes that had suddenly crashed as they were about to land or take off. The Fujita scale he established for tornado strength is still in use.

In 1974, as soon as he learned about the outbreak, Fujita launched a nationwide effort to collect as much information as possible on every one of the 148 tornadoes. He had a large team search out and make contact with every person who had seen or been near any one of the tornadoes. Every photo that he could find of any one of the tornadoes he collected and placed in a special file for later study. His approach in relation to this outbreak was completely in keeping with his earlier work, to treat every tornado as a single intricate system in order to understand the behavior of a weather system carrying many tornadoes. Before Fujita arrived in the United States, meteorologists had been in the habit of examining only the weather systems within which the storms occurred. One massive storm from the 148 hit the suburbs of Cincinnati on the evening before the opening of the 1974 Major League Baseball season, and for a short time there was uncertainty over the prospects for the following day. Vice President Gerald Ford was to throw the first ball, and the game was to air on national television. In the days that followed the devastating events of the 1974 super outbreak, Fujita made a tentative prediction based on his first reading of the data he had collected: "An event of this magnitude will never recur within the lifetimes of those alive today. It may take 500 years for a repeat."

CHAPTER 1

The Indian Monsoon

The Indian monsoon is the greatest weather event of the world because of the amount of the Earth's surface involved. It is a global phenomenon, involving the biggest area of land on earth, the biggest ocean, and the two biggest nations in terms of population. It happens twice a year, and the number of people affected by it constitutes the majority of the planet's population. It should be called the Asian monsoon, because the monsoon that begins in India affects everywhere from the southern tip of India to the northernmost limits of China. Before India was an independent country, it was a colony of the British Empire, and it was the British who first used the word "monsoon" to describe these big seasonal winds that sweep northward across all of southern Asia.

This monsoon often brings torrential rains as the moisture-laden winds rise up over the land and release their moisture. They also bring floods, droughts, powerful storms, heat waves, and surges of cold air. The moisture released sustains crops, especially rice, which is the main

Weeks of very heavy rain follow the arrival of the Indian monsoon. (Samrat35/Dreamstime.com)

The Arrival of the Monsoon

In the ordinary daily life of the people of India, no annual event carries more weight than the day the monsoon arrives. For the vast majority of the rural population, their very survival depends on its coming on time. There is a buildup to it from January to May. There is virtually no rain in most places for these five months, and temperatures steadily increase from the high 70s to the low 80s. As the first 15 days of June come and go, expectation turns to anxiety if the forecast day for the monsoon passes and the sky is still a clear blue; those farmers who set out their rice seedlings on the strength of the forecast are deeply concerned.

Nothing is more depressing than a field of rice that was planted ahead of the monsoon, its vestiges of green gradually wilting, the farmer who planted the seedlings waiting for the rain that will bring life to everything and everyone. No visitor to India can understand the intensity of joy that comes with the rain as the monsoon breaks, first into a stream of light showers, and soon thereafter becoming a seamless flow of water that goes on day after day. Only after the rain has settled into a consistent pattern for a week or two is all anxiety removed. The farmer knows that the young rice plants are safely on their way to a golden harvest later in the year. There will be food for his family this year.

food supply for hundreds of millions of people. Year after year, twice in every year, in summer and in fall, the people of this vast territory depend on the monsoon, a term derived from an Arabic word for "season." The best way to understand this effect is to compare it with a land-sea breeze, the sort of thing experienced at a beach, where the land warms more quickly than the sea. As the hot air rises over the land, its place is taken by cooler air moving in from the sea. At night, the land cools at a quicker rate than the sea, so the wind shifts, blowing from the land to the sea.

Thus the two giants in the operation of the monsoon are a large area of land and a large ocean. The temperature differences between land and sea can be very large, especially at the beginning of the summer monsoon, as much as 70°F on the sea and well over 100°F on land. High differentials like these carry the risk of excessive moisture in the incoming summer monsoon and thus a danger of flooding. For this reason the summer monsoon is often referred to as the wet season, and the return flow of air in the fall is named the dry season. The summer monsoons roar onto the subcontinent from the southwest. The torrential rainstorms often cause violent landslides that may sweep away entire villages. However, the summer monsoons are welcomed in India. Farmers depend completely on their rains to irrigate their land.

We can get a vivid picture of a typical farmer's field before the summer monsoon arrives if we look at the temperature and weather statistics for the months before June in a hypothetical, typical year. Each of the five months from January through May has had a total of less than one inch of rain. The temperatures for the same period climbed from 76°F to 86°F, setting a scene of hopelessness from the point of view of farming just at the time of year when sowing or planting must begin if there is to be a harvest. It is easy to imagine the outlook of farmers under these circumstances, eagerly waiting for the monsoon, wondering if the forecasts are accurate. They know that, on occasion in their history, the monsoon was so long in coming that they could not plant and had to face starvation. When the rains do come, June brings 20 inches of rain to this hypothetical place, and July brings 24. It is an unbroken period of rain, lasting long enough for the rice plants to be firmly launched into their growth cycle.

FORECASTING THE MONSOON

The Indian Meteorological Department (IMD) issues many forecasts for the date when the summer monsoon's rain will first reach the southwest region of Kerala. The date of arrival is critical. A farmer needs to know when to plant. If he starts too soon on land that has been completely dry for weeks under a 100°F sun, he might lose all of his rice seedlings. Over the years the date of arrival does not normally vary a great deal, and there is good reason to expect an accurate forecast because of this rather than because of any confidence in their forecasts on the part of the IMD. This organization knows that it lacks some weather data that it would like to have. Thus, every year when the forecast is close to reality, there is widespread celebration throughout the country.

If a forecast is wrong by more than six days in any given year, the IMD gets a host of questions, and they take time to explain the uncertainties with which they always have to contend. The usual answer of the director is that there are many complexities in the Indian weather system: first of all, he points out, there are many forecasts involved, each for one region of the country; along with those there is an overall forecast of drought, normal, or excess moisture for the country as a whole, so that emergency measures can be in place whenever there is a serious danger of floods or famine. It is easy for people in the Western world to forget that large numbers of Indians are totally dependent on the crops they grow; they have no insurance from their government to care for their needs if the monsoon fails. In 2008, the first forecast was very positive. All the indicators pointed to normal rainfall. The maximum deviation from the forecast would be 5 percent.

The data that is lacking for the IMD forecasters relate to the vast stretch of ocean from which the monsoon winds come. There are few places in it where daily measures of temperature, wind speed, and wind direction are taken, hence little is known about the monsoon before it is close to land. A second limitation is the presence of the high mountainous regions in northern India and beyond, the Himalayas and the Tibetan Plateau, which act as a barrier to the free flow of air. It is difficult for forecasters to predict the behavior of the winds as they strike against this barrier. One thing is known: the highest rainfalls in the world occur in the middle reaches of the Himalayas. Cherrapunji, at five thousand feet elevation in the foothills of the Himalayas, is regarded as the world's wettest place because it has a total average annual rainfall of 450 inches. This is what we would expect when winds from a warm ocean are forced upward rapidly until they release their moisture.

In 2007, the IMD fared badly in its forecasts. Instead of the usual variation of 2–3 percent, there was an 11 percent error in relation to the date of the onset of the monsoon in the southwest. Any farmer who had gone ahead with planting on the assumption that rain would arrive within three or four days would have had a big disappointment and possibly a serious loss. The IMD was also wrong in its forecasts for 2004. The quest continues to find a model that would improve forecasts, and recently the IMD had a lot of success by combining several sets of data into one model that came to be known as an ensemble forecast. Different sets of sea level pressures and land temperatures were included in this ensemble. Instrumentation for securing better data banks is added every year by the nation's minister of science.

Examples of the new technological resources that are being put in place include automatic weather stations, Doppler radar stations, and buoys, all placed on platforms in key locations across the Indian Ocean. By the beginning of the year 2008, one thousand of these platforms had been set up. There is another area of need within the IMD: qualified meteorologists. The demand for these specialists is higher than the supply year after year. It seems that the attractions of other fields of science are greater. The more likely explanation for this shortage is the increasing demand for specialists all over India as the country develops. It is likely that other departments of government, like the IMD, also have demands that are not being met. Furthermore, it is no secret that India is a favorite destination when the United States is searching for scientists to meet its domestic needs.

RICE CULTIVATION AND THE MONSOON

The major food crop of this huge region is rice, and this plant is totally dependent on the monsoon. If the rains come too late, farmers will plant few or no seedlings, fearing a drought. If there is a lack of continued showers or breaks in the rain, plant seedlings may not survive. As the crops grow, later breaks or reductions in rainfall may limit the number and size of maturing plants and thus the size of the harvest. If the rains are too hard, young plants and seedlings can be washed away. It is a precarious existence, but if it works well, it meets essential human needs and stimulates the national economy. All these factors can increase the price or decrease the availability of publicly available rice. In today's economy, there is a need for surplus quantities of rice, because more and more workers are employed in industry and technology. There is also a growing tourism industry, especially in the south of the country, and this too makes demands on the rice harvest.

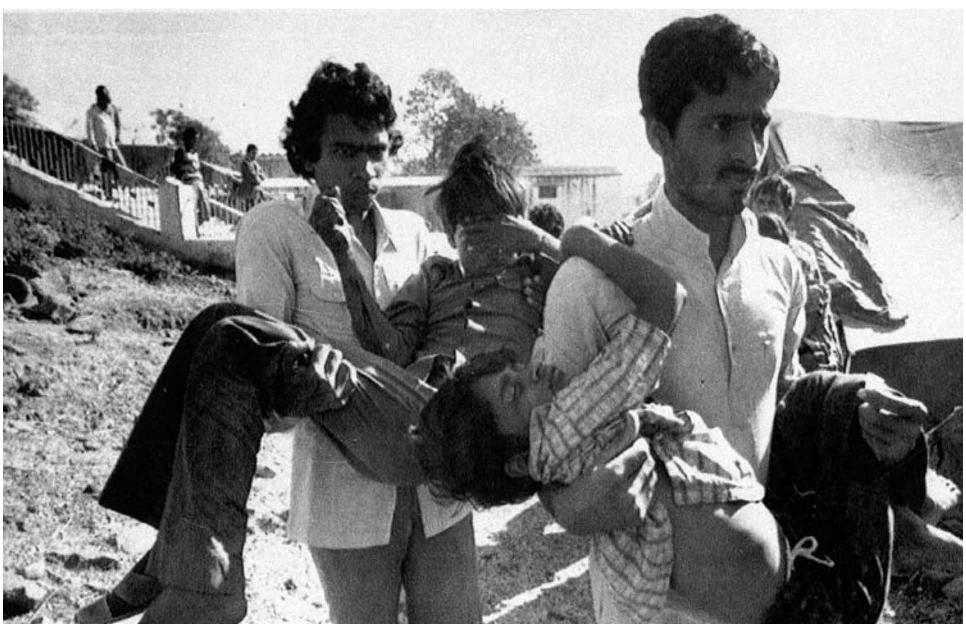
Transplanting rice seedlings. (Corel)

In the 1960s and 1970s, agriculture was strengthened by the green revolution. New varieties of rice that could increase productivity became available all across the country. New irrigation systems were installed to take advantage of the larger harvest that appeared. Nevertheless, the dominance of monsoon rain persisted, and Indians find themselves in the twenty-first century still dependent for most of their agricultural activities on the annual supply of rain from the monsoon. Use of fertilizers and pesticides helped, for a time, to increase still further the gains from the green revolution, and it was the demand for pesticides that led to the establishment of the ill-fated Union Carbide factory in Bhopal, a city in northern India. Farmers felt that they could do better if they cut back on their losses from insects and rats.

The Union Carbide plant opened in 1969, and for a time it proved to be very popular. The cost of the insecticide, even to small farmers, was offset by the greater gains they made in their harvests. Union Carbide had to ensure safety of storage for the poisonous substances used in the manufacturing process, and everyone in the government of India was satisfied with the safety precautions that had been put in place. There was less care, unfortunately, given to well-established rules that people should never live close to a factory that handles dangerous substances. The availability of low-cost housing near the plant persuaded officials to bend the rules because many of the workers could not afford to live at a distance and travel to work. Other less-developed countries have made the same mistake in industrial operations, and allowed workers to live close to the factory where they worked.

For about ten years all was well with the Union Carbide operation. The safety precautions worked satisfactorily, and the company's managers made sure that the Indian workers who had responsibility for the safety systems were thoroughly trained. In addition, because some of the company engineers from the United States left Bhopal to work in other parts of India, Union Carbide decided to pay the cost of sending Indian engineers to the United States for full training. This was well-received by the government of India, as it meant a no-cost addition to their nation of United States–trained engineers. By 1982 and 1983, everything in the operation of, and the training of staff for, the Union Carbide factory began to change because demands from farmers were dropping. They had discovered that the gains from the green revolution were so good that they could ignore the losses from rats and the insects. So they reduced their use of pesticides. Union Carbide began to implement cost-cutting measures. The length of time given to training Indian workers was reduced, and those who formerly had been trained as engineers in the United States were given shorter courses of training in Bhopal by company engineers.

In the middle of the night in December 1984, there was a leak of one of the poisonous substances used in the manufacturing process. It was caused by water accidentally entering the compartment where this substance was stored. The addition of water created a massive cloud of poisonous fumes that began to pour out into the surrounding community. A warning siren was in place to inform everyone in and around the factory that a leak had occurred, but, for some unknown reason, the night workers who should have switched it on failed to do



Injured children being taken to a hospital. Thousands were killed or injured during the Bhopal gas leak. (AP/Wide World Photos) so for an hour. By that time, the poisonous cloud had spread over an area of about 15 square miles, and thousands had already died in their sleep. Before the senior members of Union Carbide could take action to stop the spread of the poison, 250,000 people had been affected, one quarter of Bhopal's population. The victims of the tragedy experienced all kinds of symptoms. They included chest pain, breathlessness, pneumonia, and, for many, cardiac arrest. Those who lived at some distance from the factory suffered least.

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CHAPTER 2

Asian Famines and Floods

Tropical cyclones tend to be most remembered for the damage caused by wind. We identify them by their wind speeds, and this is appropriate because so much of their destructive power does come from this. However, when we think about cyclones, we tend to focus on North American cyclones—that is to say, hurricanes—where wind damage is often the main concern. It is a very different story when thinking about cyclones and typhoons in Asia, as has already been noted in Chapter One, and will be even more evident in the next chapter. These Asian cyclones occur in a very different environment, and their impact on human life is much greater. Furthermore, levels of development in many Asian countries are below Western standards: preparations for protection against severe weather are inadequate, and, worse, leadership fails at critical moments. The behaviors of Britain's colonial authorities and Myanmar's leaders are two examples of the worst of this kind of failure, about which more will be said in the next chapter.

MASS STARVATION OF INDIAN PEASANTS

In the summer of 1770, the northeast of India, a region we now recognize as Assam, Bihar, and Bangladesh, experienced a famine that affected the entire area. By the end of that year, ten million of the residents had died from starvation. The explanation given by the ruling authorities was that the tragedy was due to natural causes, but a closer examination of the circumstances associated with the sudden loss of rice, the principal food of the native people, revealed that the tragedy was due to two things: first, ignorance of rice agriculture on the part of the ruling authorities, and, second, removal of the basic necessities of life by the same rulers in order to export or sell the rice and make a profit for the British government. At this time in its history, Britain had no clear policy for its relations with colonial subjects other than to maximize its exploitation of local natural resources.

The East India Company was the ruling power in India at the time of the famine. Its work in that country dated from 1600, when the British government gave it the right to capture and control as much of India as it wished. Gradually, the company expanded its territory until it was the effective, if not the official, government of the whole country. Numerous trading posts were established along the east and west coasts, and a large number of people came from Britain to look after these trading posts. The largest ones were in Calcutta, Bombay, and Madras. A successful military campaign in Bengal in 1757 by the British leader Robert Clive, in which the local emperor was defeated, gave the East India Company complete control over the best and most extensive agricultural land in all of India. Plentiful supplies of water from the Brahmaputra and other rivers, coupled with extensive tracts of flat, rich, alluvial soils, enabled this part of India to sustain a high density of population. Summers were hot, ideally suited to rice cultivation. In addition, every summer brought the monsoon rains, high levels of rainfall that ensured adequate supplies of water for the paddy fields.

If the two causes of the tragedy are examined in more detail, the way that events unfolded becomes clear. The monsoon rains were always the key to successful cultivation of rice in Bengal. They arrived in onshore winds from the sea early in the hot summer months, and they persisted into the fall, when a reverse, cold, dry flow of air from the continental interior took their place. These gigantic movements of wind systems affected a much wider area than Bengal, and it often happened that climatic changes in more distant places delayed the arrival of the summer rains, even causing an almost total absence of rain in some years. Two years before the famine, one of these monsoon anomalies began to appear. In 1768, there was a partial shortfall of rain. As a result, there was a reduction in the amount of rice harvested, and in the following year there was even less rain and, therefore, a correspondingly smaller harvest. By September 1769, there was a severe drought, and alarming reports were coming in of rural hunger. Early in 1770, reports of widespread starvation began to arrive at the East India Company headquarters, and these were followed by news of a rapid increase in the number of deaths.

In the midst of the developing tragedy, local authorities maintained strict control over agricultural output. Their income depended on either the sale of the rice they demanded from the local small farmers or on the taxes they levied on the people producing the rice. However, the people who decided who would benefit from the harvested rice were unfamiliar with rice farming. They knew almost nothing about the vicissitudes of the monsoon rains, and they were equally ignorant of local customs, including the traditional ways of dealing with years of drought. It was normal practice among the people of this area to store some rice from abundant harvests, because they knew that on occasion they would experience the kind of situation that developed in 1768 and 1769. They would have a reserve of rice to cope with bad years. The British rulers made no arrangements for some rice to be kept for emergencies. Worse still, they prevented the local residents from having such a traditional reserve. As conditions worsened in the early months of 1770 and the death toll mounted, the only response from the local authorities was that a natural disaster had occurred and nothing could be done about it.

It is even more astonishing that the leaders of the East India Company, educated people who had come from England, where humanitarian concerns for neighbors in distress was almost instinctive, could be so indifferent to the suffering that was taking place all around them. Instead of reducing demand on the harvest of 1769 and using all of it to provide emergency food supplies for the starving residents, they went in the opposite direction and increased the demand on available supplies of rice, while continuing to increase the tax on the harvested rice. All the authorities cared about was the need to demonstrate to the British government that they made a profit. If natural conditions reduced the harvest, then, in their minds, the obvious thing to do was to increase the tax so that the profits would remain at a high level. That is what happened. From the beginning of their control in Bengal, the company had raised land taxes and trade tariffs up to half of the value of the agricultural produce. In 1770, with millions already dead from starvation, it raised these taxes and tariffs by 10 percent so that profits would remain high.

Famine was everywhere in 1770. Peasants tried to sell their possessions, even the plows and bullocks that they would need for their survival in the future. The price of rice, their staple diet, kept going up, and soon nothing that they could sell would pay for enough food. Children were sold to anyone who would buy them, and some of them ended up as slaves in European and Indian households. Conditions deteriorated to levels of desperation that give rise to cannibalism and, at the same time, to an increasing spread of disease. At first the starvation was in the rural areas, where the population as a whole depended on the rice crop. Then, as out-migrations accelerated, most headed for the colonial capital of Calcutta in the hope of finding relief there. There was little for them there, and soon the streets of that city were full of dead bodies. One or two members of the East India Company were so moved by the horror of the situation that they left the country and went back to England. Later, they recounted the events that had made such an indelible mark on their memories. They had seen human corpses mangled by hungry dogs and by jackals and vultures. When the situation became too great a danger to public health, the company employed a hundred men to pick up the dead bodies and throw them into the Ganges River.

As a result of the famine, large rural areas were depopulated and allowed to revert to natural jungle. Many cultivated lands were completely abandoned. Bengal, formerly the richest part of the nation, became destitute, and the East India Company was no longer able to maintain its formerly profitable status. The British government appointed a governor-general to take charge and replace the company's authority. The famine had taken the lives of ten million peasants, about one third of the total population of Bengal. The total may have been much higher. There had never been a census of the population, and only the painstaking work of researchers in later years made it possible to confirm that the death toll was at least as high as ten million. The famine ended as quickly as it had begun. By the end of the year 1770, substantial rainfall ensured a plentiful harvest. The whole desperately tragic event needs to be placed in the context of previous and subsequent famines in India. Altogether there were about 25 big famines in different parts of the country during the period of British rule, some in the far south and several in areas west of Bengal. Estimates for the total loss of life in all of these exceeded thirty million. None of them was as catastrophic as the 1770 one.

Famines were still present even in the final years before the country secured its independence from Britain in 1947. The last serious one came in 1943, in the middle of World War Two. Japanese forces had captured large areas of the south and the southeast of Asia, and they were advancing through Burma, at that time the largest exporter of rice in that part of the world. The British had encouraged the development of rice cultivation in Burma, and by 1940 was purchasing 15 percent of all India's rice from that country. Bengal, because it was so close to Burma, depended to a greater extent on Burma's rice. About one person in every four of Bengal's population relied on imports of rice from Burma. If anything happened to that source, there would be another famine. True to its former neglect of retaining resources to cope with possible emergencies, the British once again had nothing in reserve. What military authorities did do, and what proved to be more disastrous than anyone imagined, was to introduce emergency strategic measures all across the Bengal area. Large areas of rice cultivation near

A scene in northeast India during a 1943 famine. (Hulton Archive/Getty Images) the Burmese border were destroyed in order to slow down the advance of Japanese armies. They would be deprived of all local food resources. At the same time, almost all the rice available was transferred to other parts of India and other theaters of war. The residents of Bengal were told that they had to cope with less rice because so many of their agricultural areas had been destroyed.

In October 1942, the whole east coast of Bengal was hit by a powerful tropical cyclone. Areas of land as far as 40 miles inland were flooded. The fall crops of rice were washed away and lost. Small quantities of what was already a reduced harvest, the part of the harvest that always had to be retained as seed for planting in the months of winter that followed, had to be consumed for food. As the hot weather of 1943 arrived and there was nothing to eat because nothing had been sown in the winter growing season, famine appeared, and before the year was out four million had died. The military authorities had made no provision for food emergencies. Furthermore, all the military commanders in that region were concentrating on the war and gave little attention to domestic issues. The government of India tried to get help to the stricken areas, but no one seemed to care in faraway Britain at a time when World War Two was at a peak of activity. Subsequent records of rice production for the year 1943 revealed that there was enough available to prevent starvation, if only the military commanders had chosen to divert supplies of rice to the impoverished peasants.

In the late 1990s, Indian author Amartya Sen was awarded a Nobel Prize in economics for his studies of the Bengal and other famines in India. His conclusions were a damning indictment of British administration in India. He showed that rice production in India during the years 1941–1943 were pretty much normal and were sufficient to provide food for everyone. The totals each year varied only slightly from the normal: 1940, 8 million tons; 1941, 7 million tons; 1942, 9 million tons; and 1943, 8 million tons. Sen was convinced that the 1943 famine was caused not by a shortage of rice but by the removal of supplies from the stricken areas to meet the needs of fighting troops. His thesis went on to show that, although malnutrition and hunger remained a common condition in India, no major famine occurred in the 50 years following independence. Yet, in those years, 1951–2001, the total population grew from 360 million to more than a billion. By contrast, in one 50-year period of British rule, 1891–1941, the population grew from 287 million to 389 million. Sen selected the 50 years beginning in 1951 because the immediate aftermath of independence led to considerable strife and disruption of agriculture.

FLOODING IN CHINA, 1998 AND 2008

Severe flooding along China's Yangtze River in 1998 was one more in the long succession of floods with which the country is familiar. Millions of people were driven from their homes by floodwaters, and many more were threatened with inundation if the dikes and levees along the river give way. Wuhan, a major industrial city with a population of more than seven million people, was one center in imminent danger. More than two thousand people were killed in the early days of the rainy season that began in June, mostly because of landslides and mudflows. Five million homes were destroyed, and 14 million people had to move to safer ground.

Many of the homeless lived in makeshift shelters dependent on the government's food aid. There were constant fears of disease outbreaks such as cholera as a result of the lack of clean drinking water, and from such causes, as well as from the danger of more landslides, there was a likelihood of additional deaths. In addition, the failure of a levee on the Yangtze 50 miles upstream from the city of Wuhan in Hubei Province had a huge death toll. These circumstances were not a case of one rare tragedy. Rather they are representative of the frequent occurrences of flooding that beset China. The account of similar events in 2008, later in this section, emphasizes this reality. It is why the Chinese named the Yellow River their "River of Sorrow."

The government of China issued a state of emergency when, in the midst of all that had already happened, some additional failures of embankments occurred on the Yangtze: in the words of the New China news agency, "The Yangtze is threatening to break its banks in more than 3,000 places, most of them major breaks." In the wake of this threat, 330,000 people were evacuated by the government, sometimes forcibly, from a huge tract of rural land in order to use the area as a flood control measure. Engineers prepared to dynamite levees and open floodgates in this area in order to divert the raging floodwaters and thus safeguard cities farther downstream.

The scope of the flooding is staggering. According to government sources, more than 240 million people, nearly as many as the total population of the United States, have been affected either directly or indirectly. There is general consensus that these 1998 floods were the worst since a previous disastrous flood in 1954 that claimed the lives of 30,000 people. There is also general agreement that the main cause was the early and heavy start of the rainy season. Although most of the damage occurred in the valley of the Yangtze, warnings were sent to officials in the other great river region, that of the Yellow River, urging them to be on alert for possible flooding there.

The danger overall was far from over, as meteorologists predicted between five and seven typhoons would hit China over the following three months. These storms would intensify the danger of flooding, particularly in coastal areas. At the same time, many questions were being asked about the role of human activity in the flooding. Villagers wanted to know if flood-prevention measures were being undermined by Beijing's drive toward privatization and a market economy. Those villagers who were forced to leave flooded areas condemned local bureaucrats for stealing funds that had been provided for the maintenance of levees and dikes.

Another major factor in the flooding is the silting up of the Yangtze River itself. Poor farming techniques, deforestation, and poor land management have resulted in huge quantities of topsoil being washed away into the river system. By raising the level of the riverbed, the silting makes the river system more prone to flooding. Officials in Fujian Province, near the coast, insist that floods should not keep repeating every ten years under natural conditions. They are convinced that frequent flooding is caused in part by the dumping of construction waste from railway, dam, and road projects into waterways.

A number of Chinese scholars have pointed out that what the present government is doing in flooding rural areas to protect cities farther downstream is similar to the behavior of the old Chinese emperors: with callous indifference for the lives of their subjects, they used to open up the dikes in rural areas to save their palaces in the cities. Whatever the degree of human involvement in Chinese floods, the reality of their recurrence is plain to see. In June 2008, ten years after the disastrous 1998 flooding, weeks of rain once again pushed rivers over their banks in parts of southern China, disrupting the lives of more than a million people. About 170 people from 20 provinces were killed as a result of the flooding, and damages amounted to as much as $1.5 billion.

Raging rivers collapsed tens of thousands of homes, damaged crops across more than two million acres, with most of the destruction taking place in the lower reaches of the Pearl River, in the province of Guangdong, close to Hong Kong. Banana trees were almost swallowed up by the muddy, chocolate-brown waters of the Xijiang River that overflowed its banks. Farmers dropped their plows and waded into the neck-high waters with nets to catch fish. The Beijiang River, which joins the Xijiang near the city of Foshan, swallowed a neighborhood

A flooded area in Guangdong Province, China. (AP/Wide World Photos) that had been home to about one hundred people. People reported that water appeared so quickly that by noon on the first day of flooding all the homes were swamped.

There were no signs in the area of large encampments of displaced people, as this area is a large manufacturing zone. Residents in high-rise buildings moved to higher floors, including on rooftops under tarpaulins. Guangdong province is often called the world's factory floor because it is home to hundreds of thousands of manufacturers that churn out toys, computers, iPods, sneakers, and a myriad of other products for the global market. State television showed troops in boats rescuing stranded people, bailing water, and hastily filling sandbags to shore up dikes.

For China in a year when its focus was on hosting the Summer Olympics, this flood was the nation's third major natural calamity of 2008. In February, a series of unexpected blizzards paralyzed several southern provinces. Then came the earthquake in Sichuan province that killed nearly 70,000 people. That province struggled for a long time as it tried to cope with devastation that affected every major high-rise building. The Guangdong flood took a particularly heavy toll on the country's food supplies. This region is a large producer of rice, fruit, and vegetables, and flood damage included the destruction of two million acres of these crops as well as the displacement of more than a million people. It was the worst flood in this region in 50 years.

CHAPTER 3

Bay of Bengal Cyclones

The Bay of Bengal has long been the center of devastating Asian cyclones. They strike land from this bay, always with high death tolls. In the events described in this chapter, which affect Bangladesh in particular, but also its neighbors on both sides, we see examples of the terrible outcomes that occur again and again in this part of the world. The fundamental environmental conditions of the area, as was noted in the Introduction to this volume, are the reasons for the unavoidable tragedies that occur. Much is being done to minimize the high number of deaths. Over the long period of time for which we have records, other factors besides the local environment have affected the number of deaths and the extent of damage. In the case of the 1970 cyclone, for example, the tragedy occurred when the country was about to enter a terrible civil war. Because of this, it is unlikely that much attention was paid to the needs of the people whose lives had been devastated by the event.

While this whole region was a colony of Britain, repeated acts of incompetence or even deliberate neglect of starving people caused huge increases in the number of deaths. We saw the terrible consequences of these attitudes in the 1770 famine described in Chapter 2. In modern times, too, we saw examples of government incompetence when Myanmar was hit with a cyclone in 2008. The government's military leaders in that country could have done much more than they did for the people who suffered from the cyclone. In this chapter, we will examine the behaviors of the Bay of Bengal cyclones, most of which devastated Bangladesh while inflicting much damage on its immediate neighbors before and during the twentieth century, and more recently within the present century.

INDIA CYCLONE, 1864

On October 5, 1864, most of the city of Calcutta, India, was flooded and destroyed by a cyclone. Sixty thousand people were killed at once, and many thousands of others died later from the diseases that followed. The cyclone crossed the east coast of India south of the Hooghly River, one of the branches that constitute the delta of the Ganges River, shortly after 10 AM. As it entered the narrowing waterway, the water level rose until it became a towering 40-foot-high wall.

Its height had been raised to a maximum by the arrival of a high tide before noon on the same day. Everything was washed away in its path as the water swept inland. In the months that followed, the city, the surrounding area, and the harbor had to be rebuilt.

Different parts of the world have different names and different definitions for the storms they experience. In Asia, a storm with speeds less than 39 mph is called a tropical depression. If the circulating speed is above 39 mph, it is named a storm, and, if the speed is above 73 mph, it is classified as a cyclone. The meteorological conditions in India are very different from those in the Caribbean. Winds are stronger, rainfall is heavier, and preparations for weather extremes were almost non-existent in the nineteenth century. Hence there are records of huge losses of life and widespread damage to buildings from that period of history. Even today, as was seen when the Indonesian tsunami of 2004 struck India, many lives can be lost if preparations for coping with disasters are inadequate. A comparison of the Caribbean and southeast United States storm environment with that of India helps to explain why India's storms are enormously destructive.

The first thing to note is the temperature difference. India lies south of the Tropic of Cancer, whereas the southeast United States is north of it, so water temperatures are generally higher in the waters around India. The winds are therefore able to carry greater volumes of water vapor at any given time, and if they move over land, they bring high levels of rain. In the areas around Calcutta, especially in the mountainous regions north of it, the highest rainfall records in the world are found. Cherrapunji is a community three hundred miles northeast of Calcutta and four thousand feet in elevation. It holds the world record for being the wettest place anywhere. Its average annual rainfall is 450 inches, but many years have totals far above that figure. Calcutta's rainfall is much less than Cherrapunji's, even though it experiences the same winds, because its elevation is close to sea level. The second thing to note is the huge expanse of the Indian Ocean compared with the Caribbean and the equally massive extent of the land mass north of India. The air masses that build up over these areas are larger and denser than we find over either the Caribbean or the United States, and hence their winds are stronger when storms or cyclones form.

In the 1864 cyclone, numerous ships in the waterways of the Ganges delta were destroyed, and many thousands of Indians lost their lives. This part of India will always be at risk as the huge air masses that move over it create storms and cyclones. In addition, as we saw in Chapter One, the monsoon rains from southern India reach this part of the country. Although they do not carry high winds, they do have continuous periods of rain that flood low-lying places. No one complains about the monsoon. It is the lifeblood of agricultural India. Its benefits are felt all over the country. The rain it brings has sustained a human population that today numbers close to one billion. If these rains are delayed for any reason—and sometimes this happens, due to the unusual behavior of air masses—the results can be disastrous. Many of the accounts of famines in India are related to a major delay in the arrival of the monsoon rains. For various reasons, often because forests were cut down, the ground does not preserve much of the water that comes in the wet season. Even in Cherrapunji there is an inadequate amount of water in the dry season, and people have had to travel great distances, on foot, to find clean drinkable water.

In addition to their unfamiliarity with India's physical environment, British colonial officers had to cope with the limited knowledge of meteorology when they encountered cyclones. Temperature and pressure measurements and reports from ships at sea constituted almost all of their available data, and the ships at sea in 1864 were often sailing ships. Powerful cyclones could completely destroy both ships and their cargoes, so captains were always eager to detect approaching storms and report their findings to shore by wireless telegraph. One vessel, the *Proserpine,* was caught in the 1864 Indian storm as it made its way out of port and found itself in the spiral winds of the cyclone almost two hundred miles from its center. Within an hour of entering the storm area, the captain of the *Proserpine* discovered that the winds were too strong for his ship, even though it was a steamboat, so he just let it be carried along under the force of the winds. Three hours later he noted that the winds had greatly increased in strength, perhaps because his ship had been drawn further into the storm area. The ship began to roll violently, and the engine room started filling with water.

Over the following six hours, every member of the ship's crew was busy pumping out water. At the same time, everything that could possibly be spared was thrown overboard in order to make the ship as light as possible and so minimize its resistance to the waves that swept over it. In the hold there was a quantity of wooden beams, part of the cargo, and they too would have been thrown overboard if they had been lighter to move. As the ship lurched backward and forward, the cargo of beams also moved, and the captain was afraid that they would make a hole in the ship's hull. Twenty-four hours after their first encounter with the storm, the *Proserpine* entered calmer water beyond the storm. It had barely managed to stay afloat. Everyone was exhausted after all the hours of pumping out water. They could imagine conditions in and around Calcutta when such a powerful cyclone reached land.

BANGLADESH CYCLONE, 1876

The city of Chittagong stands near the Bay of Bengal at the southern extremity of Bangladesh. It is often a target of cyclones because of its closeness to the sea, and in 1876 a storm made a direct hit on it. At least 200,000 people in Chittagong and its surroundings died. The storm swept inland up the Meghna River, part of the Ganges River delta. As the surge of water moved upstream into the shallower and narrower stretches of the river, it rose in height until it became a monstrous wall of ocean water, 30–40 feet high. Bangladesh had to cope once more with one of these cyclones that come annually, either during the northward movement of the monsoon or when it is returning southward as the Asian land mass cools. It seems that these turning points, because they represent a mixing of the two contrasting wind systems, trigger the cyclones. The impact of this cyclone in 1876 was devastating in every way. A hundred thousand people drowned and another hundred thousand perished from disease or famine.

There is, initially, an accumulation of water in the various small sea inlets along the coast as the cyclone pushes water toward the land. This is a slow process because the Bay of Bengal is quite shallow for a distance of several miles outward from the land. Other factors, in addition to the depth of the ocean, determine the rate at which water accumulates. A spring tide, a higher than normal level of tidal water, if it were to coincide with the arrival of a cyclone, would greatly increase the breadth of destruction because tidal waters influence the entire shore. This coincidence occurred several times in the recent past, fortunately with less loss of life, presumably because disaster preparedness was greater than in 1876. The wind strength of the cyclone and the angle of impact with the shore are two other factors that influence the amount of destruction.

Bangladesh seems to have received more of the types of cyclones that result in high death rates than has any other coastal nation in all of Asia. One physical factor in the environment of Bangladesh may be a contributing cause: the country's overall low elevation makes it easy for relatively small storms to transform its coastal area into a vast sea. With regard to the future, scientists have debated the implications of global warming with respect to the nature of cyclones in the Bay of Bengal. The only tentative conclusions arrived at to date are that sea temperatures will increase and these cyclones, as a result, will likely be more intense and therefore more destructive.

Future Hurricanes and Global Warming

Will hurricanes be more frequent and more violent in the future because of global warming? A 2007 article in the scientific journal *Nature* points out that the average frequency of North Atlantic major hurricanes decreased gradually from 1760 to the early 1990s, that the number of major hurricanes was exceptionally low during the 1970s and 1980s, and that they have increased since 1995.

Meteorologist Dr. William Gray, one of the world's most famous hurricane experts, was asked in 2007 if global warming was the reason for the present increase in the number of hurricanes. His answer was a definite no, because, as he explained, although the number of Atlantic hurricanes has increased, the number of such storms has decreased in other ocean basins. While recognizing that global warming is a reality, Gray insisted that other factors are involved in determining hurricane frequency.

When asked if his view was a personal one, and not shared by other meteorologists, Gray said that he thought that most experienced meteorologists would agree with his views. He added that the people who connect frequency of hurricanes with global warming are almost always people who know very little about hurricanes. His final observation was that there is a tendency to explain every continuing change in weather as being due to global warming.

During the second half of the twentieth century, most of the world's total death toll due to tropical storms occurred in Bangladesh. This includes the single most deadly cyclone of all, the 1970 event that we will examine in the next section of this chapter. Of the ten deadliest tropical storms in world history, eight have occurred in the Bay of Bengal. Each had over 100,000 fatalities attributed to it. Once, when Bangladesh was overwhelmed by a powerful cyclone, officials described the destruction as being due to an earthquake. It was only much later that they realized the actual cause, so strong are the similarities between an earthquake and a cyclone. In the United States, when a storm surge struck New York in 1938, seismographs as far away as Alaska registered it as an earthquake.

BANGLADESH CYCLONE, 1970

High tidal waves and tropical storm surges constantly strike the northwest shores of the Bay of Bengal around the deltas of the Ganges and Brahmaputra rivers. The one that struck on November 9, 1970, surpassed all the others in terms of fatalities. It was the worst tropical cyclone disaster in history. The area receiving the main thrust of the storm was Bangladesh, known in 1970 as East Pakistan, and estimates of the death toll ranged from 350,000 to 550,000. It is an indication of the poor level of local administration that the figures had to be given as somewhere within a very wide range. At the time of the cyclone, tensions were building up between East and West Pakistan because the eastern half was losing out economically and poverty was widespread. Within four months of this storm, the two parts of Pakistan would be at war, leaving little hope for effective reconstruction after the storm. East Pakistani political leaders were very critical of the government's response to the storm and relief efforts following it. In the aftermath, the split between East and West Pakistan grew and soon deteriorated into the Bangladesh Liberation War in March 1971, which concluded with the creation of an independent Bangladesh.

The 1970 cyclone formed over the central Bay of Bengal on the morning of November 8, likely from the remnants of a tropical storm that arose in the South China Sea then moved west over the Malay peninsula on November 5 into the Bay of Bengal. The system headed northward as it intensified. India's Meteorological Department upgraded it to a cyclonic storm on November 9, and to a severe cyclonic storm two days later. As it approached the East Pakistan coast, the storm had a central pressure as low as 950 millibars, and it carried sustained winds of 115 mph, making it a Category 3 hurricane. It made landfall near Chittagong during the evening of November 12 about the same time as the day's high tide. The Chittagong meteorological station, located 59 miles to the east, recorded sustained winds of 89 mph. A ship in the port reported a gust of 138-mph wind. The storm pushed a 33-foot-high surge across the Ganges delta into Chittagong.

The surge and winds killed all those living on 13 islands near Chittagong and nearly 18 percent of the residents in the directly affected region. The southern half of Bhola Island was completely devastated, as were the rice crops on that island, Hatia Island, and the nearby mainland coastline. Survivors claimed that 85 percent of the area homes were destroyed or severely damaged. Approximately nine thousand marine fishing boats were lost, and 60 percent of the 77,000 onshore fishermen died. Fish were the major source of protein for the local inhabitants, and the loss of nearly two thirds of the fishing industry was a severe blow to this impoverished region. Agricultural production sustained similar damage due to loss of crops and the deaths of 280,000 cattle. The whole area hit by the storm is low-lying, only a few feet above sea level, so destruction was total. Places just vanished. Bamboo dwellings were carried away and their sites replaced with masses of mud.

The low earth barriers that marked off rice paddies and homes provided no protection against the flood of water. Survivors tried to hold onto palm trees until the storm passed. Warnings of the approaching storm had been issued, but there was no way of communicating them to the many living on islands and more distant coastal areas. Large numbers were asleep when the storm surge reached them, and they had no chance to escape. Because so much of the land is close to sea level, one quarter of East Pakistan's total land mass was underwater for a time. Once over land, the storm began to weaken, but it was still considered a cyclonic storm on November 13, when it sat about 65 miles to the southeast. As news of this disaster reached the outside world, relief began to arrive from both nearby and distant countries. Ferrying in supplies to remote locations by air and rescuing those needing medical attention helped save many, but the scale of the disaster was too big to reach all who were in need. Starvation, exposure, and disease kept adding to the death toll.

An unknown number of fishing vessels were washed out to sea. More than a million acres of rice paddies were lost, with their crops of rice only two weeks short of being harvested. The storm's damage estimate came to $86.4 million. The true death toll will never be known; many bodies were washed out to sea or buried in the delta. It is likely that a large number of migrant workers were not included in the fatality lists. The reaction of Western aid agencies is often to recommend introducing methods that would be considered desirable in, say, the United States or Europe. For developing countries that have very little financial resources to do more than the minimum amount of defense against the next cyclone, much simpler and quicker approaches are needed. The establishment of the "bank for poor people" described in the Introduction to this volume is a good example of the kind of instant, yet valuable, action that can be effective in such places.

Fortunately for Bangladesh, someone suggested building simple shelters that could serve as brief safe locations when the next cyclone struck. They could be erected quickly, using local material, and as long as they lasted for a short time following the next cyclone, they would

Bangladeshi survivors of a cyclone and storm surge receiving food aid by air. (AP/Wide World Photos)

have done their work. Over the years that followed this decision, many new shelters were added annually, most of them paid for by the World Bank. It is possible to see their value in the statistics of death tolls following subsequent cyclones, as long as comparisons are made between cyclones of comparable strengths. Each shelter was designed to house about a thousand people. By the 1990s, sufficient numbers of shelters were in place to house about two million, a valuable help, yet not yet sufficient to care for a coastal population of several million. In 1972, the World Meteorological Organization launched the Cyclone Preparedness Program in Bangladesh in order to raise public awareness about cyclones. This organization provided training for local people who had been designated as emergency workers.

BANGLADESH CYCLONE, 1991

Each one of the cyclones included in this chapter is selected for its uniqueness in helping us understand the extraordinary way of life that the people of Bangladesh have lived for many generations. The Bangladesh cyclone of 1991 was huge both in terms of size and wind strength. On the list of the world's deadliest tropical storms, it ranks ninth. It took nearly 140,000 lives when it struck the Chittagong district of southeastern Bangladesh. It had been spotted a week earlier as a tropical depression, and over the following two days its size expanded until it covered the whole of the Bay of Bengal. Day by day its strength increased as it grew into a tropical storm, a cyclonic storm, and finally, on April 29, into a Category

5 cyclone with sustained winds of more than 160 mph. As it reached shore, a wall of water 20 feet high broke over a wide stretch of shoreline.

The combination of high storm winds and high storm surge did a lot of damage over a lot of shoreline areas. A concrete levee erected near the mouth of one stream in the delta to protect against storm surge was washed away. A one-hundred-ton crane was lifted off its stand and thrown against a bridge. In all, a million homes and many boats in and around the Chittagong harbor were destroyed. The Bangladesh Navy and Air Force have bases in Chittagong, and these were severely damaged by the storm. The human cost was most visible in the ten million who were left homeless. Material losses were estimated at $1.5 billion. Mortality was greatest within two groups, those under ten years of age and older adults, and the cause of death for most was drowning.

There were many storm shelters in place when the cyclone arrived. They had been increasing in number each year since the 1970 cyclone. In spite of this, there were many failures in using them. Large numbers of residents could not find them. There were many reasons for these failures, not least of which is the unpredictability of the storm's path, direction, and power. Many residents received the storm warnings only a few hours before it hit. Some who did not seek the shelters reported that they refused to believe the storm would be as bad as had been forecast. From all of these reports it became clear that the 1972 Cyclone Preparedness Program had to undertake a lot more educational and training activities if the shelters were to serve the purpose for which

A coastal area of Bangladesh after the 1991 cyclone and accompanying storm surge. (Department of Defense) they were provided. Although as many as two million did reach shelters, almost half of the shelters failed because of unexpected flooding.

BANGLADESH CYCLONE, 2007

In the early years of the twenty-first century there were few destructive cyclones. The one that came in 2007 was the first to cause many deaths and much damage. As many as 15,000 were killed and seven million others were devastated in different ways. The widespread destruction included a great deal of damage to the mangrove forest UNESCO world heritage site. This cyclone arrived with sustained winds of 150 mph, and homes were shattered. Three thousand bodies were later recovered from these homes. Parents were seen tying their children to trees for safety. An international relief effort was quickly assembled with contributions from the United Nations, Britain, the United States, and the European Union. In the worst affected districts, virtually all fish stocks, such as prawn farms, and all rice crops were obliterated. Fallen trees and flooded roads seriously impeded the work of relief teams as they sought to reach coastal villages. Sometimes elephants were used for clearing away the heaviest debris.

This cyclone rates low on the list of deadly Bangladesh tropical storms, but its death toll was still high, initially estimated as 3,500 but later raised to 10,000. These are very large casualty figures indeed when we compare them with some of the worst tragedies from storms in the United States, such as Hurricane Katrina. From the point of view of its winds, however, which peaked at 160 mph, this storm was the second-strongest tropical storm to hit Bangladesh since reliable recordkeeping began in 1877. Only the 1991 storm carried more powerful winds. Both the 1991 and the 2007 storms were rated as Category 5 cyclones, and the total money value of the damages caused by the 2007 storm came close to $2 billion. The single unique feature of the 2007 storm was the damage it did to the Sunderbans, the mangrove forests of the Ganges delta, a result of the location where it made landfall, near the western border between Bangladesh and India.

It made a direct hit on the Sunderbans, a nearly uninhabited portion of the coast and a UNESCO world heritage site. This greatly reduced the number of deaths that would otherwise have occurred. However, damage to the mangrove forests was extensive. Experts on this unique region feared that many animal species, including tigers, crocodiles, king cobras, monkeys, wild boars, and deer, were swept away by the storm surge or perished under the weight of uprooted trees. About 40 percent of the forest had been seriously damaged, and some suggested that it would take 40 years to recover. The government of Bangladesh, within one month of the end of the cyclone, launched an appeal to UNESCO for the equivalent of $145 to restore the forests. In support of their appeal, they took note of two dead tigers and several deer that were found after the storm.

Mangrove Forests

Mangroves are woody, specialized types of trees native to the tropics that can live where rainforests meet oceans. They are found on sheltered coastlines and river deltas, and they grow in brackish wetlands between land and sea where other plants cannot grow. They protect the coastline and prevent erosion by collecting sediment from the rivers and streams and by slowing down the flow of water. There are about 40 million acres of mangrove forests in the warm coastlines of tropical oceans all over the world. The largest area is found along the coastline of Bangladesh and northeast India.

These mangrove forests lie at the mouth of the Ganges River, forming the seaward fringe of the delta. The whole area is now a national park, singled out by UNESCO as a world heritage site. It is intersected by a complex network of tidal waterways, mudflats, and small islands of salt-tolerant mangrove forests. This area presents an excellent example of ongoing ecological processes. The area is known for its wide range of fauna, including 260 bird species, the Bengal tiger, and other threatened species such as the estuarine crocodile and the Indian python.

MYANMAR CYCLONE, 2008

A tropical cyclone struck the southwestern shore of Myanmar (formerly Burma) on May 2, 2008. The scale of destruction and loss was massive all along the coast northwest of Yangon (formerly Rangoon), and within a week there were reports of 133,000 dead or missing, with the government still doing almost nothing to aid the victims. More than two million people were affected, a million of them having lost their homes. The monsoon had reached the area, and the rainy season had begun to intensify. People were reporting the spread of various diseases: malaria, dengue fever, and various respiratory infections. Clean water, food, and good quality shelters were the priorities, as well as more boats to carry these items to the people in need. It was a scene just like the ones frequently experienced by the people of Bangladesh because they lived similar lives in crowded settlements on the rich, low-lying areas near the sea.

The storm arrived with winds as high as 125 mph that swept along the coast and through the delta of the Irrawaddy River. The country's main city and former capital, Yangon, because it was near the sea, was devastated. The military government of the country initially declared five divisions of the country to be disaster areas, but within three days revised this estimate to two divisions. Damage was greatest in the delta region, where the effects of extreme winds were compounded by a sizable storm surge. Almost all housing in this region was destroyed. Yangon sustained a direct hit, and the storm brought power and communications lines down and inflicted major damage to buildings. For a week after the storm people remained without electricity, piped water, and communications. Roads into and out of the city were blocked by debris. The whole delta region depended on waterways for transportation, and it had lost this mode of getting help to those in greatest need.

The toll of people killed, missing, or affected remained difficult to assess, with the numbers continuing to increase daily. Three days after the

Devastation caused by Cyclone Nargis in Myanmar. (AP/Wide World Photos)

storm hit, the various ministries of the government estimated that 10,000 lives had been lost and 3,000 other people were missing. Agencies from around the world and from the United Nations were convinced that the actual numbers were much higher. The attitude of the government toward all that was happening left everyone wondering how much the government cared about the conditions among its own people. For example, the military rulers had been working on a plebiscite regarding changes to the country's constitution. Voting papers were about to be distributed all over the country when the cyclone struck. In almost any other nation this vote would have been delayed to allow every agency to concentrate on the tragedy of the cyclone. Instead, the vote went ahead, and the results were declared as a huge majority in favor of the existing government, on May 10, eight days after the arrival of the storm.

Immediately after the plebiscite, the military rulers announced the establishment of an emergency committee, headed by the prime minister, to take care of relief operations. Military and police units were deployed around the country to do the rescue work. It soon became clear that this government had no intention of allowing aid agencies into the country. Instead, it requested a billion dollars of aid money, while it contributed a little over one million from its own resources. All of the billion dollars requested was to be sent to the government, and government workers would distribute relief to those affected. The record of this particular government would make anyone concerned about such an approach. It is a secretive administration, ruthlessly dictatorial, as was seen in 1990, when, after a national election, the military rulers of the time rejected the leaders who were chosen by the voters. A dictatorship has ruled ever since that time. Aung San Suu Kyi, who led protests against the government, campaigning for a democratic government, was placed under house arrest, where she has remained. In 1991, she was awarded the Nobel Prize for Peace.

In any situation like this, the speed at which aid can reach survivors is the most important thing. It dominates all other considerations. Furthermore, the people who bring the aid must be familiar with how to use it to the greatest advantage of those who are suffering. In spite of these realities learned from experience all over the world, the military rulers of Myanmar insisted that they could provide all the help that was necessary, so they requested that the international community send them a billion dollars worth of aid. Many countries, including the United States, stood ready to help and provide all that was needed, but the military rulers held to their position for two weeks, insisting that all supplies be handed over to them. No country was convinced that these military rulers were equipped to do what was needed. Delays went on, and more people died. Finally, three weeks after the cyclone arrived, Ban Ki-Moon, secretary-general of the United Nations, went to Myanmar and was able to persuade the government of the country to allow a few aid organizations to enter the devastated zones.

Different aid agencies immediately began to assess the needs of the people and to work on a list of the most urgent things. Plastic sheeting, water purification materials, water receptacles, cooking sets, mosquito nets, emergency health kits, and food quickly topped their lists. The logistical situation they faced was the biggest challenge. Had they been able to access helicopters and planes, they might still be able to save lives, despite the weeks of neglect by the government. Extreme efforts of this kind were not to be. The ruling authorities refused to permit their use. Much of the delta land was difficult to reach even in normal times because of the generally low living standards in the country. Under the circumstances, the aid agencies did what they could. They tried to reach as many as they could of the 13 million people known to have been resident in the disaster areas. This represented one quarter of the country's total population.

Plans were made to try to preserve the lives of about one and a half million people for a period of three months. These were residents who could be reached on a sustained basis, and it was felt that this triage approach to coping with the disaster would save more lives than trying to provide minimal relief for everyone. Alongside these efforts, they had to contend with the constant challenge of regular access to those who could be helped, plus the constant administrative difficulties of bringing further relief supplies and expertise into the country. They were unable to conclude that the agencies within the country that would have to continue the relief work after the international agencies left were able or free to do what was needed. Their experiences with the intransigent government, even after the tentative agreement with the United Nations secretary-general, left a lot of questions unanswered.

Atlantic and Asian Tropical Cyclones

There are great differences between the power and destructiveness of Asian tropical cyclones compared with Atlantic ones. The table below lists the ten deadliest cyclones for both Asian and Atlantic regions throughout history.

Location	Date	Estimated Number of Deaths
Deadliest Recorded Atlantic Tropical Cyclones		
Barbados	October 1780	20,000
Guatemala	October 1998	9,000
Haiti and Cuba	October 1963	8,000
Galveston, Texas	September 1900	8,000
Honduras	September 1974	8,000
Guadeloupe	September 1776	6,000
Newfoundland Banks	September 1775	4,000
Puerto Rico and Carolinas	August 1899	3,000
Martinique and Florida	September 1928	3,000
Dominican Republic	September 1930	2,000
Deadliest Recorded Asian Tropical Cyclones		
Bangladesh	1970	550,000
India and Bangladesh	1737	350,000
Vietnam	1881	300,000
India	1839	300,000
Bangladesh	1584	200,000
Bangladesh	1876	200,000
Bangladesh	1897	175,000
China	1975	170,000
Bangladesh	1991	140,000
Myanmar	2008	140,000

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CHAPTER 4

East Asian Typhoons

The same massive movements of air that bring monsoon rains to south Asia and trigger cyclones in the Bay of Bengal also gave rise to the following typhoons that were drawn into Vietnam, South Korea, and China.

TYPHOON LINDA, 1997

During the night of November 2, 1997, Typhoon Linda hit South Vietnam, quite a rare occurrence because typhoons do not normally reach Vietnam in November, and only once in ten years do they reach the southern part of the country at any time of the year. All of the nation's southwest provinces received heavy rain, as much as six inches within the first two days. The number of casualties and the damage to property were huge, making this storm the most destructive since 1904: there were 464 people killed, 857 injured, and 3,218 missing. More than

Total devastation in southern Vietnam in 1997 from Typhoon Linda. (AP/Wide World Photos) three thousand boats were sunk, more than 70,000 homes were destroyed, and hundreds of thousands of rice paddies were inundated.

The storm went on from southern Vietnam into the Gulf of Thailand, causing 30 deaths in Cambodia as it traveled along its coast. It then disrupted life in Thailand with its surge of water. More than two hundred fishermen were later reported as missing in that country. Typhoon Linda crossed southern Thailand and finally ended its life in the Andaman Sea. It had originated, like all the other typhoons of the northwest Pacific, a long way from land, and had moved across the Spratly Islands in the South China Sea as a tropical storm. No one in Vietnam was concerned about it as it approached the southern coast of the country. Its wind speed posed no threat to shipping or to land, and there was a good possibility that it might bypass southern Vietnam and go directly into the Gulf of Thailand.

Vietnam had modernized over the approximately 25 years that followed the war with the United States, with financial help from China and Russia. Defenses against storms had been built along the coast in vulnerable locations, and a system of early warning signals was in place. The country was well prepared to deal with big storms. The greatest weakness in the system was the lack of radios in the thousands of privately owned boats that operated offshore. What happened with Linda caught everyone in Vietnam by surprise: as the storm approached land, it intensified into a powerful typhoon within a day and reached land before any of the defense mechanisms could be set up.

As many fishing boats at sea as could be contacted were urged to either return to port or take shelter in the nearest harbor. By so doing the lives of 3,500 fishermen were saved. Reserves of food and medical supplies were quickly distributed to areas that might be in greatest need. The amount of destruction proved to be too much for the country's resources, and appeals for help were sent to the United Nations and to countries around the world. The list of things that the country needed was small: rice, cooking oil, and cooking stoves; tents, blankets, and clothing; and medicines, bandages, and disinfectants.

Thus the amount of money requested from the international community was also small when compared with comparable tragedies in Western countries: two to three million dollars was sufficient. The largest portion of the donated money came from the United States; other major donor nations included Switzerland, Russia, and Australia. In later years it was concluded that El Niño, always a likely factor in Asian storms, was partly responsible for the unexpected growth in strength of Typhoon Linda. It is well-known that in 1997 the world experienced the century's most violent expression of El Niño.

TYPHOON OLGA, 1999

On August 4, 1999, Typhoon Olga reached the island of Cheju, 125 miles south of the southern tip of South Korea and more than two thousand miles north of the area that had been devastated by Typhoon Linda two years earlier. Gale-force winds uprooted trees, downed power lines,

Figure 4-1 Area occupied by Typhoon Olga, 1999. (ABC-CLIO)

and flipped over cars on the island of Cheju. From there the storm moved north across South Korea and North Korea into China. South Korea's National Disaster Countermeasures Agency reported that 35 people had been killed and 28 were missing. North Korea's Central News Agency said that high winds and heavy rain submerged more than 100,000 acres of farmland and destroyed many homes and public buildings.

Throughout South Korea, railways and highways were deep in water and about 24,000 homes were flooded. Approximately 100,000 acres of farmland, most of it paddy fields, were also flooded. The defense ministry mobilized soldiers to restore damaged bridges and build flood embankments. In a large number of places, people were without water, food, and shelter for all of August 4. The city of Seoul was flooded, but only for a day. The U.S. National Aeronautics and Space Administration (NASA) had launched a new ocean-viewing satellite in 1999, and it was able to capture the torrential rains that fell on South Korea. This satellite beams data to ground stations 15 times a day, and the ground stations relay the information to NASA headquarters and also to the U.S. National Oceanic and Atmospheric Administration (NOAA) so that it can warn people about approaching storms.

TYPHOON CHEBI, 2001

On June 9, 2001, a tropical depression formed near the Republic of Palau, east of the Philippines. It moved westward, strengthening as it moved, and within a day was renamed Tropical Storm Chebi. It continued westward and then northwestward, a direction that took it north of the Philippines. It entered the Luzon Strait on June 23 as a typhoon. Later on the same day, Chebi's winds peaked at 100 mph as the storm continued westward along a course 75 miles south of Taiwan. As it neared China, it was swept northwestward and made landfall at the coastal city of Fuzhou in the province of Fujian. All along its long route it left a trail of destruction.

In the storm's brush with the Philippines, nine were killed, there was $13 million worth of damage, and 28 people were missing. Four of the nine deaths occurred when a freighter sank during the storm. On the Penghu islands off the coast of Taiwan, 102 fishing boats were sunk, and the entire group of islands was left without power. In Hong Kong and its surrounding area, there was extensive flooding as four inches of rain fell within an hour or two. The largest amount of destruction from Chebi occurred in China, in the province of Fujian, where 82 lives were lost and more than $400 million of damage took place. The storm also destroyed thousands of acres of farmland in and around the city of Ningde.

In its final moments in the area around Shanghai, Chebi was responsible for the deaths of 22 in the city of Hangzhou when a landslide burst through a construction wall. Chebi weakened after it made contact with land. It continued northward for some distance, past Shanghai, then went back out to sea. This was not the end of its destructive activity. After it left China, it traveled across South Korea, where it brought heavy rain to a large part of the country before it dissipated in the eastern Pacific.

Three Devastating Hurricanes

The following descriptions of three hurricanes represent the worst and the deadliest hurricanes that the United States has experienced since 1900. The local factors that added to the storms' destructive power are as important as the details of the hurricanes, and they are reminders of the responsibilities that always rest with us to learn from past neglects and improve our methods in order to protect people in the future.

HURRICANE GALVESTON, 1900

On September 8, 1900, a hurricane with wind speeds of more than 140 mph created a 20-foot storm surge that covered the entire island on which the town of Galveston, Texas, stood. At least eight thousand people died, more than lost their lives in any one of the Chicago Fire, the Johnstown flood, or the San Francisco earthquake of 1906. Thousands of buildings were destroyed. U.S. Weather Bureau forecasters believed the storm would travel northeast and affect the mid-Atlantic coast. This was based on an assumption that when storms begin to curve in a particular direction they continue on that course. Weather forecasting in 1900 was largely amateurish. Few of today's technological

Hurricane damage in Galveston, Texas, 1900. (Library of Congress) tools were available. Cuban forecasters disagreed with their U.S. counterparts. They were convinced that the hurricane would continue to move to the west. Unfortunately, there was little cooperation between the U.S. and Cuban forecasters, and the U.S. view prevailed.

Early on the Saturday morning of the eighth, the level of the ocean continued to rise despite only partly cloudy skies. Largely because of this weather condition, as well as the weakness of the warnings that came in, few residents paid much attention to the threatening storm. Forecasters at the U.S. Weather Service had seen their earlier prediction fail. The storm had not reached Florida or the east coast, and reports were coming in from stations along the Gulf coast showing clearly that a storm was moving westward in the Gulf. The warnings that now came in from the Weather Service never used the word hurricane. There was a reason for not using this term. The head of the U.S. Weather Service in Galveston had long been convinced that Galveston would never be seriously damaged by a tropical storm. Thus, by Saturday afternoon few people had left the city across Galveston's bridges to the mainland. By the time people became fully aware of the impending disaster, it was too late to attempt an escape. Throughout the afternoon and into the early evening, as the sea level rose and wind speed increased, people sought shelter in homes and large buildings.

Galveston in 1900 was a major port, about 50 miles southeast of Houston, on the northeast end of the 32-mile-long Galveston Island. Highways and ferries linked the city to other places. With a population of 42,000 and an annual growth rate of 3 percent, it was the most important city in Texas at the time, just as New Orleans was for Louisiana, and it competed with Houston to gain recognition as the state's premier port. One newspaper called it "the New York of the Gulf." However, it was a city on an island where the average elevation of the land was five feet above sea level, only slightly higher than New Orleans. Furthermore, the coastal area offshore to the south of Galveston is shallow for a great distance, and the water is therefore warmer than deeper areas. As the hurricane neared landfall, it was greatly strengthened by this warm water. A storm had hit the island about 60 years earlier, submerging it to such a degree that ships were able to sail across it.

The 20-foot storm surge that swept over the island in the evening of September 8, 15 feet above the elevation of the land, leveled everything in its path with wind, waves, and the debris it collected. Houses on the waterfront were the first to go, and, as they disintegrated, their timbers became flying missiles that were lethal for anyone in their path and that destroyed any structures farther inland that were still standing. Very few buildings survived this onslaught. No one thought that the hurricane would be so violent, because no warnings had given the city any indication of its strength. All telegraph communication between the island and the mainland had been cut off by mid-afternoon. A ship at sea close to Galveston was battered by the storm and almost unable to stay afloat. It recorded a very low level of air pressure, only slightly higher than the 28.47 inches registered at Galveston during the storm.

Unfortunately, this ship had no means of transmitting this valuable information to shore.

Isaac Cline was the U.S. Weather Bureau's director in Galveston, the person who had said, nine years earlier, that it was absurd to imagine that his city would ever be seriously damaged by a storm. As the city was being destroyed, he gathered his family and 45 others around him in his house. Shortly afterward the house collapsed. Cline was among those who survived by clinging to pieces of debris. Most of those who died had drowned or been crushed as the waves pounded the debris that had been their homes hours earlier. Many survived the storm itself, but died after being trapped for several days under the wreckage of the city. Rescuers were unable to reach them. On the mainland on the other side of Galveston Bay, no news of the disaster reached the rest of the country for two days until one of the few ships that survived the storm sailed into Galveston Bay. Messages were then sent to the state governor, Joseph Sayers, and the U.S. president, William McKinley.

The bodies were so numerous that arrangements for individual burials were impossible. Funeral pyres were set up wherever the dead were found. These pyres burned for weeks. Survivors set up temporary shelters in surplus U.S. Army tents along the shore. Others constructed lumber homes from the debris. Within four days, basic water service was restored and Western Union began providing minimal telegraph service. Within three weeks, cotton was again being shipped out of the port. Reconstruction work began almost immediately. A massive

Damage from Hurricanes

How does the damage from hurricanes compare to that from tornadoes? It is easy to think that tornadoes are the more destructive because of the drama associated with a big tornado, together with its much more powerful winds. In fact, hurricanes cause far more property destruction and far more casualties. Hurricanes tend to cause much more destruction than tornadoes because of their size, duration, and the variety of ways they cause damage. The destructive circular eye wall in a hurricane can be tens of miles across, last for hours in one location, and damage structures through storm surge, rainfall-caused flooding, and wind. The tropical cyclones of Asia are a special case of extreme destruction, but the overall picture is unchanged if we examine tropical cyclones on a worldwide basis: they are the most costly natural disasters in terms of both economics and human life.

Estimates of costs to the United States at different times as a result of hurricanes reveal that these costs increase disproportionately over time. That is to say, we expect costs to go up as inflation rises and as more people are involved in the outcomes from these storms, but these factors do not explain all of the increase. As an example, over the years 1950 to 1990, costs of damage from hurricanes ran at less than $2 billion per year for all of the United States. In the decade that followed, 1990 to 2000, these annual costs jumped by a factor of more than three: the annual average was a little over $6 billion. No one would be happy with increases of this size in taxes. It is possible that the decade 1990 to 2000 was not typical of hurricane frequency or size, and, if that is the case, it should be taken into account. The important point that needs to be made is that, in the past, insufficient attention was paid to the economics of hurricane damage. This aspect is now getting much more attention.

17-foot seawall was built along the entire Gulf side of the city. It extended along the coast for eight miles. The most extraordinary effort of reconstruction was the raising of the level of the city. Dredged sand was used to accomplish this feat, bringing the whole city to a height of 17 feet above sea level. Many buildings, including St. Patrick's Church, were restored to their places in the city, now at the new elevation. In 2001, the American Society of Civil Engineers honored the reconstruction work by naming it a National Historical Civil Engineering Landmark. The real test of the efforts came in 1915, when a hurricane of the same strength as the 1900 one struck Galveston. It brought a 12-foot storm surge. The new seawall was able to repel it, and 275 people, rather than thousands, lost their lives in this storm.

HURRICANE ANDREW, 1992

The NOAA has summarized the events of Hurricane Andrew as follows:

> The most destructive United States hurricane of record started modestly as a tropical wave that emerged from the west coast of Africa on August 14. The wave spawned a tropical depression on August 16, which became Tropical Storm Andrew the next day. Further development was slow, as the west-northwestward moving Andrew encountered an unfavorable upper-level trough. Indeed, the storm almost dissipated on August 20 due to vertical wind shear. By August 21, Andrew was midway between Bermuda and Puerto Rico and turning westward into a more favorable environment. Rapid strengthening occurred, with Andrew reaching hurricane strength on the 22nd and Category 4 status on the 23rd. After briefly weakening over the Bahamas, Andrew regained Category 4 status as it blasted its way across south Florida on August 24. The hurricane continued westward into the Gulf of Mexico where it gradually turned northward. This motion brought Andrew to the central Louisiana coast on August 26 as a Category 3 hurricane. Andrew then turned northeastward, eventually merging with a frontal system over the Mid-Atlantic states on August 28.
>
> Reports from private barometers helped establish that Andrew's central pressure at landfall in Homestead, Florida was 27.23 inches, which makes it the third most intense hurricane of record to hit the United States. Andrew's peak winds in south Florida were not directly measured due to destruction of the measuring instruments. An automated station at Fowey Rocks reported 142 mph sustained winds with gusts to 169 mph (measured 144 ft above the ground), and higher values may have occurred after the station was damaged and stopped reporting. The National Hurricane Center had a peak gust of 164 mph (measured 130 ft above the ground), while a 177 mph gust was measured at a private home. Additionally, Berwick, LA reported 96 mph sustained winds with gusts to 120 mph.

Damage from Hurricane Andrew, 1992. (FEMA)

> Andrew produced a 17 ft storm surge near the landfall point in Florida, while storm tides of at least 8 ft inundated portions of the Louisiana coast. Andrew also produced a killer tornado in southeastern Louisiana.
>
> Andrew is responsible for 23 deaths in the United States and three more in the Bahamas. The hurricane caused $26.5 billion in damage in the United States, of which $1 billion occurred in Louisiana and the rest in south Florida. The vast majority of the damage in Florida was due to the winds. Damage in the Bahamas was estimated at $250 million.

Florida is no stranger to hurricanes, and throughout the twentieth century, again and again, the frequency and strength of the storms that arrived led to the waxing and waning of the state's attractiveness to northerners who wanted to enjoy its warmer temperatures. In the 40 years from 1926 to 1966, Miami was hit with hurricanes about 13 times. In the quarter century from 1966 to 1992, there were none, and during that period of time people flocked to Miami, doubling its population. New subdivisions sprung up, but supervision of building codes and other regulations was lax. There were fewer than 20 building inspectors for a population of one million. The sudden arrival of Hurricane Andrew was a great shock. Its fierce winds caused most of the damage. Houses were torn apart, cars lifted off the streets, and trees uprooted. Boarding up windows proved useless as a protection from the wind, and very few homes had basements where people could shelter. There was almost total destruction of whole subdivisions.

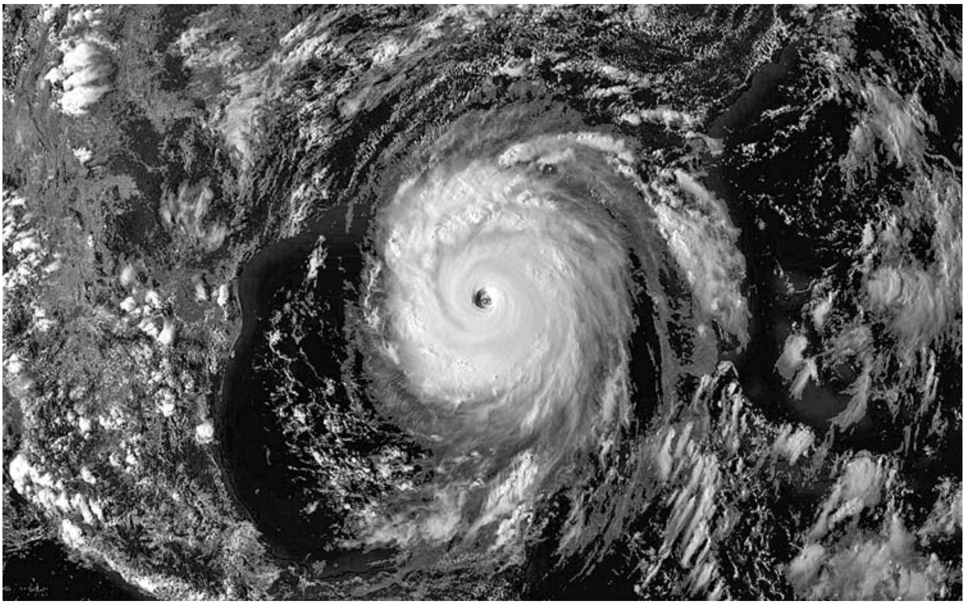
Reports from private barometers helped establish that Andrew's central pressure at landfall in Homestead, Florida, was 27.23 inches, which makes it the third most intense hurricane of record to hit the United States. Andrew's peak winds in south Florida were not directly measured because the official measuring instruments were destroyed. A storm surge of 17 feet was recorded at Homestead. Thereafter, the hurricane continued westward into the Gulf of Mexico, where it gradually turned northward. This motion brought Andrew to the central Louisiana coast on August 26 as a Category 3 hurricane. The storm surge of eight feet inundated much of the Louisiana coast. It also triggered a killer tornado in southeastern Louisiana. The storm then turned northeastward, eventually merging with a frontal system over the mid-Atlantic on August 28.

In all, 63,000 of the residences in Dade County, where Miami is, were destroyed, and another 110,000 were damaged. Nine out of every ten mobile homes were also destroyed. Hospitals, fire stations, and other emergency stations had been put out of action by the storm, and relief was slow to arrive from other places because there were no telephones or other means of communication to contact them. Andrew remained the most devastating natural disaster in U.S. history until the arrival of Hurricane Katrina in 2005. The name Andrew was retired in the spring of 1993 and will never again be used for an Atlantic hurricane. It was replaced with Alex in the 1998 season.

HURRICANE KATRINA, 2005

Hurricane Katrina was the costliest and one of the deadliest hurricanes in the history of the United States. It was the sixth-strongest Atlantic hurricane ever recorded and the third-strongest land-falling U.S. hurricane ever recorded. Katrina occurred late in August during the 2005 Atlantic hurricane season and devastated much of the north-central Gulf coast of the United States. Most notable in media coverage were catastrophic effects in the city of New Orleans, Louisiana. Katrina's sheer size devastated a one-hundred-mile stretch of the Gulf coast. The storm surge that swept over New Orleans was as high as 27 feet, but that was not the main cause of the damage. The levees were fundamentally flawed. They had not been given proper foundations. The soil beneath them was washed away, opening the city to the water of Lake Pontchartrain, a source of water beyond anything that the storm surges could produce. The city was drowned.

Katrina was the eleventh named storm, fifth hurricane, third major hurricane, and second Category 5 hurricane of the 2005 Atlantic season. It formed over the Bahamas on August 23, 2005, and crossed southern Florida as a moderate Category 1 hurricane before strengthening rapidly in the Gulf of Mexico and becoming one of the strongest hurricanes ever recorded in the Gulf. The storm weakened considerably before making its landfall near New Orleans as a Category 3 storm



Area occupied by Hurricane Katrina, 2005. One inch represents 500 miles. (NOAA)

on the morning of August 29. The storm surge caused major or catastrophic damage all along the coastlines of Alabama, Mississippi, and Louisiana, including the cities of Mobile, Biloxi, Gulfport, and Slidell. Levees separating Lake Pontchartrain from New Orleans were undermined by the surge, ultimately flooding roughly 80 percent of the city and many areas of neighboring parishes.

Although the states of Florida, Alabama, Mississippi, and Louisiana all got hit by Katrina, New Orleans became the focus for more than one reason. To begin with, it was the biggest city in the area, with a population of about a half million people, and after the first levees began to collapse, the entire city was really stuck in the middle of an ocean because the water had reached a level where only boats could provide access from one part of the city to another. And, of course, power and telephone communications began to collapse in the process of all this. All this flooding along with the 27-foot high storm surge completely overwhelmed the levees, which were never designed to handle that level of water. So the flooding really destroyed New Orleans, much as the fire that burned Chicago in 1871 destroyed that city and the earthquake and fires in 1906 had destroyed San Francisco. Each of these disasters destroyed the economic and cultural centers of an entire region. It was a similar story in Galveston, Texas, in the famous hurricane of 1900. And even beyond New Orleans, the span of destruction cast by Katrina was widespread all over the coastal areas. Towns and cities, small and large, were destroyed or heavily damaged by the hurricane. However, the focus remained on New Orleans. It was there that the greatest damage had occurred, and it was there that the greatest challenge was presented to all levels of government as to how to secure rescue of the many stranded people.

When we compare the reaction of the authorities in New Orleans to the approaching storm with the experiences of the people in Florida, we find a sharp contrast. In Florida, because they are so accustomed to serious hurricanes, there is a highly developed system of preparation and a coordinated set of organizations that ensure predictable and safe action well ahead of the storm's arrival. New Orleans rarely has had a serious hurricane, yet it is far more vulnerable than any other place in all of the United States, so one would expect that given a repeated series of warnings, there should have been much greater action in preparation for the storm than there actually was.

As early as the beginning of May, the director of the National Oceanic and Atmospheric Administration, which is the overall organization that predicts and follows the movement of hurricanes, gave a warning for the upcoming season that it was, in all likelihood, going to be much more violent than in previous years. The director's estimate was that storms for the year 2005 would have a 70 percent higher chance of an exceptional season, and after the first two months of the season had passed all events had confirmed that earlier prediction.

On Tuesday, August 23, almost a week before Katrina actually hit New Orleans, the National Weather Service identified a tropical depression in the area of the Bahamas that looked as if it would develop into a serious hurricane. Military authorities and all other responsible agencies began to issue warning alerts and began to follow the path of this storm every moment of every day. Within a day, this tropical storm off the Bahamas had been identified, given the name Katrina, and on the following day it had strengthened to a tropical storm. A day later, on August 25, it was a Category 1 hurricane. It made landfall in south Florida later that day with winds up to 80 miles per hour. The volume of rain and destruction was quite severe; 14–15 inches of rain were dropped in some parts, and the overall death toll during its one-day passage over Florida was more than a dozen. More than a million people lost power, and flooding occurred in a number of areas. The total damage to Florida amounted to about $2 billion.

As the storm passed into the Gulf of Mexico and traveled northward, federal authorities arranged for emergency quantities of food and water to be shipped to all of the states along the Gulf, including Alabama, Mississippi, Louisiana, and Texas, and to Georgia and South Carolina as well. The recognition was made at that stage, on the evening of August 25, that a very serious hurricane was moving toward the coastal area of the northern part of the Gulf of Mexico. On the afternoon of August 26, the National Hurricane Center pointed out that Katrina would make its next landfall as a Category 4, or even 5, the highest possible, somewhere along the Gulf coast, just east of New Orleans. As the hurricane moved, it seemed more and more certain that the path it projected was being followed precisely as anticipated. In addition to the direction of landfall and the location of landfall, the prediction was that flooding to the level of as much as 20 feet above normal tide levels could be anticipated.

Now, that one factor alone should have been sufficient to terrify every person in New Orleans, had it been observed with greater care, because it is well-known that a flood tide of 20 feet was beyond what the levees could withstand. This was now well into August 26, three days before the landfall that would cause all the trouble in New Orleans. But at that point, apart from issuing a state of emergency, the governor of Louisiana had not taken any additional direct action, and the mayor of New Orleans, who was responsible for the evacuation of half a million people, took no action, either on that day or on the following day, August 27. It was late on August 27, after the governor of Louisiana became aware of the indifference on the part of large numbers of people, that she decided to enact what are called counterflow traffic arrangements. That is a system whereby all incoming traffic to New Orleans is cut off and only exit from New Orleans is permitted. That action began late on August 27. Action had still to be taken by the mayor to get people moving and get them out of the city, especially those who had no transportation of their own and required buses to be made available for them. By this time, because the storm was moving northward from the Gulf of Mexico, and because there was no outlet for the heightened waves that were created ahead of the storm, the water level along the Louisiana coast and at New Orleans was already rising far above the highest tide level.

In fact, this rise in the water level began to leak through one of the levees, not overtopping it, but simply creating a leak by the pressure from outside, and so a beginning was made to the destruction of the levees long before the height of the water caused it. So serious did the danger of the hurricane appear to the director of the National Hurricane Center that he did something he had never previously done. He personally called the mayor of New Orleans, warning him of the extreme danger from the hurricane and urging him to do everything possible. Despite that further warning, the mayor of New Orleans did not begin a mandatory evacuation until the following morning, Sunday, August 28. In fact, it was too late for many of the people who had no cars and no friends who could accommodate them in their cars, and from that came the dire situation of the many stranded in the city.

Like Chicago in its early battles with flooding, New Orleans' principal concerns center on water, but to a far greater extent than Chicago ever experienced. It might even be said that the greatest engineering challenge facing this city at the mouth of the Mississippi River is to keep it from drowning. Additionally, the city has very weak conditions in its foundation, so much so that it has been described as the flattest, lowest, and geologically youngest of any major city in the United States. Average elevation is less than two feet above sea level, and no surficial deposits are older than 2,500 years. About half of the urbanized area is at or below sea level. Floods on the Mississippi at times reach 20 feet above sea level, and hurricane surges on Lake Pontchartrain to the north of the city have exceeded six feet above sea

Flooding in New Orleans during Hurricane Katrina, after the levees broke. (Department of Defense)

level. Rainfalls of ten inches within a period of 12 hours have been recorded on several occasions!

It is rare to find a city whose unconsolidated foundations date within the period of human history. The foundations of New Orleans belong to the Holocene Epoch and range in depth from 15 feet to more than 45 feet. New Orleans is about 45 miles from the Gulf of Mexico and more than twice that distance from the mouth of the Mississippi. It is part of that river's delta, a broad region of bayous and wetlands. The main built-up part of the modern city is free from marshes as a result of the extensive measures taken to drain or pump away the water. Both natural and built levees run east and west within the city between the Mississippi River and Lake Pontchartrain.

Levees extend along both sides of the lower Mississippi for a total distance of 1,500 miles. Farther up the valley of the river, these levees are quite high, as much as 36 feet with base widths of 360 feet, but those around the city area average only 15 feet above the natural levee ridges on which they were built. Because the differences in elevation between the water level inside the levees and the lowest parts of the city are so big, there is a great need for a thoroughly dependable levee system. Fortunately the natural levees overlie coarse-grained inorganic deposits, and these are the best shallow foundation soils in the New Orleans area. In addition to the levees, there is a floodway through which water can be bypassed during a river flood.

As far as the city is concerned, hurricane-induced flooding can be just as catastrophic as a Mississippi flood. Rarely does a hurricane pass over the center of New Orleans, but when it happens, the devastation is widespread and costs are enormous. Flooding of populated areas is a certainty. The amount of advance warning is usually less than a day because, although its path can be traced for several days before it strikes land, its behavior as it approaches landfall is unpredictable. What can be done when flooding occurs? To move even a small percentage of the city's population to safe ground out of town requires more than a day. The only practicable alternative is to evacuate vertically—that is, move people to floors of homes or buildings that are above flood level.

Diversion of water is the usual method of minimizing threats to the city. To the west is a large floodway that begins far upstream and continues down the Atchafalaya Basin into the Gulf, affectionately named Old River Control Structure. Half of all the water in the Mississippi when it is at flood stage can be bypassed in this way. On the western outskirts of the city, on the main river, is another diversion, the Bonnet Carre Spillway. It can be opened to divert water from the river into Lake Pontchartrain. It is seldom used but is always available. There is a continuing concern about the stability of these protective measures because of the nature of the underlying sediments. During a major flood in 1973, for instance, part of the Atchafalaya was undermined, and one wall failed.

Because there is so much unconsolidated material everywhere in and around the city, compaction of these sediments from time to time is the major cause of subsidence. Land sinking, shoreline erosion, and saltwater encroachment all are active, and contribute to this problem of maintaining a consistent level of land. At times these forces cause sudden changes to buildings and facilities. Differential settlement, bank failures, and flooding are the sorts of things that happen. If allowance is made for sea level variations, the general picture of subsidence rates is about seven inches a century. Local groundwater withdrawals further aggravate the situation.

About one in ten homes and the same proportion of commercial buildings, plus one out of every three streets and sidewalks, show signs of differential subsidence. Structures on the natural levees rarely are at risk, but the large number built on organic swamp and marsh deposits stand on a very unstable base. Typical conditions include buckling of patios and exposure of foundation slabs. Driveways subside to such an extent that it is impossible to drive into carports. Gas and water leaks occur as underground utility lines sag. The problem worsens with development, as new impermeable coverings of streets, parking lots, and buildings lead to dewatering and compaction in the organic soils beneath and hence subsidence.

When the first settlers occupied some high ground on the banks of the Mississippi almost three hundred years ago, there was little thought about the problems of growth but gradually, as the settlement expanded, the risks increased. Today, the city continues to push its frontiers farther and farther into low-lying marshy tracts where building is possible only with the best of modern technology. Structures six hundred feet tall stand where formerly the ground could not support the weight of one person. Water levels, when the river is in flood, can be as high as 27 feet above the lowest areas of the city. There seems to be great faith in the stability of the dikes, but those responsible for them are always on alert, especially when strong winds blow. Early building techniques used the natural levees. Crossed timber supports and masonry footings constituted the foundations. Later, piles were introduced for the bigger structures. These piles were driven down to the first sand stratum at a fairly shallow depth, where sufficient resistance was encountered to indicate a safe foundation. In the late 1930s, one 20-story hospital was constructed in this way, with piles that went down 20 feet. Within a year or two the building began to settle, and before long it had to be abandoned.

Unstable layers of deposits beneath the sandy foundation gave way. At that time, there was little detailed knowledge of subsurface geology, so no one knew about this weakness. Over time, thousands of borings to depths of 180 feet or more identified the nature of the underlying layers, not only the sand strata that seemed to be strong enough to hold up buildings, but beyond that into the deeper Pleistocene deposits. When, in the late 1950s, a second hospital was built close to the site of the former failed one, more than two thousand piles were driven 75 feet into the ground, deep enough to reach the Pleistocene deposits, even though the building had only nine stories. Some settlement of the ground was anticipated and construction plans took account of this. That building has stood well. The Pleistocene deposits are now the bedrock on which buildings need to rest. Where they are close to the surface, pile lengths and numbers can be few. Even so, there are deeper strata within the Pleistocene strata where compaction occurs if the load is great enough. The general rule now is this: the higher the building, the deeper the piles. Both the number and type of concrete piles are other considerations. A 1968 building of 45 stories had piles going down 150 feet, and a still more recent one, having 50 stories, used octagonal piles with diameters of 20 inches and depths of two hundred feet.

CHAPTER 6

Three Terrifying Tornadoes

Tornadoes, often called twisters, are a primarily U.S. phenomenon. More of them touch down in the United States than in any other country. It would be easy to count more than a thousand in any given year if it were possible to find all of them. Those who have lived through a tornado of F4 or F5 level strength, which have wind speeds over 200 mph, will never forget their experience as long as they live.

Tornadoes are one of nature's most violent storms. In an average year, the United States today has 1,200 of them. A tornado is a violently rotating column of air extending from a thunderstorm to the ground. The most violent tornadoes are capable of tremendous destruction with wind speeds of 250 mph or more. Damage paths can be in excess of one mile wide and 50 miles long. Tornadoes come in all shapes and sizes, and can occur anywhere in the United States at any time of the year. In the southern states, peak tornado season is March through May, and peak months in the northern states are during the summer. Tornadoes have their own mythology, and recently the U.S. Weather Service decided to investigate some common beliefs about these storms. One widely held conviction is that tornadoes do not touch down at the confluence of major rivers. There is no basis for this view, because tornadoes have touched down at the confluence of the Ohio and Mississippi Rivers. There are other assumptions that have also been discounted by events. Among them are the following: (1) tornadoes don't go up and down steep or high hills; and (2) tornadoes will not follow terrain into steep valleys.

A tornado begins as a thunderstorm, but not every thunderstorm becomes a tornado. It is at the boundary between the warm tropical air from the Gulf and the cold Arctic air from Canada that the necessary high contrasts in temperature make tornadoes possible. Updrafts are created, forming a super cell, which is several cells operating at different times and heights as heat from the ground triggers the upward movements of air. Moving air at different altitudes and speeds, part of the jet stream, creates a circular motion in the updrafts, and this develops into the characteristic spinning updraft and a rise of the super cell to higher altitudes. It is the downdraft, with its high wind speed and rain, that causes all the damage on the ground. If the tornado does not touch the ground, it is called a funnel cloud. In the three descriptions of tornadoes that follow in this chapter, we have a picture of the

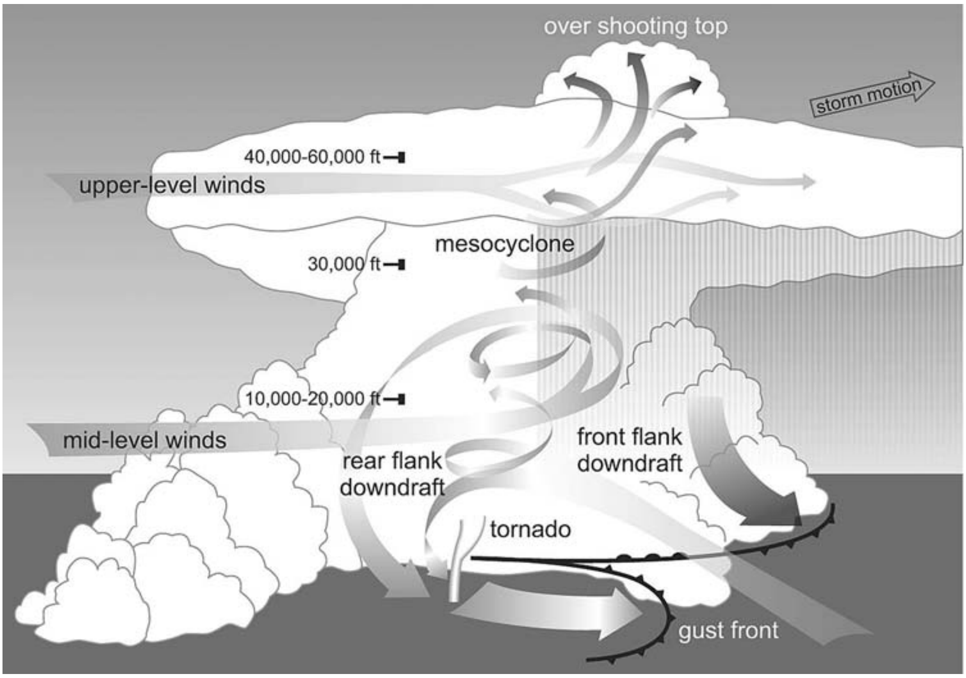


Figure 6-1 Supercell thunderstorms cause flash flooding and tornadoes. (NOAA)

history of tornadoes in the United States over a period of 167 years. The first two represent earlier periods of time, when fatalities were high because knowledge was low. The third one, from 2007, reflects present knowledge.

NATCHEZ, MISSISSIPPI, 1840

Shortly after noon on May 7, 1840, a mile-wide tornado slammed into Natchez, Mississippi, a city on the lower Mississippi River about 150 miles north of New Orleans. The storm was loaded with all kinds of debris it had picked up along its path. No one expected it, and no one was warned of its approach, even though the sounds of its destruction farther down the river could be heard in Natchez. Unlike the present time, there was no national weather service to alert people to an approaching storm, and there were none of the things that individuals could have used to warn others, such as two-way radios, telephones, or cell phones. As the tornado struck Natchez, banks, homes, stores, steamboats, and other vessels were completely destroyed. Houses burst open. Three hundred seventeen people lost their lives. It was the second most deadly tornado in U.S. history. About an hour before it struck Natchez, a thunderstorm with driving rain had formed in an area about 20 miles to the south, and moments later a tornado began to form out of that same storm. It gathered strength as it moved northward along the Mississippi valley.

The United States gets about one thousand significant tornadoes every year, more than the total number experienced by all other countries combined. Only one in every hundred is as powerful as the one that struck Natchez. At the present time, in sharp contrast to 1840, few are killers. We now have the ability to identify the kind of weather that is likely to lead to a tornado, and we can trace the paths of these twisters so that those in their paths can take shelter. Forecasting, detection, communications, and raised public awareness of the danger all help to minimize the number of fatalities. People in 1840 were only able to report on what was visible and measurable locally in terms of wind speed, temperature, and humidity. There was no system of communication that could relay these data quickly enough to provide a warning to those who were in the tornado's path.

As the tornado tracked northeast, heading for Natchez, people took advantage of the cooling rain to sit out on their porches, or to walk about, even in the rain, because the rain provided a cooler atmosphere than the usual hot, dry conditions. Many were preparing to eat, fully aware of the dangers that any thunderstorm would present, but unaware that this particular storm was much more than a thunderstorm. At the very moment that the tornado struck, the dinner bells in large hotels had rung, and most citizens were sitting at their tables.

The approaching tornado raced up the river from a point seven miles south of Natchez. As it traveled, it stripped the forest from both sides of the river. Those on the river were the first to hear what must have been a thunderous roar from the river as it churned with massive waves and whitecaps. Up and down the river on either side of Natchez, scores of vessels, steamboats, flatboats, and skiffs were crowded together in great numbers, along with many itinerant boatmen who traded everything from furs to liquor. Flatboats and people were tossed into the air like toys, and as they came down, they were drowned. The volume of debris as well as the tumultuous state of the water made it impossible for anyone to be rescued. One or two survived because they were thrown onto the land. As the tornado swept northward, the central and northern parts of the town were demolished. Survivors described the air as being black, filled with spinning pieces of walls, roofs, and chimneys, and with large timbers flying through the air as if shot by a catapult. Beneath the ruins lay the crushed bodies of many strangers. There were many escapes and many heart-rending scenes. Mrs. Alexander was rescued from the ruins of the Steam Boat Hotel. She was seriously injured and was holding onto two dead children.

The destruction of the flatboats was an immense blow to the economy of the area. At least 60 of them were lost. It was impossible to calculate the total value of the boats and their contents. The steamboat *Hinds,* with most of her crew, went to the bottom of the river, and the *Prairie* from St. Louis was wrecked so badly that it was unfit for use. The steamer *St. Lawrence* at the upper cotton press was also a total wreck. It was difficult to tell how widespread the ruin had been. Reports of major damage came in from plantations 20 miles away in

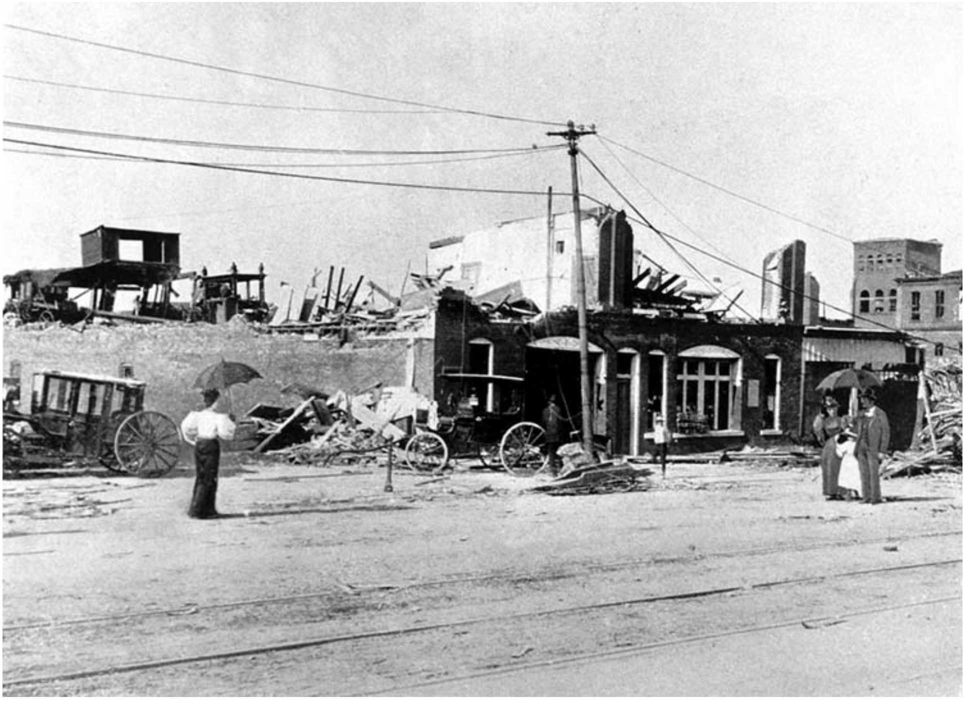
Louisiana. Looking back from today's vantage point, these losses were all the more unfortunate because there were none of the aid organizations with which we are now familiar: Red Cross, National Guard, presidential disaster decree, and mobilization of doctors and emergency personnel from other places. The townsfolk did the best they could, and the unexpected was attributed to the deliberate action of God. One newspaper described the whole scene as the voice of the Almighty, and hence prudence should dictate reverence rather than execration. Total costs of the disaster were estimated at $1.3 million at the 1840 value of money.

ST. LOUIS AND EAST ST. LOUIS, MISSOURI, 1896

At 6:30 PM on May 27, 1896, two F4 tornadoes that had been part of a major outbreak across the central United States made landfall near and at St. Louis, Missouri, both arriving almost simultaneously. One passed over the city and moved in a southeasterly direction, leveling entire farms in such communities as Richview and Irvington 60 miles east of St. Louis. The other, a much more powerful one, was the third-deadliest tornado in U.S. history, responsible for the deaths of 255 people on both sides of the Mississippi River before it finally petered out in East St. Louis, Illinois. People died in homes, factories, saloons, hospitals, mills, railroad yards, and churches as the half-mile-wide swath of this killer tornado cut its way across the center of St. Louis. At least 137 people died and 300 were seriously injured. People living on shanty boats may have perished in the Mississippi River, but were not counted because their bodies were washed downstream.

At East St. Louis, the swath of the tornado narrowed, and, as so often happens in such circumstances, the funnel's speed and power increased. Devastation was complete, and 118 people died. At least $2 million worth of damage had been done in East St. Louis. In most areas, roofs and trees were not carried away. Instead, they were thrown to the ground. Homes were swept away in some areas. Lafayette Park became a wasteland of stripped trees and stumps. One record of barometric pressure was retained. It stood at 26.74 inches, a rare level of low pressure and a clear definition of the power of the tornado. One bridge across the Mississippi had been built to be tornado-proof in the aftermath of earlier tornadoes, with an iron plate covering five-sixteenths of an inch thick. The tornado pierced it with a two-by-ten-inch white pine plank. It did not weaken the strength of the bridge, but it illustrated the ability of a powerful tornado to generate missiles.

On every side lay the bodies of dead horses and overturned heavy freight cars that had been lifted from their tracks in their entirety and hurled yards away, frequently plunging down embankments and landing upside down. By the water's edge were the battered steamboats, thrown high and dry upon the shore. Many steamboats went to the bottom of the river. One agency estimated the property loss at $50 million. This



Damage to St. Louis, Missouri, from tornadoes in 1896. (NOAA)

loss was as complete and thorough as though its equivalent in money had been thrown into the ocean, for there was so little tornado insurance carried in the city that its total covered only a small fraction of the losses. A fund of $15,000 for the immediate relief of the homeless was quickly raised on the floor of the Merchant's Exchange, and this sum could have been increased to $100,000 if necessary. Congressman Joy introduced a resolution in Congress, arranging for the use of army tents for those who were homeless. President Cleveland promised to sign it. Conditions in East St. Louis were worse than in St. Louis because of the greater power of the tornado as it reached that place.

This pair of tornadoes together became one of the deadliest and most destructive tornado events in U.S. history. So much damage had been done to the city that there was some question about St. Louis being able to host the 1896 Republican National Convention. It is somewhat rare for the core of a large city to be hit directly by a tornado (due to their relatively small area and the relative lack of large cities in the highest tornado threat region), especially a large intense tornado, yet several other tornadoes have tracked through the City of St. Louis, and several of these tornadoes were also very deadly and destructive. Among these events are the following: 1871 (9 killed), 1890 (4 killed), 1904 (3 killed, 100 injured), 1927 (79 killed, 550 injured, second-costliest in U.S. history), and 1959 (21 killed, 345 injured). This makes St. Louis the worst tornado-afflicted urban area in the United States. Additionally, the greater St. Louis area is the scene of even more historically destructive and deadly tornadoes.

GREENSBURG, KANSAS, 2007

On May 4, 2007, Greensburg, a town of about 1,500 people, was hit by a powerful tornado that destroyed 95 percent of the town and killed a number of people. Like much of Kansas, Greensburg is familiar with tornadoes, but nothing like this had been experienced in decades. Perhaps it is because of its past acquaintance with tornadoes that this state was selected as the setting for the famous Judy Garland movie *The Wizard of Oz*. Eleven lives were lost in Greensburg on May 4, and 60 people were injured. In addition, two were killed in a nearby community, quite a major tragedy for a place of Greensburg's size. Thanks to the modernization that had developed in the National Weather Service, there was a 20-minute warning of the approaching storm, and sirens were sounded throughout the town. This was followed by a ten-minute emergency signal before the 205-mph twister hit. Undoubtedly these advance signals saved lives.

This tornado was the first to be rated as an EF5 under the revised rating of the older Fujita scale. The details of this scale and the reasons for the revision can be found in Appendix D. The tornado was about 1.7 miles in width, and it had traveled for nearly 22 miles as part of an active system of 136 tornadoes that extended from western Nebraska to the Texas panhandle. The governor of Kansas, Kathleen Sebelius, and President George W. Bush both declared Kiowa County a disaster area, opening up the area for national and international aid. In the days that followed the disaster, there was a good deal of pessimism about the future. Some wanted to abandon the town altogether.

Fortunately, a different mood prevailed. The city council decided they would rebuild Greensburg, not as it was, but as a new kind of

Tornado devastation, Greensburg, Kansas, 2007. (AP/Wide World Photos)

Tetsuya Fujita

Tetsuya Fujita (1920–1998) was born on the island of Kyushu, in southern Japan. He studied at the Kyushu Institute of Technology and was an associate professor there until 1953, when Howard Byers, who was working on a research project at the University of Chicago related to thunderstorms, invited him to Chicago. The reason for the invitation dated back to 1950, when Fujita was working as a meteorologist, measuring air currents and thunderstorms on a mountain near his home. One day he happened to find, at a U.S. Air Force base in Kyushu, a description of Byers' work on thunderstorms, so he sent him a copy of his work. Byers was so impressed with its quality that he offered him the chance to come to Chicago to conduct research on thunderstorms.

From his first day of study at the University of Chicago, Fujita began to change the ways and the speed with which research on severe storms was done. He studied single thunderstorms in the same way that researchers used to examine larger systems. He saw every storm as a weather system. The super outbreak of 1974 was the high point of this approach. He was able to map the entire path of many of the 148 tornadoes. He rigorously analyzed photographs of tornadoes, quite a new level of forensic meteorology. Over time, his research revolutionized our knowledge of severe thunderstorms, tornadoes, hurricanes, and typhoons, the last of these being a longstanding interest of his.

He discovered downbursts and microbursts, and he developed the Fujita scale of tornado strength that is in use today. He was often called "Mr. Tornado" by his associates and by the media. This was how Tom Grazulis, director of The Tornado Project, described Fujita's work: "More than anyone else in the history of meteorology, Tetsuya Theodore (Ted) Fujita increased our knowledge of severe storms, especially tornadoes."

town, a green one. All buildings would be built to Leadership in Energy and Environmental Design (LEED) standards, still a new idea in 2007, and so it happened that Greensburg happened to be the first town in the nation to take this step. With the help of a nonprofit organization, Greensburg took shape. Residents learned about and implemented the new green living initiative. One year after the disastrous events of 2007, Greensburg was very much alive. The town was well on its way to becoming the nation's most thoroughly environmentally friendly town. Public buildings and some commercial structures were being constructed to meet the highest standards for energy-efficient design, and residents were adding green features such as solar panels and double-pane windows to their new homes. President George W. Bush delivered the high school graduation address in 2007.

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CHAPTER 7

Major Tornado Outbreaks

In 1999, experts from the storm prediction center in Norman, Oklahoma, prepared a list of the major tornado outbreaks that took place in the United States in the course of the twentieth century. Notes regarding developments in technological and policy improvements that occurred in the course of the century were included in their list of events. What is meant by a tornado outbreak? Reference books define it as multiple occurrences of tornadoes within a particular weather system. Generally, there is no agreed definition among experts. Most would accept the statement, "more than six tornadoes in a day in the same region" as an acceptable definition. In the selected list below from the National Weather Service, it seems that the number of tornadoes is less important to experts than the violence and damage that is caused.

SUPER TORNADO OUTBREAK OF 1974

This is the super outbreak that Fujita studied in detail (see Chapter 6). At the end of his investigations he said that another like this one might come again in 500 years. He spent many hours flying from place to place, recording as much detail as possible on every one of the 148 tornadoes.

This was by far the most impressive and devastating tornado outbreak in the twentieth century. It lasted 16 hours within the two days of April 3 and 4, 1974, and produced a total of 148 tornadoes across 13 states from Illinois, Indiana, and Michigan southward through the Ohio and Tennessee valleys into Mississippi, Alabama, and Georgia. It produced more long-track tornadoes than any other, killing 315 people and injuring more than five thousand. The most notable individual tornado was the one that moved into Xenia, Ohio, just before 4:30 PM. It destroyed much of the town, including the town square and high school, killing 35 people.

Twenty-five years ago, National Weather Service forecasters could see only green blobs on their radar screens, and they had to wait for visual confirmation of the tornado before issuing a tornado warning. Today's forecasters, thanks to a $4.5 billion weather service modernization effort, are able to view evolving storms in graphic detail and can issue warnings before tornadoes even form, with an average lead time of 11 minutes.

This was how one observer described the 1974 outbreak:

> About a half hour after the tornado warning I observed a thunderstorm approaching. A lowered cloud base along the edge of the storm was clearly evident, but I did not see a tornado. I had a good view of the storm. As the lowered cloud base moved overhead, I first observed the funnel cloud forming and was able to see the circulation of air within the descending vortex.
>
> Quite suddenly an instrument shelter that had been bolted to a rooftop deck collapsed on its side in front of my window. The tornado circulation had reached the roof without a visible funnel. I crossed to the other side of the building to look towards the City of Louisville. The tornado was now clearly visible on the ground and was racing northeast into the densely populated city. An I-beam, ripped from the rooftop and thrown on to a car in the adjacent parking lot, marked the beginning of a trail of damage affecting 900 homes and causing millions of dollars of property loss.
>
> This tornado was one of the 148 twisters recorded during the outbreak. For me, it was most spectacular, since it was the first tornado I had witnessed and the only one I have viewed from such a perspective.

"Deadly storms such as the 1974 super outbreak can and will happen again," said Ken Haydu, a meteorologist in charge of the National Weather Service's forecast office in Wilmington, Ohio. "The people who experienced the super outbreak have an important story about tornado awareness and preparedness to pass on to later generations."

In all, 13 states were struck by one or more of the 148 twisters: Alabama, Georgia, Illinois, Indiana, Kentucky, Michigan, Mississippi, North Carolina, Ohio, South Carolina, Tennessee, Virginia, and West Virginia. Damage amounted to $3.5 billion. Casualties added up to 315, six thousand were injured, and 27,000 families suffered property losses. In all, this was the largest tornado outbreak on record for a single 24-hour period.

Never before had so many violent (F5 and F4) tornadoes been observed in a single weather phenomenon. There were six F5 tornadoes and 24 F4 tornadoes. The outbreak began in Morris, Illinois, at around 1 PM on April 3, 1974. As the storm system moved east, where daytime heating had made the air unstable, the tornadoes grew more intense. A tornado that struck near Monticello, Indiana, was an F4 and had a path length of 121 miles, the longest path length of any tornado for this outbreak.

The first F5 tornado of the day struck the city of Xenia, Ohio, at 4:40 PM. It killed 34, injured 1,150, completely destroyed about one-fourth of the city, and caused serious damage in another fourth of the city. Five more F5s were observed—one each in Indiana, Ohio, and Kentucky, and two in Alabama. At one point, forecasters in Indiana, frustrated because they could not keep up with all of the simultaneous tornado activity, put the entire state of Indiana under a blanket tornado warning. This was the first and only time in U.S. history that an entire state was under a tornado warning.

Xenia experienced the deadliest tornado of the 148. The tornado named after this place touched down at 4:30 PM nine miles southwest of Xenia and entered the city about ten minutes later. It continued northeastward on a path 32 miles long, from Xenia and Wilberforce into Clark County. It killed 32 people. About half of the buildings in the city of 27,000 were damaged, and three hundred homes were destroyed. Nine Xenia churches were destroyed, as were seven of the 12 schools in the city. Fortunately, the tornado occurred an hour after classes had been dismissed. The roof and windows were blown from the Greene County courthouse. A train passing through Xenia was struck by the tornado, and seven of its 47 cars were thrown on their sides, blocking Main Street.

More than 1,300 people were treated for injuries at Green Memorial Hospital. Restaurants that were not destroyed handed out thousands of free meals to residents and rescue workers in Xenia. Convoys of generators, floodlights, bulldozers, and dump trucks arrived overnight from nearby Wright-Patterson Air Force Base. The tornado also struck Wilberforce University and Central State University, destroying many buildings and injuring several people on each campus.

Thirty-four were killed in the disaster, including two Ohio Air National Guard servicemen on April 17 in a fire that swept through

Tornado damage, Xenia, Ohio, 1974. (AP/Wide World Photos) their temporary barracks in a furniture store. About 1,150 were injured in Xenia alone. About half of the town, or about 1,400 buildings, were damaged heavily or destroyed. Damage was estimated at $400 million. President Richard Nixon visited Xenia and declared the area a federal disaster area. It took several months for the city to recover from the tornado. The Red Cross and the Ohio National Guard assisted in the recovery efforts.

The Xenia tornado was rated an F5. It was one of two F5s that affected Ohio during the outbreak, the other being in the Cincinnati area. In fact, this tornado was so intense that it is one of only two tornadoes to ever hit any part of the United States that was so strong that meteorologists were tempted to rate it as an F6. Prior to the 1974 storm, the city had no tornado sirens. However, after the F5 hit, ten sirens were installed across the surrounding area. A memorial was installed near Xenia City Hall to commemorate the tornado victims.

OTHER TORNADO OUTBREAKS

Technological advancements in the second half of the century have contributed to better, more accurate severe weather watches and warnings from the National Weather Service, ultimately saving countless lives. The biggest advancement for severe weather forecasting was the development of Doppler radar. National Oceanographic and Atmospheric Association (NOAA) scientists and other researchers took the

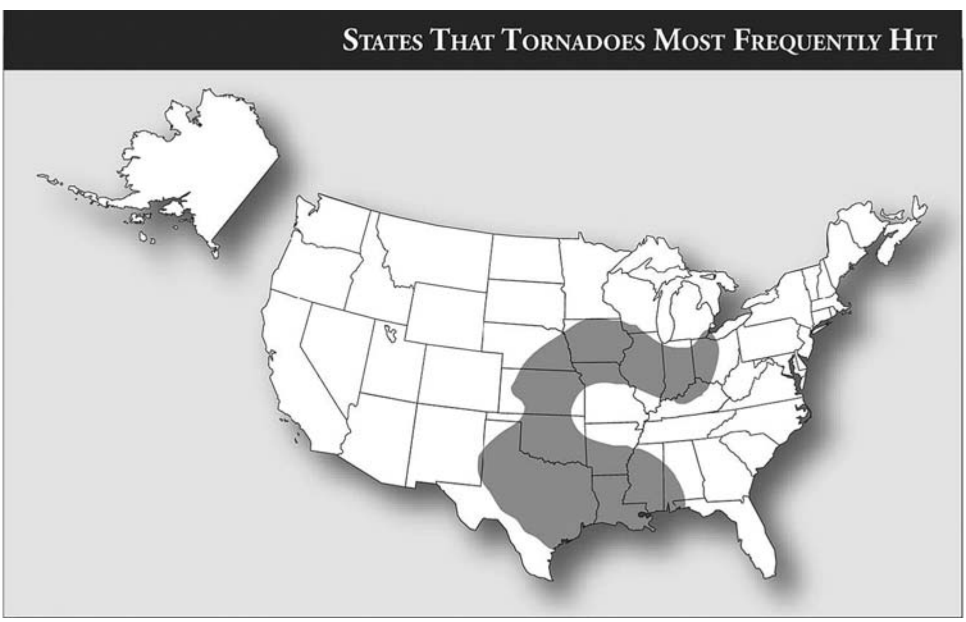

Figure 7-1 The most violent weather phenomenon, a tornado is a rapidly turning column of air usually associated with large cumulonimbus clouds and often connected with thunderstorms. (ABC-CLIO)

airborne radar developed by the U.S. military during World War Two and applied it to weather forecasting and severe storm identification. The ultimate result was the Next Generation Radar (NEXRAD) Doppler weather radar system currently in use.

Advancements in computer technology also have created continued advancements in numerical weather prediction, allowing meteorologists to apply physics in replicating motions of the atmosphere. This, combined with diligent analysis to recognize weather patterns, helped advance severe weather prediction to its current level of an average lead time of more than 11 minutes for tornado warnings issued by National Weather Service forecasters.

The most impressive and devastating tornado outbreak in the twentieth century was the super outbreak of April 3–4, 1974. The following timeline, produced by severe weather experts at NOAA's Storm Prediction Center in Norman, Oklahoma, provides a succinct introduction to other tornado outbreaks in the United States in the twentieth century.

1900–1909

The outbreak of April 24–26, 1908, included violent tornadoes that moved through parts of Louisiana, Mississippi, and Alabama, killing 324 people and injuring 1,652 others. The worst damage took place in Amite, Louisiana, where 29 people died.

1910–1919

A long-track tornado on May 26, 1917, traveled across Illinois and Indiana for 293 miles, lasting seven hours and 20 minutes. The tornado killed 101 people and injured 638 others. Another tornado moved through the town of Mattoon, Illinois, destroying everything in a 2.5-block-wide path for 2.5 miles.

1920–1929

The Tri-State tornado of March 18, 1925, developed near Ellington, Missouri, and then in the next 3.5 hours killed more people and destroyed more schools, homes, and farmsteads than any other tornado to this point in history. The tornado cut across southern Illinois into southern Indiana, killing 695 people, 234 of them in the town of Murphysboro, Illinois, and injuring 2,027. Other tornadoes occurred in Kentucky, Tennessee, and Alabama. A total of nine tornadoes were reported, leaving 747 dead and nearly 2,300 people injured.

1930–1939

On March 21–22, 1932, a total of 330 people died as a result of tornadoes that touched down across northern Alabama. One tornado hit the northeast part of the state, killing 38 and injuring 500.

During the Tupelo/Gainesville outbreak on April 5–6, 1936, 17 tornadoes were scattered across parts of northern Mississippi and northern Georgia. A massive pair of tornadoes hit Gainesville, Georgia, in the morning, killing 203 people and causing 1,600 injuries.

1940–1949

Three major outbreaks occurred during this decade. The first, on March 16, 1942, left 152 dead and 1,284 injured from tornadoes that raked across parts of Illinois, Mississippi, Tennessee, and Kentucky. As many as 63 people perished in a tornado northwest of Greenwood, Mississippi, that hit as buses carried school children home. Five hundred people were injured.

A total of 154 people died and nearly a thousand were injured on June 23, 1944, as tornadoes struck parts of Ohio, Pennsylvania, West Virginia, Maryland, and Delaware. The worst affected areas were parts of northeast West Virginia and western Maryland, where a tornado family killed 30 and injured three hundred.

On April 9, 1947, a tornado outbreak that included eight tornadoes raked across parts of Texas, Oklahoma, and Kansas. One tornado killed 107 people in Woodward, Oklahoma. Devastation covered one hundred city blocks, and one thousand homes were damaged or destroyed. Cost of the damage at that time was estimated at $6 million. Clean-up afterward was hampered by cold and snow.

1950–1959

On May 11, 1953, a violent tornado hit downtown Waco, Texas, killing 114 people and destroying about two hundred business buildings. Heaps of bricks up to five feet high filled the streets. Survivors were buried for up to 14 hours.

A tornado outbreak in early June 1953 produced two major tornadoes. On June 8, a tornado hit in Flint, Michigan, leaving 116 people dead. The next day, June 9, a tornado described as "a huge cone of black smoke" carrying debris eastward over the Boston area and out over the Atlantic Ocean caused 94 deaths and nearly 1,300 injuries in Worcester, Massachusetts. In the United States, the death toll was 116 from tornadoes in Michigan, Ohio, Massachusetts, and New Hampshire. Other tornadoes occurred in Canada.

The hardest-hit area from a tornado outbreak in Oklahoma and Kansas on May 25, 1955, was Udall, Kansas. Eighty people were known dead and 270 were injured, which was more than half of the people in Udall. The town was destroyed. In the entire outbreak, tornadoes killed 102 people and injured 563.

A tornado moved across southeast parts of Kansas City, hitting the area of Ruskin Heights on May 20, 1957. Forty-four people were killed and 531 were injured. More than 825 homes and businesses were damaged or destroyed, including the local high school. The outbreak itself spread from northeast Kansas and northeast Oklahoma through Missouri into Iowa and Illinois. In all, 17 tornadoes killed 59 people and injured 665 others.

1960–1969

The second most damaging outbreak of the century, known as the Palm Sunday outbreak, occurred April 11–12, 1965. Nearly 50 tornadoes struck parts of the Great Lakes region from Wisconsin and Illinois eastward through lower Michigan and northern Ohio. The outbreak resulted in 256 deaths and 3,402 injuries. Twin tornadoes moved into Goshen, Indiana, destroying nearly one hundred trailer homes. A large tornado hit Russiaville, Indiana, damaging or destroying 90 percent of the buildings. As many as 44 people died and 612 were injured as one tornado followed another tornado across Steuben and Monroe Counties in lower Michigan. Tornadoes devastated areas in northern Toledo, Ohio, killing 18 people. Other tornadoes moved through areas about 15 miles southwest of Cleveland, just northeast of Strongsville. Six homes literally vanished, 18 people were killed, and two hundred others were injured.

On June 8, 1966, a tornado brought massive damage to Topeka, Kansas, causing $100 million in damage. This became the most expensive tornado to date.

1970–1979

The most prolific tornado outbreak of the twentieth century was the super outbreak of April 3–4, 1974. During a 16-hour period, 148 tornadoes occurred from Illinois and Indiana into Michigan and Ohio, and southward through the Tennessee valley into Mississippi and Alabama. This outbreak produced the largest number of tornadoes, with 30 causing F4 damage or worse. At one point, as many as five large tornadoes were on the ground at one time. The outbreak killed 315 people and resulted in 6,142 injuries. One tornado hit Xenia, Ohio, at 4:30 PM, moved through the center of town, and demolished the high school. Thirty-four people died and 1,150 were injured in Xenia as three hundred homes were destroyed and 2,100 homes were damaged.

Five years later, a tornado hit Wichita Falls, Texas, on April 10, 1979, killing 42 people and injuring 1,740.

1980–1989

Thirty tornadoes spread out across parts of northeast Ohio into western Pennsylvania on May 31, 1985. The outbreak killed 76 people and injured 876 others. Twelve people died from one tornado that moved from Ashtabula County, Ohio, into Erie County, Pennsylvania. Sixteen people were killed by a tornado that started over Trumbull County, Ohio, then moved east-northeast across parts of Pennsylvania.

Another outbreak moved across Iowa and Minnesota into Wisconsin on June 7–8, 1984. The town of Barneveld, Wisconsin, was hit by a tornado just before midnight. All but the water tower was demolished, and nine people were killed. As many as 45 tornadoes in the entire outbreak killed 13 people.

1990–1999

The role of videotape and the advances in media technology provided many breathtaking views of tornadoes in the 1990s. People came from miles around to film the Hesston, Kansas, tornado on March 13, 1990. One tornado started near Goshen, only to merge with a second near Hesston and track northeast to just southwest of Topeka, Kansas.

Another notable Palm Sunday tornado occurred on March 27, 1994, when 22 people died in Goshen, Alabama, after a tornado hit a church.

Most recently, a large tornado mowed through areas of southwest Oklahoma City and Moore, Oklahoma, on May 3, 1999, demolishing or damaging more than eight thousand homes and ringing up more than $1 billion in damage. This tornado was part of an outbreak of 74 tornadoes that affected parts of Oklahoma and southern Kansas, killing 48 people.

Advancements in communications through radio and television helped issue advanced watches and warnings to the public. Plus, meteorological advancements from research in storm structure using Doppler radar helped forecasters identify tornadic storms, improving warnings from a few minutes to as many as 20 minutes, and increasing public response.

CHAPTER 8

Volume Three Review

This volume deals with the most violent storms experienced anywhere across the globe: cyclones, typhoons, and tornadoes. The opening chapters described the lives of Indians, Chinese, and others who are largely dependent for survival on the crops they can grow and harvest each year. The main crop is rice, and the annual monsoon that arrives in summer brings an extended period of the rain that is needed for successful agriculture. The monsoon's time of arrival and the distribution of its rain vary a good deal over time, and floods and famines have been experienced as a result. Powerful cyclones are triggered in the Bay of Bengal, as well as typhoons in the northwest Pacific, as a result of the huge movements of air that the monsoon brings. These storms have been responsible for enormous amounts of damage and great loss of life.

The Atlantic storms that bring destruction to North America, the hurricanes, and the tornadoes that originate along the Polar Front and cause even more violent destruction, are the equivalent of the Asian cyclones and typhoons. The hurricanes make landfall in the United States 10° farther north than do the cyclones in Asia, so their destructive power is much less. This cannot be said about tornadoes; their violence is unbounded, but fortunately it is limited to small areas of land and generally of short duration. From time to time, tornadoes arrive in clusters, outbreaks that strike many states within a short period of time. One outstanding example of this type, a super outbreak, occurred in 1974, when 148 tornadoes were involved. Among hurricanes, the memorable example of a worst-case was Hurricane Katrina. It not only brought high winds and flooding, it also took advantage of weak construction in the levees protecting New Orleans to release huge amounts of water from Lake Pontchartrain, creating a flood that overwhelmed the city.

IMPORTANT TERMS

Tornado outbreak

Indian monsoon

Microburst

Fujita scale

Meteorologist

Asian cyclone

Asian typhoon

A colony

Himalayas

Tibetan Plateau

Irrigation

Doppler radar

Automatic weather stations

Green revolution

Fertilizers

Pesticides

Levees

Hurricane

Storm surge

F5 tornado

QUESTIONS

Why is it difficult today to give an adequate warning about tornadoes?

What are the world's two biggest countries in terms of population?

How is rice grown?

Why is land sometimes warmer than the ocean and at other times the opposite?

What causes famines and floods for some people in Asia?

Is it safe to use pesticides to control insect pests? Are there alternatives?

What precautions can be taken to protect people during a cyclone?

Why is the protection of New Orleans against hurricanes particularly difficult?

Why do very few tornadoes make landfall in Connecticut or Maine?

Where should a person hide for safety when a tornado strikes?

WEB SITE FOR FURTHER STUDY

The National Hurricane Center's Web site is designed to provide information about hurricanes (http:\\www.nhc.noaa.gov). This is its opening statement: "History teaches that a lack of hurricane awareness and preparation are common threads among all major hurricane disasters. By knowing your vulnerability and what actions you should take, you can reduce the effects of a hurricane disaster."

Appendix A: Important Dates in Weather and Climate History

1238 The hottest and driest summer of the millennium in England.

1281 A North Sea storm surge hit the Netherlands in January, flooding large tracts of land and drowning 60,000 people.

1421 Worst North Sea storm surge hit the Netherlands in November, causing the deaths of 100,000 people.

1586 England's first colony in America, established on Roanoke in 1585, had to be abandoned because of severe weather.

1737 The second-deadliest Asian cyclone in recorded history killed 300,000.

1772 The biggest U.S. snowfall (before official records began) occurred in January, when three feet fell in the Washington-Baltimore area. It has been called the Washington-Jefferson snowstorm because it was recorded in both of their diaries.

1780 A hurricane traveled the length of the Windward Islands chain in the Caribbean in October, with St. Lucia and St. Vincent the worst affected, causing the deaths of 24,000 residents.

1791 Cuba was hit in June with a powerful hurricane that took three thousand lives.

1816 The year that was called "the year without a summer." In Savannah, Georgia, the Fourth of July had a high temperature of 46°F. Because it was so cold across the eastern United States, crops were ruined. Snow fell in June, heaviest in New England, with snow drifts of 18 inches. It was the same story in Canada and in Europe. These changes in weather were attributed to the 1815 eruption of Mount Tambora in Indonesia.

1824 In St. Petersburg, Russia, in November, a powerful storm from the Baltic Sea brought a storm surge into the Sea of Finland that swept inland, flooding the Imperial Capital and its palace and drowning 570.

1831 The Caribbean island of Barbados experienced its worst hurricane, which destroyed thousands of buildings and killed 1,500, representing 2 percent of the island's total population

1840 The second-deadliest tornado in U.S. history, Natchez, killed 317.

1870 U.S. Weather Bureau was founded and placed under the office of the Secretary of War.

1881 The third-deadliest Asian cyclone of all time, the Haiphong Typhoon in Vietnam, killed 300,000.

1887 San Francisco's greatest snowfall came in February, with a total of four inches in the downtown area.

1888 The Blizzard of 1888 affected the eastern United States in March. Over four feet of snow fell in the Albany and Troy areas of northeastern New

York state. More than 400 people lost their lives, mainly due to exposure to strong winds and cold temperatures.

1896 The third-deadliest tornado in U.S. history, St. Louis, killed 255.

1899 In February a cold wave caused a massive east coast blizzard and induced bitter cold temperatures across two-thirds of the United States. It was the only occasion that saw true blizzard conditions in the state of Florida.

1900 The second-deadliest Atlantic cyclone in U.S. history, Galveston, hit in September, killing 12,000.

1913 The highest U.S. temperature on record was recorded in Death Valley, California, on July 10, at 134°F.

1913 Several tornadoes hit southwest England and central Wales on October 27.

1921 On September 10, Thrall, Texas, experienced the greatest U.S. 24-hour rainfall on record up to that date. The total was 38.2 inches.

1922 A community in Libya, Africa, on September 13, claimed the world record for the highest temperature of 136.4°F.

1925 The deadliest tornado in U.S. history, Tri-State, killed 689.

1934 On April 12, Mount Washington, New Hampshire, experienced a gust of wind at 231 mph, accepted as the U.S. record for the highest wind speed.

1936 The fourth-deadliest tornado in U.S. history, Tupelo, killed 216.

1940 The U.S. Weather Bureau moved to the U.S. Department of Commerce.

1947 At Snag in the Yukon Territory of Canada, on February 3, the temperature was –81.4°F. This is the lowest on record for all of North America.

1949 In October Guatemala experienced a week of heavy rain from a stalled tropical cyclone. The results were flash floods and mudslides and a death toll of 40,000.

1952 From December 2 to December 6, London, England, experienced its deadliest weather disaster, the great smog that paralyzed the city, stopping all traffic and almost all pedestrian movements, and killed 6,000.

1953 The worst North Sea storm surge of modern times hit the Netherlands and southeastern England on January 31, killing more than 2,000.

1954 In Qazvin, Iran, a violent thunderstorm over the Elburz mountains triggered a flash flood over this city, killing 10,000.

1959 Due to an unusually wet summer monsoon season the Yellow River in northern China overflowed its banks and caused the deaths of an estimated two million people, the highest death toll ever for a meteorological disaster.

1963 The third-deadliest Atlantic cyclone in U.S. history, Flora, hit Haiti and Cuba in October, killing 8,000.

1964 At Oymyakon, Siberia, Russia, in February, the lowest temperature for the northern hemisphere was registered at –96°F

1964 Karachi, Pakistan, in December, experienced a major tropical cyclone that took the lives of 10,000.

1970 The deadliest Asian cyclone of all time, the Great Bhola of Bangladesh, killed 550,000.

1974 A tropical cyclone hit Darwin, Australia, on December 25, killing 65.

1975 The eighth-deadliest Asian cyclone of all time, the Super Typhoon Nina, hit China, killing 170,000.

1983 In Vostok, Antarctica, on July 12, the world's lowest temperature of –138.6°F was recorded.

1992 Hurricane Andrew, the United States' costliest meteorological disaster, swept across Dade County in August with devastating results.

1993 Missouri–Mississippi flooding, greatest U.S. flood of the century.

2005 Hurricane Katrina, costliest storm in U.S. history.

2008 The tenth-deadliest Asian cyclone of all time, Nargis, hit Myanmar, killing 140,000.

U.S. WEATHER AND CLIMATE FROM AD 1000 TO 2000

There are no written records for the first half of this millennium, so there are no details of actual weather conditions. However, there is a huge amount of archeological, botanical, and zoological evidence available, and we can construct from them a picture of the prevailing conditions at different periods of time. At the beginning of the last millennium, both in the United States and throughout Europe, warm weather was widespread, and this continued for the first two centuries, from 1000 to 1200.

The overall regime of warmth was accompanied with abundant, reliable rainfall across the Great Plains, giving rise to extensive wooded areas, the kind of landscape that remained unique to this time period of 1000 to 1200. This was also the time when a large population could be sustained in heartland America. One place in southern Illinois had 50,000 inhabitants between 1100 and 1200. All of this changed in the early years of the thirteenth century; by its first decade, what is now the United States became much colder and drier. The warm and moist air masses from the Gulf Stream were replaced by a strengthening that developed in the westerly flow across the continent. Within the following 40 years the woodlands had retreated from the U.S. Interior, and the Great Plains became grasslands, the habitat of the buffalo that would become, at a later time, so familiar to early European explorers.

Native American populations declined as a result of the change in climate. Settlements were abandoned, and people migrated westward and southward. It was a similar story farther to the north, where the first Europeans had settled for a long time during the warm period on the island of Newfoundland in Canada. By the fourteenth century, they had to abandon their North American settlement as well as those they had founded in Greenland and Iceland. Most of the United States remained cold for the long period that came to be known as the Little Ice Age. The first English colony that was established on an island off the coast ofVirginia had to be abandoned within a year due to low temperatures. An overall warming trend, one that affected all of the United States, began to arrive toward the end of the nineteenth century, but it did not become a settled pattern until the second half of the twentieth century.

EVOLUTION OF CLIMATE CHANGE CONCERNS

1970s For much of this decade, mainly because evidence of global cooling had been experienced over the previous three decades, scientific interests and publications focused on the prospect of a return to ice-age conditions.

1980 A report to the president of the United States from the Federal Council on Environmental Quality pointed out that human-caused climate change as a result of greenhouse gas emissions would probably be evident to all within the following 20 years.

1988 The World Meteorological Organization and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC).

1993 The scientific journal *Nature* published the findings of the scientists who had extracted a two-mile ice core from the Greenland ice sheet in order to identify climatic conditions 12,000 years ago. These scientists were astonished at both the rapidity and extent of the climate changes they identified, in particular the 1,300-year cold snap that appeared relatively suddenly. This period of time is often called the Younger Dryas after an Arctic flower.

1997 The scientific journal *Science* published an article that identified the slowdown in recent years of the Gulf Stream as a development that closely resembles the rapid changes in the Younger Dryas time.

2005 The Kyoto Protocol, a set of obligations related to the IPCC, came into force in February, and many developed countries agreed to follow its prescriptions. These related to reductions in levels of greenhouse gases by a specific date.

2007 The Norwegian Nobel Committee awarded the Nobel Peace Prize in two equal parts, to the IPCC and Albert Arnold (Al) Gore Jr., for their efforts to build up and disseminate greater knowledge about manmade climate change and to lay the foundations for the measures that are needed to counteract such change.

APPENDIX B: SOME EXTREME GLOBAL WEATHER EVENTS

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as well as Appendix C, which focuses specifically on U.S. extremes, is to provide a larger context to which the individual references can be linked. When it comes to global extremes, the nations of Asia still dominate. Again and again, even after a century of improved methods of protection from tropical cyclones and interior floods, weather events are far more severe in Asia than we are accustomed to in North America. Numbers of casualties and the extent of environmental damage are often huge. One reason for this is the high terrain that borders nations such as Bangladesh and Vietnam; another is that the Pacific Ocean is much bigger than the Atlantic, and storms reach the Asian mainland with huge volumes of moisture after moving across great stretches of water.

The two biggest nations of Asia in terms of population are China and India, and they epitomize two extremes of weather: flooding in China and drought in India. The extremes of flooding in China are described in Volumes 1 and 2, and the drought problems of India are explained in some detail in Volume 3. The China flood of 1931, described next, was by far the most extreme in centuries, and the drought that hit India in 1900, along with the accompanying famine and starvation, was the worst of the entire twentieth century. Extremes of tropical cyclones, just like floods and droughts, are usually greatest in Asian countries, but occasionally other parts of the world experience exceptional storms. The two examples included here are of this character, Hurricane Mitch of Central America and Cyclone Wanda of Australia. The fifth extreme event included here took place in the Sahel of Africa, selected because it is an area that experienced so many droughts in the twentieth century that the United Nations set up a special task force to study the problem and identify the causes.

CHINA FLOOD, 1931

In the United States it is easy to think of hurricanes and tornadoes as the causes of more deaths than other weather events. In fact, in the United States, and to a far greater extent in Asia, floods cause far more deaths. In China, in particular, there is a tragic history associated with flooding, and Chapter 5 of Volume 1 shows this in the tragic story of

the great 1887 flood. The 1931 flood went far beyond the 1887 one in terms of deaths and damage. Nothing equal to it had happened in China in centuries of experiences of flooding. It began during the summer months, and the worst flooding occurred on the Yangtze River, although the heavy rains and rapid snow melt affected many other rivers in central China at the same time. About 51 million people were affected, representing a quarter of the nation's population at that time.

The U.S. National Oceanic and Atmospheric Association (NOAA) considered this 1931 event the most extreme weather-related disaster of the twentieth century, possibly the deadliest natural disaster ever recorded. The number of deaths was approximately four million, not all due to drowning. In 1931 China was still predominantly a rural society, and people earned their livelihood from agriculture. There was no national organization that could provide emergency food supplies, so, as water destroyed their food crops, mostly rice, people had nothing to eat beyond the supplies they might have saved from previous crops. Thus many died from hunger. Many others became infected with deadly diseases from polluted water. The causal factors that led up to this tragedy were a combination of extended droughts, from 1928 to 1930, followed by an equally protracted period of heavy rain. In winter much of the precipitation fell as snow, and in the following spring, the thaw added quantities of water to the rainfall, greatly increasing the volume of water in the rivers.

Rainfall persisted throughout the summer months and, in July alone, the area on the Yangtze River near the capital of that time, Nanjing, was hit with seven tropical cyclones, each of which added substantially to the amount of water in the rivers. Normally this part of China experiences about two tropical cyclones a year. By July of 1931, Nanjing had become an island in a massive flooded area. The high-water mark on the Yangtze reached 53 feet above normal by the middle of August. The immediate cause of flooding in China is nearly always a result of failure of the levees. Historically these are built of sods, so they offer little resistance to a sudden rise in the level of the river, especially if the rise in river flow occurs on a downward slope. These levees get built up over time to compensate for the rise in elevation of the riverbed, as more and more silt is deposited in it, so the river runs at an elevation above the surrounding plain.

Thus, as soon as a breach occurs in a levee, the rapid flow of water through the opening quickly expands the opening and increases the volume of water escaping into the lower land below. Toward the end of August the water flowing through the Grand Canal near the mouth of the Yangtze washed away the supporting dikes and drowned 200,000 people. In modern China the ancient forms of levees and dikes have been replaced in critical areas of the country by protective walls of concrete so that the enormous tragedies of the past will not be repeated. Additionally, hydroelectricity is being produced in many locations on rivers, and the dams serve as control points to prevent overtopping during sudden increases in river flows. The huge undertaking to dam the Yangtze River in order to secure much greater amounts of hydroelectricity provides protection from flooding all along the river.

HURRICANE MITCH, 1998

Deadly tropical cyclones frequently strike coastal areas along the Bay of Bengal, causing enormous loss of life and extensive environmental destruction. The Bangladesh cyclone of 1970 that is described in Volume Three of this series was the nation's greatest disaster of the twentieth century. Winds coupled with a storm surge killed between 300,000 and 500,000 people. The tropical cyclones we experience in North America, which we call hurricanes, do not generally reach these levels of destruction, but occasionally there are extreme examples of deadly hurricanes. Hurricane Mitch of 1998 was one of these. It was a late-season arrival, forming in the western Caribbean in October and moving westward over the mountainous areas of Central America. This storm weakened as it reached Honduras. Perhaps because it arrived late in the season, it did not have the strength to continue westward after reaching Honduras so it stalled over that country.

Hurricanes that travel across the warm waters of the Caribbean carry large amounts of water, and this volume of moisture is usually spread over an extensive area of land when precipitation takes place and the storm moves along. It is a very different story when a hurricane operating in the warm waters of latitude 15° north stalls over land, and especially when it stalls over mountainous land, as Mitch did. It unleashed precipitation amounts estimated as high as 75 inches. The resulting floods devastated the entire infrastructure of Honduras and also severely impacted other countries in the Central American region. The final estimated death toll was 11,000, the greatest loss of life from a tropical system in the western hemisphere since 1780. The fact that this was an estimated death toll tells us a lot about the level of development, and preparedness for hurricanes, in the countries affected.

Extensive wind damage and devastating floods occurred all over Honduras, particularly on the northern seaboard and in the Bay Islands that are located off the northern coast. Approximately 1.4 million persons were left homeless, more than 92 bridges were damaged or destroyed, and nearly 70 percent of crops were lost. The U.S. Geological Survey was called to help assess and map the damage and to provide technical help with landslide mitigation. Fortunately, the recent date of this hurricane makes possible the use of techniques to accurately assess the extent of the damage and provide expert help in recovery.

INDIAN DROUGHT, 1900

In contrast to the famines that occur in China due to the country's frequent floods, the Indian famines are caused by the absence of rain. The monsoon is the name given to the annual arrival of massive amounts of rain that reach land after traveling thousands of miles across the warm waters of the Indian Ocean. It is the greatest weather event in the world for two reasons: it travels over an area of water greater than

that of any other weather system, and it affects a bigger population than is ever affected by another single series of rainfalls. This main weather event of the year begins with rain arriving in early summer in the south of the country and often continuing unabated for weeks before dying down. It is common for rivers to overflow and communities to be flooded, but no one objects because this summer rain is the lifeblood of the whole nation. Even today, most of India is still a rural, agricultural society. In 1900 everyone depended on what could be grown in order to survive and, in this hot tropical climate, every crop depended on rain.

India has a second monsoon that arrives in the fall of each year. It is quite different from the summer one because it travels south over dry land and so carries much less moisture. If we think of India together with the large mass of continental land that lies north of it in the Himalayas, China, and Siberia, the enormity of these two annual events can be visualized. In summer, because land heats up much quicker than water, the air that had been circulating over long stretches of warm ocean water, and that therefore carries large quantities of moisture, is attracted toward the low-pressure areas over land. As it rises over higher ground water is precipitated, and the summer rains begin. People talk about it as rain, rain, and rain again; clothes damp, bed linen damp, walls damp, food damp, everything damp. Rain hammers a tattoo on corrugated iron roofs, tears up roads, and smashes down vegetation. The opposite movement of air happens in the fall as the land cools below sea temperatures, and a reverse flow of air takes place. It is the summer rains that are always the focus of interest. They sustain crops, especially rice, for the hundreds of millions of Indians. Billions of rice seedlings are in the fertilized, prepared plots of land in May or early in June awaiting the arrival of the monsoon.

What happens if it fails to arrive at the time the weather forecasters gave? In 1900 forecasting the exact date of arrival involved quite a bit of guesswork. There were few weather stations serving the land areas, and nothing on the ocean except reports from passing ships. A primitive form of statistical prediction operated. That is to say, forecasters knew that, on average, the monsoon would arrive within ten days of the middle of June, so they used whatever data they had to fix a date within that timeframe. However, even if the statistical average proved to be true for 30 years, the elders in Indian communities knew that occasionally there were huge exceptions. They knew of the terrible years of 1768, 1769, and 1770, when inadequate rain arrived and ten million people died. Somehow these anomalies had been forgotten in the year 1900. There had been exceptionally low amounts of rain in 1899 and again in 1900. Because of the possibilities of weak monsoons, farmers had been in the habit of storing some grain each year as a kind of insurance against a famine, but for some reason this had not been done before 1899 and 1900.

Severe shortages of rice were reported all over southern India in 1899 and over the rest of the country a year later. Unlike modern times

in India, in which food reserves are on hand to cope with disasters like this one of 1900, there was nothing that could be done for the farmers who had inadequate amounts of rice. A certain amount of sharing was done within communities, but the overall picture deteriorated into widespread famine by the fall of 1900. Disease and a breakdown in social order followed. There were many deaths. Subsequently it was discovered that there had been low levels of rain in the monsoons of 1896 and 1897, and these conditions led to the inability of farmers to put some grain aside as a reserve for emergencies. The British colonial authorities of the time paid no attention to these failures in the monsoons. They were only concerned with securing their quota of rice in order to satisfy their superiors. The final tally of deaths from famine and disease ranged from two million to ten million. The uncertainty about the numbers is a sad commentary on the failure of the colonial power to look after the people over whom they ruled.

AUSTRALIAN CYCLONE WANDA, 1974

Australia is quite well acquainted with extremes of climate. It has a very large desert area, and its location in a tropical zone means it gets the full effect of the unexpected heavy rains and high temperatures that are commonplace in that part of the world. During the summer of 1974 there happened to be one of the wettest seasons that Australia had ever known. The climatic variation called La Niina had been one of the most extreme of the entire twentieth century. As result of both of these conditions, rainfall was torrential and continuous through most of January 1974, as the inter-tropical zone settled over northern Australia. On January 25 of the same year, Cyclone Wanda moved over the interior of Queensland and New South Wales, dumping more than 12 inches of rain in 24 hours over a very wide area. As a result, because the summer rains had completely saturated the ground, massive flooding occurred on all the nearby river systems.

The city of Brisbane was the worst hit. It had not experienced a major flood for more than 70 years, and few suspected that anything like this would ever happen. After the last occasion when a major flood had hit the city, in 1893, very strict regulations were established for building on areas below a certain elevation. These restrictions were laid out for the parts of the city that would be at risk in the event of a major flood. Sadly, these regulations were not maintained for one reason or another, and subdivisions were allowed to develop on the areas on which no homes or other buildings were to be built. It is a story that is similar to what we have seen in the aftermath of the San Francisco earthquake, where areas that should never have been built on were once again rebuilt. Throughout Brisbane on January 25 there was a general failure of disaster warnings. There was no central authority that was able to receive details on the amount of flooding that occurred in different areas, so that local flooding in key areas was never reported to the authorities. About 70 percent of the

residents who were questioned afterward about the flood said that they had received no official warning.

January 25, 1974, the peak of the damage caused by Wanda, will be remembered as the worst floods in Australian history. Flooding covered an area slightly larger than the entire drainage basin of the Mississippi River. It reached from the dry interior at Alice Springs all the way to the Pacific Ocean, and from the extreme north of the country to the areas around Sydney, including the Murray River system. Military airplanes had to be used to supply isolated towns that were cut off by the floodwaters with emergency food for both humans and animals. In Brisbane, all bridges across the Brisbane River were damaged or destroyed, and 35 people drowned. At its height, the river broke its banks and ran through the central business district of the city. Water levels peaked at 20 feet by January 29. In one of the subdivisions 1,200 homes were destroyed. Overall, 20,000 people were left homeless. There was no adequate relief organization at this time, and about half of the victims depended on church contacts and a large number of volunteers for the help they did receive. By the end of January much of Australia, normally the dry continent, was submerged in water. Crops were destroyed, and there were outbreaks of disease.

Major flooding like this is so rare in Australia that the disasters of January 1974 are unique in the history of the country. In the aftermath, thoughts were concentrated on appropriate action that would prevent future disasters. Almost immediately the Queensland Government introduced a series of flood mitigation measures that expanded earlier ones. The experience was a wake-up call for Australia.

SAHELIAN DROUGHTS

This region, which stretches for three thousand miles across Africa south of the Sahara Desert, from Senegal at the Atlantic Ocean to Eritrea at the Red Sea, is a focus for all the world in the study of drought. It is an extreme example of aridity because of the extent and persistence of the droughts that overwhelm it. From 1968 to 1973 most of the region suffered from lack of rain, and the Sahelian Office at the United Nations created a special unit in 1973 to investigate the causes and recommend ways of coping with droughts. Occasionally the whole world becomes aware of the deadly nature of these times of aridity when international aid efforts are launched. One of these efforts is described in Chapter Six of Volume One: half a billion dollars was raised by Live Aid to help Ethiopia cope with a famine that had already taken the lives of 300,000 people. Overall, in the Sahel as a whole, between the 1960s and 1980s, famines took the lives of a million people, and many millions more were affected.

The 50 million people of the Sahel pursue different livelihoods. These include agriculture, livestock herding, fishing, and short- and

long-distance trading. Farming is almost entirely reliant on three months of summer rainfall, except for places that happen to be near a major river such as the Niger. Researchers from The United Nations, as they examine the region's economic fragility, recognize that the vast majority of the population is dependent on some form of rain-fed agriculture, including pastures for animal production. Three major droughts have occurred this century, in 1910–16, 1941–45, and a long period of below average rainfall that began in the late 1960s and continued, with some interruptions, into the 1980s. Absolute minimum rainfall levels were recorded at many stations in 1983 and 1984. The period of poor rainfall in the 1970s was particularly hard for many Sahelian farmers and pastoralists. An estimated 100,000 died from it.

Sahelian droughts and their effects have been studied extensively since the 1970s as part of the international response to this environmental emergency. It is only since 2000, however, that the long-term impacts of the famines of the 1970s have become evident. Those events provoked a rethinking of the links between population growth, drought, and sociopolitical change, and also helped to refocus development policy away from expensive and unsuccessful interventions toward more considerate strategies targeted at boosting local capacities. A complicating factor was increases in migration and international trade. Food distribution in famine situations by donors and governments has not been successful, despite the establishment of national cereals boards in most Sahelian nations, and the construction of roads into more remote rural areas. Rural residents still have to pay for government grain, and not all households are able to pay.

Originally it was believed that the problems in the Sahel were caused by humans overusing natural resources through overgrazing, deforestation, and poor land management. The expansion of farming and herding into marginal areas was said to have produced a spiral of changes, in which reduced vegetation caused reduced rainfall, producing further decreases in vegetation and thence a further reduction in rainfall. The series of Sahelian studies and climate modeling carried out by an agency of the NOAA over some years, and published in 2005, present a very different story: the problems are caused by changing sea surface temperatures that, in turn, were created by greenhouse gases and atmospheric aerosols from volcanic eruptions. In other words, global warming and climate change are the primary villains. The NOAA studies also point out that these human-induced changes in sea temperature could lead to a substantial reduction in the Sahel's rainfall in the course of this century.

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APPENDIX C: SOME EXTREME U.S. WEATHER EVENTS

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as with Appendix B, is to provide a larger context to which the individual references can be linked. This list of U.S. extremes begins with two volcanic eruptions, one from Alaska, the biggest that occurred anywhere on earth during the twentieth century, and one from Washington State, the biggest ever within the contiguous United States. They are reminders of the unpredictable element brought by volcanic eruptions to the ongoing changes occurring in our atmosphere. Volume 1 describes the role of volcanic eruptions in considerable detail, with regard to their influences both now and in the future.

The other three extreme events included in this appendix are two extremes of temperature, cold and hot, and one of the most violent hurricanes of modern times, Camille of 1969. The extreme of heat is interesting because it arrived in the midst of widespread talk about global warming and climate change and is a reminder that the addition of carbon dioxide to the atmosphere has different effects in different places. In this instance, the high heat of the year 2006 is almost identical to that of the year 1936, the time of the Dust Bowl. The years 2006 and 1936 were the two hottest of the twentieth century.

MOUNT KATMAI, ALASKA, 1912

Katmai was the biggest eruption of the twentieth century anywhere on earth. A volume of volcanic ash greater than the amount from all other volcanic eruptions in Alaska was ejected, and it devastated every place within miles of the source. It created the Katmai Caldera and the Valley of Ten Thousand Smokes. Volcanic ash devastated areas hundreds of miles away. Within four hours of the initial eruption, ash had reached Kodiak, lying one hundred miles to the southeast, and by the end of the event, both Vancouver, British Columbia, and Seattle, Washington, were showered with sulfurous ash. The cloud produced by the eruption had reached Virginia by June 7. Ten days later, it had reached North Africa.

Kodiak suffered greatly during the three-day eruption. Ash and sulfurous smoke caused a slew of health problems ranging from respiratory illness to sore eyes. Additionally, the eruption rendered Kodiak's water

supply undrinkable, disrupted radio communications, and destroyed many buildings, some of which burned and others of which collapsed under the weight of mountains of ash.

As a result of the Katmai disaster, several villages were abandoned forever. Additionally, the eruption caused untold environmental havoc, and many animals, ranging from bears to birds, died of starvation. Aquatic organisms were also affected where waters were shallow and became choked with ash. This devastated local salmon fisheries for years.

Despite the fact that the eruption was so close to the continental United States and comparable in magnitude to that of Krakatau of 1883, it was hardly known at the time because Mount Katmai was so remote from the world's main population centers.

Almost a hundred years after it happened, researchers are still paying attention to Katmai because it is near the Arctic Circle, and its impact on global climate appears to be quite different from that of volcanoes in lower latitudes. Unlike eruptions in the tropics, the aerosols emitted by Arctic volcanoes tend to stay at high latitudes, because the stratosphere's average circulation is poleward from the equator. As a result, these particles remain effectively "bottled up" in the Arctic, dispersing into the rest of the earth's atmosphere only very gradually. Professor Alan Robock of Rutgers University has argued that this trapping of aerosols in the Arctic has an unexpected side effect: the weakening of the Indian monsoon. Robock reached these conclusions using complex calculations; however, the basic concept is that cooling in the northern hemisphere caused by the Katmai eruption set in motion a chain of events ultimately affecting air flow over the Himalayas and thus rainfall in south Asia.

To check his results, Robock and colleagues have been examining weather and river flow data from Asia, India, and Africa from 1913, the year after Katmai. They have also investigated the consequences of other high-latitude eruptions in the last few centuries. The fact that the stratosphere in high latitudes is shallower than at the tropics means that even small eruptions near the North Pole may deposit more aerosols than bigger events in the tropics. Furthermore, they would remain in circulation longer, as happened with Katmai. Indians will need to keep an eye on future Arctic eruptions.

It is unlikely that another eruption on the scale of Katmai will occur in the same region in the foreseeable future. However, volcanologists have confirmed that at least seven Katmai-scale eruptions have occurred over the last four millenia within a five-hundred-mile radius of the city of Anchorage, Alaska, so such a recurrence is far from outside the realm of possibility.

MOUNT ST. HELENS, WASHINGTON, 1980

The eruption of Mount St. Helens was the largest ever in the history of the contiguous United States. It had a VEI of 5. Mount St. Helens is the

youngest of the Cascades' volcanic peaks, and the explosion of 1980 is just the most recent of the many intermittent eruptions that took place over the past 40,000 years. Pumice and ash from these past events now cover large areas of the Pacific Northwest. From the 1950s onward, the mountain was intensively monitored, perhaps to a greater degree than any other. Days before the fateful event of Sunday May 18, 1980, there were many signs of impending danger, but no one was quite prepared for what finally happened. It all seemed to take place in seconds. Seattle's air traffic control tower tracked the mass of ash and rocks hurtling out of the mountain and concluded that it was traveling at close to 300 mph. The earthquake that triggered the explosion measured 5.1 on the Richter scale, but the energy released might be more accurately defined as the equivalent of thousands of Hiroshima-size bombs.

An avalanche of mud, rock, and ice roared down the mountainside, and the ash cloud rose as high as 54,000 feet. What had moments before been a beautiful 9,000-foot-high peak was reduced to a 7,500-foot decapitated mountain. Ash high in the atmosphere drifted eastward across the country, covering the ground everywhere it went with a layer of ash and blocking out sunlight in several communities near the mountain. Two hundred square miles of forest was flattened. Mudflows rushed westward down river valleys toward the Columbia River, blocking the navigation channel for ships with logs and mud for a distance of ten miles. It was estimated that 57 people lost their lives on that first day.

A Boeing 737 jet flying from Reno, Nevada, to Vancouver, Canada, at six thousand feet, was 40 miles south of Mount St. Helens when the mountain exploded. The pilot saw the explosion and swung away from his course, a path that would have taken him directly over the eruption, escaping in so doing a dirty gray cloud that was rising quickly to meet him. His 737 rocked in the air from the shock of the explosion as if it were a ship at sea. Fortunately his flight had been delayed for 30 minutes at Reno, or all 122 passengers plus crew would have been added to the list of deaths for May 18. The earthquake that triggered the event was not an unusual event in a region that experiences frequent earthquakes of this strength and stronger ones, but the scale of the eruption was a very different matter. It was a rare event even in historical time. Volcanic eruptions are identified by a volcanic eruption index number (VEI) based on the volume and speed of the rock and ash that is ejected. The index is numbered similarly to the Richter scale, each number representing ten times the volume of the one immediately below it, and one tenth that of the next number above it.

For this event of VEI 5, a volume of eruption greater than any other in the contiguous United States, one has to go back into earlier times to find a meaningful comparison. Vesuvius in the year 79 or Krakatau in 1883 each had VEIs of 6, or they were ten times more powerful than Mount St. Helens. Volcanoes in the Cascade Range are fairly new in geological time. A few date back several million years. Mount St. Helens is one of the youngest. Much of its visible cone was

formed within the last thousand years. It was frequently active during that time, and because of that geologists were convinced that a major eruption would occur sometime in the twentieth century. Further evidence in support of that expectation came more recently when it was found that the mountain had been more active and more violent over the past few thousand years than any other volcanic mountain in the contiguous United States. From the evidence in ash deposits across the western Cordillera, it is clear that some of these older eruptions must have had VEIs of 6.

The most recent well-documented eruption, prior to 1980, occurred in 1842. Eyewitness accounts from that time described seeing vast columns of smoke and fire. Ash from that time was subsequently located at The Dalles in Oregon, about 65 miles away. Fireworks continued intermittently over a 15-year period. Then came a three-year lull followed by a lot of activity in the year 1857. After that date the volcano seemed to have slept for the 123 years before 1980. The moment of eruption on May 18 of that year was indelibly etched in many memories. David Johnston, the expert geologist from the U.S. Geological Service who was monitoring the mountain on the morning of the explosion, talked to news reporters early on that day. He described Mount St. Helens as a keg of dynamite with a lit fuse whose length you do not know. He was well aware of the risks of being so close to the summit, but he stayed there right up to the moment of the eruption. He told the reporters that it was extremely dangerous to stand where they were at that time. "If the mountain explodes," he told them before they left, "we would all die." Soon afterward they heard his final words as he yelled into his radio, "Vancouver, Vancouver, this is it!"

A family watched their dream $100,000 home smashed and washed down the chocolate-brown Toutle River. A couple on a camping and fishing trip on the same river tried to grab their camping gear when they heard the explosion, but quickly saw there was no time to escape in their car. They were thrown into the water and carried along in a mass of mud, logs, and rocks, grimly clinging to one log. They were lucky. The log was shunted sideways out of the main stream. Some time later, a helicopter picked them up. A television cameraman a kilometer and a half from the base of the mountain filming the event saw the mass of mud and debris heading for him. He dropped everything, got into his car, and drove madly to keep ahead of destruction. He was able to stay ahead of it.

Farther east, travelers were stranded in numerous small communities, altogether 10,000 of them in three states. One couple driving west from Spokane saw the black oncoming cloud. Soon they could only inch along the highway at less than eight kilometers per hour. They abandoned their car and joined the other stranded ones. Everywhere around, trains, buses, airplanes, and cars came to a stop. Walking was the only thing that worked. Digging out from under the ash was yet another hazard. It proved to be as hard as getting around it. For some time people wore masks of whatever material they could find for fear of toxic fumes.

As is common in volcanic eruptions, the magma that had risen and caused the explosion left the inner chamber empty for a time until new magma moved up from below. The interior dome then began to grow until pressure rose to a level that caused another eruption. Several of these subsequent eruptions came in May, June, July, August, and October of 1980. By 1983 the dome had grown to six hundred feet and the crater in which it sat was two miles in diameter, waiting for the moment of the next event, and meanwhile continuing to grow.

How can volcanic eruptions and earthquakes be predicted? The answer remains elusive, but experience from Mount St. Helens shows us some of the things that can be done. As mentioned earlier in this chapter, this mountain received more monitoring since the 1950s than almost any other, and the small number of people who were killed is largely due to this, as well as to the actions that were taken in the months before May 18, 1980. The first earthquake in Mount St. Helens struck on March 20, 1980, and immediately afterward seismologists met with local authorities to warn of the danger ahead and make some preliminary plans.

One week later steam and ash exploded from the summit of the volcano, and this was followed by several minor eruptions over the following weeks. As these eruptions became more frequent, public authorities closed off the area around the mountain, causing heated opposition from the general public. Later they lowered the water level in the Swift Dam reservoir to minimize damage from mudflows. Still closer to the time of the eruption, the governor of Washington declared a state of emergency in order to use the National Guard to staff the roadways. So angry were some over the closure that they found ways of circumventing the law by using little-known roads and footpaths to gain access. Some, including Harry Truman, a veteran resident of the mountain, refused to leave their homes on the north side and died.

ARCTIC OUTBREAK, 1989

America's coldest spell of the century arrived in December 1989. In the South, New Orleans experienced 64 consecutive hours at or below 32°F and a total of 81 out of 82 hours below freezing. A total of 15 hours were below 15°F, with the lowest reading of 11°F on the morning of December 23. A low of 8°F was recorded at Baton Rouge. Snow and sleet paralyzed transportation systems in New Orleans, and there were a hundred fires in the city, a result of inadequate heating systems. The greatest impact was on breakage of water pipes in homes and businesses. Five weather-related deaths occurred in the area during this rare Arctic outbreak.

The story was similar in the Midwest: it was the coldest day of the season for south central Nebraska and north central Kansas, and most locations experienced subzero temperatures. This Arctic outbreak peaked around December 15 and continued for about ten days. Low temperature records were broken throughout the United States. Nothing comparable

is found in weather records until we go back to 1899, when a similar chill occurred. The events in both of these years were quite similar: both were fast-moving, very powerful Arctic outbreaks that stretched across most of the United States and reached into Mexico and Florida.

GREAT HEAT WAVE, 2006

In 2006, from June 1 to August 31, as summer is defined by the National Climatic Data Center, the United States experienced its greatest heat wave in 70 years. The average temperature across the country was 74.5°F, based on readings from hundreds of weather stations. It was the second-hottest summer temperature since the government started to keep records in 1895. The only comparable heat wave was in 1936. At the 2006 peak, temperatures greater than 100°F covered the Great Plains, Midwest, South, and much of the Northeast. The year 1936 is a reminder of the Dust Bowl years that are described in Volume One.

With air conditioning being quite limited in its coverage in 1936, many people were forced to sleep in their yards or in parks. The death toll was high, estimated at about 50,000 total. The heat was especially deadly in large Midwestern cities such as St. Louis, Minneapolis, and Detroit. The total number of deaths from a heat wave is rarely given out by media for various reasons: deaths from heat are silent killers, they do not cause visible destruction where they occur, and causes of deaths are difficult to identify.

HURRICANE CAMILLE, 1969

Camille was one of only three hurricanes in the history of the United States to make landfall as a Category 5. It was an extreme hurricane, one of the most violent storms of the twentieth century. It arrived from western Cuba on August 14 and entered the warm waters of the Gulf, reaching Bay St. Louis on the evening of August 17 with sustained wind speeds of 190 mph. It almost totally destroyed the Mississippi coast. Before it left the mainland United States it had caused the deaths of more than 250 people and injured 8,900, and destroyed 6,000 homes and damaged 14,000. The total costs of the destruction it caused were in excess of a billion dollars. Millions of Gulf coast residents were made aware of the strength of the storm before nightfall on August 17. Before the storm reached Bay St. Louis, about 200,000 residents had fled the coastal areas into sheltered places.

As the storm moved across the coast in darkness, homes, motels, apartments, restaurants, and other buildings were swept off their foundations and deposited in mountains of rubble. It was the same for almost everything movable and for much, such as trees, that was not. Camille maintained its hurricane strength for ten hours. On the morning after

the storm, thousands searched among the wreckage for anything that might have been left. There was no semblance of normal life in the region around New Orleans for days, but fortunately the levees around the city were not affected because the storm was centered a few miles to the east. About 15,000 people were left homeless. There was no water, food, or fuel. The storm had wiped out all means of communication, and roads, bridges, airports, and even railways were impassable or destroyed. Gulfport Hospital had closed down and evacuated all of its patients to hospitals farther inland.

Adding to the devastated landscape was a serious vermin problem. There were thousands of dead animals of all kinds, and insects and rodents had quickly overrun the stricken area to feed on these and on the rotting food. Rattlesnakes, fire ants, and rats bit dozens of victims who were sifting through the rubble. In an attempt to control the ants, low-flying planes roared up and down the Mississippi coast, dropping quantities of mirex. At the time of Camille this product was not considered dangerous to humans, but eight years later the U.S. Environmental Protection Agency banned it as a possible carcinogen. President Nixon sent a thousand troops to help, and the state governor declared a state of emergency in order to control crime. Using federal troops and state police, all roads leading into the area where the eye had crossed the coast were sealed off. Military and local police imposed a curfew. The first problem to overcome was the thousands of dead farm animals, pets, and wildlife. Camille's incredible 25-foot storm surge had drowned thousands of animals. Heavy equipment was brought in to bury these thousands of animals.

The National Hurricane Center took note of Camille's weather data because of the unusual ferocity of this storm. The lowest barometric pressure recorded on land during the evening of August 17 was 26.85 inches. That was at Bay Saint Louis. This was the second-lowest barometric pressure ever measured in the United States. Only the 1935 Labor Day hurricane produced a lower pressure in the middle keys. That figure was 26.35 inches. The highest tidal surge ever recorded in the United States belongs to Camille. It was officially recorded as 22.6 feet above mean sea level, but high-water marks on buildings, still clearly visible long after the storm had passed, showed water heights of 25 feet. Camille moved inland and then gradually weakened to a tropical depression over northern Mississippi on August 19. It had picked up a lot of moisture over the Gulf of Mexico, and this led to torrential rain over the mountains of Virginia. In eight hours, 28 inches of rain fell on Nelson County, an amount that more than tripled the state's 24-hour record, which had been set in 1942 and has not been broken since. In other parts of the state, 14 inches came down during the night. Afterward, Camille turned eastward to emerge into the Atlantic near Virginia Beach on August 20.

APPENDIX D: MEASURING WEATHER AND CLIMATE EVENTS

MEASUREMENT CONVERSIONS

1 inch equals 2.54 centimeters

1 centimeter equals 0.39 inches

1 meter equals 3.28 feet

1 kilometer equals 0.62 miles

1 square meter equals 10.76 square feet

1 square kilometer equals 0.39 square miles

1 hectare equals 2.47 acres

1 cubic meter equals 35.31 cubic feet

1 cubic kilometer equals 0.24 cubic miles

1 degree Fahrenheit equals 9/5 degree Celsius plus 32

1 degree Celsius equals 5/9 degree Fahrenheit minus 32

FUJITA F AND EF SCALES FOR TORNADOES

The F scale was created by Japanese American meteorologist Tetsuya Fujita in 1951 to classify tornadoes.

F0 40–72 mph (light)

F1 73–112 mph (moderate)

F2 113–157 mph (significant)

F3 158–206 mph (severe)

F4 207–260 mph (devastating)

F5 261–318 mph (incredible)

Half of all tornadoes worldwide are F1 or less. Only 1 percent of all are F5.

Over the years, the F scale has revealed weaknesses: (1) too much reliance on the estimated wind speeds, and (2) oversimplification of the

damage description. Fujita recognized that improvement was necessary. When the committee met to develop the enhanced Fujita scale, one point was made very clear: it must continue to support and maintain the original tornado database; in other words, there must be some conformity to the F scale that is listed in the database.

F Scale

F0 40–72 mph

F1 73–112 mph

F2 113–157 mph

F3 158–207 mph

F4 208–260 mph

F5 261–318 mph

EF Scale

EF0 65–85 mph

EF1 86–110 mph

EF2 111–135 mph

EF3 136–165 mph

EF4 166–200 mph

EF5 Over 200 mph

SAFFIR-SIMPSON SCALE FOR HURRICANES

Developed in the later 1960s by Herbert Saffir to quantify potential wind damage from hurricanes, and expanded in the early 1970s by Robert Simpson, director of the National Hurricane Center, the Saffir-Simpson scale is used to measure hurricane strength. Wind speed is the determining factor in the scale, but storm surges caused by wind are highly dependent on the slope of the continental shelf and the shape of the coastline.

Category 1 74–95 mph (minimal)

Category 2 96–110 mph (moderate)

Category 3 111–130 mph (extensive)

Category 4 131–155 mph (extreme)

Category 5 155 mph or more (catastrophic)

VOLCANIC EXPLOSIVITY INDEX (VEI)

To compare the magnitudes of volcanic eruptions, scientists have developed a volcanic explosivity index (VEI) in which each level is ten times as powerful as the previous level. The index measures eruptions on a scale of 0 to 8. The VEI of any eruption is based on the volume of rocks and ash that is emitted. A VEI of 1 could represent a Hawaiian eruption, a gentle oozing of lava with no violent activity; a VEI of 8, a very rare event, would apply to Toba, an Indonesian eruption of gigantic proportions that occurred 74,000 years ago. Krakatau of 1883 had a VEI of 6. Mount St. Helens of 1980 had a VEI of 5.

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GLOSSARY

absorption of radiation. Transfer of electromagnetic energy into heat energy.

adiabatic process. Temperature change in a gas or in air due to compression or expansion. No heat is gained or lost from the outside in the process.

advection fog. A fog that develops when condensation occurs within moist air close to the earth's surface.

acid rain. The presence of acidic elements in rain that tend to destroy plants and trees.

aerosols. Tiny substances in the atmosphere, so small that the slightest movement of air keeps them aloft.

air. The mixture of gases that make up our atmosphere.

air mass. A large body of air that has defined temperature and humidity characteristics. It may extend over thousands of square miles and be miles in depth.

air pollution. A harmful substance put into the atmosphere from the earth

albedo. The amount of solar radiation that is reflected by a part of the earth's surface, usually expressed as a percentage.

alcohol thermometer. *See* thermometer.

anemometer. An instrument for showing wind speed.

Antarctic Circle. The parallel of latitude at 66.5° south.

anthropogenic. Caused by human activities.

anticyclone. High pressure mass of air with winds circulating clockwise in the northern hemisphere or counterclockwise in the southern hemisphere.

Arctic Circle. The parallel of latitude at 66.5° north.

Arctic front. The zone of interaction between polar and Arctic air masses.

armada. A Spanish word meaning a very large group of warships.

Asian cyclone. A tropical cyclone or typhoon that occurs in Asia. *See* typhoon.

atmosphere. The gaseous envelope surrounding the earth, mostly consisting of nitrogen and oxygen, concentrated within an area 30 miles above the earth.

atmospheric pressure. The force exerted by the weight of the atmosphere on an area.

aurora borealis. Lights visible near the North Pole, caused by interaction between the sun's radiation and molecules in the earth's atmosphere.

automatic weather stations. Weather stations, often at sea, that record and transmit data to a central location for weather forecasting.

barometer. An instrument for measuring atmospheric pressure.

biosphere. The part of the earth system that contains all living things, in or on the land, in the atmosphere, and in or on the oceans.

blizzard. Violent winter storm that lasts for several hours or longer.

caldera. A steep-sided circular depression in the ground, the end result of a volcanic eruption.

carbon dioxide. Gas that is a byproduct of burning fossil fuels or biomass. It also occurs naturally.

Celsius scale. A temperature scale in which the freezing point of water is zero degrees and the boiling point is one hundred degrees.

Chinook wind. A very dry wind that flows down the eastern side of the Rocky Mountains.

chlorofluorocarbons (CFCs). Compounds used in refrigerators, aerosol products, and solvents. Now banned in many products because of their harmful influence on the earth's ozone layer.

climate. The average pattern of weather in a given area over a long period of time.

climate classification. Division of the earth's climates into a system of regions, each defined by specific climatic elements.

climograph. A graph that shows the monthly totals for two climatic variables such as temperature and precipitation.

cirrus cloud. A high-level cloud, stringy and layered.

cloud. A suspended concentration of water or ice particles.

cloud base. The lowest elevation where cloud particles such as water droplets or ice crystals can be observed.

cold front. At the boundary between two air masses of different temperatures and humidities, the cold front is the heavier of the two, so it pushes the warm air mass upward.

colony. A territory owned and administered by a colonial power, usually a European power.

condensation. A physical process in which water vapor is changed into a liquid, that may take the form of a cloud, fog, or dew.

condensation nucleus. A tiny substance in the atmosphere on which water vapor condenses to form a drop of water.

convection. Transference of heat in a gas or liquid by upward movement of the heated and therefore less dense part.

Coriolis effect. A force caused by the earth's rotation that turns air movements to the right in the northern hemisphere and to the left in the southern hemisphere.

cumulonimbus. A heavy and dense cloud with a substantial vertical component.

cumulus cloud. A cloud made up of a rising mass of air that can be found at any level in the lower atmosphere.

cyclone. An area of low atmospheric pressure with inwardly rotating winds.

D-Day. The day selected to launch a massive attack by sea from Britain to France near the end of World War Two.

depression. An area of the atmosphere in which sea-level pressures are lower than those of the surrounding region, often the early stage of a middle-latitude cyclone.

desert. An ecosystem with less than four inches of rain a year.

dew. Water that has condensed on things near the ground.

dew point temperature. The temperature at which a mass of air holds its maximum amount of water vapor.

diurnal. Daily.

doldrums. A belt of calm seas near the equator.

doppler radio. A radar tracking system that enables a meteorologist to determine the speed of a moving object.

downburst. Violent and damaging downdraft associated with a severe thunderstorm.

drought. When an area experiences rainfall levels significantly below normal.

dust storm. A heavy mass of dust in a disturbed air mass.

El Niño. The fluctuating warm temperatures of the equatorial Pacific Ocean that affect global circulation of air.

energy balance. Globally, the total energy input from the sun equals the total energy output.

equator. The parallel of latitude that is midway between the North and South Poles.

equinox. The moment in time when the sun is directly overhead at the equator.

evaporation. The change of a liquid into a gas.

eye of tropical cyclone. The clear and calm area inside the rotating wall of convective clouds.

Fahrenheit scale. A temperature scale where the freezing point of water is 32 degrees and the boiling point is 212 degrees.

fall equinox. When the sun is overhead at the equator in autumn. It occurs around September 23.

fertilizers. Substances added to soil to make it more fertile.

flash flood. A flood caused by heavy rainfall within a short period of time.

flood. A stream that overtops its banks and covers the surrounding area.

flood stage. A particular level on a stream at which flooding occurs.

fog. A cloud at ground level.

forecast. A prediction about future weather conditions.

frost. Small ice crystals that form on or near the ground when temperatures are below freezing.

Fujita scale. The method used for calculating the strength of tornadoes.

global energy balance. The balancing of solar short-wave incoming energy with outgoing long-wave energy from the earth

global warming. An overall increase in the earth's average surface temperature.

greenhouse effect. Absorption of long-wave radiation, especially by water vapor and carbon dioxide, and reflection of heat back to earth to raise ground level temperatures.

greenhouse gases. Atmospheric gases that absorb and reflect long-wave radiation, causing the greenhouse effect. The two most important gases of this type are water vapor and carbon dioxide.

green revolution. The use of new quick-ripening, high-yield plants for use in developing countries.

guerilla-type attacks. The use of individual soldiers or small groups of soldiers to carry out raids on enemy positions.

Gulf Stream. The warm ocean current that flows northward along the east coast of the United States.

hailstorm. Pellets of ice falling from thunderclouds.

heat island. An area within an urban zone that has higher temperatures than those of the surrounding areas.

Himalayas. A mountain chain on the border between India and China.

humidity. The amount of water vapor in an air mass, measured as a percentage of the maximum that it could carry.

hurricane. A North Atlantic or Caribbean tropical cyclone.

ice age. A geological period in which ice sheets covered much of North America.

iceberg. A mass of floating ice.

Indian monsoon. *See* monsoon.

insolation. The technical term for the energy that reaches the earth from the sun.

irrigation. Water that is taken to fields from ponds or streams.

isobar. A line on a weather map connecting places that have the same atmospheric pressure.

jet streams. High-speed air flows about 15 miles above the earth, usually running from west to east.

L'Anse Aux Meadows. A Heritage site on the island of Newfoundland where the first Europeans to reach North America lived.

La Niña. The fluctuating cold temperatures of the equatorial Pacific Ocean that affect global circulation of air.

latent heat. Energy being absorbed from the air during changes from water to water vapor and released to the surrounding air during changes back from water vapor to water.

levees. Embankments to prevent rivers from flooding.

mercury thermometer. *See* thermometer.

meteorologist. A person who understands, studies, and predicts weather conditions.

microburst. A very narrow downburst.

monsoon. A persistent seasonal wind with a change in direction from season to season, usually associated with the wind patterns to and from the Asian interior in relation to the Indian Ocean.

NOAA. U.S. National Oceanic and Atmospheric Administration.

nor'easter. An extra-tropical storm along the coasts of Atlantic Canada and from Maine to New York, frequently referred to by this name because its winds come from the northeast.

Norwegian school of meteorology. The group of meteorologists who discovered and used air mass theory in forecasting the weather.

Northwest Passage. The north shore of Canada, the shortest sea route to Asia from Europe, now no longer permanently covered by ice.

ocean conveyor belt. Another name for the thermohaline-driven global ocean current.

ozone. A gas in the higher reaches of the atmosphere, created both naturally and through photochemical reactions, that absorbs ultraviolet radiation from the sun, an activity that is vital to the preservation of life on earth.

ozone layer. A region of the stratosphere stretching from about eight miles to 25 miles above the earth that contains large concentrations of naturally occurring ozone.

permafrost. Permanently frozen areas of the earth's surface.

pesticides. Chemical substances used to destroy insects or other organisms that are harmful to growing crops.

photosynthesis. The process by which plants take carbon dioxide from the air and release oxygen into the air.

polar front. The front between cold polar air masses and warm tropical air masses.

precipitation. A general term for different forms of water that may either be falling from or held in suspension in the air. Included in this term are rain, drizzle, snow, hail, and ice pellets.

rain gauge. Instrument for measuring the amount of rain that has fallen.

relative humidity. *See* humidity.

Rossby waves. Planetary waves in the atmospheric westerly circulation, characterized by great length and amplitude.

Sahel. The dry southern part of the Sahara Desert.

Santa Ana winds. Hot and dry winds that come from the interior desert regions of California and pass over the coast mountains to reach the Pacific Ocean.

sensible heat. Heat that can be measured by a thermometer.

sleet. A mixture of snow and rain.

smog. Fog combined with smoke, a common problem in large cities.

solar constant. The intensity of solar radiation on one unit of area when it is at right angles to the incoming sun's rays.

spring equinox. When the sun is overhead at the equator in the spring. It occurs around March 21.

statistical average. A calculation made by adding a collection of numbers and then dividing the answer by the total number of individual items in the collection.

Stevenson screen. A shelter for housing such weather measuring instruments as thermometers.

storm surge. The temporary increase in the height of the sea at a particular location due to a hurricane or a strong wind.

stratosphere. The part of the atmosphere above the troposphere, from about eight to 30 miles above the earth.

sublimation. The change of ice directly to water vapor or vice versa without passing through the liquid phase.

subsolar point. A place where the sun's rays are perpendicular to the earth's surface.

summer monsoon. Inflow of air from the Indian Ocean toward the continental Asian low-pressure center.

summer solstice. When the sun is overhead at 23.5° north, at the Tropic of Cancer. It occurs around September 23.

tar sands. The rich oil-bearing sands of northern Alberta, Canada.

thermometer. An instrument that measures temperature by using the properties of either alcohol or mercury as they respond to heating.

thunderstorm. Sudden electrical discharges, usually from convective clouds such as cumulonimbus, followed by lightning, thunder, and rain.

Tibetan Plateau. The highest extensive elevation of land north of the Himalayas.

tornado. A violent rotating storm of small diameter, a twister, usually appearing as a funnel cloud extending from the base of a cumulonimbus to the ground.

tornado F5. The most destructive type of tornado.

tornado outbreak. A succession of powerful tornadoes occurring within a short period of time.

trade winds. Winds that blow from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.

tropopause. The boundary between the troposphere and the stratosphere.

troposphere. The lowest part of the atmosphere, extending upward from the earth for about seven miles.

trough. A layer of the atmosphere with low pressure.

typhoon. A tropical cyclone occurring in the western Pacific Ocean.

urban heat island. An area at the center of a city where temperatures are higher than they are in the surrounding areas.

volcanic eruptions. The ejections of masses of lava and other material from a volcano.

warm front. The transition zone between warm and cold air masses. The warm front is the lighter of the two, so it is pushed upward by the cold air mass.

water vapor. Water when it is in gaseous form.

wave cyclone. A mid-latitude cyclone, usually originating at the polar front.

westerlies. Winds from the west between the latitudes 35° north and 65° south.

wind chill. A temperature based on actual temperature and wind strength. It indicates the cooling effect of wind on exposed parts of the body.

winter monsoon. Outflow of continental air from the Siberian high to southeast Asia and the Indian Ocean.

winter solstice. When the sun is overhead at 23.5° south, at the Tropic of Capricorn. It occurs around December 22.

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A Student Guide to

Climate and Weather

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A Student Guide to

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Climate Change

VOLUME 4

Angus M. Gunn

GREENWOOD

AN IMPRINT OF ABC-CLIO, LLC
Santa Barbara, California • Denver, Colorado • Oxford, England

Library of Congress Cataloging-in-Publication Data
Gunn, Angus M. (Angus Macleod), 1920-
A student guide to climate and weather / Angus M. Gunn.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-313-35568-4 (set: hardcover: alk. paper) — ISBN 978-0-313-35569-1 (set: ebook: alk. paper) — ISBN 978-0-313-35570-7 (v. 1: hardcover: alk paper) — ISBN 978-0-313-35571-4 (v. 1: ebook) — ISBN 978-0-313-35572-1 (v. 2: hardcover: alk paper) — ISBN 978-0-313-35573-8 (v. 2: ebook) — ISBN 978-0-313-35574-5 (v. 3: hardcover: alk paper) — ISBN 978-0-313-35575-2 (v. 3: ebook) — ISBN 978-0-313-35576-9 (v. 4: hardcover: alk paper) — ISBN 978-0-313-35577-6 (v. 4: ebook) — ISBN 978-0-313-35578-3 (v. 5: hardcover: alk paper) — ISBN 978-0-313-35579-0 (v. 5: ebook)
1. Climatology. 2. Meteorology. 3. Climatic changes—Effect of human beings on. I. Title.
QC861.3.G86 2010
551.5—dc22 2009042256

14 13 12 11 10 1 2 3 4 5

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Manufactured in the United States of America

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Introduction

This is Volume Four of a set of five books on weather and climate designed for schools and universities. These books are intended to provide two kinds of information: an understanding of the scientific processes at work in weather and climate, and an analysis of the ways in which weather and climate impact human life and the places where we live. The second of these goals is the more important of the two, as there are a number of books in print dealing with the scientific processes involved in weather and climate, but few on how weather influences our lives. Beginning in the first volume with aspects of the subject that impinge on us daily, such as the unpredictable nature of weather, we go on in the second and third volumes to deal with characteristic global weather patterns, before moving, in the last two books, into more general themes such as global warming and earth-sun relationships. A list of reference materials will appear at the end of each book to assist in linking together the different aspects dealt with in individual volumes.

Volume Four is completely devoted to the problem of global warming and climate change because of its importance both now and in the foreseeable future. A consensus has been reached among the world's scientists that human activities over the past approximately 150 years are responsible for the root cause of many changes that have taken place: greenhouse gases in our atmosphere, emanating from industrial and agricultural enterprises, have changed the longstanding natural process in the global energy balance by which average temperatures at the surface of the earth are kept within a small range. The most dramatic example of the effects of this at the present time is seen in the melting of Arctic sea ice, a process that happened so fast that even the scientists who work on the problem were taken by surprise. A small island off the coast of Alaska that for two centuries was a safe place of residence for Inuit hunters began to experience severe flooding beginning in 2005 to such an extent that plans were underway by 2008 to move the island's entire population to a new location.

The Arctic surprise should have been a wake-up call for countries such as the United States that have been unwilling to do anything about the greenhouse gas problem because they feel it might weaken

Walrus rest on pack ice at the surface and feed on clams at the bottom of the ocean. As the pack ice recedes northward, where the ocean is much deeper, walrus have difficulty surviving. (Vladsilver/Dreamstime.com)

their economy. The United States has another reason for refusing to act: it sees countries such as China and India that comprise almost a third of the world's population refusing to do anything until Western nations show some leadership in dealing with the problem. Both of these objections were advanced by many nations at the planning conference held in Indonesia in 2007. This conference was arranged in order to prepare for a later event at which the Kyoto Protocol, the 2005 attempt to get international agreement on action, will be replaced by an improved version. One of the major problems with the Kyoto Protocol was its exclusion of developing countries from any obligation to reduce greenhouse gases. At the Indonesian conference, agreement was reached by every country of the world to share responsibility in dealing with the problem. The United States and several other nations agreed to be involved in appropriate action because now every nation would carry responsibility.

There was another outcome from the melting of Arctic sea ice that carried profound implications for Europe, especially northwest Europe. It may explain why Europe has been the strongest supporter of making tough decisions on global warming. All along the eastern shores of the United States, and extending northward and eastward to the latitude of Iceland, there is a warm ocean current, part of a global ocean circulation, locally known as the Gulf Stream. Its high temperature has maintained for centuries the mild climate of Britain, France, and Scandinavia. At its northernmost extremity, this current traditionally encountered the salty, cold water that ensured continued circulation; the added weight of the cold saltwater carried the water down into the ocean depths to form a return flow. The Gulf Stream, however, has been changing over the past few decades. It is slowing down. If this continues and the Arctic temperatures rise high enough, the Gulf Stream could stop completely, with catastrophic consequences for life in Europe. If, additionally, the Greenland ice cap were to melt by the beginning of the next century, sea levels would rise substantially, and there would be significant flooding of all coastal areas.

Chapter Four deals with the scientific evidence that validates the existence of global warming and climate change. The evidence from this chapter is very important and is noted here first because, even today, in the face of evidence from thousands of scientists worldwide, there are people who question it. In 2008, for example, the Republican candidate for vice president, Sarah Palin, although conceding that humans influence global warming, refused to agree that humans are the main cause of the problem. Such skeptical views of scientific findings are sometimes held by followers of certain Christian churches because they conflict in their minds with Biblical statements. A now-discredited theory that was defended by some scientists around the year 1970 is often used to defend such skepticism. They say, in defense of their

A car illustrates the nature of the greenhouse effect. On a warm day, short-wave rays of the sun enter the car and are transformed into long-wave heat energy as objects in the car absorb them. The heat waves cannot escape through the glass, so they are reflected back into the car, raising the inside temperature. (iStockPhoto.com) position, that if some of the world's top scientists were wrong about global warming in 1970, perhaps they are wrong now too. To help to clarify the nature and role of scientific evidence in this debate, we will list the details of the theories of 1970 and give the reasons for their being rejected.

In the period around 1970, several scientific articles about atmospheric temperatures were published in peer-reviewed publications. (In peer-reviewed publications, the articles are first examined and approved by scientists who have expertise in the subject of the articles before they are accepted for publication.) Several of these articles suggested that the world might be moving toward a cooling period because temperatures in the northern hemisphere had been moving lower, on average, over the previous three decades. The popular press, picking up on these reports, used language that suggested we were moving into another ice age, and that, unfortunately, gave validity in the public mind to the scholarly articles. One of these articles, written by an expert climatologist, pointed out that increases of carbon dioxide in the atmosphere would cause a decrease in the earth's surface temperatures. A colleague challenged this writer, pointing out to him that every bit of evidence indicated the very opposite. The writer of the article had concluded that temperatures would decrease because of the presence of some other substances, but he had no evidence for this view. His theory was rejected. This is exactly how good science works. Other scientists demolish indefensible theories.

THE SCIENTIFIC EVIDENCE

Research and reporting on factors affecting global warming and climate change have been going on for several decades, but only in the closing years of the twentieth century were decisions finally made to act on what was known. Quite a lot has been learned: more than ninety percent of all the investigations made over the past 150 years were made in the second half of the twentieth century, and all of these, cumulatively, represent advances in our understanding of climate. Our need for these advances is great because, unlike many branches of science, meteorology and climatology cannot arrive at conclusions by performing controlled experiments in labs. Their lab is the whole of planet earth, a situation rather like astronomy and cosmology, in which the scientists' lab is either a galaxy or the whole cosmos. One place in particular has been accumulating contemporary knowledge on greenhouse gases and their effects on climate: the U.S. National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies, under its director, James Hansen. It is a research center deeply concerned about what goes on at all times in the atmosphere, if only to ensure that space launches are safe.

In June 1988, James Hansen warned a U.S. Senate committee that the planet was already warming as a result of human activity. The data he brought and the strength of his convictions confirmed in the senators' minds the truth of the global warming crisis. Political pressures prevented the senators from taking action but, quite independently of the U.S. Congress, and coincidentally in the same year that Hansen made his presentation, two organizations of the United Nations did take action: the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) launched a new United Nations institution, the Intergovernmental Panel on Climate Change (IPCC). This organization was charged with collecting, validating, and coordinating all existing knowledge about global warming and climate change. IPCC has been doing this work since 1988, bringing together from time to time experts in meteorology from all over the world and publishing reports on their work. The IPCC is now the undisputed custodian of the world's scientific consensus on the causes and consequences of global warming.

Chapter Four, using the conclusions of the IPCC about the present condition of our atmosphere, explains how global warming, and with it climate change, occurs. The image of a greenhouse is often used to help people visualize what is happening. It is important to note that the atmosphere is a more complicated system than a greenhouse. Solar radiation comes through the glass windows of a greenhouse because it consists of very short wavelengths. These wavelengths are absorbed by plants and other things inside the greenhouse and, as a result, are re-radiated as infrared, long, wavelengths. These do not go through glass and are therefore reflected back from the windows into the greenhouse, making it warmer. This process continues until someone opens a window to let heat escape.

On earth, certain gases in the atmosphere play the role of the glass in producing a greenhouse effect. Water vapor has always been the most abundant of these greenhouse gases. For millions of years, water vapor and other greenhouse gases naturally reflected infrared waves back to earth to maintain a healthy temperature for humans. Water never stays long in the atmosphere, generally only for a few days. More water is always being evaporated from the oceans or from lakes to enter the atmosphere and replace what comes down as rain or snow. This cycle continues today, but new greenhouse gases are now being emitted into the atmosphere. These newcomers stay, not just for a few days, but for as long as two hundred years. By adding to the natural amount of reflection of infrared radiation back to earth, the whole system is being upset, and the earth gets warmer and warmer with the passage of time. Two important greenhouse gases are carbon dioxide and methane. The former comes mainly from industrial operations or cars that use fossil fuels. It stays longer in the atmosphere than any of the other greenhouse gases, and is therefore the one that gets the most attention from the IPCC. The human contribution of methane to the atmosphere comes largely from the raising of ruminant livestock, particularly cows, which release methane to the environment as a result of herbaceous digestion. Methane remains in the atmosphere for less time than carbon dioxide does, usually less than 12 years.

As has already been said, the metaphor of a greenhouse does not provide a complete picture of what actually happens in the air above us. In reality, the atmosphere has so many interrelated elements that interference with any one of them upsets all the others. One expert described the atmosphere as chaotic. That may be an exaggeration, because we do know what happens when we change some things in the whole system. For example, as human-emitted greenhouse gases build up in the atmosphere, the temperature at the surface of the earth increases, and additional quantities of water are also added to the atmosphere. That happens because of a basic law of physics, namely, that the amount of water that the atmosphere can hold increases as the temperature increases. Thus there is more water vapor, and more clouds, in the air as the temperature increases. There is also more infrared radiation reflected back to earth, which increases the earth's temperature still more. It is this cumulative effect, as a result of the new greenhouse gases, that is most frightening. Increases in temperature accelerate in their rate of growth, and action to stop them becomes more urgent.

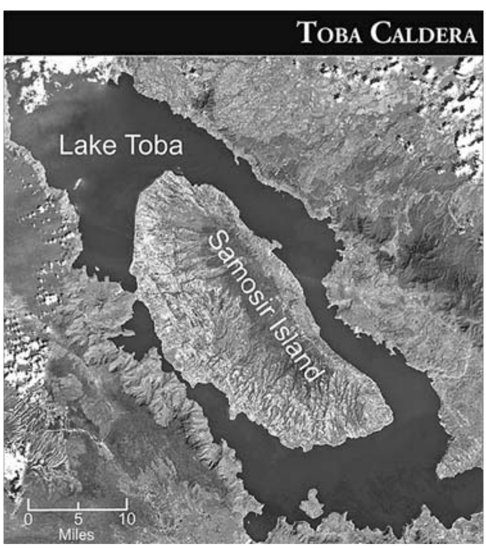
A good illustration of this cumulative effect occurred in the course of the melting of the Arctic sea ice. All the experts were taken by surprise by the speed of melting. The reason for the rapid melting was the nature of the surface receiving solar radiation. As the earth's surface became warmer, the sea ice began to melt. This occurred slowly at first because neighboring areas of ice reflected most of the solar radiation back into space. However, as soon as a large area of ice had melted, the temperature of the open water increased because water is a good absorber of solar radiation. Thus, the rate of melting sped up. The issue now, in the face of mounting evidence about not only global warming and climate change, but also the acceleration in the process, is what the nations of the world are going to do about it. We do know that national interests still dominate in many places, and these will have to be overcome. Take the role of trees and forests as one example of this. Everyone knows that these are powerful collectors of carbon dioxide. Yet about 30 million acres of forests are being cut down globally every year.

THE IMPACTS OF VOLCANIC ERUPTIONS

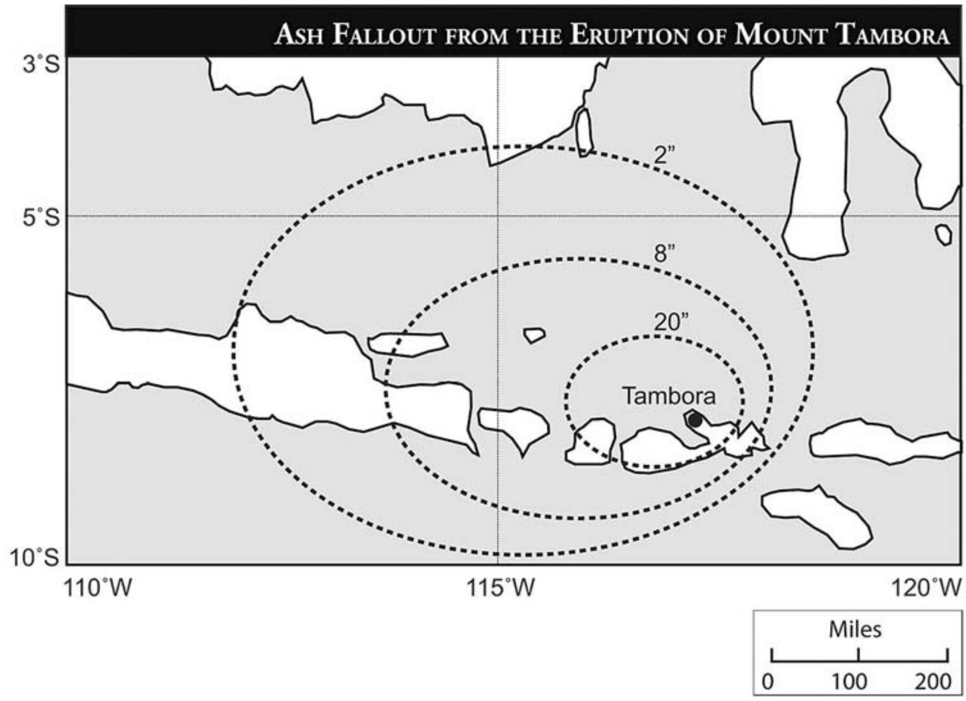
All over the world and throughout earth's history, volcanic eruptions have repeatedly interfered with traditional patterns of weather and climate. This has been most significant globally for eruptions that have occurred in tropical areas because in such cases the volcanic ash and gases reach the stratosphere all over the world within a few months and stay there. We saw this clearly when the tropical Mount Pinatubo erupted in 1991. As is the usual outcome in these instances, the northern hemisphere experienced a drop in temperature that persisted for two years. That change had devastating effects on a developing flood scene in the United States as weather patterns shifted: there was sustained and very heavy rainfall in the Mississippi-Missouri river system from April to July 1993, the greatest that had been experienced since weather records began to be kept in 1875. This was a consequence of the eruption of Mount Pinatubo to a greater extent than all the other causal factors combined. Volcanoes could be called the one certain source of climate change, past, present, and future.

Fortunately, very large eruptions like those we know occurred in the distant past have not appeared within the period of documented human history. However, we know that they will appear again in the future. The last of the really big ones, the only one about which we know a great deal through contemporary geological and meteorological research, was Toba. It had a volcanic explosivity index (VEI) of 8, and it erupted in the place we now know as Indonesia about 74,000 years ago. Its impact on humanity is described in Chapter Two. This eruption became, in the minds of scientists, the model of a worst-case event, much like the doomsday scenario of a nuclear winter that was outlined at the height of the cold war between the United States and the Soviet Union. Geneticists are now convinced that Toba's eruption reduced the entire human population to a few thousand people, and held them at that edge of extinction for thousands of years before their numbers began to significantly increase.

The eruption of Tambora in 1815 was the only eruption since 1800 that reached the level of 7 on the VEI scale. All others since that time had VEIs of 6 or less. Tambora was the closest event to Toba that humans have experienced in recorded history. It provides insight into the massive eruptions, even though it was much weaker.



Toba caldera. The island in the middle of the caldera is the result of mini-eruptions that occurred over time, the latest of which happened in the 1930s. (NASA/GSFC/METI/ERSDAC/JAROS and U.S./Japan ASTER Science Team)



Map depicting the ash fallout, in inches, from the 1815 eruption of Mount Tambora, the largest volcanic eruption in recorded history. (ABC-CLIO)

Tambora was a huge mountain, 13,000 feet high. The top four thousand feet of this mountain was blown off by the eruption, and the main mass of the displaced material darkened the sky for several days as it circled the earth. The heaviest particles fell back to earth, crushing many homes. Overall, in eastern Indonesia, there were more than 90,000 deaths, most of them a result of starvation and disease, because everything around people's homes had been obliterated. Mount Tambora burned for three months before coming to rest. The effects of this event were felt all around the world because the finer particles continued to circle the earth for years, reducing the amount of heat received from the sun. Temperatures dropped all over the northern hemisphere, and crops failed. In the United States, in the year that followed Tambora's eruption, the whole year came to be known as the year without a summer because of the widespread reduction in the amount and quality of crops.

Global warming and climate change problems will not disappear within the present century, even in the unlikely event that every nation succeeds in cutting back its greenhouse gas emissions to the levels that were sent into the atmosphere in 2000. The greenhouse gases, especially carbon dioxide, that are presently in the atmosphere will remain in place for at least another hundred years. It is therefore essential, in any discussion of global warming, to anticipate, as well as we can, the likelihood of future very large volcanic eruptions. This is the subject

Global Dimming: Reducing the Amounts of Solar Energy Reaching the Earth

The large number of particles that fill the air over industrial regions of the world reduces the amount of solar energy that reaches those areas. Extensive research on the atmosphere throughout the world, over both industrial areas such as western Europe and the northeastern United Stase and non-industrial areas such as the Sahel of the southern Sahara, has established that the average amount of solar radiation that reaches industrial areas is about 3 percent less than they were probably receiving before industrialization. Along with the loss of solar energy, industrialized areas are experiencing higher rainfall amounts because the number of particles in polluted air is ten times greater than in non-industrialized regions, and these particles offer places where water vapor can condense. Scientists now wonder whether this additional rainfall in northern industrialized regions may be depriving some southern regions of their normal rainfall regimes. In particular, they wonder if the droughts in the Sahel in the 1970s and 1980s were caused by global shifts in rainfall patterns as a result of the additional rainfall in northern regions.

dealt with in Chapter Eight, and, to find an example of what could happen, we can look at what happened in the past within the contiguous United States. There is evidence of three supervolcanoes like Toba in the past history of the United States, and all of these will erupt again sometime in the future: They are in Yellowstone, Long Valley, and Valdes. All three, in their last eruptions, had VEIs of 8.

The Yellowstone supervolcano is much more than a past event that will, sometime, erupt again. Scientists have identified its recurrence rate, that is to say the number of years between eruptions. It lies between 600,000 and 800,000 years. Its last big eruption happened

Expert geologists at Yellowstone's volcano observatory are constantly monitoring the region's underground activity. In this photo, a special seismic instrument is being installed. (Bob Smith/University of Utah/U.S. Geological Survey)

640,000 years ago. Experts therefore talk about another eruption being overdue, but that may mean another one in five thousand years or within the next year. There is another good reason for focusing on Yellowstone both in order to understand what is happening now and to plan for action should evidence point to a possible new eruption. If we know what to do with a Yellowstone emergency, we will know what to do with a Long Valley one or one at Valdes. That is why the U.S. government established the Yellowstone Volcano Observatory (YVO). It has a staff of several scientists at Yellowstone National Park who take daily measurements of all the changes that are taking place in the magma, miles below ground, along with those occurring on the surface around the caldera.

WHAT CAN BE DONE NOW?

Even though global warming and climate change are very large problems, individuals, small communities, and private organizations can do much. Not all responses have to come from governments. Although it remains true that decisions that apply to everyone and carry the force of law must be made by governments, people everywhere, now that the urgency of the problem is filtering down to all levels of society, are getting involved in taking action. In the process of global warming, as infrared radiation is reflected down to the earth's surface from carbon dioxide molecules or clouds, the amount of additional warming that takes place depends on the nature of the surface. The term *albedo* is used to describe this variable reflective property of surfaces. A surface described as having a high albedo will reflect most of the radiation that comes in. Low albedo describes the reverse. One research laboratory at the University of California decided to investigate this phenomenon to find out how the information could be used to slow down global warming and climate change. The staff of this research institution knew that white surfaces have high albedo and black have low albedo. They were encouraged by an edict from the state government requiring all new flat commercial structures to have white roofs.

Their findings were dramatic: if the one hundred largest urban areas of the world installed white roofs and changed their pavements from black asphalt to light-colored concrete, the amount of global cooling would be massive. A white roof of one thousand square feet will offset the warming effect of ten tons of carbon dioxide by reflecting radiation back into space. For these urban areas, changing the surface properties would amount to a reduction in global warming that would offset more than 40 billion tons of carbon dioxide in the atmosphere. It is well-known that urban areas are generally warmer than less dense communities, so any move to reduce their ambient warmth would also mean greater comfort. It would also reduce the cost of air conditioning. The researchers who conducted this research now want to persuade the United Nations, particularly its IPCC, to undertake a campaign aimed at convincing cities around the world to alter their roofing and their pavements.

At the level of everyday life, a plethora of behaviors is emerging as answers to global warming. Some newspapers and media outlets have daily tips on things that individuals can do, ranging from switching off lights that are not needed to adjusting the temperature in a refrigerator to make it more efficient and, at the same time, improve the quality of the food. The rising cost of gasoline combines with the encouragement from local governments to reduce emissions of carbon dioxide by using public transit instead of driving to work. Large numbers of people have followed this recommendation, and, as a result, many cities have had to add more buses and more trains. These additions, in turn, have had the cumulative effect of increasing the numbers of users, because one of the complaints about public transit is that services do not arrive sufficiently fast. At a much higher level of enterprise, higher energy costs, combined with the damage that energy generation does by emitting carbon dioxide, are inspiring many new ventures in alternative energy technologies.

The coal and oil industries are spending huge sums of money on experiments aimed at capturing carbon dioxide from their installations before it reaches the atmosphere, then storing it deep underground, hopefully permanently. At a microscopic level, research is going on regarding the use of microbes and tiny organisms both to uncover new fields of heavy oil and to generate a new energy source that will not emit any carbon dioxide. Using microbes to produce heavy oil involves feeding, or fertilizing, microbes that live deep underground and are already naturally producing heavy oil. Researchers are trying to alter their habits in order to have them produce natural gas and, possibly, ultimately hydrogen. A venture that is being run by Craig Venter, of

Rendering of a clean coal-fired power plant designed to capture carbon dioxide emissions before they enter the atmosphere. (Department of Energy) human genome fame, involved genetic modification of certain tiny lifeforms to make them produce nonpolluting energy from natural materials and to produce it, in due course, in huge quantities. That is the dream of Craig Venter, and he has been supported in this attempt by funds from the Ford Foundation.

The whole subject of energy, particularly the prospects of finding green energy, is now one of the biggest of all the attempts to reduce the quantities of greenhouse gases that are being emitted. Chapter Seven deals with this subject in some detail. It is not a new subject. Green forms of energy, that is to say, energy sources that do not emit greenhouse gases as part of their production, have been in use for centuries. Hydroelectricity, at the present time widely used throughout the world, was common in the early years of settlement in North America; streams were dammed so that water wheels could grind oats or corn for human or animal food. Animal and human energy is also green, and is still used throughout the world for similar purposes. One recent observation identified many countries in Africa and South America that have huge potential sources of hydroelectricity, yet the countries concerned continue to employ energy sources that are based on fossil fuels because they cost less than the construction of hydroelectric dams. These countries are now being urged by the IPCC to undertake the development of hydroelectricity for their own use and possibly for transmission to neighboring countries.

The high cost of oil and its destructive influence on our atmosphere are not the only two reasons for searching out green sources of energy. There is, in addition, the whole subject of national security and the danger of heavy dependence on imported oil from countries that are unstable and therefore unpredictable. Imagine what could happen if there were a repeat of the 1973 threat by Middle East countries to cut off all oil shipments to the United States, and if, the next time, the threat were to be carried through, something that fortunately did not happen last time. If green sources of energy could be developed in quantity within a short period of time, this danger would be averted, along with a major step forward in controlling the emissions of greenhouse gases. Such a hope—some would call it a dream—is not unrealistic. History is full of accounts of new discoveries that so transformed human life that we wonder now how people ever could have managed without them. Think of the refrigerated train or ship, the elevator, or even the humble bicycle, once the universal mode of transportation in China, before the country industrialized and changed to cars that burn fossil fuels.

All that is needed for plentiful green energy is the discovery of creative ways of using what we already have. For example, the high-level jet streams have enough wind energy to move trains. They presently assist jet planes, helping them save time and fuel. Researchers have not yet figured out how to collect and transport this energy. Take another example, that of the world's highest tides, which appear twice a day in the Bay of Fundy, Nova Scotia, about three hundred miles north of Boston. They reach a height of 60 feet in places each time they come, and the volume of water involved is far greater than any hydroelectric dam in the world. A height of 60 feet with all this volume of water would generate enormous quantities of green energy. The United States could also generate enormous quantities of green nuclear energy if there were not a fear among some that such plants are not safe. Japan and France use this source extensively.

There are numerous wind and solar energy sites in North America that could be developed once researchers have shown that they are both economically and practically feasible. Solar energy is much better known than wind as the ideal energy alternative. It represents the direct, rather than the indirect, use of the sun's energy, the same energy that is used by every plant and every animal on earth. Solar panels on the roofs of homes are a familiar sight in city and rural settings. Perhaps it is the economical factor rather than anything else that stifles development among those who may have less sense of responsibility about global warming. If coal is so much cheaper, why switch? People who think this way need to know that the whole world is waiting to see successful green energy products, and people will pay for them. The little nation of Denmark discovered that economic truth, and it is now the world's supplier of wind energy turbines. Decades ago, Denmark placed wind turbines along its coast. These turbines soon supplied 20 percent of the country's energy needs. Along the way, Danish engineers learned how to design turbines that would cope with all kinds of winds. Now, they have a new wind industry with a large labor force, one that serves Denmark and the world.

CHAPTER 1

Global Warming and Climate Change

As we begin this book on global warming and climate change, the words so often attributed to Mark Twain offer a good introduction to the subject: "Everybody talks about the weather, but nobody does anything about it." All over the world, people are talking about the challenge of the changes taking place in both weather and climate, and there are many opinions about what should be done about them. Unlike Mark Twain's conclusion, there is no shortage of efforts to do something about this new challenge, but there are many disagreements about which of the various efforts will be best. First, the terms we use need to be defined: global warming means an increase in the average temperature over the entire surface of the earth; climate change means changes in specific climatic regions of the world.

Weather is basically the way the atmosphere is behaving, mainly with respect to its effects upon life and human activities. The difference between weather and climate is that weather consists of the short-term changes in the atmosphere. Most people think of weather in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high or low pressure. In most places, weather can change from minute to minute and from hour to hour. Climate, in contrast, is the average of weather over time and space. An easy way to remember the difference is that climate is what you expect, like a very hot summer, and weather is what you get, like a hot day or a rainy morning.

In short, climate is the description of the long-term pattern of weather in a particular area. Some scientists define climate as the average weather for a particular region and time period, usually taken over 30 years. It's really an average pattern of weather for a particular region. When scientists talk about climate, they're looking at averages of precipitation, temperature, humidity, sunshine, wind velocity, and other measures like these that occur over a long period of time in a particular place. For example, after looking at rain gauge data, lake and reservoir levels, and satellite data, scientists can tell if, during a particular summer, an area was drier than average. If it continued to be drier than normal over the course of many summers, then it would likely indicate a change in the climate.

There are important differences between the two phrases, global warming and climate change. Sometimes, there can be a small rise in overall average temperature of the earth, but only some climatic regions are affected. If the temperature change is large, all regions are likely affected. In a few cases, there is a direct connection between a rise in average global temperature and a major change in a particular climate. The clearest illustration of this can be seen in the continued reality of Arctic ice melting and the slower speed of the Gulf Stream as a result. The reasons for this effect have been described in Volume One of this set. When the Gulf Stream slows down, the climatic region we know as northwest Europe gets colder in proportion to the degree of change in the Gulf Stream's speed. Predictions of regional impacts are beginning to emerge from climate models, indicating that some regions will benefit, but most will experience negative effects.

CAUSES OF CLIMATE CHANGE

Climate change, because it describes changes over substantial periods of time and over extensive tracts of the earth's surface, is the thing about which we need to be particularly aware. Its effects are much broader than the weather. What, then, are the elements that determine the state of the earth's climates? There are two systems involved, and within each there are additional variables. The first is external to the earth and is all about the sun, our one and only source of energy and warmth. Until recently, scientists thought that the sun's output of radiation was so constant that its trivial variations over time would not affect the amount reaching the earth. More recent measurements show that variations in the sun's output are greater than had been assumed. As much as 0.1 percent reduction was observed around 1990, and this reduction persisted for a year and a half. Scientists calculated that, if this were to continue for many years, it could reduce our average temperature over the whole earth by 0.1°F—not enough to be concerned about in the context of the big changes that may occur under global warming.

The behavior of the earth in its orbit around the sun creates a very different problem with respect to the amount of solar energy reaching us. These annual multimillion-mile trips of the earth around the sun are never perfect ellipses, but the slight changes that occur in a year are so small that we rightly ignore them. However, over very long periods of time, far beyond the lifetime of any one person, these changes add up to the earth being much farther from the sun that it had been, and therefore the amount of the sun's energy reaching it is reduced. That is why planets such as Mercury that orbit close to the sun have very high temperatures and those such as Saturn that are always farther away from the sun are much colder. These changes in the earth's orbit can develop over a stretch of time as long as 100,000 years, and we only learn about them when we study ancient climates such as those of the ice ages. There are other wobbles too in the behavior of the earth, including in the angle of its axis in relation to its daily rotation, and these also can add up to a gain or loss of incoming energy.

The second system that can change climates is the internal situation within the earth, as distinct from its relation to the sun, and here many elements are involved. Concentrations of different kinds of gases in the atmosphere can reduce the amount of solar radiation reaching the earth and thus change climates all over the world. Similarly, changes in the distribution of land and water around the earth, which happen regularly, each over a very long stretch of time, will alter the albedo of the surfaces onto which the sun's rays come. If the albedo is high, as it is when the surface is ice, the amount of energy received by the earth will be less than if the albedo is low, as it will be if the surface is water. Of even more dramatic effect on climates is the influence of major volcanic eruptions. The biggest of these was Toba, mentioned in the Introduction to this volume and also discussed in detail in Volume One. That eruption occurred 76,000 years ago in Indonesia and did much more than change climates: it almost wiped out the entire human race of that time. More recently there were three volcanic eruptions of sufficient strength to modify the atmospheric system, and thus the climates of the world, for years.

The year 1816 was widely regarded all over Europe and North America as the year without a summer because of the cooling effects from an 1815 eruption, that occurred, like Toba, in Indonesia. The volcano's name was Tambora, and enough volcanic ash, gases, and rocks were thrown into the atmosphere to block off normal levels of incoming energy from the sun for more than a year. The debris that did the most damage in this case was the sulfur dioxide gas component of the ejected matter, because it was light enough to stay aloft for almost three years. Furthermore, it reacted with water vapor to form a bright layer that reflected much of the incoming solar radiation.

In Mexico, in 1982, there was a powerful volcanic eruption from El Chichón. In 1991, there was an even more powerful eruption from Mount Pinatubo in the Philippines. Subsequent research showed that Pinatubo's ashes and gases cooled the entire globe for the two years following the eruption by as much as 2°F. The disruption of seasonal patterns of rainfall because of this was particularly evident in the Mississippi-Missouri floods of 1993, the costliest and most devastating floods that ever occurred in the continental United States, causing $15 billion in damage.

Over the past three centuries, the concentration of carbon dioxide has been increasing in the earth's atmosphere because of human influences. This now represents a threat to the world's climatic regions that is the most serious in all of recent human history. Activities such as the burning of fossil fuels, conversion of natural prairie to farmland, and deforestation have together been responsible for an accumulation of carbon dioxide in the atmosphere that, if not stopped and reduced in quantity, will threaten human existence within the present century. This is not a new development. Since the early 1700s, carbon dioxide has been increasing from 280 parts per million to 380 parts per million as the Industrial Revolution, with its high consumption of fossil fuels,

The clear-cutting of forest areas in Success, New Hampshire, in 2005, received widespread disapproval. (AP/Wide World Photos)

expanded all over the world. The present result is a continuing and accelerating growth in the greenhouse effect. Already the changing patterns of temperature and humidity in the atmosphere are transforming a few climatic regions.

EVIDENCE FOR THE GLOBAL CHANGES

It is the mounting evidence of the increase in carbon dioxide in the atmosphere that has led the vast majority of scientists today to support the conclusions of the Intergovernmental Panel on Climate Change (IPCC). The work and the findings of this organization will be described in Chapter 5. It is very important that this attitude on the part of scientists is understood. In the very nature of good science lies the constant search for weaknesses in its findings. The phrase used by scientists, "theory of," is always intended to show that, even where great confidence exists regarding some discoveries, the opportunity is always open for someone to come up with a new theory to replace the previous one if evidence seems to support it. Unfortunately, for people unfamiliar with science and scientific research, this openness to new discoveries suggests that all scientific knowledge is tentative and not proven. This of course is not true, but it provides an excuse for people who want, for their own private reasons, to reject the IPCC's findings.

For example, during the years before 1970, many leading scientists thought that the earth might be tending toward a new ice age because the temperature statistics pointed in that direction. These same scientists now support the IPCC findings. Opponents of the IPCC, however, continue to point out that there was a different opinion about the earth's future in the 1970s, so perhaps, they say, scientists will change their minds again. The people who use this unscientific argument are often involved in the kinds of economic activities that are causing the increases in carbon dioxide in the atmosphere, activities such as coal mining, oil production, and production of high-powered automobiles—the very industries that will have to change if the destructive influences of global warming and climate change are to be removed. It is very important, therefore, to clearly show, in this introductory chapter, the scale of support that is given to the IPCC. No other individual or single scientific organization has ever been given comparable support for its claims, and this fact is evidence in itself of the high quality of the scientific research that lay behind IPCC's conclusions.

Much of the documentation that follows is deliberately repetitive, in order to establish the strength of the IPCC's position and, at the same time, to provide sufficient evidence to persuade those whose livelihoods may be disrupted by what is being said, those who are especially eager not to find solid proof of the threat from carbon dioxide. If we think for a moment about the last ice age and the difference in average temperature between that time and today, the numerical difference between these two times is exactly the same as the amount of warming we will see, because of carbon dioxide, in this century, unless something is done about it. Even though the present threat is one of increasing global average temperature, it needs to be noted that the ensuing climate changes will vary greatly in their effects on regimes of temperature and humidity throughout the world. Present developments in the Arctic are giving us an advance illustration of this last point. They are also showing us what can happen, because they have already gone beyond all expectations.

It is now clear to everyone that the Arctic melting, involving both the sea ice and the land areas that carried ice sheets and glaciers, is and has been accelerating faster than any of the experts predicted. Already there are squabbles among nations bordering the Arctic because they see open water in the fabled Northwest Passage and untold undersea mineral, oil, and gas resources potentially accessible for the first time. Consider now the potential effect of this global warming on climate change. The thermohaline circulation (THC) in the world's oceans is part of the planet's temperature regulation system. The Gulf Stream is the part of the THC that circulates near the coast of North America, warming the land areas on both sides of the Atlantic. However, this Gulf Stream is dependent on regular additions of cooler and saltier water to ensure that its northernmost extension will sink and sustain the return circuit at a deeper level. The saltier, and therefore heavier, water comes from fresh water being withdrawn to form ice. Without these ingredients, the Gulf Stream will slow down and eventually stop, and a cooler climate will appear in northwest Europe and parts of the United States.

It's tempting to think that all of these changes to the world's climatic regions will average out over time and everything will be fine.

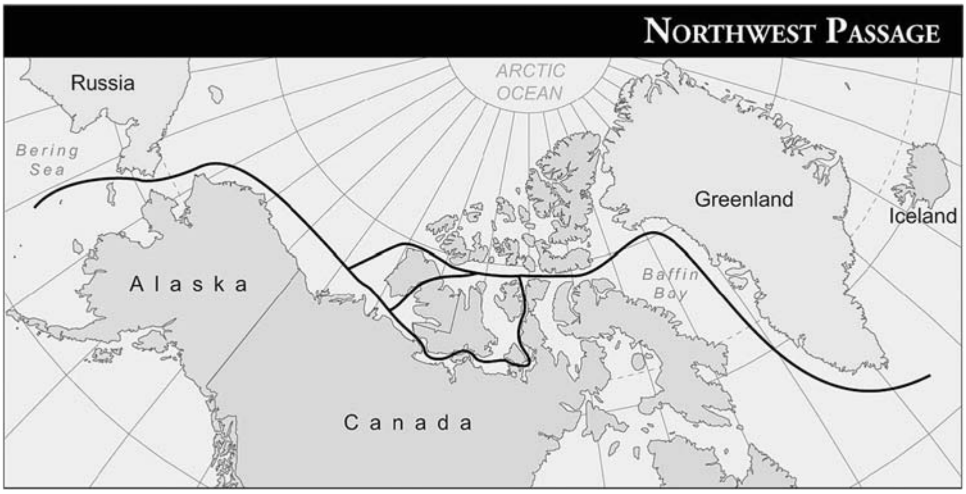


Figure 1-1 The Northwest Passage, coveted for centuries by shipowners, is now becoming accessible due to the melting of Arctic sea ice. (ABC-CLIO)

Colder climates such as Canada may even see improved agricultural yields as their seasonal temperatures rise. It is very hard to think of people moving today to more favorable agricultural locations as they might have done a thousand years ago, so there is a big challenge to existing environments that may have to change. Humanity has made a huge investment in things where they are now. Massive social and industrial infrastructures are in place, and they cannot be moved easily. A place like central California, presently a rich agricultural region, could readily become a drier, warmer area that is unable to sustain the kinds of crops being grown there at the present time. This is just one example of how global warming could lead to a regional climate change that would cause a huge disruption in the local economy as well as in the nation's food supply.

The IPCC stated that new and stronger evidence shows that most of the global warming observed over the last 50 years is attributable to human activities, that is to say, the type of activities that add huge amounts of carbon dioxide to the atmosphere. This position is on the summary from the enormous number of researchers involved in the organization. The views of individual scientists, although they are always heeded, are not given status in these statements. Neither university contributions nor those from self-selected lists of individuals are included. Early IPCC reports were reaffirmed in February 2007 when the organization released its summary of the Fourth Assessment Report, again reasserting that the cause of global warming is human activity. The following is typical of their reports: The world's leading climate scientists have said that global warming has begun, is very likely caused by man, and will be unstoppable for centuries. Since 2001, there have been consistent supporting statements of the IPCC position from the joint science academies, representing the national science academies of Brazil, Canada, China, France, Germany, Italy, India, Japan, Mexico, Russia, South Africa, the United Kingdom, and the United States. Year after year, they have issued statements, typical of which are the following:

- 2001: "We acknowledge the IPCC position as representing the scientific consensus on climate change science."
- 2005: "We explicitly endorse the IPCC consensus; the scientific understanding of climate change is now sufficiently clear to justify nations taking prompt action."
- 2008: "We reiterate our position that climate change is happening and many physical and biological systems are being influenced. We urge all nations to take appropriate action to accelerate transition to a low carbon society and to encourage and effect changes in individual and national behavior."

In 2007, four international societies gave support to the work of IPCC: The Inter Academy Council of the world's scientific and engineering academies, the International Council of Academies of Engineering and Technological Sciences, the European Academy of Sciences and Arts, and the African Science Academies, representing the nations of Cameroon, Ghana, Kenya, Madagascar, Nigeria, Senegal, South Africa, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe. Their joint statements were, as reported by the IPCC, "Most of the observed global warming since the mid-twentieth century is very likely due to human-produced emission of greenhouse gases. The warning from this organization will continue unabated if present anthropogenic emissions continue or, worse, expand without control. We therefore endorse the many recent calls to decrease and control greenhouse gas emissions to an acceptable level as quickly as possible."

Numerous additional scientific societies have since 2003 given their continued support to the IPCC's statements: the American Association for the Advancement of Science, the World Meteorological Organization, the Royal Meteorological Society, the Australian Meteorological and Oceanographic Society, and the American Meteorological Society. A 2003 statement from the last-mentioned is representative of the views of all: "There is now clear evidence that the mean annual temperature at the earth's surface, averaged over the entire globe, has been increasing in the past 200 years. There is also clear evidence that the abundance of greenhouse gases in the atmosphere has increased over the same period. In the past decade, significant progress has been made toward a better understanding of the climate system and toward improved projections of long-term climate change. Because greenhouse gases continue to increase, we are, in effect, conducting a global climate experiment, neither planned nor controlled, the results of which may present unprecedented challenges to our wisdom and foresight." There is now a consensus within the global scientific community regarding global warming and climate change. This is rare because in the very nature of science total agreement on such a scale is never expected.

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CHAPTER 2

Evidence of Past Climate Changes

In Chapter One, the details of the things that determine global warming and climate change were outlined, and it was made clear that variations in the amount of solar radiation reaching the earth dominate. It was also noted that changes in both the earth's annual orbit and in the orientation of its axis as it rotates affect the amount of solar energy reaching the earth. These gradual variations in the movements of the earth occur over long periods of time, so they tend to be ignored when it comes to intervals of time of a few years. This perspective on the multimillion-year saga of the great ice ages seems to fit the facts. Fifty million years ago the earth was relatively warm. Tropical conditions extended into northern Spain. The difference between the polar and equatorial average temperatures was much less than it is today. Trees grew in both the Arctic and the Antarctic. Subsequently, warming and cooling trends followed, each separated from its predecessor by hundreds of thousands or even millions of years. There were average temperature differences between warming and cooling phases of as much as 20°F.

Over the millions of years of earth's history, geological evidence enables us to date some of the big changes that occurred on the earth's surface and in its atmosphere. The ones closest to our own time are the most valuable, because they help us envision possible future events. We know that there were three warm periods within the last half million years: one between 350,000 and 300,000 years ago, in which average global temperatures ranged from –14°F to 5°F; a second one between 250,000 and 200,000 years ago, with a range of –10°F to 3.5°F; and a third one between 150,000 and 100,000 years ago, with a range of –16°F to 5°F. The work of a team of scientists at the University of New Hampshire enables us to get much more detail from the second of these warm periods, right down to the times of human history. These scientists drilled through the ice sheet that covers the island of Greenland, and, from the core of ice withdrawn, they were able to date and describe climatic conditions over long stretches of time. This work of digging into the past took four years, and the ice core went two miles down. One valuable benchmark from this work was the recognition of the end of the last interglacial phase. That occurred around 122,000 years ago.

Thus, from that date to the present time we are able to tell an almost continuous story of earth's history as far as climate is concerned. There are always unpredictable things that happen, because one small change can affect all the other elements of the system. The average level of the ocean and its influence on the rest of the earth is one of these unpredictable things. At the height of a cooling phase in the distant past, the amount of water withdrawn from the oceans to form ice on land, often forming mile-thick sheets of ice, caused the average elevation of the earth's oceans to be lowered by three hundred feet or more. Land areas were also reduced in elevation, but that happened more slowly as ice accumulated on them. We know from geological evidence that in the last of these times Florida was much bigger than it is today. Its coastline was far out into the Atlantic on one side and into the Gulf of Mexico on the other. When the last cooling phase ended and the ice had melted, the oceans gradually recovered their former elevations. The recovery of their former elevations was much slower on land. Even today, with the elevations of the oceans fully restored, very small increases in the elevations of land areas happen every year.

WITHIN HUMAN HISTORY

As we come closer to the time of recorded human history, the details on global warming and climate changes become much clearer, because we have more data with which to work. We tend to think of modern times independently of former events. That is not how climatologists see it. They talk about us living in an interglacial period because they know that new ice ages will return in the future, even though they may be hundreds of thousands of years away. Climatologists describe the present interglacial period as the Holocene. It began about ten thousand years ago as the last of the land areas were freed from ice. In the middle of the Holocene, there was a warm period, peaking approximately five thousand years ago, with temperatures higher than we experience at the present time. There has been a gradual drop in global temperature over the remainder of the Holocene. Throughout the past two thousand years, except for three periods of time, the climate has been relatively stable.

Climatologists identify three departures from this long stretch of stable conditions: the Medieval Warm Period, the Little Ice Age, and the Industrial Era. Between the medieval years of 900 and 1300 AD, Europe and most of Asia experienced a level of warmth that was above average. Most of our information about these times comes from Europe, Greenland, and the eastern part of North America, so the global extent of the warming is uncertain. It was between 900 and 1300 AD that some of the most daring and dangerous ventures were undertaken by Europeans, so it seems clear that the added warmth was a major factor in their decisions to travel. The marauding Vikings from Scandinavia swept all over Europe, including Russia, stealing all the wealth they could find. They also traveled westward across the Atlantic Ocean to Iceland, Greenland, and Newfoundland, in Canada, settling

L'Anse aux Meadows, site of the first European settlement in North America, in the place now known as Newfoundland, Canada. It was occupied by Vikings from Scandinavia in 1000 AD. (Dylan Kereluk)

and farming for long periods of time until changes in climate forced them to return to Scandinavia. They arrived in North America in the year 1000 AD, five hundred years before Columbus. The other adventurers of the Medieval Warm Period were the Crusaders who, encouraged by the Pope, traveled to Palestine to try to capture Jerusalem from its Arab rulers.

Between the fifteenth and nineteenth centuries, Europe and North America experienced temperature levels that were much lower than those of today. This four-hundred-year period came to be known as the Little Ice Age because it extended over such a long period of time. The extremes of temperature and the variations in rainfall that occurred were not exceptional by present-day standards but, in an era almost totally dependent on agricultural production, one or two degrees Fahrenheit can make an enormous difference in the value of crops. Stories of great hardship have come from both Europe and North America from those centuries. Famines were frequent, and epidemics of disease took hold because people were unable to resist them. Sir Walter Raleigh's attempt to establish a settlement near North Carolina in 1585 had to be abandoned after six years because of the low temperatures.

New explanations of the causes of this extended cold period have recently come from scientists at NASA's Goddard Institute for Space Studies.

Their findings are based on what they called "a dimmer sun." By this phrase they meant that the so-called regularity of the amount of energy given off by the sun failed to some extent. This is quite a new idea because, although there have been regular maxima and minima, such as the sunspot cycles at eleven-year intervals, at which the sun's energy increases or decreases, there had never before been reports of changes that extended over a long period of time such as the Little Ice Age. It is quite clear that if new discoveries are being made about variations in the sun's output, all aspects of the climate system on earth will be affected. Through detailed analysis of atmospheric conditions, starting with today and going back to the period from 1400 to 1800, the Goddard Institute scientists came to the firm conclusion that the amount of the sun's energy received by the earth within those years was less than normal.

They made use of data from other scientists to establish the validity of their conclusion. Galileo Galilei, the Italian scientist who revolutionized the understanding of the solar system, beginning in the year 1611 made drawings of sunspots, and his notes showed that only 50 sunspots appeared over a 30-year period. The normal amount for that length of time is more than 40,000. Clearly, the sun's output, always greater during most of the sunspot cycle, was considerably less during much of the Little Ice Age. In addition to their investigations into the sun's total output of energy, the Goddard Institute scientists looked at the influence of lower amounts of energy being received by different parts of the earth. They discovered that there was a striking drop in both the strength of the westerly winds and the prevailing temperatures in winter over Europe, the area that was most affected by the Little Ice Age.

The critical data from Galileo's study of sunspots contained more evidence of the cold winters close to what has been called the Maunder Minimum, from 1645 to 1715, the Little Ice Age's coldest years. One further confirming piece of information came from the sun's output of ultraviolet radiation. It is at a low level when the sun's output is weak, and the researchers were able to confirm the presence of this lower level of ozone in the upper atmosphere. The Maunder Minimum represented a lowering of average temperatures in winter in Europe by more than 2°F, the lowest for the whole millennium, as data from tree rings and ice cores subsequently confirmed. The third departure from the temperature regimes of the past two thousand years is, of course, the Industrial Era, the last 150 years, which is the focus of this volume, and the challenge that humanity now has to face as the problem of climate change worsens.

VOLCANIC ERUPTIONS AND CLIMATE CHANGE

Before leaving the subject of past climate changes, the impact of volcanic eruptions must be mentioned briefly. A more detailed account will follow in Chapter 8. These events have appeared from time to time, always unexpectedly and with devastating consequences, throughout the entire history of the earth. Their impacts on global warming and climate change have been huge, and they will continue to be huge in the future. Volcanic eruptions could be called the one certain source of climate change, past, present, and future. The last of the really big eruptions, the only one about which we know a great deal through contemporary geological and meteorological research, was Toba. A brief description of it here is a fitting conclusion to this chapter.

Toba was a volcanic mountain that erupted 76,000 years ago. It has become the model by which in the future we may be able to predict a recurrence. This supervolcano had an effect similar to the scenario drawn up by scientists for the consequences of a nuclear war, generally described as nuclear winter. Geneticists are now convinced that Toba's eruption reduced the entire human population to a few thousand people, and held them at that edge of extinction for thousands of years. Lake Toba, in the middle of northern Sumatra, Indonesia, is all that remains today of that colossal eruption. It is more than 50 miles in length and 20 miles in breadth. At its center stands an island, created by the accumulation of mini-eruptions over the millennia. It is a big, deep lake because Toba was a big eruption, the largest that has occurred anywhere on earth within the past two million years. It was a high mountain when it erupted, and it blew skyward a mass of ash and volcanic debris three thousand times the total amount that erupted from Mount St. Helens in 1980.

The entire subcontinent of India was covered with ash, and sunshine was reduced all around the globe. Temperatures dropped by several degrees and stayed at that level for years. Throughout the world of that time, millions of all forms of life died. Thousands of species vanished. Ordinary levels of volcanic activity are familiar to us because we see them frequently. It is no surprise to visitors in Hawaii when magma pours onto the surface daily from deep volcanic vents. Occasionally, however, a super volcanic eruption occurs, one that affects the entire globe. The destructive power is enormous, and the timing is not always predictable. Toba was one of these, the biggest of all that we have been able to identify in detail, one that will appear again sometime in the future. It is known that Toba also erupted half a million years ago and a little over one million years ago. These are what are called recurrence rates, that is to say, estimates of the time between successive eruptions. This provides information about when the next one might come. Recurrence rates for other ancient eruptions are also now being determined.

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CHAPTER 3

Evidence for Climate Change Today

The reality of climate change has been known for a long time within the scientific community. However, uncertainties within that same community placed public opinion at a disadvantage. It was known that the average global temperature of the earth's surface rose by more than 1°F in the course of the twentieth century, an increase that was probably the greatest in any one century for a thousand years. The 1990s was the warmest decade of the century, and 1998 was possibly the warmest year within the last five hundred years. Furthermore, it was clear to the scientific community long before the end of the twentieth century that human activities were responsible for the additional warmth. By 2000, they had evidence that rapid warming had been taking place in parts of the Arctic since 1970.

Today the Arctic is the poster child of the United Nations Intergovernmental Panel on Climate Change (IPCC), the organization that, along with former U.S. Vice Present Al Gore, received the 2007 Nobel Prize for Peace. This organization points to the present extremely rapid increases in Arctic temperatures as a preview of the future unless we take action to prevent climate change. The details of these dramatic developments in the Arctic were described in Volume One. They leave no doubt about the dangers that face the global community. Residents there see temperature increases of 2°F or more year after year. Buildings, airports, and highways subside as the underlying permafrost

White Roofs Slow Global Warming

Since 2005, California has required flat commercial structures to have white roofs because white roofs will reflect a lot of the incoming energy from the sun and thus lower temperatures at ground level. The term albedo, based on a Latin word for whiteness, is used to describe the amount of the sun's rays that are reflected back into space by a surface. If the albedo is high, as in a white surface, the earth's surface is cooled. If the albedo is low, as in black asphalt, the earth's surface is warmed. In 2008, California's Climate Change Conference at its annual meeting urged the world's one hundred biggest cities to install white roofs and also to change the color of their pavements from black to a lighter color. Conference organizers pointed out that the global cooling effect of such action would be huge. We know that this is true because we have seen the results from higher albedo in the Arctic. There, as ice, which has a high albedo, melts, the ocean, which has a much lower albedo, warms the surface and thus increases the rate of melting of the remaining ice.

collapses; biological cycles are upset; forests get destroyed as insect enemies arrive earlier in the season and stay longer. Much of this was becoming evident more than a generation ago, but the Arctic is far removed from the world's centers of population, and few were concerned. Many scientists were unsure about the global implications of this kind of evidence.

Scientists were being influenced by short-term data that kept appearing in important scientific journals. "The cooling world" was a phrase that appeared several times in these journals around the year 1970. Later, as people looked back, it was evident that leading scientists had become victims of modern society's demands for instant answers and were making predictions on the basis of inadequate amounts of information. The National Oceanic and Atmospheric Administration (NOAA), always the gold standard for information about the weather, had pointed out in one of its reports that ground temperatures north of the equator dropped by an average of 0.5°F between 1945 and 1968. This information, because of where it came from, was accepted as an important trend. Thus it transpired in the 1960s and around 1970 that many experts became convinced that the earth's weather had begun to change in a negative direction, posing problems for food production all over the world. Evidence in support of this trend came from different places. In Britain, farmers had seen their growing season decline by as much as two weeks since 1950. Meteorologists were almost unanimous in the view that the cooling trend in the weather would continue for the rest of the twentieth century.

NEW EVIDENCE OF CLIMATE CHANGE

In the 1970s, at the request of President Carter, a small group of well-known scientists prepared a report that warned the nation of danger from the human activities causing global warming through emissions of greenhouse gases. In their report they made it clear that the conclusions they had drawn would be vindicated within the following 20 years. No one took much notice of this report at the time because other important political events overshadowed national life, but meteorologists began to notice that temperatures were beginning to move upward. In June 1988, James Hansen, director of the NASA Goddard Institute for Space Studies, warned a U.S. Senate committee that the planet was already warming as a result of human activity. Ten years later, in 1998, he returned to the same Senate committee with a more immediate warning: safe levels of atmospheric carbon dioxide have already been exceeded, and we are at a planetary emergency. The earth had warmed more in the first five months of 1998, he pointed out, than in any comparable period since measurements began in 1868. The predictions of the Carter scientists had indeed been vindicated.

Despite the opposition from business groups representing coal and oil producers who argued that scientists were uncertain as to whether climate change was really a threat, the combined evidence from Carter's team and from NASA established that climate change due to human action was a reality and that it had to be faced. It was no accident that the IPCC was established in the same year that James Hansen first gave his testimony to the Senate committee. Once the seriousness of the climate change problem was accepted at both national and international levels, more attention was paid to relevant evidence from other researchers. A Danish climatologist at the University of Copenhagen had been investigating for many years the climatic conditions of 20,000 years ago. He was using data from ice cores that a U.S. Army team had obtained in the 1960s in Greenland. This climatologist was the first person to identify specific climatic conditions over time from a form of oxygen he was able to extract from the ice.

His findings confirmed earlier suspicions that climate change had often been sudden in the past, a finding that ran counter to longstanding assumptions about climates, namely that they changed very slowly over time. This finding proved to be a valuable asset; scientists had to sort out whether present trends were going to continue at their present rate or accelerate unexpectedly. We know now that, at least in the Arctic, rates of change in global warming are exceeding all expectations. In another study of climate, this time at Columbia University, scientists had been working on an investigation of the oceans in order to understand better their role in climate change. Their work, along with research from

Drilling ice cores in Greenland. (NOAA)

the Scripps Institution of Oceanography in La Jolla, California, the U.S. National Oceanic and Atmospheric Administration, and a British team working on a parallel research project, was examined in 2005. They provided the strongest evidence to date that the rise in ocean temperatures was triggered by human activity.

In modern science, as distinct from the older observational style of research, scientists create models of what is known about a particular problem. The model is then tested against real-world data to see if it is predictive. If it fails that test, a new model is needed. In the case of the research in which these scientists were involved, the problem was finding the cause or causes of rising ocean temperatures. These temperatures had been increasing by an average of about 1.5°F over the past 40 years. Researchers, using data from the U.S. National Oceanic and Atmospheric Administration, examined more than seven million observations of temperature, salinity, and other variables in the world's oceans and compared them with those that are predicted by computer models of various potential causes of climate change.

It found that natural variation in the earth's climate, or changes in solar activity or volcanic eruptions, which had been suggested as explanations for rising temperatures, could not explain the data collected in the real world. In other words, natural elements could only explain some of the observed data. However, when models based on the effects of human emissions of greenhouse gases were added to the investigation, they matched the observed data. All of the scientists involved claimed that the results were so clear and accurate that they should end all controversy about both the causes of rising ocean temperatures and the impact on the environment of greenhouse gases. The most persuasive aspect of these investigations is that two models were used, one from Britain and one from the United States, in which natural as well as greenhouse gas emissions data were included. Both, independently, came up with the same excellent fit with respect to real-world data.

THE GLOBAL OCEAN CONVEYOR BELT

This flow of water exemplified by the global ocean conveyor belt is often referred to as the thermohaline circulation (THC) because of its important relationship with both heat and salt. ("Therm" refers to heat and "haline" to salt.) Some scientists are concerned that the THC may be vulnerable to rising temperatures, and thus may be affected by global warming. Take, for example, the following statistic from the Woods Hole Oceanographic Institution in Massachusetts: it established that between 1965 and 1995, more than eight thousand square miles of freshwater ice melted in the Arctic. All of this freshwater was added to the ocean, making it less salty than before. The big question being asked at Woods Hole, the same one that was asked elsewhere by other scientists, is this: if this continues, could the Gulf Stream, the northernmost extension of the global THC, stop flowing? The implication for

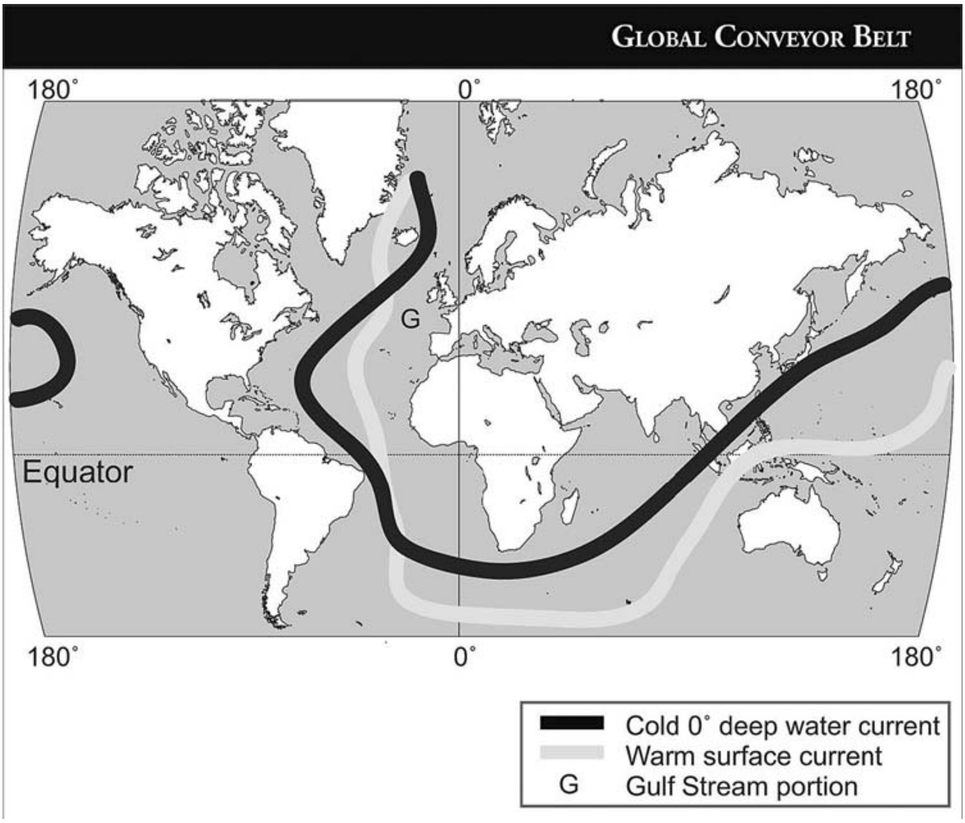


Figure 3-1 Global conveyor belt; G is the Gulf Stream portion of the whole, often described as the Thermohaline Circulation. (ABC-CLIO)

Britain and other parts of northwest Europe, if this were to happen, is very serious. Their average temperature could drop by as much as 10°F.

Consider the different factors at work in relation to this question and see if they are important with regard to the operation of the Gulf Stream. First, we have the average increase in ocean temperatures of 1.5°F over 40 years, as identified by the Scripps Institution of Oceanography. That calculation must apply in part to Arctic waters, even if the warming there is less than the average. Second, the huge increase in the amount of freshwater added to the ocean makes it less salty. As the Gulf Stream flows northward along the surface of the ocean, past the Florida coast and all the way to the coast of Greenland, three things happen: the east coast of the United States and the coasts of northwest Europe are warmed, the Gulf Stream cools and therefore gets heavier, and, because water was traditionally withdrawn from the ocean to form ice, both the surrounding ocean and the Gulf Stream get saltier and heavier. The heavier Gulf Stream then sinks down into deeper water to form the return circuit.

The Norwegian Meteorological Institute in Oslo, Norway, a country that would suffer greatly if the Gulf Stream slowed down a lot, estimates from its own research that it would take a century at least for this

Most of this South Pacific country, Tuvalu, is less than three feet above sea level. Its citizens fear that rising sea levels will make their nation uninhabitable. This picture of the capital, Funafuti, was taken in 2004. (AP/Wide World Photos)

to happen, and at least two centuries for the current to stop completely. These calculations were based on present trends, and they excluded the possibility that the nations of the world would cut back on greenhouse gas emissions. Furthermore, we have learned from the accelerated rate of melting in the Arctic that rapid changes can occur and upset all of our predictions. The future of the Gulf Stream is also related to the whole question of sea level changes. Water expands as it gets warmer, and this raises sea levels. Additional increases in sea levels come as more and more of Greenland's ice cap and Antarctic's ice melt. A rise of three feet is often quoted as a reasonable expectation, and such a rise in sea level would be catastrophic for many island nations and territories. Tuvalu, Nauru, Kiribati, and Tokelau in the Pacific would be in danger of flooding, as would the Maldives and Seychelles in the Indian Ocean. Numerous coastal areas of other countries would also suffer.

CHAPTER 4

Carbon Dioxide: The Scientific Evidence

There are two stories of the greenhouse effect on earth. The first one is very old, millions of years old. It is the natural greenhouse effect that has for all of that time kept the earth warm enough for human life to flourish. The second one is only a little more than a hundred years old, but it is the one that is causing most of our concern over global warming and climate change. It is caused by too much carbon dioxide getting into the atmosphere. The natural greenhouse effect is primarily mediated by water vapor. The new one is the carbon dioxide greenhouse effect. The natural one is by far the most important: three thousand times as much water in the form of water vapor goes into the atmosphere every day as the amount of carbon dioxide that goes there. The big difference between the two is that the water comes back down every day in the form of precipitation. Carbon dioxide stays in the atmosphere, or at least enough of it stays to create a problem and upset the longstanding natural greenhouse effect that has served us so well for so long.

The earth is kept at a moderate average temperature by the right amount of water vapor in the atmosphere. If this amount went much higher, we would suffer from too much heat; and if there were much less water vapor in the atmosphere, we would see the earth's temperature drop perilously low. This is how the greenhouse effect works: rays of energy from the sun enter the earth's atmosphere; some of it bounces off clouds and tiny particles and is lost in space, but most reaches the earth, where it is absorbed and re-emitted as long-wave energy, also known as infrared waves. Thus the earth's surface becomes a radiator of infrared energy back into the atmosphere. Most of this energy, however, never gets into space because it is absorbed by water vapor, which creates additional warmth that in turn is reflected back to earth. The cycle of earth sending heat toward space is then repeated as long as infrared energy is available.

We are all familiar with this natural greenhouse effect from everyday experience. If the sky is clouded over on a cold day, the temperature does not change very much at night, but if there are no clouds anywhere, the drop in temperature by evening is very evident. Scientists do not have an answer for the healthy balance that persists by having the right amount of water vapor in the air at any time. Fortunately, the whole system is well balanced, but it is a big system, and we are discovering that when small changes occur in the amount of greenhouse gases, big changes can happen in the whole system. This is what is happening now as carbon dioxide, along with some other gases, upset the natural balance. They may only amount to a tenth of the natural greenhouse effect caused by water vapor, but their effect on the whole system is great because, unlike water vapor, they stay in the atmosphere for a long time, for as long as two hundred years in the case of carbon dioxide, the most crucial greenhouse gas.

ATMOSPHERIC COMPLICATIONS REGARDING GREENHOUSE GASES

Scientists are anxious to know what is happening on earth as a result of the temperature increases in the atmosphere that are caused by additional carbon dioxide. If it were a simple research question of the kind with which researchers are familiar, it could be figured out: what will happen on the earth's surface if there is a change in earth's temperature due to an increase in carbon dioxide while all other things in the earth's climate system remain the same? Unfortunately, no research project in this arena is as simple as this. Everything in the earth's temperature and climate systems changes when one thing changes. It's like sticking something in a hornet's nest: the whole colony explodes in activity in all directions. If we take just one thing, like water, that certainly will change when additional carbon dioxide is added to the atmosphere, the universality of the changes that take place in other locations will become clear, because water has always been the main greenhouse gas with or without the presence of other gases. As soon as the atmospheric temperature increases, more water is added to the atmosphere in the form of water vapor.

The reason for this is that the maximum amount of water that the atmosphere can hold at any given time depends on the air temperature. This is one of the basic laws of physics. If we increase the temperature, the atmosphere can hold more water; if we decrease it, it holds less. But, if we increase the amount of water in the atmosphere through adding carbon dioxide, still more infrared radiation will be reflected back to earth by the additional water vapor, and there will be additional increases in the overall temperature on earth. When the simple experiment that was described above is done in a laboratory, keeping out all other possible changes, the result is known. It would be between 3°F and 4°F when the amount of carbon dioxide in the atmosphere is doubled. That is a lot, as we know from past records of the earth, but in fact the change in the temperature of the real atmosphere would be more than that.

This illustration of the complexity of just one change in one element is not the whole story. If we continue the examination of what happens when the temperature of the atmosphere is changed, and there are more clouds because there is more water vapor, something else happens: with more clouds, more of the incoming solar radiation is reflected back into space, reducing the amount that reaches the earth's surface and therefore cooling the earth's surface. It is because of complexities like these that scientists experience difficulties in designing models of existing conditions. Before leaving the topic of the changes taking place in the atmosphere and affecting the whole climate system, we should note that there are other greenhouse gases involved in what is happening. Some of these will be mentioned later in this chapter. There is also another influence at work: aerosols, tiny particles from industrial operations that float upward and behave like little clouds in the sense that they deflect some solar radiation and provide places where water vapor can condense.

CHANGES ON THE EARTH'S SURFACE

From all the information scientists are gathering about changes that have been taking place over time on the surface of the earth and in the ocean, it may be that these changes are as much responsible for global warming and climate change as anything that occurs in the atmosphere. Take, for example, a single tree: we know that it absorbs carbon dioxide, so it is a good helper in our attempts to slow down global warming. Yet trees are being cut down all over the world at an alarming rate. Does anyone think about replacing the ones that were cut down? The answer must be no, for the most part, as we look at the figures on deforestation. Since 1950, globally, 30 million acres of trees have been cut down annually. Indonesia, within the years 2005 to 2008, gained the reputation of being the world's fastest destroyer of trees, as 20 square miles of trees were being cut down every year. According to the United Nations Food and Agricultural Organization, in Latin America and the Caribbean five million square miles of trees were being taken down annually; in Africa it amounted to one and a quarter million square miles. Even in the United States, from 1850 to today, the amount of land given to trees has shrunk from 900 million acres to 600 million acres.

All plants absorb carbon dioxide, but trees do this best. They process significantly more than smaller plants due to their large size and extensive root structures. In essence, trees are the kings of the plant world, and they are the most efficient carbon sinks. ("Carbon sink" is the term used to define things that absorb large amounts of carbon dioxide.) Slower-growing trees can store more carbon dioxide and keep it for longer periods of time, but scientists are often impatient over delays in countering greenhouse gases so they urge governments and other agencies to grow as many trees as possible, making sure that the trees selected are the best for a particular region's temperature, soils, and humidity regimes. Again, as we have seen in the atmosphere's almost chaotic variability, those who plant trees need to take account of rising temperatures and changing levels of rain. Some species of trees can flourish in different environments, but others will fail. Trees that require

Big Trees in Urban Environments

Environmentalists have expressed concern over the loss of the old-growth trees that are frequently cut down to make room for new homes or offices in populated areas. These trees are usually replaced with younger, smaller ones, but rarely is it recognized that the tree removed was extracting from the atmosphere more than three hundred pounds of carbon dioxide every year, compared with a few pounds by the new, younger tree. For places across the south and east of the United States, the old-growth trees have an additional important quality: they intercept 75 percent of the rainfall that would otherwise go into storm sewers, a big safety factor when ten or more inches of rain accompanies a hurricane. Transplanting old-growth trees within an urban area has been common in Europe for decades, but only recently has the practice spread in North America, largely because of the lack of adequate equipment for the job. Now, with growing awareness of the value of retaining these older trees, manufacturing companies are marketing machines that can excavate and move the whole root ball of a tree, even if it is 14 feet in diameter, with all the root systems preserved or cut in a way that makes new root growth easy.

substantial amounts of maintenance need to be avoided because maintenance usually requires machinery that will add carbon dioxide to the atmosphere. Most of the earth's animals live in wooded areas so, quite apart from their value as carbon sinks, trees, or woodlands, preserve the habitats of thousands of the earth's most important species.

The ocean is the biggest carbon sink, absorbing more than 90 percent of the carbon dioxide being released across the globe. However, as its temperature increases, the ocean's capacity to absorb carbon dioxide decreases and its acidity level increases, threatening

Destruction of forests for plantations, Indonesia. (AP/Wide World Photos) the existence of important forms of ocean life. Phytoplankton, the food of many microscopic marine animals, absorbs carbon dioxide, and these animals form the basis of a food web for all marine life. Because photosynthesis, the basic life process for plants, including phytoplankton, requires light, phytoplankton grow only near the surface where sufficient light can penetrate. The deeper part of the ocean, and the marine life that is there, can be served from an unexpected source: under conditions of a warming ocean and the danger of too much carbon dioxide remaining in it, cold water, in particular the Arctic waters, can absorb much larger amounts of carbon dioxide than, say, tropical areas, and in this way carbon dioxide can be circulated into the deeper parts of the ocean through the return circuit of the Gulf Stream and its links with the rest of the global thermohaline circulation.

Earlier it was mentioned that there are additional greenhouse gases besides carbon dioxide. Two of them are directly related to the aftermath of deforestation: nitrous oxide (N_2O) and methane (CH_4). This is an important feature of the post-industrial world of the nineteenth and twentieth centuries. Before industrialization, land use, particularly farming, was the normal occupation of most families, but it was a style of farming involving both arable and pastoral activities on a small scale, and it involved all of the members of a family. There were no jobs in industry and no use of modern machinery that would have increased the amount of greenhouse gases in the atmosphere. By using crop rotation and a range of crops, animals, and poultry, the environment was safeguarded from the destructive effects of monoculture. All of this changed as work shifted to cities and factories, and agriculture became

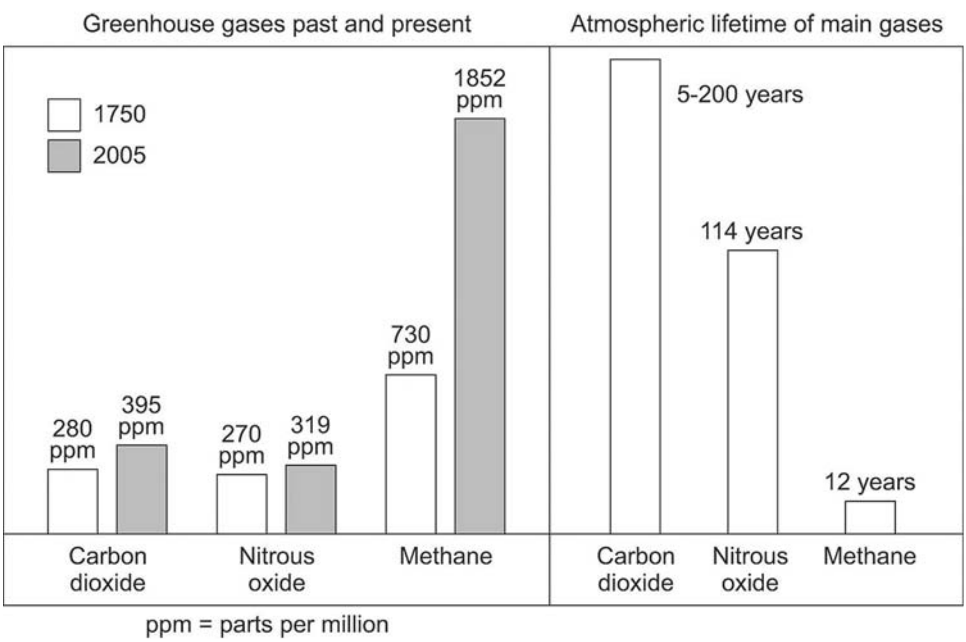


Figure 4-1 Main greenhouse gases that contribute to climate change. (ABC-CLIO)

a series of industries, each specializing in one product. It was because of these changes, particularly the new use of land in monoculture for growing grain or rearing livestock, that nitrous oxide and methane emissions increased.

The amount of nitrous oxide added to the atmosphere (50 parts per billion) as a result of industrialization is due to deforestation and the conversion of forest, savanna, and grassland ecosystems into agricultural fields and rangeland. Methane increases (1,200 parts per billion) are greater and are due to the same causes. Together, they have contributed a third of the greenhouse gases causing the present increases in temperature. Methane is 20 times more powerful than carbon dioxide in trapping heat in the atmosphere. Fortunately, its lifetime in the atmosphere is quite short, a little more than ten years. Nitrous oxide is 300 times more powerful than carbon dioxide as a greenhouse gas. It has relatively long life, about half that of carbon dioxide. Fortunately, the total amount in the atmosphere is much lower than that of methane. A main source of nitrous oxide is nitrogen-based fertilizers and the use of livestock manure; both of these sources can be found in quantity in developing countries, where fertilizers are increasingly used to increase rice production.

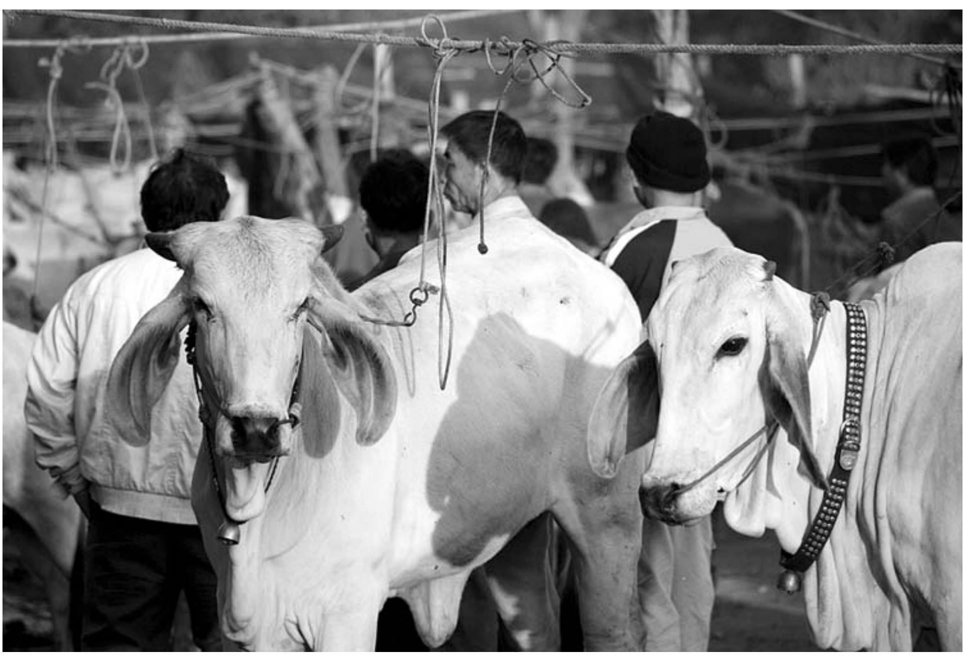
An important source of the increase in methane is the raising of animals, especially cattle. Grazing animals release methane to the environment as a result of herbaceous digestion. Some researchers believe that the methane from this source has more than quadrupled since 1900. Lesser amounts come from landfills as organic wastes decompose over time. A 2006 report from the United Nations Food and Agriculture Organization (FAO) states that the livestock sector,

Animals Can Cause Climate Change

The Arctic musk ox and caribou are herbivores that eat huge quantities of plant material all over northern Canada and Greenland. In so doing, they accelerate global warming and climate change in the Arctic. Plants are powerful mitigating factors in climate change because they store carbon dioxide. Anything that adds to existing processes of warming in the Arctic is particularly unwelcome because this part of the globe seems to be warming at a faster rate than anywhere else. Although this contribution to global warming of animals in the Arctic is particularly important, the role of animals in global warming is a general one, evident all over the earth. Agriculture is responsible for 14 percent of the world's greenhouse gases, most significantly because of its production of a large quantity of methane, a greenhouse gas that is 21 times more powerful than carbon dioxide. Cows emit a massive amount of methane. Statistics vary regarding how much, but estimates suggest it is about the same in the course of a day as the amount of carbon dioxide from an automobile over the same time. To understand why cows produce methane, it's important to know a bit more about how they work. They have four stomachs, and they digest their food in their stomachs instead of in their intestines, as humans do. They eat food, regurgitate it as cud, and eat it again. The stomachs are filled with bacteria that aid in digestion and also produce methane. A three-year study, begun in April 2007 by Welsh scientists, is examining whether adding garlic to cow feed can reduce methane production. The study is continuing, but it is likely that garlic will halve the methane.

globally, generates more greenhouse gas emissions than transportation. It is also a major source of environmental degradation. The FAO's explanation for this is that people are consuming more meat and dairy products every year. It estimates that global meat production will double between 1999 and 2050, and milk consumption will increase by the same amount within the same period. The FAO goes on to say that these increases come at a high environmental price: they add 10 percent of the carbon dioxide greenhouse gas, 65 percent of nitrous oxide, and 37 percent of methane.

Furthermore, the FAO goes on to report, the global livestock sector is growing faster than any other aspect of agriculture. It provides livelihoods to about 1.3 billion people and contributes about 40 percent to global agricultural output. For many poor farmers in developing countries, livestock is both a source of renewable energy for hauling and an essential source of organic fertilizer for crops. Livestock now uses 30 percent of the earth's entire land surface. This is mostly permanent pasture, but it includes a third of all the arable land used to produce food for livestock. Hence emerges one of the main reasons for forests being cut down, and why few new forests are being planted to replace them. It is one more example of the conflicts that keep appearing within the global climate system as we attempt to reduce the volume of gases that cause global warming. The forests of the Amazon River basin, the most extensive carbon-capture forests in the world, are one area of concern: about 70 percent of their forested land has already become pasture.



The world's rapidly growing cattle population is producing methane at an alarming rate. (Stucorlett/Dreamstime.com)

In spite of all the negative publicity about global warming and climate change, we tend to forget that there are benefits from it for some people in some places. To mention this does not minimize the urgency of doing all we can to reduce the amount of greenhouse gases that are emitted into the atmosphere. Rather it provides valuable information on the temporary advantages that will make it much easier for some people to cope and, by coping more easily, to have an opportunity to begin to work on, for example, the alternative energy sources that will one day be widely used. The Arctic areas of northern Canada are one place where there might be benefits, because some of the most severe increases in global warming have occurred there, making them examples of possible futures for the rest of the globe. Crops that never flourished in Arctic areas in the past can now grow there, and less heat will be required in homes in winter. The Arctic happens to be a location where high winds are common at times, so, in terms of taking advantage of easier living conditions to investigate ways of using wind energy, the residents of this area could do valuable experimental work for the rest of us on efficient ways to produce and use wind energy.

CHAPTER 5

Results of Climate Change in the United States

The IPCC is now regarded as the most reliable source of information on global warming and climate change. That is not to say that every country accepts either its findings or its recommendations for action. Different countries have reacted differently to the reports presented to them by the IPCC at the Bali Conference of 2007. Nevertheless, by enlisting expert meteorologists from around the world, the IPCC has managed to establish a consensus of scientific opinion—a rare achievement—regarding present levels of greenhouse gases throughout the world. As we look at temperature and climate changes across the United States, and their implications for the welfare of the people in different locations, the projections from the 2007 assessment of the IPCC will be our guide. Any changes that are noted will continue to come in the future because of temperature, precipitation, and extreme weather events, as well as the influences of interconnected economies and movements of people worldwide.

Annual average temperatures increased in the United States between 1955 and 2005, with the most dramatic increases occurring in Alaska and neighboring areas of the Arctic. Two days have been added to the length of the growing season in every decade since 1955, with most of the increases being evident as earlier springs. Although some natural factors contributed to the temperature increases, the main sources of warming were greenhouse gases and sulfate aerosols. Precipitation amounts increased for most of the United States. There were decreases in the southwest, and the amount of precipitation that used to fall as snow changed to rain at most weather stations throughout the western mountains. In general, there was much less snow in these mountains during the ten-year measurement period from 1994 to 2004. All of these indicators point to a problem all across the United States as demand for water exceeds supply under the multiple pressures of population growth, economic development, and new demands from agriculture, municipalities, and industries.

Ecosystems responded to the changing environment. Daily satellite pictures showed the evidence of an early agricultural spring in the ten extra green days. Plants of all kinds, shrubs, and trees also appeared earlier than before. Across the United States, especially in the central plains, the nation as a whole saw net primary production increase by 10 percent between 1982 and 1998. For forests, warmth brings mixed advantages. There is an increase in rates of growth, but there are also

Forest fires in Apache-Sitgreaves National Forest, Arizona. (U.S. Forest Service)

more insects and diseases attacking the trees. Wildfires appeared in many places, and the western areas saw a dramatic increase in fires between 1977 and 2007. Since 1980, an average of more than ten thousand square miles of forests were lost to fires every year, almost twice the area lost to fires between 1920 and 1980. In Canada, losses of trees to fires were three times greater than in the United States since 1990. The pine beetle, always a serious threat to the boreal forest, extended its range of activity in the same time period, reaching areas that formerly were too cold for it.

Coastal areas of the United States are increasingly vulnerable for two reasons: rising sea levels increase the impacts of storm surges on homes, and the costs that result from these impacts keep rising every year. The reason for the increase in costs is the rising demand for coastal properties; the value of any home rises when an increasing number of people want to buy it. Much of the city of New Orleans is below average sea level, and we know from events such as Hurricane Katrina in 2005 how easy it is for such a place to be flooded when sea levels rise. San Francisco has tide-gauge data going back for 140 years. These have been examined for the period from 1950 to the present, and the results show an increase in winter storms compared with the earlier years and, as a result, an acceleration in coastal flooding. A number of Alaskan villages have received attention since 2000 because their stability appeared to be threatened. The costs of adding protection to these places, or relocating them to higher ground, as was necessary for some, amounted to $54 million.

ECONOMIC LIFE, HEALTH, AND SETTLEMENTS

In the Midwestern states, between 1970 and 2000, corn yield increased by 58 percent and soybean yield by 20 percent, but weather fluctuations caused huge reductions in some years. Heavy rainfall, for example, between 1951 and 1998 reduced the value of the corn crop by an average of $3 billion per year. In California, for some time, warmer nights increased the quantity and quality of wine grapes, but there is doubt that additional warmth will be helpful for this industry. Forest growth has been slowly accelerating over recent years in a few regions where formerly it was limited because of low temperatures and a short growing season. In Alaska, white spruce that traditionally flourished on south-facing slopes has seriously decreased over several decades due to drought. Fisheries have suffered substantially because of global warming. Salmon ocean fisheries in particular are in steep decline. The salmon increasingly move farther and farther north and recently have been found in Arctic waters.

Human health is always at risk when normal climate regimes change to greater warmth or to drought. In California, in the early 1990s, there was an epidemic of valley fever following five years of drought. The strain of the West Nile virus that emerged in the United States in 1999 is dependent on warmer temperatures, and the large number of people who were infected in 2002 and 2004 was due to the above-average temperatures of those years. The threats to homes and the people who live in them under conditions of rising temperatures are closely tied to migrations to coastal locations. Because such places have been in high demand for many years, they tend to attract the wealthier members of society, who tend to have the biggest homes. As a result, the damage to infrastructure is huge, even though the total number of people involved is a small percentage of the total U.S. population. In 2005, for example, of the $19 trillion of insurance money spent by those at risk from hurricanes, half of that amount was spent by homeowners in coastal areas.

IPCC ASSUMPTIONS ABOUT FUTURE TRENDS

Extreme weather is likely to continue increasing. The first requirement for survival is effective adaptation to change. Costs associated with events such as hurricanes are accelerating, not so much because of changes in the frequency or power of these storms, but rather because of the increasing value of the infrastructure affected. Between 1980 and 2006, the total value of hurricane damage to the contiguous United States rose from less than $5 billion to more than $25 billion. Lives were disrupted and some were lost in this period of time, and the hardships were particularly painful for the socially and economically disadvantaged. Because of the increasing numbers of people in urban centers, human health and safety are likely to be worsened by urban heat islands, air and water pollution, aging infrastructure, and poor water quality. Overall, climate change coupled with expanded economic development and population growth will limit all aspects of water supply. Already lower water levels in the Great Lakes and in major rivers are impeding navigational systems and hydroelectric generation.

The environmental impacts of climate change show profound regional differences. In the Arctic, the impacts exceed the changes forecast for all other regions. Furthermore, in the Arctic, the complexity of responses in biological as well as human systems is so great that it is difficult for the IPCC to be confident about any of its assumptions. The best predictions include substantial increases of greenness in parts of the Arctic, increases in biological productivity, shifts in vegetation from tundra to shrub, and a latitudinal change northward of the northern limit for tree growth. The migration toward the North Pole of existing species, and competition from invading species, are already occurring. These developments will continue to alter species composition as well as their numbers in both land and water areas. Indigenous people are already adapting to change. They have been doing this for thousands of years. They are changing wildlife management regimes and hunting practices.

The massive changes that are seen today in the volume of freshwater in the Arctic have implications far beyond the local area. These changes have been accelerated by discharges from Russian rivers over the past

Inuit woman ice fishing for cod, a new way of surviving as global temperatures rise. (U.S. Fish and Wildlife Service)

70 years. These increases in freshwater are raising ocean levels worldwide, fortunately thus far by only very small amounts. If the ice on Greenland were to thaw, ocean levels would rise by substantial amounts, and many places around the world would be threatened. For years, scientists assumed that such a thawing could not come before the end of the twenty-second century. Now, just as they are uncertain about other developments in the Arctic, they are not so sure about when that thaw might happen. The other development that could emerge from large amounts of freshwater in the Arctic is the slowing of the Gulf Stream. It depends for its operation on large quantities of ice remaining on and around the Arctic Ocean. Much of Europe and parts of North America depend on the Gulf Stream to maintain a warm climate. Evidence of its slowing began to appear two decades ago.

DEVELOPMENTS UNDER UNFCCC AFTER KYOTO

UNFCCC is the UN Framework Convention on Climate Change, an international treaty that acknowledges the possibility of harmful climate change. It has the legal authority to make decisions on climate change. The IPCC, the Intergovernmental Panel on Climate Change, is a scientific body that evaluates the risk of climate change caused by human activity. It was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), both organizations of the United Nations. IPCC members from all over the world, ever since the institution's inception in 1988, have been working on the possible outcomes arising from the increase of carbon dioxide in our atmosphere and on what actions should be recommended to the nations of the world. The efforts of this organization were rewarded in 2007, along with former Vice President Albert Gore, with the Nobel Prize for Peace. The IPCC does not carry out research, nor does it monitor climate or related phenomena. Its activities are focused on publishing special reports on topics that relate to the decisions of the UNFCCC.

The UNFCCC was adopted in 1992 as an authority that would deal with the growing concern over greenhouse gases in the atmosphere. In 1994, it came into operation as a branch of the United Nations with working links to many nations of the world. Three years later, its first major decision was made, the adoption of the Kyoto Protocol, so called because the final meeting of the planning group was held in the city of Kyoto, Japan. This protocol to the UNFCCC categorizes the nations of the world into developing or developed status, with the larger responsibility for dealing with greenhouse gases being placed on the developed countries. This new responsibility came into force in 2005. On that date all the developed countries were required to take action to reduce their greenhouse gas emissions to the levels that had been specified in the Kyoto Protocol. As of 2008, 182 nations had ratified the protocol, 36 of them being developed countries, the ones that have the major responsibilities for action.

Some opponents of Kyoto argued that the split between developed and developing countries was unfair, and that all countries without exception need to reduce their emissions. Some countries claim that their costs of following the Kyoto Protocol will stress their economy too much. These were some of the reasons given by George W. Bush, President of the United States, for not forwarding the Kyoto Protocol to the United States Senate. Opposition to the Kyoto Protocol was not restricted to a few nations. A major article in the scientific journal *Nature*, as recently as 2007, pointed out that no reductions in greenhouse gases took place since 2005. Furthermore, it was pointed out in that same article that the sharp focus on one solution distracted nations from considering alternative policy approaches, and it also prevented them from taking action on behalf of very poor countries such as Bangladesh that will experience the greatest amount of destruction from increases in greenhouse gases.

In summary, experts in climatology and meteorology increasingly point out that the Kyoto Protocol was always the wrong tool for the job that had to be done. It was modeled on past treaties such as those designed for tackling ozone depletion, acid rain, and the spread of nuclear weapons. Climate change is based on a complex set of variables. It cannot be corrected either by focusing on just one thing or by forgetting that almost all of the buildup in greenhouse gases is related to only 20 nations. Kyoto was designed to end in 2012, so, throughout the year 2007, in preparation for a conference in Indonesia later that year to draft a plan for Kyoto's successor, many groups of scientists met to work out ways of designing a better model for reducing greenhouse gases. Their principal guidelines came from the IPCC's synthesis report, which summarized all of its findings since its inception in 1998. This report will be discussed later in this chapter. It was received and welcomed by all the delegates who met in Bali, Indonesia, on December 3, 2007, but the attempts to transform it into decisions for action by representatives of more than one hundred nations was a very different matter.

Greenhouse Gases a Low Priority

Some people oppose efforts to reduce greenhouse gases because they think that the money expended in doing this could be better used for more urgent needs. A group of economists, including five Nobel Prize winners, who met in Denmark in May 2008 were asked about the best way to spend $75 billion, given the many needs and challenges facing humanity. They made a list and prioritized it. Their first choice was to give vitamin A and zinc supplements to 140 million poor children around the world. It would cost $60 million per year, and it would add $1 billion worth of benefits to society. The second-best investment, they said, would be to implement the World Trade Organization's plan to reduce barriers to international trade and migration. That, in the opinion of the group, would increase global income by as much as $3 trillion, most of which would be gained by the developing world. The list of priorities went on to 28 additional projects. The last of the 30 was about focusing exclusively on cutting greenhouse gas emissions.

A document that was supportive of the IPCC's challenging synthesis report, a summary of various global temperature regimes, was presented to the conference delegates by the UN's World Meteorological Organization. It showed that 2007 was going to be remembered as the warmest on record. Additional data in this document included the following: the linear global warming trend over the last 50 years was almost twice that for the last hundred years, and the 11 warmest years since records began occurred within the span of 1994 through 2007. In terms of cyclones, 2007 was a devastating year: Cyclone Sidr hit Bangladesh, affecting more than eight million people, and Cyclone Gonu made landfall in Oman, disrupting the lives of 20,000 people. In the Arctic seas in 2007, there was an unexpected increase in the rate of melting of sea ice to such an extent that one hundred voyages were made through the Northwest Passage.

The nations' representatives gathered on Bali with hopes of finding a roadmap toward a new agreement. As the conference opened, Australia's new prime minister, Kevin Rudd, signed the Kyoto Protocol, limiting his country's greenhouse gas emissions. That act earned a standing ovation in Bali, and focused attention on the failure of the United States to sign the protocol. It was the only developed nation not to have done so. The U.S. organization the Union of Concerned Scientists accused the Bush administration of obstructing progress on climate change. The senior U.S. negotiator denied that his country was blocking progress and added that the true picture was that his country had chosen a different course of action. From earlier statements it is clear that the U.S. position was the same as that of the many others who felt it was wrong to have singled out developed countries for action rather than all countries.

There was a tendency during the conference by Saudi Arabia and China to change the text in order to play down the consequences of global warming and climate change. Developing nations, however, the ones that will have to cope with the consequences of climate change, were much more forceful than at previous meetings in opposing these efforts. As they felt more and more threatened by the sea and storms, they insisted that the final report be quite clear about taking specific action, not just, as one of them put it, documenting general agreement on ideals. About one future uncertainty in particular they wanted great clarity: the future melting of ice sheets in Greenland and western Antarctica. In earlier reports, the panel's scientists acknowledged that these two places might melt over a period of thousands of years. Now, by contrast, there is evidence to suggest that it could happen much faster, perhaps over a few centuries.

The Bali Roadmap, agreed upon by more than 180 countries at the end of the conference, provided a clear agenda for the key issues to be negotiated by 2009. They included action for adapting to the negative consequences of climate change, ways to reduce greenhouse gas emissions, ways to deploy climate-friendly technologies, and ways to finance both adaptation and mitigation measures. The UN secretary-general

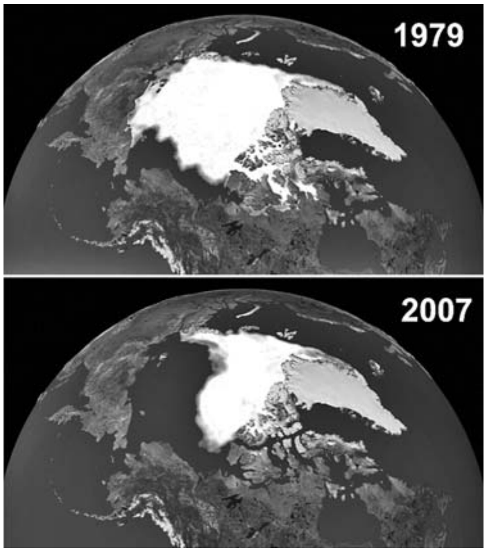
Ban Ki-moon expressed his pleasure at the outcomes: launching negotiations on a global climate change agreement, agreeing to an agenda for the negotiations, and agreeing to complete them by 2009. The World Wild Fund for Nature, a global environmental conservation organization, said that the Bali Roadmap fell short because it was weak on substance. Greenpeace also said that the climate agreement has been stripped of the emission reduction targets that scientific opinion demands.

The media focused on the quantitative recommendations of the IPCC and the armwrestling over the reference to these recommended targets in the roadmap. This is an important issue, but that focus can be misleading. From the organizers' point of view, the conference was not a failure. The meeting decided to negotiate an agreement to replace Kyoto. The stated objective is to adopt a new agreement in 2009, at the fifteenth conference of the parties in Copenhagen. It will establish a long-term global goal and urge the implementation of the convention's recommendations. These will require deep cuts in global emissions of greenhouse gases. The Bali Roadmap was signed by all of the delegations. A careful reading shows that the compromise with the United States mainly involved the following point: there is no direct reference to the numerical recommendations of the IPCC figures in the text, only an indirect reference in the preamble.

THE IPCC'S SYNTHESIS REPORT

The IPCC's Synthesis Report summarizes all of the IPCC's findings since its inception in 1998. It begins with observed changes in climate and their effects. Warming of the world's climate system is no longer in doubt. It is widely evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea levels. Eleven of the years from 1995 to 2006 rank among the 12 warmest years in the record of global surface temperatures since 1850. The one-hundred-year linear trend in temperature between the years 1906 and 2005 is larger than the corresponding trend between the years 1901 and 2000. Temperature increases are widespread all over the globe and are greater at higher northern latitudes.

Land regions have warmed faster than the oceans. Rising sea level is consistent with warming. Global average sea level has risen since 1961 at an average rate of more than half an inch and since 1963 slightly more, aided by contributions from thermal expansion, melting glaciers, melting ice caps, and melting polar ice. Whether the faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear. Observed decreases in snow and ice extent are also consistent with warming. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.5 percent per



Satellite images of Arctic ice coverage at the same time of year in 1979 and 2007. (NASA)

decade, with larger decreases in summer of three times that rate per decade.

Mountain glaciers and snow cover on average have declined in both hemispheres. From 1900 to 2005, precipitation increased significantly in eastern parts of North and South America, in northern Europe, and in northern and central Asia, but declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia. Globally, the area affected by drought has likely increased since the 1970s. It is very likely that over the past 50 years, cold days, cold nights, and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. It is likely that heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975, the incidence of extreme high sea level has increased worldwide. There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones.

It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970. Average northern hemisphere temperatures during the second half of the twentieth century were very likely higher than during any other 50-year period in the last five hundred years, and likely the highest in at least the past 1,300 years. Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. Changes in snow, ice, and frozen ground have increased the number and size of glacial lakes, increased ground instability in mountain and other permafrost regions, and led to changes in

Plastic Bags and the Oceans

You can still see them at checkout counters at stores, the once-thought-great solution to efficiency in packaging. The trouble is that plastics do not degrade, ever. They go into the garbage and, in due course, end up in the ocean, where they stay, largely invisible. After some time they become part of the food chain. The tiny creatures known as zooplankton are at the bottom of the ocean's food chain, and pieces of plastic have been found in their bodies. This means that the whole food chain is affected. Several food stores have already decided to eliminate plastic bags and replace them with biodegradable ones. In the process of so doing, one store reported that it saved thousands of dollars from not having to buy plastic bags.

some Arctic and Antarctic ecosystems. There is high confidence that some hydrological systems have also been affected through increased runoff and earlier spring peak discharge in many glaciers and snow-fed rivers and through effects on thermal structure and water quality of warming rivers and lakes.

In terrestrial ecosystems, earlier timing of spring events and poleward and upward shifts in plant and animal ranges are with very high confidence linked to recent warming. In some marine and freshwater systems, shifts in ranges and changes in algal, plankton, and fish abundance are likely associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels, and circulation. Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89 percent are consistent with the direction of change expected as a response to warming. However, there is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries.

There is medium confidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. These include effects of temperature increases on agricultural and forestry management at northern hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests. Some aspects of human health, such as heat-related mortality in Europe, changes in infectious disease vectors in some areas, and allergenic pollen in northern hemisphere high and mid-latitudes are evident, as are some human activities in the Arctic and in lower-elevation alpine areas,

The second part of the Synthesis Report dealt with causes of change. Changes in atmospheric concentrations of greenhouse gases and aerosols, land cover, and solar radiation all alter the energy balance of the climate system. Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70 percent between 1970 and 2004. Carbon dioxide is the most important anthropogenic greenhouse gas. Its annual emissions grew by about 80 percent between 1970 and 2004. The long-term trend of declining carbon dioxide emissions per unit of energy supplied reversed after 2000. Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly as a result of human activities since 1750, and now far exceed pre-industrial values, as determined from ice cores that span many thousands of years.

Atmospheric concentrations of carbon dioxide and other greenhouse gases exceed by far the natural range over the last 650,000 years. Global increases in carbon dioxide concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in other greenhouse gases is predominantly due to agriculture and fossil fuel use. The increase in nitrates is primarily due to agriculture. There is very high confidence that the net effect of human activities since 1750 has been one of warming. Most of the observed increase in global average temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica. During the past 50 years, the sum of solar and volcanic influences would likely have produced cooling. Observed patterns of warming and their changes are simulated only by models that include anthropogenic influences. Difficulties remain in simulating and attributing observed temperature changes at smaller than continental scales.

The third part of the Synthesis Report dealt with outcomes. There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global greenhouse gas emissions will continue to grow over the next few decades. The IPCC Special Report on Emissions Scenarios projects an increase of global greenhouse gas emissions by 25 to 90 percent between 2000 and 2030, with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. More recent scenarios without additional emissions mitigation are comparable in range. Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the twenty-first century that would very likely be larger than those observed during the twentieth century. For the next two decades, a warming of about 0.5°F per decade is projected for a series of emissions scenarios.

Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.4°F per decade would be expected. Temperature projections increasingly depend on specific emissions scenarios. The range of projections is broadly consistent, but uncertainties and upper ranges for temperature are larger mainly because the broader range of available models suggests stronger climate–carbon cycle feedbacks. Warming reduces terrestrial and ocean uptake of atmospheric carbon dioxide, increasing the fraction of anthropogenic emissions remaining in the atmosphere. The strength of this feedback effect varies markedly among models. Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate.

The Survival of Coral Reefs

About one third of the total amount of carbon dioxide reaching the atmosphere is absorbed back into the oceans. Although this is a valuable mitigating factor in climate change, too much carbon dioxide is a pollutant in the ocean. If the amount of carbon dioxide reaching the atmosphere continues to increase in the future from the present 380 parts per million (ppm) to, say, 500 ppm, because humans failed to reduce these emissions, the world's population of coral polyps would be wiped out, because the acid in the water would prevent the calcification of coral and thus ensure premature death. Coral reefs are formed over long periods of time from the limestone skeletons of dead polyps. The life cycle of the coral involves removing calcium from the sea to build a skeleton. Limestone is then added to the lower parts of their bodies. When they die, their whole skeleton is added to the reef with which they were associated

CHAPTER 6

The U.S. Government and Climate Change

The U.S. government was very slow to accept the findings of the world's best scientists regarding global warming and climate change. Read this letter from the U.S. President to members of the Senate in the U.S. Congress. It was dated March 13, 2001. Then read the statements that follow:

> Thank you for your letter of March 6, 2001, asking for the Administration's views on global climate change, in particular the Kyoto Protocol and efforts to regulate carbon dioxide under the Clean Air Act. My Administration takes the issue of global climate change very seriously.
>
> As you know, I oppose the Kyoto Protocol because it exempts 80 percent of the world, including major population centers such as China and India, from compliance, and would cause serious harm to the U.S. economy. The Senate's vote, 95–0, shows that there is a clear consensus that the Kyoto Protocol is an unfair and ineffective means of addressing global climate change concerns.
>
> As you also know, I support a comprehensive and balanced national energy policy that takes into account the importance of improving air quality. Consistent with this balanced approach, I intend to work with the Congress on a multi-pollutant strategy to require power plants to reduce emissions of sulfur dioxide, nitrogen oxides, and mercury. Any such strategy would include phasing in reductions over a reasonable period of time, providing regulatory certainty, and offering market-based incentives to help industry meet the targets. I do not believe, however, that the government should impose on power plants mandatory emissions reductions for carbon dioxide, which is not a "pollutant" under the Clean Air Act.
>
> A recently released Department of Energy Report, "Analysis of Strategies for Reducing Multiple Emissions from Power Plants," concluded that including caps on carbon dioxide emissions as part of a multiple emissions strategy would lead to an even more dramatic shift from coal to natural gas for electric power generation and significantly higher electricity prices compared to scenarios in which only sulfur dioxide and nitrogen oxides were reduced.
>
> This is important new information that warrants a reevaluation, especially at a time of rising energy prices and a serious energy shortage. Coal generates more than half of America's electricity

supply. At a time when California has already experienced energy shortages, and other Western states are worried about price and availability of energy this summer, we must be very careful not to take actions that could harm consumers. This is especially true given the incomplete state of scientific knowledge of the causes of, and solutions to, global climate change and the lack of commercially available technologies for removing and storing carbon dioxide.

Consistent with these concerns, we will continue to fully examine global climate change issues—including the science, technologies, market-based systems, and innovative options for addressing concentrations of greenhouse gases in the atmosphere. I am very optimistic that, with the proper focus and working with our friends and allies, we will be able to develop technologies, market incentives, and other creative ways to address global climate change.

I look forward to working with you and others to address global climate change issues in the context of a national energy policy that protects our environment, consumers, and economy.

Sincerely,
George W. Bush

VARIED REACTIONS TO THE U.S. GOVERNMENT'S POSITION

This letter was written in response to a request from the Senate asking for a policy statement on the U.S. government's position on global warming and climate change. The letter was written at the start of President George W. Bush's first term, and it contains four firm assertions, representing positions that remained substantially unchanged throughout his two terms as president: we must preserve our economic strength and care for the interests of consumers, because of the incomplete state of scientific knowledge of the causes of, and solutions to, global climate change, and the lack of commercially available technologies for removing and storing carbon dioxide. The third of these assertions, "the incomplete state of scientific knowledge of the causes," was an outright rejection of the position taken by the world's scientists. In June 1988, the same year that the World Meteorological Association and the UN formed the IPCC, James Hansen, director of the NASA Goddard Institute for Space Studies, warned a U.S. Senate committee that the planet was already warming as a result of human activity. Ten years later, in 1998, he returned to the same Senate committee with a more immediate warning: safe levels of atmospheric carbon dioxide have already been exceeded, and we are at a planetary emergency.

Under the Bush administration, the White House distanced itself from the consensus among the world's scientists that humans are causing climate changes. In 2002, the U.S. Environmental Protection Agency (EPA) issued a detailed report in which it was acknowledged that human activities are responsible for global warming. However, the president rejected his agency's report as "the product of a bureaucracy." He went on to say that he did not support the Kyoto Protocol, again for the same reasons as before: it is not good for consumers, and it is harmful to the economy. He went on to say that the policy of the U.S. government will be to tackle environmental problems as they arise, through technology. The earlier position, questioning the validity of scientific opinion as to the causes of global warming, was then reiterated, and a further qualification was added, namely, that whatever scientific findings do emerge, they must be differentiated on the basis of relevance to different regions of the world.

It is important to include here, because of the president's insistence that the global consensus was wrong, the additional details and warnings that formed part of the report from the EPA. U.S. greenhouse gas emissions were expected to increase by 43 percent between 2000 and 2020 despite his administration's policy to encourage voluntary reductions in greenhouse gas emissions and investigate the use of technology to store or sequester excess carbon dioxide. The rise in emissions would disrupt rain and snowfall patterns, reducing freshwater supplies in reservoirs fed by melting snow. Dangerous heat waves would strike with increasing frequency in urban centers, and coastal wetlands, homes, and businesses might be inundated by rising sea levels. Some natural habitats could disappear completely. A few ecosystems, such as alpine meadows in the Rocky Mountains and some barrier islands, would be likely to disappear entirely in some areas. Other ecosystems, such as southeastern forests, are likely to experience major species shifts or break up into a mosaic of grasslands, woodlands, and forests. Some of these changes have already begun, and little can be done to stop them. Some of the goods and services lost through the disappearance or fragmentation of natural ecosystems are likely to be costly or impossible to replace.

Despite this dire prognosis, the EPA report did not recommend that the United States adopt the emissions reductions required by the Kyoto Protocol, which President Bush had already abandoned. To the contrary,

The Kyoto Protocol

The protocol (or the rules) on climate change was signed in Kyoto, Japan. It was the best arrangement the different governments could make because there was no single plan that pleased everyone. Those who met at Kyoto on behalf of the United Nations knew that they had to get some international agreement, because the problem of greenhouse gases affected every part of the world. There were limitations in the agreement simply because many countries were unwilling to make decisions on how much of the greenhouse gas emissions from their countries were to be changed within a given period of time. There was no agreement about reducing emissions from the two most populous countries in the world, India and China. The world's largest emitter, the United States, refused to agree to actions that would require reducing the amount of greenhouse gases it produced within a given timeframe.

many of the projected effects of global warming in the United States could be positive. Global warming will likely increase agricultural productivity in many regions by boosting rainfall in regions that grow cotton, citrus fruit, sorghum, and soybeans. Based on studies to date, unless there is inadequate or poorly distributed precipitation, the net effects of climate change on the agricultural segments of the U.S. economy over the twenty-first century are generally projected to be positive. Humans need to work on adapting to those climate changes that the report sees as being inevitable, rather than spending money and other resources on futile attempts to prevent the global warming caused by decades of greenhouse gas emissions. Because of the momentum in the climate system and natural climate variability, adapting to a changing climate is inevitable. The question is whether we adapt poorly or well, and one suggested tactic to help humans adapt well includes increased availability of air conditioning to reduce the health impacts of heat waves.

IMPLEMENTING AND REPLACING THE KYOTO PROTOCOL

Many nations, in sharp contrast to the position taken by the United States, accepted the recommended proactive actions in the Kyoto Protocol. They included Japan, Russia, and the European Union. Together these three constituted three of the four places that emit the largest volumes of carbon dioxide, the fourth being the United States. In summary, the protocol requires at least 55 nations to accept the plan and that those nations include the countries that emit 55 percent or more of the world's emissions of carbon dioxide gas. All of these countries have committed to reducing their carbon dioxide emissions to an average of 5.2 percent below their 1990 levels in the course of the period from 2008 to 2012, the year in which the Kyoto Protocol ends.

A meeting was held in Bali, Indonesia, in 2007, to draw up a roadmap for the conference in 2009, in Copenhagen, at which the successor to Kyoto would be finalized. The 2009 conference is to establish a long-term global goal and to urge all nations to implement the conference's recommendations. A very large number of countries attended the Bali conference, and the United States, for the first time, committed itself to be part of the new agreement in 2009. Although considerations in relation to consumer needs and economic growth were major aspects of the U.S. rejection of Kyoto, the most important reason was the feature of Kyoto that placed all responsibility for countering the buildup of greenhouse gases on the industrial nations. President Bush insisted that every nation had to be involved if the plan were to work. He knew that China, despite its long history of being a developing country, was now a dominant developed nation, one that was emitting as much greenhouse gases as most of the industrial countries. Agreement was reached before the Bali conference ended that the new plan, in 2009, would involve every nation.

Protest by environmental activists during the UN Indonesian Conference of 2007, at which a replacement for the Kyoto Protocol was planned in anticipation of the UN Conference of 2009 in Denmark. (AP/Wide World Photos)

In the year following the Bali Conference, the Group of Eight developed nations met in Japan and, among their various deliberations, a good deal of time and discussion dealt with the challenge of global warming and climate change. President Bush went one step further during this conference, adding to his Bali commitment that he would be willing to seriously consider a 50 percent cut in greenhouse gas emissions by 2050. Representatives from China and India had been invited to attend the G8 conference as observers in order to talk further within a smaller group about their responsibilities in cutting back on carbon dioxide emissions. They both refused to commit to any fixed reductions, in spite of the U.S. concession, insisting that they had to see some action along this line on the part of the older industrial nations before making firm commitments. The G8 conference ended with only a vague reference in their final

The Carbon Tax

The carbon tax is an idea that many organizations have advanced as the best way to reduce greenhouse gas emissions. It works this way: a business or factory pays a sum of money to its government every year on the basis of the amount of greenhouse gases it sent into the atmosphere in the year. The government uses this money in two ways: first, to reward businesses that had very low emissions; and second, to develop new forms of energy that would not pollute the atmosphere. Businesses and factories that undertake to develop and use green energy sources have the opportunity to make double gains instead of having to pay. They are rewarded for developing new green sources and they pay less because they are emitting less.

declaration to a long-term goal for reducing global emissions and a pledge for rich and poor countries to work together. Only a few of the less-industrialized nations, including Indonesia, Australia, and South Korea, agreed to back the 50 percent by 2050 reduction target. A lot of work remains to be done before the nations meet in 2009 in Copenhagen.

REACTIONS TO THE NEW KYOTO PLAN

On his return to Washington, President Bush said that agreement had been reached with all the G8 members to provide an annual sum of $10 billion for technical research and development on greenhouse gases. On the whole, it seemed that an enormous amount of movement had occurred in the opinions of a man who previously had questioned the science on global warming, who was opposed to international treaties, and who rejected international targets. The events of the days immediately after President Bush's return revealed a very different picture, a return to the earlier positions of taking no action on greenhouse gases because such a move would cripple the economy. The economy, as everyone in the United States knew, was in worse shape in July that it had been earlier in the year, so the decision to give top priority to economic matters was more than a reversion to earlier positions; it was a clear statement of priorities, particularly a reminder that, in the United States, nothing ranks higher than economic strength. Within days of the president's return, the EPA was informed by the president that it was ill-suited for dealing with global warming problems. Yet the Supreme Court had ruled that the EPA was the appropriate agency to deal with them.

It seems that Congress was equally overwhelmed with the growing economic downturn, and it decided to ignore the dangers from greenhouse gases. Supporters of regulating greenhouse gases could get only 48 votes in the one-hundred-member Senate. Several hearings on the problem had been held, but no votes were taken on any bill addressing it. Both of the presidential candidates, Republican John McCain and Democrat Barack Obama, endorsed variations of the approach rejected by the Senate. The EPA had earlier laid out in some detail how to reduce greenhouse gases from cars, ships, trains, power plants, factories, and refineries, but, presumably on orders from above, the EPA director described the proposals drafted by his staff as putting a square peg into a round hole. He then added that moving forward on such a basis would be irresponsible. Attorneys general from several states were appalled at this outcome and called the administration's findings inadequate. Typical of the reactions from states was this one from the attorney general of Massachusetts: "the time has long passed for open-ended pondering; what we need now is action."

The rejection of the EPA's work raised tensions between the administration in Washington and different scientific organizations over responses to global warming. The president kept on insisting that the nation was experiencing extraordinary economic pressures and hence

Global warming protest, Washington, D.C., 2007. (iStockPhoto.com)

all efforts must be focused on these rather than on the impacts of global warming. The president of Clean Air Watch, an environmental advocacy group, accused the government of stalling all efforts directed toward action. He added that it seemed the White House was ignoring the Supreme Court. It became clear to observers that the president had decided to do nothing new on global warming during the remaining days of his time as president and, in fact, to leave all further action to his successor. The EPA's response to this situation was to solicit public comment on the threat of global warming to both human health and welfare, and to collect this information over the following eight months.

Criticism of what finally emerged as a do-nothing policy arrived from many media centers. It seemed, they all pointed out, that to defer compliance with the Supreme Court's demand, the government had walked a strange policy path, editing its officials' congressional testimony, refusing to read documents prepared by career employees, requesting changes in computer models to lower estimates of the benefits of curbing carbon dioxide, and editing estimates on fuel-economy standards. It was claimed that officials were unwilling to allow the EPA to state officially that global warming harms human welfare because doing so would legally trigger sweeping regulatory requirements under the Clean Air Act, one of the pillars of U.S. environmental protection policy. Furthermore, it was claimed, new regulations affecting the nation's economy should await the attention of the next administration.

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CHAPTER 7

The Search for Green Energy

With accelerating concern about the amounts of carbon dioxide being emitted from coal and oil sources, a new urgency has arisen in the search for green energy, that is to say, energy that will not add carbon dioxide to the atmosphere. There is little agreement on how quickly the change can be made, or by whom, or by what methods. Energy is probably the highest-cost item in a modern society, and that fact alone compounds the challenge of switching to different sources. Everybody needs it, whether for an electric toothbrush, a light, to heat a cup of coffee, or for getting to work in a car. At the present time, one tenth of the world's total wealth is spent on producing energy, and this figure will soon change to one fifth, simply because huge countries such as India and China are modernizing and demanding more and more energy. Together, these two giants could consume more energy than all of Europe and North America put together. Furthermore, because of increasing demand, the price of oil, and therefore gas for our cars, has steadily increased.

Coal is cheap and plentiful; probably enough lies in the United States to meet all energy demands for the next hundred years. Natural gas and oil are not quite so plentiful, but there are huge amounts available, and new fields all over North America, such as Canada's tar sands, could provide enough oil to replace what North Americans import from the Middle East. The big question that now confronts us is this: is it worthwhile continuing to use coal and oil? Are the economic costs of production less than the increasing carbon tax that will inevitably be imposed on every energy producer that adds carbon dioxide to the atmosphere? People, and especially political leaders, have to be convinced that green energy is, after all, in the longer term, cheaper than coal or oil. The response from coal and oil producers is that they hope to capture carbon dioxide before it reaches the atmosphere and store it underground or in the ocean. Success in those endeavors has yet to be seen. Huge investments are being made by oil companies in attempts to do this, and this is adding substantially to their production costs.

There are many potential green energy sources. The two questions that need to be asked about every one are costs and availability. By availability is meant getting them to the places where they are needed. For example, if production of a particular source is a thousand miles from the nearest big population center, then transmission towers or underground cables have to be installed to bring the energy to market,

Capturing and Isolating Carbon Dioxide

For years scientists and mining engineers have been experimenting with ways of capturing and isolating in underground spaces the carbon dioxide that normally goes into the atmosphere from power stations and industrial operations. In one location in Texas, a team of scientists has been injecting carbon dioxide into an aquifer above an old oil reservoir thousands of feet beneath the ground. They hope that the carbon dioxide will become a heavy liquid at these depths and stay there. A new approach to the problem was reported in 2008 in the Proceedings of the National Academy of Sciences. The author of the report, David Goldberg, a geophysicist from Columbia University, proposed injecting liquefied carbon dioxide into the Juan De Fuca tectonic plate that lies offshore from Washington State and more than a mile below sea level. Goldberg's plan, although very expensive and requiring decades of time both to engineer and to allow the gas to react with the plate's basalt, would have the carbon end up as a solid carbonate, where it would stay as part of the plate.

and these costs could outweigh the value of the energy. Compare, as an illustration of this, wind energy and nuclear energy. The former, as will be shown later in this chapter, can be installed in a thousand locations, with each installation producing small quantities but, because the energy can be used locally, it does not incur transmission costs. A nuclear power plant, on the other hand, has to be a very big producer because of the high cost of building it. As a result, it has to be close to big population centers, and often this is resented by communities because of failures and leaks in earlier nuclear plants. Thus, if this were a problem in a particular place, the installation would have to be built elsewhere and the energy brought to market by transmission cables at great cost.

ENERGY FROM THE WIND AND SUN

Two European countries have succeeded in making wind energy economically viable. They are Spain and Denmark, with Spain being Europe's leading producer. Denmark, although its total production is small, has been using this energy source for decades, and because of its years of experience it has become a producer of wind turbines for the world. It seems that Denmark is the first producer that has not only make wind power serve local needs but, at the same time, has created a new industry that is adding wealth to the country. Turbine design is quite a sophisticated business; the blades have to be able to deflect when very high winds come along and then flip back to normal afterward so as to maintain a continuous output of energy. Worldwide, energy production from wind is increasing daily, presently amounting to about 1 percent of the total requirements of the United States. This is expected to rise to 15 percent by 2020. One vice president of General Electric is quite convinced that half of all the new energy produced in the United States will come from wind power by the year 2012.

Copenhagen, Denmark, wind farm, 2009. Denmark leads the world in this form of green energy. (Tedholt/Dreamstime.com)

Supporters of wind energy point out that improved marketing techniques and linking the outputs of wind generators to national energy grids would greatly reduce their costs. On improved marketing techniques, they say that users of energy could be persuaded to accept certain times and days for using wind energy on the basis of lower costs for these times. With regard to linking with the national energy grid, wind-generated energy could be made available anywhere. So great are the global sources of wind energy that the World Energy Council estimates that one tenth of the total, if it were developed, would be sufficient to meet the entire world's demand for electricity. Probably the single biggest reserve of wind energy is located in the ten-mile-high jet streams that cross the North American continent continually from west to east. At the present time, obtaining energy from them is a very distant prospect because of the difficulties of

Denmark's Energy Resources

Stretching eastward from Denmark toward its neighbor Sweden, across the ocean that lies between them, stands a long line of wind turbines. Fortunately, the sea is quite shallow in this area, so it was comparatively easy for the Danish government to install these devices. They have been operating for a long time, and they produce 20 percent of the country's energy needs. Because of their long history of developing this source of energy, Denmark has become the country to which other nations look as they seek to use wind power in their own countries. As a result, a huge manufacturing industry has sprung up as the country produces and sells wind turbines and blades. Between 1997 and 2007, this wind industry added 13,000 new jobs to Denmark's workforce.

transmitting their power to consumers. In spite of that, many researchers are trying to find a method of transmitting energy from this source.

Solar energy is much better known than wind as the ideal energy alternative. It represents the direct, rather than the indirect, use of the sun's energy. Even in northern latitudes and in wet climates, solar panels are in evidence as people aim to reduce their energy costs and, at the same time, be responsible environmentalists. Until very recently, the costs of these solar panels were prohibitive, but, thanks to researchers such as Emanuel Sachs of MIT, the costs are coming down, by as much as 60 percent since 1990. Innovations in solar technology have brought the cost of a watt of solar energy down to the production price of a watt from a coal-fired power station, and without the addition of carbon dioxide emissions. Two solar panel manufacturers claim that the panels they now make can be used as material for the roofs of homes rather than as additions to existing roofs. Their designs are a response to the governor of California's request in 2006 that the state have a million solar roofs as soon as possible.

NUCLEAR ENERGY

Nuclear energy is no friend of many environmentalists because of the history of accidents such as those at Chernobyl and at Three Mile Island, and even more because of the bombing in World War Two, but all of that was before the era of greenhouse gases and the dire future they represent. Now everyone knows that nuclear energy is the one proven, carbon dioxide–free source of energy that is big enough to fill all demands. It already produces one seventh of the world's electricity. In Japan and in France, as well as in some other countries, it is the main source of energy. Today a nuclear power generator can produce electricity for 6.5 cents a kilowatt, not much more than coal at 5 cents, and without producing any greenhouse gases. In the United States, there are plans for building 14 new reactors after 20 years or more of total neglect. The big problem with nuclear energy as the answer to green energy is twofold: cost and the time involved in construction.

A bigger problem relates to the developing world, which, for now, includes China and India. Any attempt to reduce greenhouse gases must involve all the world's nations, especially these very big ones that are fast becoming developed countries. Motivation, however, to shift to nuclear energy among those countries seems to be lacking. For poor countries or poorer parts of countries, the pivotal problem is the allocation of scarce resources. Their financial authorities cannot easily justify subsidizing nuclear energy at the expense of more pressing needs in health, education, and poverty reduction. Furthermore, many have abundant non-nuclear energy alternatives. Cleaner coal-burning technologies would reduce emissions not only of greenhouse gases but

French nuclear energy plant. Most of this country's energy comes from nuclear power. (Smithore/ Dreamstime.com)

also of soot and other by-products that cause local and regional pollution. They are more attractive targets for national attention.

Currently, 435 nuclear reactors operate around the world, with an electrical generating capacity that provides for 17 percent of the world's electricity. Various analysts had optimistically foreseen a steep rise in those numbers. For instance, a 2003 interdisciplinary study by the Massachusetts Institute of Technology outlined a scenario of nuclear growth that would ensure a tripling of nuclear generation by 2050. The contribution of the developing nations, it was assumed, would soar to a third of the whole. No economic modeling figured into that estimate; the analysts assumed that the developing nations would aim for the same share of electricity from nuclear power that the rest of the world would adopt. Further practical considerations added to the reluctance of many developing countries to get into a nuclear energy program. One of these related to their electrical grids: Those with capacities of less than 10 gigawatts do not work properly with nuclear reactors.

HYDROELECTRIC AND GEOTHERMAL GREEN ENERGY

There are numerous potential sources of green energy beyond wind, sun, and nuclear. These three are given first consideration by many people because they are already available, or could soon be available, all over the world, and the economics and environmental risks of using them have been tested. It is essential that ideas about green energy apply to any and every nation because greenhouse gases do not pick and choose where they go in the atmosphere; every person is affected by them, and every nation has to do what it can to reduce its amounts in the air we breathe. Hydroelectric power is a green source of energy, and countries that have the environmental conditions to develop this source have been making use of it. In the United States, 10 percent of the nation's energy requirements is provided by hydroelectricity, and in Canada, because of its large water resources, most of the nation's energy comes from hydroelectricity.

There are many countries around the world that could be using hydroelectricity instead of fossil fuels, and some do take advantage of this source. However, there are just as many countries that could but have not fully implemented their hydroelectric power options: worldwide, only about one third of the economical hydroelectric potential has been tapped so far, and in sub-Saharan Africa, that figure is far below one third. It is a story similar to the poor rural regions in Latin America, India, and China.

Hydroelectricity is usually thought about in terms of dams and turbines on freshwater lakes or rivers within countries, but this overlooks the enormous potential for energy generation of the world's oceans. All over the Western world, scientists have been experimenting for decades on ways of generating electricity from the up-and-down wave action of waves, and also from the changing levels of coastal waters as tides come and go. Although problems persist related to how to collect and transport energy from such sources, the mechanical energy that theoretically can always be translated into hydroelectricity is always there.

For centuries, all across the eastern part of North America, water wheels have been employed to grind grains for food for humans and animals. Streams were dammed in order to get the higher elevations for water that would give it the necessary kinetic power to move the water wheel. In modern times, the United States and Canada learned to use the enormous kinetic power of Niagara Falls to generate enough electricity to meet the needs of millions of people. Many streams are now being re-examined around the world to see if, even with all the energy demands of a modern society, they could be developed to meet the needs of small communities. Similar developments are taking place in oceanic locations. In Canada's Bay of Fundy, about 300 miles north of Boston, twice every day the bay fills and empties one hundred billion tons of water, creating the highest tides in the world. Water rises higher than 50 feet in the course of the tide; it's a source of power comparable to Niagara's, and it is likely that North America's first tidal hydroelectric power station will very soon be in operation there.

Geothermal is an energy source that, theoretically, is available anywhere in the world, simply because the temperature of the earth's surface gets warmer and warmer from the surface down. Not every place is easily exploited, however, in order to make use of this

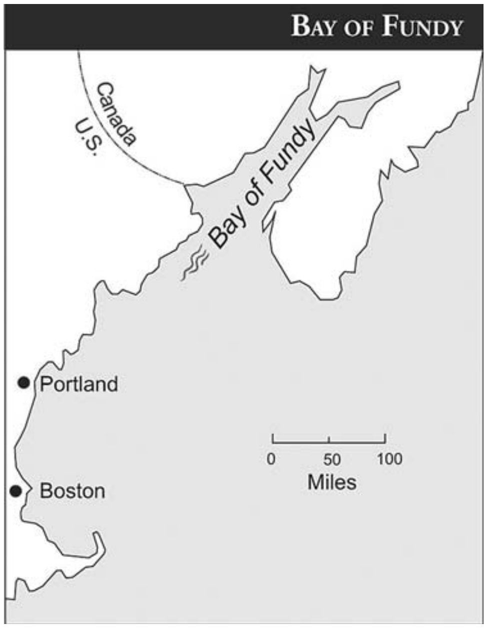

Figure 7-1 The Bay of Fundy has the highest tides of any tidal area on earth. Waters sweep into this bay twice a day, often rising as high as 50 feet. The volume of water involved in this twice-daily tide is greater than the total of all the earth's fresh water rivers. (NASA/ABC-CLIO)

information. The type of surface rock and the depth to which one would have to drill to get a big temperature difference could be prohibitive for some locations. The world's total from this kind of energy source is enough to provide for the total energy needs of 60 million people. Hawaii, because of its volcanic nature, is one place that is able to make use of geothermal energy. It has one plant that uses this source. California is another. It has 33 geothermal plants. These and a few in other places together provide less than 1 percent of the nation's needs so, overall, geothermal energy will not be a big contributor to U.S. needs. It is a very different story in the island state of Iceland. Because of its special geological situation, sitting on top of the mid-Atlantic Ridge, from which magma and hot water emerges continually, geothermal energy is extensively used.

This energy is so inexpensive that in the wintertime, some pavement in the cities of Reykjavik and Akureyri are heated. There are five major geothermal power plants. They produce about a quarter of the country's electricity. In addition, geothermal heating meets the heating and hot water requirements for 90 percent of the nation's buildings. Overall, the following are the proportions of different energy sources used in Iceland: a quarter from geothermal, almost three quarters from hydroelectricity, and approximately one tenth from fossil fuels. It would be nice if this were the case with the other nations of the world.

There is one more thing that needs to be said about the problem of changing from fossil fuels to green energy. We all know that this must happen as soon as possible, but we also know that habits change slowly and people are reluctant to change their ways even when they know they must. In 1850, most of our energy was obtained from wood. It took another 50 years before we made the big switch to coal. Then, in the second half of the twentieth century, as hydroelectricity and natural gas became plentiful, coal began to fade quite a lot from its former dominant position. Yet even by 2000, coal still provided one fifth of the nation's energy, and very little progress had been made on alternative green energy sources. Much patience is needed in the quest for green energy.

CHAPTER 8

The Future: Climate Change Challenges

In Volume One of this series of books, we saw that the present time, from a geological point of view, is regarded as an interglacial phase, with a certainty that another ice age will come again in the future. What about the future of weather and climate? Will they too be a repeat of what has happened in the past?

This is a bigger question than global warming and climate change, but it includes both of these. In one sense, the future will certainly be a repeat of what happened in the past, because there are well-known cycles that keep repeating, some over short periods of time, others much more widely spaced in time. The unknown extra in the future, in any future, is the growth in population and the effects that it will have on land use, on the atmosphere, and on urban populations. It is clear from recent developments that most increases in population will occur in urban areas, and many of these big urban areas will be in places that are known to carry high-risk potential for storms or volcanic eruptions, a direct consequence of past preferences and present choices. Thus, the foreseeable future is likely to have many disasters, some involving the deaths of tens of thousands of people.

Natural meteorological events that ended in disasters as a result of storms, or because of volcanic eruptions, have always been part of the earth's history. Fortunately, the worst eruptions arrived before the times of modern human history, but the fact that they did happen, again and again, over the past five hundred million years, means that they are likely to recur. Less frequent over past times have been what are known as near-earth objects (NEOs), asteroids that circle the sun just as the earth does but also, like the earth, occasionally change their orbits slightly. One of these severely damaged the earth about 65 million years ago, causing a mass extinction of different species. Disasters from NEOs have always been extremely rare, and they can be eliminated from discussion about the future for this reason and also because we are now able to detect them decades or even centuries before they strike, and so can take preventive action; this is because their behavior, once they change their orbits, makes them circle the earth for many years at great distances. During this time, their locations are continuously recorded before they reach the earth.

The predictions of the effects in the future from global warming and climate change are varied. They depend a lot on what action is taken by countries around the world to slow down the accumulation of greenhouse gases. If nothing is done, then, by the end of this century, the IPCC's estimated increase of 5°F for the average global temperature is likely to be the situation at that time, something that has not been known on earth for many thousands of years. By that time, the population of the United States would be more than a billion, and the complications associated with such a big increase would be an added challenge. There is an additional risk associated with a huge alteration in temperature over a short period of time: the danger of reaching a threshold beyond which things cannot be put back to an earlier state however much effort is put into it. This is related to the chaotic nature of the atmosphere because of the many variables involved and the possibility that one troublesome variable can create a permanent change in the system.

Temperature increases are normally expected to lead to extremes of warmth, but these extremes are often influenced by other meteorological factors such as changes in wind patterns or loss of the amount of evaporation that is counted on to provide cooling. As a result, places get hit with extraordinary heat waves that go beyond anything previously known, such as the one that overwhelmed France in the summer of 2003, the hottest in five hundred years. There are two other areas of concern that may develop with global warming, but at a rate beyond present expectations: one is the rapid slowing of the Gulf Stream as Arctic water loses its salinity, leading to dramatic lowering of temperatures across northwest Europe; the other is the increasing

Extreme heat wave, Paris, 2003. (AP/Wide World Photos) concern over the possibility that Greenland's huge ice mass might melt within the next hundred years. Until recently, it was assumed that such would not happen before the end of the next century at the earliest. All of these potential future prospects are based on the assumption that no large reduction will occur in the amount of greenhouse gases in the atmosphere. Such is a worst-case scenario, and there are good reasons to expect that substantial reductions will occur in the amounts of carbon dioxide in the atmosphere.

The higher risks that accompany greater populations in small locations, however, will remain. The six million residents of the Galveston Bay region were reminded of this in 2008 when Hurricane Ike struck. The city of Galveston, now with a population of more than 60,000, was substantially destroyed, despite the seawall that was erected after a 1900 disaster, when the city's population was a little more than 40,000. Hurricane Ike swept past Galveston and Galveston Bay and crashed into the Houston metropolitan area, taking out windows on the first 30 floors of high-rise buildings and scattering glass everywhere. One of the tall buildings had a gravel roof, and this was picked up by the wind to form a hailstorm that further damaged all the buildings. Beyond the effects of storms like Ike—and there are, and will be, many of them all over the world—the greatest dangers of the future, as far as climate change is concerned, will always be from volcanic eruptions. The rest of this chapter is therefore devoted to them.

FUTURE VOLCANIC ERUPTIONS

The eruption of Tambora in 1815 was the only eruption since 1800 that reached the level of 7 on the VEI scale. There was another of comparable strength to Tambora, Kuwae Island, which was discovered recently by scientists through ice core evidence from Greenland. That volcano had erupted on one of the islands of today's Pacific nation of Vanuatu in the 1450s. In the future there will be many volcanic eruptions at levels higher than 7, and these supervolcanoes are the ones that must be considered. Much has already been said one this subject in earlier chapters and volumes of this set, enough to tell us that they pose challenges to human survival far beyond anything that has been experienced within the past ten thousand years. Reference was made in Volume One to the Toba eruption of 74,000 years ago, the nearest supervolcano to our time, about which we know a lot through modern investigations of old volcanic deposits all over the world.

To understand the activities of supervolcanoes, we need go no further than the United States. There are three supervolcanoes in the contiguous United States, and there's also the volcanic island chain of Hawaii, whose eruptions receive little attention because they are so quiet, at a VEI of 0 or 1. Hawaii constitutes what is probably the biggest visible series of old volcanic eruptions anywhere on earth. Every one of the chain of islands that constitute the state of Hawaii was built from magma and ash that emerged from what is known as a hot spot on the earth's surface, a place where volcanic rock and ash constantly move upward from great depths, through the great Pacific tectonic plate, toward the surface. From time to time the magma flows out onto the surface, making Hawaii a popular tourist destination. The Pacific plate may be over the hot spot for a few million years before it moves away westward toward Asia. Over these millions of years, however, each of the islands of Hawaii has had ample time to form. The magmatic deposits built up from the seabed. One part of Hawaii, Mauna Kea, on the island of Hawaii, is 13, 799 feet above sea level, but, when measured from seabed, it is 33,465 feet high, almost three quarters of a mile higher than Mount Everest.

The impact on the atmosphere of these frequent slow-flowing eruptions is very great. They interfere with air movements, precipitation, and patterns of air pressure. There is repeated heating of the atmosphere coupled with injections of light particles of ash and cinder, and fragile strands of volcanic glass that stay aloft for a long time. All three of the supervolcanoes in the contiguous United States will certainly erupt again. They are identifiable at the present time by their calderas: the Yellowstone caldera in the park that bears its name; the Long Valley caldera, southeast of Yosemite; and the Valles caldera west of Los Alamos, New Mexico. All three in their last eruptions carried a VEI of 8. The most active of the three are Long Valley and Yellowstone, both of which erupted three times within the past two million years.

MONITORING MOVEMENTS IN YELLOWSTONE'S CALDERA

The study of the Yellowstone supervolcano takes priority at this time. The reason for this is that its recurrence rate has been found to lie between 600,000 and 800,000 years, and its last big eruption happened 640,000 years ago. Many scientists talk about another eruption being overdue. However, that may mean another one in five thousand years or one within the next year. There is another good reason for focusing on Yellowstone in order to understand what is happening now and to plan for action should evidence point to a possible new eruption: if we know what to do with a Yellowstone emergency, we will know what to do with a Long Valley one or one at Valles under similar circumstances. The U.S. government established the Yellowstone Volcano Observatory (YVO) as a partnership among the U.S. Geological Survey (USGS), Yellowstone National Park, and the University of Utah to strengthen the long-term monitoring of volcanic and earthquake activity in the region. There are numerous activities going on all the time in a caldera as active as that of Yellowstone, and it is vital that scientists know what they mean. The following summary of one month's observations at Yellowstone from 2008 gives an indication of the extent and amount of detail associated with this work:

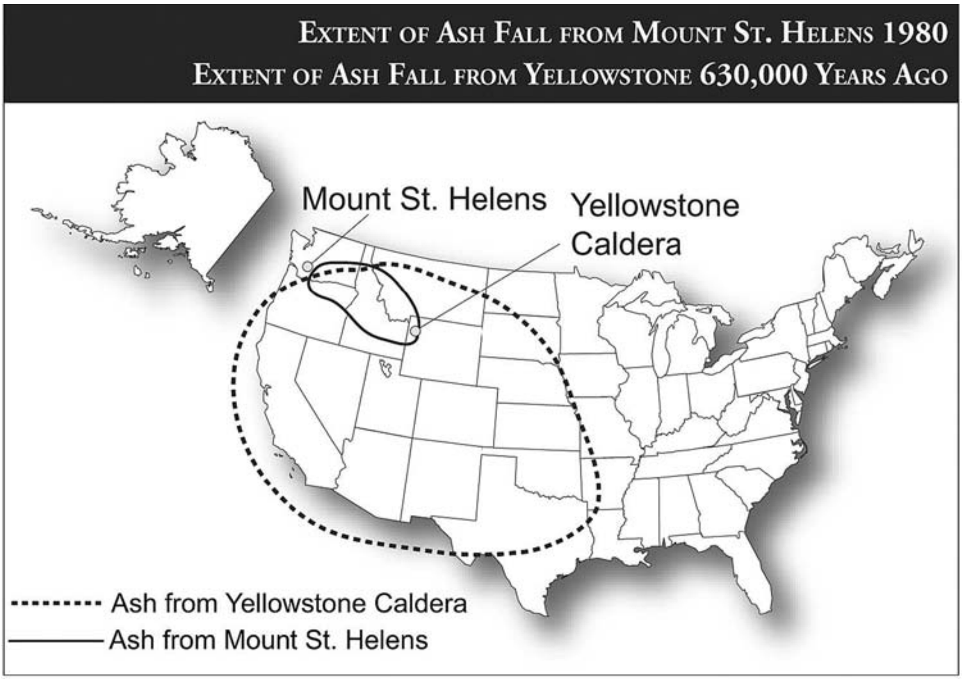

Figure 8-1 Ash fallout locations from the most recent super-eruption of Yellowstone, compared with the amount of ash from the eruption of Mount St. Helens. (ABC-CLIO)

> August 2008: 1. Summary of seismicity. There were 146 earthquakes within the Yellowstone Region, the largest of them having a magnitude of 2.3. It was located 17 miles west northwest of the area defined on maps as West Yellowstone, Montana, and it occurred at 7:31 on August 31. Three swarms of earthquakes occurred during the month of August. The first was a continuation of one that started on July 28 on the Madison Plateau. This swarm continued until August 5 with an additional 52 events of magnitudes approaching 2.1, bringing the total for the swarm to 184 earthquakes. The second swarm, between August 3 and 7, included 28 events and was located 16 miles east northeast of West Yellowstone, Montana with magnitudes up to 1.4. The third swarm on August 7 and 8 included 32 events, and was located 6 miles southeast of West Thumb. Magnitudes in this case ranged up to 2.1. Overall, earthquake activity in the Yellowstone region as a whole is presently at relatively low levels.
>
> 2. Summary of Ground Deformation. Through August 2008 continuous Global Positioning System (GPS) data show that much of the Yellowstone caldera continued moving upward, though at a lower rate than the past several years. The maximum measured ground uplift over the past 48 months is eight inches at the White Lake GPS station. The levels of uplift will continue to be monitored closely by the YVO staff.

New research suggests that how often Old Faithful and other Yellowstone geysers erupt may depend on annual rainfall patterns.

USGS scientist Shaul Hurwitz and colleagues at Stanford and Yellowstone National Park have discovered that changes of water supply to a geyser's underground plumbing may have a large influence on eruption intervals, that is, the time between eruptions. For example, geysers appear to lengthen and shorten their intervals on cycles that mimic annual dry and wet periods. The study results were published in the article "Climate-Induced Variations of Geyser Periodicity in Yellowstone National Park, USA," in the June 2008 issue of the journal *Geology*. Geysers are rare hot springs that periodically erupt bursts of steam and hot water. Yellowstone National Park has more than half of the world's geysers. Old Faithful has remained faithful for at least the past 135 years, showering for appreciative tourists every 50 to 95 minutes on average.

An eruption on the scale we have been considering will have plenty of evidence of its approach because of the scale of such an event compared with the kinds of eruptions we have witnessed in the twentieth century. Humanity, therefore, should not be taken by surprise. Our modern civilization has not suffered from a super eruption, so large-scale volcanic symptoms have not been experienced. By scaling up from smaller events, the time scales and types of super-eruption signals around a particular volcano such as Yellowstone can be understood. These are expected to be signs such as seismic unrest, ground heating and swelling, changes in groundwater temperature and chemistry, and changes in the composition and fluxes of volcanic gases. Many of these changes are ongoing at Yellowstone, where they are measured routinely. Because the damage and disruption from a supervolcano will affect everyone everywhere, it is highly recommended that the work being carried on at Yellowstone be matched by similar efforts at all the other sites of recently active supervolcanoes. Stephen Self, a British expert on volcanic eruptions who visited Alaska in 2006 and gave several lectures to scientists there, said this about any supervolcano: "It would put brakes on life as we know it."

There is another Federal Government Volcano Observatory in Fairbanks, Alaska, somewhat similar to the one at Yellowstone. Its

Geothermal Energy in the United States

Most power plants need steam to generate electricity. The steam rotates a turbine that activates a generator, which produces electricity. Many power plants still use fossil fuels to boil water for steam. Geothermal power plants, however, use steam produced from reservoirs of hot water found a couple of miles or more below the earth's surface. Dry steam power plants draw from underground resources of steam. The steam is piped directly from underground wells to the power plant, where it is directed into a turbine/generator unit. The geysers in Yellowstone National Park in Wyoming, especially the one known as Old Faithful, are one place where geothermal energy is available and is used.

director has been assessing the changes that might accompany a supervolcano eruption in Alaska. A big eruption would pump so much ash and particulates into the air that the whole planet would cool by as much as 18°F. Crops would fail, and sulfur dioxide would eat holes in the ozone. Stephen Self said that there is basically no way to prepare for a super eruption, and it is perhaps foolish to worry about them, but how can a scientist not think of them? Even though they are very, very rare, it's worthwhile to go through the mind exercise of imagining what they might be like. One member of the Alaska Volcano Observatory (AVO), seeking to underline the more horrific aspects of a supervolcano eruption, said that an entire season of crop failures from such an event is entirely possible. There is a message that keeps getting repeated by experts: unprepared, we face communications failure, health care overload and breakdown, food and water contamination and scarcity, livestock deaths, food processing and plant breakdowns, mass starvation, residential cave-ins from volcanic debris, and masses of desperate homeless refugees.

The economic costs of weather-related disasters rose sharply in the second half of the twentieth century, and people living in southern and southeastern states began for the first time to take out adequate insurance to cover against possible hurricane damage. Hurricane Andrew of 1992 was a particularly costly event, about $30 billion, far greater than any previous U.S. hurricane. Insurance covered only half of the costs that were incurred. Although this trend has continued, and levels of insurance have matched costs much more closely after 1992, arranging insurance for a possible supervolcano's arrival is very hard to do, almost impossible in fact, because of the unpredictable elements involved. A small illustration of the type of unexpected outcomes that could arise surfaced at the time of Hurricane Katrina in 2005. Residents had taken out adequate coverage against the most powerful hurricane that might arrive. Their homes, however, were destroyed by flooding, due to the failure of levees, not by the hurricane, according to the position taken by the insurance companies. They therefore failed to pay anything for the disasters.

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CHAPTER 9

Volume Four Review

This Volume Four, in the set of five books on weather and climate, is completely devoted to the problem of global warming and climate change, the most serious environmental problem that humanity has had to face in a very long time. There is now a world consensus among scientists, a rare event because science by its very nature is always open to correction as new evidence appears. This new certainty has come about because of the dangers of continuing to allow greenhouse gases to accumulate. These dangers are acute because the rate of climate change has accelerated, especially in the Arctic. Humanity therefore does not have a lot of time available to stop the accumulation of these gases in the atmosphere.

Each chapter in this volume deals with one aspect of the impact of warming on climate change, beginning with a review of past changes, both warming and cooling ones. Three of the chapter topics are key to an understanding both of the processes at work and their implications for human life. The scientific description of carbon dioxide as the main greenhouse gas in the atmosphere is one of the three; the attitude of the United States toward the problem over the past seven years is a second. This subject is particularly important because the United States sends more greenhouse gases into the atmosphere than any other nation. The third key topic deals with the future, especially the future in the light of volcanic eruptions. These eruptions in the future will be as great as, or greater than, the worst we have encountered over the past 150 years.

IMPORTANT TERMS

Carbon dioxide

Climate change

Albedo

Goddard Institute

Troposphere

Indian Ocean

Infrared energy

Green energy

Carbon storage

IPCC

Pyroclastic

Stratosphere

Thermohaline

NOAA

Caldera

Interglacial period

Geothermal

Nitrous oxide

Scripps Institution

Methane

QUESTIONS

How do greenhouse gases cause global warming?

Is water vapor a greenhouse gas?

Which greenhouse gas is related to automobiles?

Which greenhouse gas is related to dairy farming?

Why does deforestation increase global warming?

When did global warming first become dangerous?

Does global cooling ever happen in modern times?

Can global warming be a good thing for some places?

Do volcanic eruptions slow down global warming?

What would happen if the Gulf Stream stopped?

WEB SITE FOR FURTHER STUDY

The following Web site is designed to provide supplementary information about global warming and climate change: http:\\www.ipcc.ch.

Appendix A: Important Dates in Weather and Climate History

1238 The hottest and driest summer of the millennium in England.

1281 A North Sea storm surge hit the Netherlands in January, flooding large tracts of land and drowning 60,000 people.

1421 Worst North Sea storm surge hit the Netherlands in November, causing the deaths of 100,000 people.

1586 England's first colony in America, established on Roanoke in 1585, had to be abandoned because of severe weather.

1737 The second-deadliest Asian cyclone in recorded history killed 300,000.

1772 The biggest U.S. snowfall (before official records began) occurred in January, when three feet fell in the Washington-Baltimore area. It has been called the Washington-Jefferson snowstorm because it was recorded in both of their diaries.

1780 A hurricane traveled the length of the Windward Islands chain in the Caribbean in October, with St. Lucia and St. Vincent the worst affected, causing the deaths of 24,000 residents.

1791 Cuba was hit in June with a powerful hurricane that took three thousand lives.

1816 The year that was called "the year without a summer." In Savannah, Georgia, the Fourth of July had a high temperature of 46°F. Because it was so cold across the eastern United States, crops were ruined. Snow fell in June, heaviest in New England, with snow drifts of 18 inches. It was the same story in Canada and in Europe. These changes in weather were attributed to the 1815 eruption of Mount Tambora in Indonesia.

1824 In St. Petersburg, Russia, in November, a powerful storm from the Baltic Sea brought a storm surge into the Sea of Finland that swept inland, flooding the Imperial Capital and its palace and drowning 570.

1831 The Caribbean island of Barbados experienced its worst hurricane, which destroyed thousands of buildings and killed 1,500, representing 2 percent of the island's total population

1840 The second-deadliest tornado in U.S. history, Natchez, killed 317.

1870 U.S. Weather Bureau was founded and placed under the office of the Secretary of War.

1881 The third-deadliest Asian cyclone of all time, the Haiphong Typhoon in Vietnam, killed 300,000.

1887 San Francisco's greatest snowfall came in February, with a total of four inches in the downtown area.

1888 The Blizzard of 1888 affected the eastern United States in March. Over four feet of snow fell in the Albany and Troy areas of northeastern New

York state. More than 400 people lost their lives, mainly due to exposure to strong winds and cold temperatures.

1896 The third-deadliest tornado in U.S. history, St. Louis, killed 255.

1899 In February a cold wave caused a massive east coast blizzard and induced bitter cold temperatures across two-thirds of the United States. It was the only occasion that saw true blizzard conditions in the state of Florida.

1900 The second-deadliest Atlantic cyclone in U.S. history, Galveston, hit in September, killing 12,000.

1913 The highest U.S. temperature on record was recorded in Death Valley, California, on July 10, at 134°F.

1913 Several tornadoes hit southwest England and central Wales on October 27.

1921 On September 10, Thrall, Texas, experienced the greatest U.S. 24-hour rainfall on record up to that date. The total was 38.2 inches.

1922 A community in Libya, Africa, on September 13, claimed the world record for the highest temperature of 136.4°F.

1925 The deadliest tornado in U.S. history, Tri-State, killed 689.

1934 On April 12, Mount Washington, New Hampshire, experienced a gust of wind at 231 mph, accepted as the U.S. record for the highest wind speed.

1936 The fourth-deadliest tornado in U.S. history, Tupelo, killed 216.

1940 The U.S. Weather Bureau moved to the U.S. Department of Commerce.

1947 At Snag in the Yukon Territory of Canada, on February 3, the temperature was –81.4°F. This is the lowest on record for all of North America.

1949 In October Guatemala experienced a week of heavy rain from a stalled tropical cyclone. The results were flash floods and mudslides and a death toll of 40,000.

1952 From December 2 to December 6, London, England, experienced its deadliest weather disaster, the great smog that paralyzed the city, stopping all traffic and almost all pedestrian movements, and killed 6,000.

1953 The worst North Sea storm surge of modern times hit the Netherlands and southeastern England on January 31, killing more than 2,000.

1954 In Qazvin, Iran, a violent thunderstorm over the Elburz mountains triggered a flash flood over this city, killing 10,000.

1959 Due to an unusually wet summer monsoon season the Yellow River in northern China overflowed its banks and caused the deaths of an estimated two million people, the highest death toll ever for a meteorological disaster.

1963 The third-deadliest Atlantic cyclone in U.S. history, Flora, hit Haiti and Cuba in October, killing 8,000.

1964 At Oymyakon, Siberia, Russia, in February, the lowest temperature for the northern hemisphere was registered at –96°F

1964 Karachi, Pakistan, in December, experienced a major tropical cyclone that took the lives of 10,000.

1970 The deadliest Asian cyclone of all time, the Great Bhola of Bangladesh, killed 550,000.

1974 A tropical cyclone hit Darwin, Australia, on December 25, killing 65.

1975 The eighth-deadliest Asian cyclone of all time, the Super Typhoon Nina, hit China, killing 170,000.

1983 In Vostok, Antarctica, on July 12, the world's lowest temperature of –138.6°F was recorded.

1992 Hurricane Andrew, the United States' costliest meteorological disaster, swept across Dade County in August with devastating results.

1993 Missouri–Mississippi flooding, greatest U.S. flood of the century.

2005 Hurricane Katrina, costliest storm in U.S. history.

2008 The tenth-deadliest Asian cyclone of all time, Nargis, hit Myanmar, killing 140,000.

U.S. WEATHER AND CLIMATE FROM AD 1000 TO 2000

There are no written records for the first half of this millennium, so there are no details of actual weather conditions. However, there is a huge amount of archeological, botanical, and zoological evidence available, and we can construct from them a picture of the prevailing conditions at different periods of time. At the beginning of the last millennium, both in the United States and throughout Europe, warm weather was widespread, and this continued for the first two centuries, from 1000 to 1200.

The overall regime of warmth was accompanied with abundant, reliable rainfall across the Great Plains, giving rise to extensive wooded areas, the kind of landscape that remained unique to this time period of 1000 to 1200. This was also the time when a large population could be sustained in heartland America. One place in southern Illinois had 50,000 inhabitants between 1100 and 1200. All of this changed in the early years of the thirteenth century; by its first decade, what is now the United States became much colder and drier. The warm and moist air masses from the Gulf Stream were replaced by a strengthening that developed in the westerly flow across the continent. Within the following 40 years the woodlands had retreated from the U.S. Interior, and the Great Plains became grasslands, the habitat of the buffalo that would become, at a later time, so familiar to early European explorers.

Native American populations declined as a result of the change in climate. Settlements were abandoned, and people migrated westward and southward. It was a similar story farther to the north, where the first Europeans had settled for a long time during the warm period on the island of Newfoundland in Canada. By the fourteenth century, they had to abandon their North American settlement as well as those they had founded in Greenland and Iceland. Most of the United States remained cold for the long period that came to be known as the Little Ice Age. The first English colony that was established on an island off the coast of Virginia had to be abandoned within a year due to low temperatures. An overall warming trend, one that affected all of the United States, began to arrive toward the end of the nineteenth century, but it did not become a settled pattern until the second half of the twentieth century.

EVOLUTION OF CLIMATE CHANGE CONCERNS

1970s For much of this decade, mainly because evidence of global cooling had been experienced over the previous three decades, scientific interests and publications focused on the prospect of a return to ice-age conditions.

1980 A report to the president of the United States from the Federal Council on Environmental Quality pointed out that human-caused climate change as a result of greenhouse gas emissions would probably be evident to all within the following 20 years.

1988 The World Meteorological Organization and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC).

1993 The scientific journal *Nature* published the findings of the scientists who had extracted a two-mile ice core from the Greenland ice sheet in order to identify climatic conditions 12,000 years ago. These scientists were astonished at both the rapidity and extent of the climate changes they identified, in particular the 1,300-year cold snap that appeared relatively suddenly. This period of time is often called the Younger Dryas after an Arctic flower.

1997 The scientific journal *Science* published an article that identified the slowdown in recent years of the Gulf Stream as a development that closely resembles the rapid changes in the Younger Dryas time.

2005 The Kyoto Protocol, a set of obligations related to the IPCC, came into force in February, and many developed countries agreed to follow its prescriptions. These related to reductions in levels of greenhouse gases by a specific date.

2007 The Norwegian Nobel Committee awarded the Nobel Peace Prize in two equal parts, to the IPCC and Albert Arnold (Al) Gore Jr., for their efforts to build up and disseminate greater knowledge about manmade climate change and to lay the foundations for the measures that are needed to counteract such change.

Appendix B: Some Extreme Global Weather Events

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as well as Appendix C, which focuses specifically on U.S. extremes, is to provide a larger context to which the individual references can be linked. When it comes to global extremes, the nations of Asia still dominate. Again and again, even after a century of improved methods of protection from tropical cyclones and interior floods, weather events are far more severe in Asia than we are accustomed to in North America. Numbers of casualties and the extent of environmental damage are often huge. One reason for this is the high terrain that borders nations such as Bangladesh and Vietnam; another is that the Pacific Ocean is much bigger than the Atlantic, and storms reach the Asian mainland with huge volumes of moisture after moving across great stretches of water.

The two biggest nations of Asia in terms of population are China and India, and they epitomize two extremes of weather: flooding in China and drought in India. The extremes of flooding in China are described in Volumes 1 and 2, and the drought problems of India are explained in some detail in Volume 3. The China flood of 1931, described next, was by far the most extreme in centuries, and the drought that hit India in 1900, along with the accompanying famine and starvation, was the worst of the entire twentieth century. Extremes of tropical cyclones, just like floods and droughts, are usually greatest in Asian countries, but occasionally other parts of the world experience exceptional storms. The two examples included here are of this character, Hurricane Mitch of Central America and Cyclone Wanda of Australia. The fifth extreme event included here took place in the Sahel of Africa, selected because it is an area that experienced so many droughts in the twentieth century that the United Nations set up a special task force to study the problem and identify the causes.

CHINA FLOOD, 1931

In the United States it is easy to think of hurricanes and tornadoes as the causes of more deaths than other weather events. In fact, in the United States, and to a far greater extent in Asia, floods cause far more deaths. In China, in particular, there is a tragic history associated with flooding, and Chapter 5 of Volume 1 shows this in the tragic story of

the great 1887 flood. The 1931 flood went far beyond the 1887 one in terms of deaths and damage. Nothing equal to it had happened in China in centuries of experiences of flooding. It began during the summer months, and the worst flooding occurred on the Yangtze River, although the heavy rains and rapid snow melt affected many other rivers in central China at the same time. About 51 million people were affected, representing a quarter of the nation's population at that time.

The U.S. National Oceanic and Atmospheric Association (NOAA) considered this 1931 event the most extreme weather-related disaster of the twentieth century, possibly the deadliest natural disaster ever recorded. The number of deaths was approximately four million, not all due to drowning. In 1931 China was still predominantly a rural society, and people earned their livelihood from agriculture. There was no national organization that could provide emergency food supplies, so, as water destroyed their food crops, mostly rice, people had nothing to eat beyond the supplies they might have saved from previous crops. Thus many died from hunger. Many others became infected with deadly diseases from polluted water. The causal factors that led up to this tragedy were a combination of extended droughts, from 1928 to 1930, followed by an equally protracted period of heavy rain. In winter much of the precipitation fell as snow, and in the following spring, the thaw added quantities of water to the rainfall, greatly increasing the volume of water in the rivers.

Rainfall persisted throughout the summer months and, in July alone, the area on the Yangtze River near the capital of that time, Nanjing, was hit with seven tropical cyclones, each of which added substantially to the amount of water in the rivers. Normally this part of China experiences about two tropical cyclones a year. By July of 1931, Nanjing had become an island in a massive flooded area. The high-water mark on the Yangtze reached 53 feet above normal by the middle of August. The immediate cause of flooding in China is nearly always a result of failure of the levees. Historically these are built of sods, so they offer little resistance to a sudden rise in the level of the river, especially if the rise in river flow occurs on a downward slope. These levees get built up over time to compensate for the rise in elevation of the riverbed, as more and more silt is deposited in it, so the river runs at an elevation above the surrounding plain.

Thus, as soon as a breach occurs in a levee, the rapid flow of water through the opening quickly expands the opening and increases the volume of water escaping into the lower land below. Toward the end of August the water flowing through the Grand Canal near the mouth of the Yangtze washed away the supporting dikes and drowned 200,000 people. In modern China the ancient forms of levees and dikes have been replaced in critical areas of the country by protective walls of concrete so that the enormous tragedies of the past will not be repeated. Additionally, hydroelectricity is being produced in many locations on rivers, and the dams serve as control points to prevent overtopping during sudden increases in river flows. The huge undertaking to dam the Yangtze River in order to secure much greater amounts of hydroelectricity provides protection from flooding all along the river.

HURRICANE MITCH, 1998

Deadly tropical cyclones frequently strike coastal areas along the Bay of Bengal, causing enormous loss of life and extensive environmental destruction. The Bangladesh cyclone of 1970 that is described in Volume Three of this series was the nation's greatest disaster of the twentieth century. Winds coupled with a storm surge killed between 300,000 and 500,000 people. The tropical cyclones we experience in North America, which we call hurricanes, do not generally reach these levels of destruction, but occasionally there are extreme examples of deadly hurricanes. Hurricane Mitch of 1998 was one of these. It was a late-season arrival, forming in the western Caribbean in October and moving westward over the mountainous areas of Central America. This storm weakened as it reached Honduras. Perhaps because it arrived late in the season, it did not have the strength to continue westward after reaching Honduras so it stalled over that country.

Hurricanes that travel across the warm waters of the Caribbean carry large amounts of water, and this volume of moisture is usually spread over an extensive area of land when precipitation takes place and the storm moves along. It is a very different story when a hurricane operating in the warm waters of latitude 15° north stalls over land, and especially when it stalls over mountainous land, as Mitch did. It unleashed precipitation amounts estimated as high as 75 inches. The resulting floods devastated the entire infrastructure of Honduras and also severely impacted other countries in the Central American region. The final estimated death toll was 11,000, the greatest loss of life from a tropical system in the western hemisphere since 1780. The fact that this was an estimated death toll tells us a lot about the level of development, and preparedness for hurricanes, in the countries affected.

Extensive wind damage and devastating floods occurred all over Honduras, particularly on the northern seaboard and in the Bay Islands that are located off the northern coast. Approximately 1.4 million persons were left homeless, more than 92 bridges were damaged or destroyed, and nearly 70 percent of crops were lost. The U.S. Geological Survey was called to help assess and map the damage and to provide technical help with landslide mitigation. Fortunately, the recent date of this hurricane makes possible the use of techniques to accurately assess the extent of the damage and provide expert help in recovery.

INDIAN DROUGHT, 1900

In contrast to the famines that occur in China due to the country's frequent floods, the Indian famines are caused by the absence of rain. The monsoon is the name given to the annual arrival of massive amounts of rain that reach land after traveling thousands of miles across the warm waters of the Indian Ocean. It is the greatest weather event in the world for two reasons: it travels over an area of water greater than

that of any other weather system, and it affects a bigger population than is ever affected by another single series of rainfalls. This main weather event of the year begins with rain arriving in early summer in the south of the country and often continuing unabated for weeks before dying down. It is common for rivers to overflow and communities to be flooded, but no one objects because this summer rain is the lifeblood of the whole nation. Even today, most of India is still a rural, agricultural society. In 1900 everyone depended on what could be grown in order to survive and, in this hot tropical climate, every crop depended on rain.

India has a second monsoon that arrives in the fall of each year. It is quite different from the summer one because it travels south over dry land and so carries much less moisture. If we think of India together with the large mass of continental land that lies north of it in the Himalayas, China, and Siberia, the enormity of these two annual events can be visualized. In summer, because land heats up much quicker than water, the air that had been circulating over long stretches of warm ocean water, and that therefore carries large quantities of moisture, is attracted toward the low-pressure areas over land. As it rises over higher ground water is precipitated, and the summer rains begin. People talk about it as rain, rain, and rain again; clothes damp, bed linen damp, walls damp, food damp, everything damp. Rain hammers a tattoo on corrugated iron roofs, tears up roads, and smashes down vegetation. The opposite movement of air happens in the fall as the land cools below sea temperatures, and a reverse flow of air takes place. It is the summer rains that are always the focus of interest. They sustain crops, especially rice, for the hundreds of millions of Indians. Billions of rice seedlings are in the fertilized, prepared plots of land in May or early in June awaiting the arrival of the monsoon.

What happens if it fails to arrive at the time the weather forecasters gave? In 1900 forecasting the exact date of arrival involved quite a bit of guesswork. There were few weather stations serving the land areas, and nothing on the ocean except reports from passing ships. A primitive form of statistical prediction operated. That is to say, forecasters knew that, on average, the monsoon would arrive within ten days of the middle of June, so they used whatever data they had to fix a date within that timeframe. However, even if the statistical average proved to be true for 30 years, the elders in Indian communities knew that occasionally there were huge exceptions. They knew of the terrible years of 1768, 1769, and 1770, when inadequate rain arrived and ten million people died. Somehow these anomalies had been forgotten in the year 1900. There had been exceptionally low amounts of rain in 1899 and again in 1900. Because of the possibilities of weak monsoons, farmers had been in the habit of storing some grain each year as a kind of insurance against a famine, but for some reason this had not been done before 1899 and 1900.

Severe shortages of rice were reported all over southern India in 1899 and over the rest of the country a year later. Unlike modern times

in India, in which food reserves are on hand to cope with disasters like this one of 1900, there was nothing that could be done for the farmers who had inadequate amounts of rice. A certain amount of sharing was done within communities, but the overall picture deteriorated into widespread famine by the fall of 1900. Disease and a breakdown in social order followed. There were many deaths. Subsequently it was discovered that there had been low levels of rain in the monsoons of 1896 and 1897, and these conditions led to the inability of farmers to put some grain aside as a reserve for emergencies. The British colonial authorities of the time paid no attention to these failures in the monsoons. They were only concerned with securing their quota of rice in order to satisfy their superiors. The final tally of deaths from famine and disease ranged from two million to ten million. The uncertainty about the numbers is a sad commentary on the failure of the colonial power to look after the people over whom they ruled.

AUSTRALIAN CYCLONE WANDA, 1974

Australia is quite well acquainted with extremes of climate. It has a very large desert area, and its location in a tropical zone means it gets the full effect of the unexpected heavy rains and high temperatures that are commonplace in that part of the world. During the summer of 1974 there happened to be one of the wettest seasons that Australia had ever known. The climatic variation called La Niina had been one of the most extreme of the entire twentieth century. As result of both of these conditions, rainfall was torrential and continuous through most of January 1974, as the inter-tropical zone settled over northern Australia. On January 25 of the same year, Cyclone Wanda moved over the interior of Queensland and New South Wales, dumping more than 12 inches of rain in 24 hours over a very wide area. As a result, because the summer rains had completely saturated the ground, massive flooding occurred on all the nearby river systems.

The city of Brisbane was the worst hit. It had not experienced a major flood for more than 70 years, and few suspected that anything like this would ever happen. After the last occasion when a major flood had hit the city, in 1893, very strict regulations were established for building on areas below a certain elevation. These restrictions were laid out for the parts of the city that would be at risk in the event of a major flood. Sadly, these regulations were not maintained for one reason or another, and subdivisions were allowed to develop on the areas on which no homes or other buildings were to be built. It is a story that is similar to what we have seen in the aftermath of the San Francisco earthquake, where areas that should never have been built on were once again rebuilt. Throughout Brisbane on January 25 there was a general failure of disaster warnings. There was no central authority that was able to receive details on the amount of flooding that occurred in different areas, so that local flooding in key areas was never reported to the authorities. About 70 percent of the

residents who were questioned afterward about the flood said that they had received no official warning.

January 25, 1974, the peak of the damage caused by Wanda, will be remembered as the worst floods in Australian history. Flooding covered an area slightly larger than the entire drainage basin of the Mississippi River. It reached from the dry interior at Alice Springs all the way to the Pacific Ocean, and from the extreme north of the country to the areas around Sydney, including the Murray River system. Military airplanes had to be used to supply isolated towns that were cut off by the floodwaters with emergency food for both humans and animals. In Brisbane, all bridges across the Brisbane River were damaged or destroyed, and 35 people drowned. At its height, the river broke its banks and ran through the central business district of the city. Water levels peaked at 20 feet by January 29. In one of the subdivisions 1,200 homes were destroyed. Overall, 20,000 people were left homeless. There was no adequate relief organization at this time, and about half of the victims depended on church contacts and a large number of volunteers for the help they did receive. By the end of January much of Australia, normally the dry continent, was submerged in water. Crops were destroyed, and there were outbreaks of disease.

Major flooding like this is so rare in Australia that the disasters of January 1974 are unique in the history of the country. In the aftermath, thoughts were concentrated on appropriate action that would prevent future disasters. Almost immediately the Queensland Government introduced a series of flood mitigation measures that expanded earlier ones. The experience was a wake-up call for Australia.

SAHELIAN DROUGHTS

This region, which stretches for three thousand miles across Africa south of the Sahara Desert, from Senegal at the Atlantic Ocean to Eritrea at the Red Sea, is a focus for all the world in the study of drought. It is an extreme example of aridity because of the extent and persistence of the droughts that overwhelm it. From 1968 to 1973 most of the region suffered from lack of rain, and the Sahelian Office at the United Nations created a special unit in 1973 to investigate the causes and recommend ways of coping with droughts. Occasionally the whole world becomes aware of the deadly nature of these times of aridity when international aid efforts are launched. One of these efforts is described in Chapter Six of Volume One: half a billion dollars was raised by Live Aid to help Ethiopia cope with a famine that had already taken the lives of 300,000 people. Overall, in the Sahel as a whole, between the 1960s and 1980s, famines took the lives of a million people, and many millions more were affected.

The 50 million people of the Sahel pursue different livelihoods. These include agriculture, livestock herding, fishing, and short- and

long-distance trading. Farming is almost entirely reliant on three months of summer rainfall, except for places that happen to be near a major river such as the Niger. Researchers from The United Nations, as they examine the region's economic fragility, recognize that the vast majority of the population is dependent on some form of rain-fed agriculture, including pastures for animal production. Three major droughts have occurred this century, in 1910–16, 1941–45, and a long period of below average rainfall that began in the late 1960s and continued, with some interruptions, into the 1980s. Absolute minimum rainfall levels were recorded at many stations in 1983 and 1984. The period of poor rainfall in the 1970s was particularly hard for many Sahelian farmers and pastoralists. An estimated 100,000 died from it.

Sahelian droughts and their effects have been studied extensively since the 1970s as part of the international response to this environmental emergency. It is only since 2000, however, that the long-term impacts of the famines of the 1970s have become evident. Those events provoked a rethinking of the links between population growth, drought, and sociopolitical change, and also helped to refocus development policy away from expensive and unsuccessful interventions toward more considerate strategies targeted at boosting local capacities. A complicating factor was increases in migration and international trade. Food distribution in famine situations by donors and governments has not been successful, despite the establishment of national cereals boards in most Sahelian nations, and the construction of roads into more remote rural areas. Rural residents still have to pay for government grain, and not all households are able to pay.

Originally it was believed that the problems in the Sahel were caused by humans overusing natural resources through overgrazing, deforestation, and poor land management. The expansion of farming and herding into marginal areas was said to have produced a spiral of changes, in which reduced vegetation caused reduced rainfall, producing further decreases in vegetation and thence a further reduction in rainfall. The series of Sahelian studies and climate modeling carried out by an agency of the NOAA over some years, and published in 2005, present a very different story: the problems are caused by changing sea surface temperatures that, in turn, were created by greenhouse gases and atmospheric aerosols from volcanic eruptions. In other words, global warming and climate change are the primary villains. The NOAA studies also point out that these human-induced changes in sea temperature could lead to a substantial reduction in the Sahel's rainfall in the course of this century.

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Appendix C: Some Extreme U.S. Weather Events

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as with Appendix B, is to provide a larger context to which the individual references can be linked. This list of U.S. extremes begins with two volcanic eruptions, one from Alaska, the biggest that occurred anywhere on earth during the twentieth century, and one from Washington State, the biggest ever within the contiguous United States. They are reminders of the unpredictable element brought by volcanic eruptions to the ongoing changes occurring in our atmosphere. Volume 1 describes the role of volcanic eruptions in considerable detail, with regard to their influences both now and in the future.

The other three extreme events included in this appendix are two extremes of temperature, cold and hot, and one of the most violent hurricanes of modern times, Camille of 1969. The extreme of heat is interesting because it arrived in the midst of widespread talk about global warming and climate change and is a reminder that the addition of carbon dioxide to the atmosphere has different effects in different places. In this instance, the high heat of the year 2006 is almost identical to that of the year 1936, the time of the Dust Bowl. The years 2006 and 1936 were the two hottest of the twentieth century.

MOUNT KATMAI, ALASKA, 1912

Katmai was the biggest eruption of the twentieth century anywhere on earth. A volume of volcanic ash greater than the amount from all other volcanic eruptions in Alaska was ejected, and it devastated every place within miles of the source. It created the Katmai Caldera and the Valley of Ten Thousand Smokes. Volcanic ash devastated areas hundreds of miles away. Within four hours of the initial eruption, ash had reached Kodiak, lying one hundred miles to the southeast, and by the end of the event, both Vancouver, British Columbia, and Seattle, Washington, were showered with sulfurous ash. The cloud produced by the eruption had reached Virginia by June 7. Ten days later, it had reached North Africa.

Kodiak suffered greatly during the three-day eruption. Ash and sulfurous smoke caused a slew of health problems ranging from respiratory illness to sore eyes. Additionally, the eruption rendered Kodiak's water

supply undrinkable, disrupted radio communications, and destroyed many buildings, some of which burned and others of which collapsed under the weight of mountains of ash.

As a result of the Katmai disaster, several villages were abandoned forever. Additionally, the eruption caused untold environmental havoc, and many animals, ranging from bears to birds, died of starvation. Aquatic organisms were also affected where waters were shallow and became choked with ash. This devastated local salmon fisheries for years.

Despite the fact that the eruption was so close to the continental United States and comparable in magnitude to that of Krakatau of 1883, it was hardly known at the time because Mount Katmai was so remote from the world's main population centers.

Almost a hundred years after it happened, researchers are still paying attention to Katmai because it is near the Arctic Circle, and its impact on global climate appears to be quite different from that of volcanoes in lower latitudes. Unlike eruptions in the tropics, the aerosols emitted by Arctic volcanoes tend to stay at high latitudes, because the stratosphere's average circulation is poleward from the equator. As a result, these particles remain effectively "bottled up" in the Arctic, dispersing into the rest of the earth's atmosphere only very gradually. Professor Alan Robock of Rutgers University has argued that this trapping of aerosols in the Arctic has an unexpected side effect: the weakening of the Indian monsoon. Robock reached these conclusions using complex calculations; however, the basic concept is that cooling in the northern hemisphere caused by the Katmai eruption set in motion a chain of events ultimately affecting air flow over the Himalayas and thus rainfall in south Asia.

To check his results, Robock and colleagues have been examining weather and river flow data from Asia, India, and Africa from 1913, the year after Katmai. They have also investigated the consequences of other high-latitude eruptions in the last few centuries. The fact that the stratosphere in high latitudes is shallower than at the tropics means that even small eruptions near the North Pole may deposit more aerosols than bigger events in the tropics. Furthermore, they would remain in circulation longer, as happened with Katmai. Indians will need to keep an eye on future Arctic eruptions.

It is unlikely that another eruption on the scale of Katmai will occur in the same region in the foreseeable future. However, volcanologists have confirmed that at least seven Katmai-scale eruptions have occurred over the last four millenia within a five-hundred-mile radius of the city of Anchorage, Alaska, so such a recurrence is far from outside the realm of possibility.

MOUNT ST. HELENS, WASHINGTON, 1980

The eruption of Mount St. Helens was the largest ever in the history of the contiguous United States. It had a VEI of 5. Mount St. Helens is the

youngest of the Cascades' volcanic peaks, and the explosion of 1980 is just the most recent of the many intermittent eruptions that took place over the past 40,000 years. Pumice and ash from these past events now cover large areas of the Pacific Northwest. From the 1950s onward, the mountain was intensively monitored, perhaps to a greater degree than any other. Days before the fateful event of Sunday May 18, 1980, there were many signs of impending danger, but no one was quite prepared for what finally happened. It all seemed to take place in seconds. Seattle's air traffic control tower tracked the mass of ash and rocks hurtling out of the mountain and concluded that it was traveling at close to 300 mph. The earthquake that triggered the explosion measured 5.1 on the Richter scale, but the energy released might be more accurately defined as the equivalent of thousands of Hiroshima-size bombs.

An avalanche of mud, rock, and ice roared down the mountainside, and the ash cloud rose as high as 54,000 feet. What had moments before been a beautiful 9,000-foot-high peak was reduced to a 7,500-foot decapitated mountain. Ash high in the atmosphere drifted eastward across the country, covering the ground everywhere it went with a layer of ash and blocking out sunlight in several communities near the mountain. Two hundred square miles of forest was flattened. Mudflows rushed westward down river valleys toward the Columbia River, blocking the navigation channel for ships with logs and mud for a distance of ten miles. It was estimated that 57 people lost their lives on that first day.

A Boeing 737 jet flying from Reno, Nevada, to Vancouver, Canada, at six thousand feet, was 40 miles south of Mount St. Helens when the mountain exploded. The pilot saw the explosion and swung away from his course, a path that would have taken him directly over the eruption, escaping in so doing a dirty gray cloud that was rising quickly to meet him. His 737 rocked in the air from the shock of the explosion as if it were a ship at sea. Fortunately his flight had been delayed for 30 minutes at Reno, or all 122 passengers plus crew would have been added to the list of deaths for May 18. The earthquake that triggered the event was not an unusual event in a region that experiences frequent earthquakes of this strength and stronger ones, but the scale of the eruption was a very different matter. It was a rare event even in historical time. Volcanic eruptions are identified by a volcanic eruption index number (VEI) based on the volume and speed of the rock and ash that is ejected. The index is numbered similarly to the Richter scale, each number representing ten times the volume of the one immediately below it, and one tenth that of the next number above it.

For this event of VEI 5, a volume of eruption greater than any other in the contiguous United States, one has to go back into earlier times to find a meaningful comparison. Vesuvius in the year 79 or Krakatau in 1883 each had VEIs of 6, or they were ten times more powerful than Mount St. Helens. Volcanoes in the Cascade Range are fairly new in geological time. A few date back several million years. Mount St. Helens is one of the youngest. Much of its visible cone was

formed within the last thousand years. It was frequently active during that time, and because of that geologists were convinced that a major eruption would occur sometime in the twentieth century. Further evidence in support of that expectation came more recently when it was found that the mountain had been more active and more violent over the past few thousand years than any other volcanic mountain in the contiguous United States. From the evidence in ash deposits across the western Cordillera, it is clear that some of these older eruptions must have had VEIs of 6.

The most recent well-documented eruption, prior to 1980, occurred in 1842. Eyewitness accounts from that time described seeing vast columns of smoke and fire. Ash from that time was subsequently located at The Dalles in Oregon, about 65 miles away. Fireworks continued intermittently over a 15-year period. Then came a three-year lull followed by a lot of activity in the year 1857. After that date the volcano seemed to have slept for the 123 years before 1980. The moment of eruption on May 18 of that year was indelibly etched in many memories. David Johnston, the expert geologist from the U.S. Geological Service who was monitoring the mountain on the morning of the explosion, talked to news reporters early on that day. He described Mount St. Helens as a keg of dynamite with a lit fuse whose length you do not know. He was well aware of the risks of being so close to the summit, but he stayed there right up to the moment of the eruption. He told the reporters that it was extremely dangerous to stand where they were at that time. "If the mountain explodes," he told them before they left, "we would all die." Soon afterward they heard his final words as he yelled into his radio, "Vancouver, Vancouver, this is it!"

A family watched their dream $100,000 home smashed and washed down the chocolate-brown Toutle River. A couple on a camping and fishing trip on the same river tried to grab their camping gear when they heard the explosion, but quickly saw there was no time to escape in their car. They were thrown into the water and carried along in a mass of mud, logs, and rocks, grimly clinging to one log. They were lucky. The log was shunted sideways out of the main stream. Some time later, a helicopter picked them up. A television cameraman a kilometer and a half from the base of the mountain filming the event saw the mass of mud and debris heading for him. He dropped everything, got into his car, and drove madly to keep ahead of destruction. He was able to stay ahead of it.

Farther east, travelers were stranded in numerous small communities, altogether 10,000 of them in three states. One couple driving west from Spokane saw the black oncoming cloud. Soon they could only inch along the highway at less than eight kilometers per hour. They abandoned their car and joined the other stranded ones. Everywhere around, trains, buses, airplanes, and cars came to a stop. Walking was the only thing that worked. Digging out from under the ash was yet another hazard. It proved to be as hard as getting around it. For some time people wore masks of whatever material they could find for fear of toxic fumes.

As is common in volcanic eruptions, the magma that had risen and caused the explosion left the inner chamber empty for a time until new magma moved up from below. The interior dome then began to grow until pressure rose to a level that caused another eruption. Several of these subsequent eruptions came in May, June, July, August, and October of 1980. By 1983 the dome had grown to six hundred feet and the crater in which it sat was two miles in diameter, waiting for the moment of the next event, and meanwhile continuing to grow.

How can volcanic eruptions and earthquakes be predicted? The answer remains elusive, but experience from Mount St. Helens shows us some of the things that can be done. As mentioned earlier in this chapter, this mountain received more monitoring since the 1950s than almost any other, and the small number of people who were killed is largely due to this, as well as to the actions that were taken in the months before May 18, 1980. The first earthquake in Mount St. Helens struck on March 20, 1980, and immediately afterward seismologists met with local authorities to warn of the danger ahead and make some preliminary plans.

One week later steam and ash exploded from the summit of the volcano, and this was followed by several minor eruptions over the following weeks. As these eruptions became more frequent, public authorities closed off the area around the mountain, causing heated opposition from the general public. Later they lowered the water level in the Swift Dam reservoir to minimize damage from mudflows. Still closer to the time of the eruption, the governor of Washington declared a state of emergency in order to use the National Guard to staff the roadways. So angry were some over the closure that they found ways of circumventing the law by using little-known roads and footpaths to gain access. Some, including Harry Truman, a veteran resident of the mountain, refused to leave their homes on the north side and died.

ARCTIC OUTBREAK, 1989

America's coldest spell of the century arrived in December 1989. In the South, New Orleans experienced 64 consecutive hours at or below 32°F and a total of 81 out of 82 hours below freezing. A total of 15 hours were below 15°F, with the lowest reading of 11°F on the morning of December 23. A low of 8°F was recorded at Baton Rouge. Snow and sleet paralyzed transportation systems in New Orleans, and there were a hundred fires in the city, a result of inadequate heating systems. The greatest impact was on breakage of water pipes in homes and businesses. Five weather-related deaths occurred in the area during this rare Arctic outbreak.

The story was similar in the Midwest: it was the coldest day of the season for south central Nebraska and north central Kansas, and most locations experienced subzero temperatures. This Arctic outbreak peaked around December 15 and continued for about ten days. Low temperature records were broken throughout the United States. Nothing comparable

is found in weather records until we go back to 1899, when a similar chill occurred. The events in both of these years were quite similar: both were fast-moving, very powerful Arctic outbreaks that stretched across most of the United States and reached into Mexico and Florida.

GREAT HEAT WAVE, 2006

In 2006, from June 1 to August 31, as summer is defined by the National Climatic Data Center, the United States experienced its greatest heat wave in 70 years. The average temperature across the country was 74.5°F, based on readings from hundreds of weather stations. It was the second-hottest summer temperature since the government started to keep records in 1895. The only comparable heat wave was in 1936. At the 2006 peak, temperatures greater than 100°F covered the Great Plains, Midwest, South, and much of the Northeast. The year 1936 is a reminder of the Dust Bowl years that are described in Volume One.

With air conditioning being quite limited in its coverage in 1936, many people were forced to sleep in their yards or in parks. The death toll was high, estimated at about 50,000 total. The heat was especially deadly in large Midwestern cities such as St. Louis, Minneapolis, and Detroit. The total number of deaths from a heat wave is rarely given out by media for various reasons: deaths from heat are silent killers, they do not cause visible destruction where they occur, and causes of deaths are difficult to identify.

HURRICANE CAMILLE, 1969

Camille was one of only three hurricanes in the history of the United States to make landfall as a Category 5. It was an extreme hurricane, one of the most violent storms of the twentieth century. It arrived from western Cuba on August 14 and entered the warm waters of the Gulf, reaching Bay St. Louis on the evening of August 17 with sustained wind speeds of 190 mph. It almost totally destroyed the Mississippi coast. Before it left the mainland United States it had caused the deaths of more than 250 people and injured 8,900, and destroyed 6,000 homes and damaged 14,000. The total costs of the destruction it caused were in excess of a billion dollars. Millions of Gulf coast residents were made aware of the strength of the storm before nightfall on August 17. Before the storm reached Bay St. Louis, about 200,000 residents had fled the coastal areas into sheltered places.

As the storm moved across the coast in darkness, homes, motels, apartments, restaurants, and other buildings were swept off their foundations and deposited in mountains of rubble. It was the same for almost everything movable and for much, such as trees, that was not. Camille maintained its hurricane strength for ten hours. On the morning after

the storm, thousands searched among the wreckage for anything that might have been left. There was no semblance of normal life in the region around New Orleans for days, but fortunately the levees around the city were not affected because the storm was centered a few miles to the east. About 15,000 people were left homeless. There was no water, food, or fuel. The storm had wiped out all means of communication, and roads, bridges, airports, and even railways were impassable or destroyed. Gulfport Hospital had closed down and evacuated all of its patients to hospitals farther inland.

Adding to the devastated landscape was a serious vermin problem. There were thousands of dead animals of all kinds, and insects and rodents had quickly overrun the stricken area to feed on these and on the rotting food. Rattlesnakes, fire ants, and rats bit dozens of victims who were sifting through the rubble. In an attempt to control the ants, low-flying planes roared up and down the Mississippi coast, dropping quantities of mirex. At the time of Camille this product was not considered dangerous to humans, but eight years later the U.S. Environmental Protection Agency banned it as a possible carcinogen. President Nixon sent a thousand troops to help, and the state governor declared a state of emergency in order to control crime. Using federal troops and state police, all roads leading into the area where the eye had crossed the coast were sealed off. Military and local police imposed a curfew. The first problem to overcome was the thousands of dead farm animals, pets, and wildlife. Camille's incredible 25-foot storm surge had drowned thousands of animals. Heavy equipment was brought in to bury these thousands of animals.

The National Hurricane Center took note of Camille's weather data because of the unusual ferocity of this storm. The lowest barometric pressure recorded on land during the evening of August 17 was 26.85 inches. That was at Bay Saint Louis. This was the second-lowest barometric pressure ever measured in the United States. Only the 1935 Labor Day hurricane produced a lower pressure in the middle keys. That figure was 26.35 inches. The highest tidal surge ever recorded in the United States belongs to Camille. It was officially recorded as 22.6 feet above mean sea level, but high-water marks on buildings, still clearly visible long after the storm had passed, showed water heights of 25 feet. Camille moved inland and then gradually weakened to a tropical depression over northern Mississippi on August 19. It had picked up a lot of moisture over the Gulf of Mexico, and this led to torrential rain over the mountains of Virginia. In eight hours, 28 inches of rain fell on Nelson County, an amount that more than tripled the state's 24-hour record, which had been set in 1942 and has not been broken since. In other parts of the state, 14 inches came down during the night. Afterward, Camille turned eastward to emerge into the Atlantic near Virginia Beach on August 20.

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APPENDIX D: MEASURING WEATHER AND CLIMATE EVENTS

MEASUREMENT CONVERSIONS

1 inch equals 2.54 centimeters

1 centimeter equals 0.39 inches

1 meter equals 3.28 feet

1 kilometer equals 0.62 miles

1 square meter equals 10.76 square feet

1 square kilometer equals 0.39 square miles

1 hectare equals 2.47 acres

1 cubic meter equals 35.31 cubic feet

1 cubic kilometer equals 0.24 cubic miles

1 degree Fahrenheit equals 9/5 degree Celsius plus 32

1 degree Celsius equals 5/9 degree Fahrenheit minus 32

FUJITA F AND EF SCALES FOR TORNADOES

The F scale was created by Japanese American meteorologist Tetsuya Fujita in 1951 to classify tornadoes.

F0 40–72 mph (light)

F1 73–112 mph (moderate)

F2 113–157 mph (significant)

F3 158–206 mph (severe)

F4 207–260 mph (devastating)

F5 261–318 mph (incredible)

Half of all tornadoes worldwide are F1 or less. Only 1 percent of all are F5.

Over the years, the F scale has revealed weaknesses: (1) too much reliance on the estimated wind speeds, and (2) oversimplification of the

damage description. Fujita recognized that improvement was necessary. When the committee met to develop the enhanced Fujita scale, one point was made very clear: it must continue to support and maintain the original tornado database; in other words, there must be some conformity to the F scale that is listed in the database.

F Scale

F0 40–72 mph

F1 73–112 mph

F2 113–157 mph

F3 158–207 mph

F4 208–260 mph

F5 261–318 mph

EF Scale

EF0 65–85 mph

EF1 86–110 mph

EF2 111–135 mph

EF3 136–165 mph

EF4 166–200 mph

EF5 Over 200 mph

SAFFIR-SIMPSON SCALE FOR HURRICANES

Developed in the later 1960s by Herbert Saffir to quantify potential wind damage from hurricanes, and expanded in the early 1970s by Robert Simpson, director of the National Hurricane Center, the Saffir-Simpson scale is used to measure hurricane strength. Wind speed is the determining factor in the scale, but storm surges caused by wind are highly dependent on the slope of the continental shelf and the shape of the coastline.

Category 1 74–95 mph (minimal)

Category 2 96–110 mph (moderate)

Category 3 111–130 mph (extensive)

Category 4 131–155 mph (extreme)

Category 5 155 mph or more (catastrophic)

VOLCANIC EXPLOSIVITY INDEX (VEI)

To compare the magnitudes of volcanic eruptions, scientists have developed a volcanic explosivity index (VEI) in which each level is ten times as powerful as the previous level. The index measures eruptions on a scale of 0 to 8. The VEI of any eruption is based on the volume of rocks and ash that is emitted. A VEI of 1 could represent a Hawaiian eruption, a gentle oozing of lava with no violent activity; a VEI of 8, a very rare event, would apply to Toba, an Indonesian eruption of gigantic proportions that occurred 74,000 years ago. Krakatau of 1883 had a VEI of 6. Mount St. Helens of 1980 had a VEI of 5.

GLOSSARY

absorption of radiation. Transfer of electromagnetic energy into heat energy.

adiabatic process. Temperature change in a gas or in air due to compression or expansion. No heat is gained or lost from the outside in the process.

advection fog. A fog that develops when condensation occurs within moist air close to the earth's surface.

acid rain. The presence of acidic elements in rain that tend to destroy plants and trees.

aerosols. Tiny substances in the atmosphere, so small that the slightest movement of air keeps them aloft.

air. The mixture of gases that make up our atmosphere.

air mass. A large body of air that has defined temperature and humidity characteristics. It may extend over thousands of square miles and be miles in depth.

air pollution. A harmful substance put into the atmosphere from the earth

albedo. The amount of solar radiation that is reflected by a part of the earth's surface, usually expressed as a percentage.

alcohol thermometer. *See* thermometer.

anemometer. An instrument for showing wind speed.

Antarctic Circle. The parallel of latitude at 66.5° south.

anthropogenic. Caused by human activities.

anticyclone. High pressure mass of air with winds circulating clockwise in the northern hemisphere or counterclockwise in the southern hemisphere.

Arctic Circle. The parallel of latitude at 66.5° north.

Arctic front. The zone of interaction between polar and Arctic air masses.

armada. A Spanish word meaning a very large group of warships.

Asian cyclone. A tropical cyclone or typhoon that occurs in Asia. *See* typhoon.

atmosphere. The gaseous envelope surrounding the earth, mostly consisting of nitrogen and oxygen, concentrated within an area 30 miles above the earth.

atmospheric pressure. The force exerted by the weight of the atmosphere on an area.

aurora borealis. Lights visible near the North Pole, caused by interaction between the sun's radiation and molecules in the earth's atmosphere.

automatic weather stations. Weather stations, often at sea, that record and transmit data to a central location for weather forecasting.

barometer. An instrument for measuring atmospheric pressure.

biosphere. The part of the earth system that contains all living things, in or on the land, in the atmosphere, and in or on the oceans.

blizzard. Violent winter storm that lasts for several hours or longer.

caldera. A steep-sided circular depression in the ground, the end result of a volcanic eruption.

carbon dioxide. Gas that is a byproduct of burning fossil fuels or biomass. It also occurs naturally.

Celsius scale. A temperature scale in which the freezing point of water is zero degrees and the boiling point is one hundred degrees.

Chinook wind. A very dry wind that flows down the eastern side of the Rocky Mountains.

chlorofluorocarbons (CFCs). Compounds used in refrigerators, aerosol products, and solvents. Now banned in many products because of their harmful influence on the earth's ozone layer.

climate. The average pattern of weather in a given area over a long period of time.

climate classification. Division of the earth's climates into a system of regions, each defined by specific climatic elements.

climograph. A graph that shows the monthly totals for two climatic variables such as temperature and precipitation.

cirrus cloud. A high-level cloud, stringy and layered.

cloud. A suspended concentration of water or ice particles.

cloud base. The lowest elevation where cloud particles such as water droplets or ice crystals can be observed.

cold front. At the boundary between two air masses of different temperatures and humidities, the cold front is the heavier of the two, so it pushes the warm air mass upward.

colony. A territory owned and administered by a colonial power, usually a European power.

condensation. A physical process in which water vapor is changed into a liquid, that may take the form of a cloud, fog, or dew.

condensation nucleus. A tiny substance in the atmosphere on which water vapor condenses to form a drop of water.

convection. Transference of heat in a gas or liquid by upward movement of the heated and therefore less dense part.

Coriolis effect. A force caused by the earth's rotation that turns air movements to the right in the northern hemisphere and to the left in the southern hemisphere.

cumulonimbus. A heavy and dense cloud with a substantial vertical component.

cumulus cloud. A cloud made up of a rising mass of air that can be found at any level in the lower atmosphere.

cyclone. An area of low atmospheric pressure with inwardly rotating winds.

D-Day. The day selected to launch a massive attack by sea from Britain to France near the end of World War Two.

depression. An area of the atmosphere in which sea-level pressures are lower than those of the surrounding region, often the early stage of a middle-latitude cyclone.

desert. An ecosystem with less than four inches of rain a year.

dew. Water that has condensed on things near the ground.

dew point temperature. The temperature at which a mass of air holds its maximum amount of water vapor.

diurnal. Daily.

doldrums. A belt of calm seas near the equator.

doppler radio. A radar tracking system that enables a meteorologist to determine the speed of a moving object.

downburst. Violent and damaging downdraft associated with a severe thunderstorm.

drought. When an area experiences rainfall levels significantly below normal.

dust storm. A heavy mass of dust in a disturbed air mass.

El Niño. The fluctuating warm temperatures of the equatorial Pacific Ocean that affect global circulation of air.

energy balance. Globally, the total energy input from the sun equals the total energy output.

equator. The parallel of latitude that is midway between the North and South Poles.

equinox. The moment in time when the sun is directly overhead at the equator.

evaporation. The change of a liquid into a gas.

eye of tropical cyclone. The clear and calm area inside the rotating wall of convective clouds.

Fahrenheit scale. A temperature scale where the freezing point of water is 32 degrees and the boiling point is 212 degrees.

fall equinox. When the sun is overhead at the equator in autumn. It occurs around September 23.

fertilizers. Substances added to soil to make it more fertile.

flash flood. A flood caused by heavy rainfall within a short period of time.

flood. A stream that overtops its banks and covers the surrounding area.

flood stage. A particular level on a stream at which flooding occurs.

fog. A cloud at ground level.

forecast. A prediction about future weather conditions.

frost. Small ice crystals that form on or near the ground when temperatures are below freezing.

Fujita scale. The method used for calculating the strength of tornadoes.

global energy balance. The balancing of solar short-wave incoming energy with outgoing long-wave energy from the earth

global warming. An overall increase in the earth's average surface temperature.

greenhouse effect. Absorption of long-wave radiation, especially by water vapor and carbon dioxide, and reflection of heat back to earth to raise ground level temperatures.

greenhouse gases. Atmospheric gases that absorb and reflect long-wave radiation, causing the greenhouse effect. The two most important gases of this type are water vapor and carbon dioxide.

green revolution. The use of new quick-ripening, high-yield plants for use in developing countries.

guerilla-type attacks. The use of individual soldiers or small groups of soldiers to carry out raids on enemy positions.

Gulf Stream. The warm ocean current that flows northward along the east coast of the United States.

hailstorm. Pellets of ice falling from thunderclouds.

heat island. An area within an urban zone that has higher temperatures than those of the surrounding areas.

Himalayas. A mountain chain on the border between India and China.

humidity. The amount of water vapor in an air mass, measured as a percentage of the maximum that it could carry.

hurricane. A North Atlantic or Caribbean tropical cyclone.

ice age. A geological period in which ice sheets covered much of North America.

iceberg. A mass of floating ice.

Indian monsoon. *See* monsoon.

insolation. The technical term for the energy that reaches the earth from the sun.

irrigation. Water that is taken to fields from ponds or streams.

isobar. A line on a weather map connecting places that have the same atmospheric pressure.

jet streams. High-speed air flows about 15 miles above the earth, usually running from west to east.

L'Anse Aux Meadows. A Heritage site on the island of Newfoundland where the first Europeans to reach North America lived.

La Niña. The fluctuating cold temperatures of the equatorial Pacific Ocean that affect global circulation of air.

latent heat. Energy being absorbed from the air during changes from water to water vapor and released to the surrounding air during changes back from water vapor to water.

levees. Embankments to prevent rivers from flooding.

mercury thermometer. *See* thermometer.

meteorologist. A person who understands, studies, and predicts weather conditions.

microburst. A very narrow downburst.

monsoon. A persistent seasonal wind with a change in direction from season to season, usually associated with the wind patterns to and from the Asian interior in relation to the Indian Ocean.

NOAA. U.S. National Oceanic and Atmospheric Administration.

nor'easter. An extra-tropical storm along the coasts of Atlantic Canada and from Maine to New York, frequently referred to by this name because its winds come from the northeast.

Norwegian school of meteorology. The group of meteorologists who discovered and used air mass theory in forecasting the weather.

Northwest Passage. The north shore of Canada, the shortest sea route to Asia from Europe, now no longer permanently covered by ice.

ocean conveyor belt. Another name for the thermohaline-driven global ocean current.

ozone. A gas in the higher reaches of the atmosphere, created both naturally and through photochemical reactions, that absorbs ultraviolet radiation from the sun, an activity that is vital to the preservation of life on earth.

ozone layer. A region of the stratosphere stretching from about eight miles to 25 miles above the earth that contains large concentrations of naturally occurring ozone.

permafrost. Permanently frozen areas of the earth's surface.

pesticides. Chemical substances used to destroy insects or other organisms that are harmful to growing crops.

photosynthesis. The process by which plants take carbon dioxide from the air and release oxygen into the air.

polar front. The front between cold polar air masses and warm tropical air masses.

precipitation. A general term for different forms of water that may either be falling from or held in suspension in the air. Included in this term are rain, drizzle, snow, hail, and ice pellets.

rain gauge. Instrument for measuring the amount of rain that has fallen.

relative humidity. *See* humidity.

Rossby waves. Planetary waves in the atmospheric westerly circulation, characterized by great length and amplitude.

Sahel. The dry southern part of the Sahara Desert.

Santa Ana winds. Hot and dry winds that come from the interior desert regions of California and pass over the coast mountains to reach the Pacific Ocean.

sensible heat. Heat that can be measured by a thermometer.

sleet. A mixture of snow and rain.

smog. Fog combined with smoke, a common problem in large cities.

solar constant. The intensity of solar radiation on one unit of area when it is at right angles to the incoming sun's rays.

spring equinox. When the sun is overhead at the equator in the spring. It occurs around March 21.

statistical average. A calculation made by adding a collection of numbers and then dividing the answer by the total number of individual items in the collection.

Stevenson screen. A shelter for housing such weather measuring instruments as thermometers.

storm surge. The temporary increase in the height of the sea at a particular location due to a hurricane or a strong wind.

stratosphere. The part of the atmosphere above the troposphere, from about eight to 30 miles above the earth.

sublimation. The change of ice directly to water vapor or vice versa without passing through the liquid phase.

subsolar point. A place where the sun's rays are perpendicular to the earth's surface.

summer monsoon. Inflow of air from the Indian Ocean toward the continental Asian low-pressure center.

summer solstice. When the sun is overhead at 23.5° north, at the Tropic of Cancer. It occurs around September 23.

tar sands. The rich oil-bearing sands of northern Alberta, Canada.

thermometer. An instrument that measures temperature by using the properties of either alcohol or mercury as they respond to heating.

thunderstorm. Sudden electrical discharges, usually from convective clouds such as cumulonimbus, followed by lightning, thunder, and rain.

Tibetan Plateau. The highest extensive elevation of land north of the Himalayas.

tornado. A violent rotating storm of small diameter, a twister, usually appearing as a funnel cloud extending from the base of a cumulonimbus to the ground.

tornado F5. The most destructive type of tornado.

tornado outbreak. A succession of powerful tornadoes occurring within a short period of time.

trade winds. Winds that blow from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.

tropopause. The boundary between the troposphere and the stratosphere.

troposphere. The lowest part of the atmosphere, extending upward from the earth for about seven miles.

trough. A layer of the atmosphere with low pressure.

typhoon. A tropical cyclone occurring in the western Pacific Ocean.

urban heat island. An area at the center of a city where temperatures are higher than they are in the surrounding areas.

volcanic eruptions. The ejections of masses of lava and other material from a volcano.

warm front. The transition zone between warm and cold air masses. The warm front is the lighter of the two, so it is pushed upward by the cold air mass.

water vapor. Water when it is in gaseous form.

wave cyclone. A mid-latitude cyclone, usually originating at the polar front.

westerlies. Winds from the west between the latitudes 35° north and 65° south.

wind chill. A temperature based on actual temperature and wind strength. It indicates the cooling effect of wind on exposed parts of the body.

winter monsoon. Outflow of continental air from the Siberian high to southeast Asia and the Indian Ocean.

winter solstice. When the sun is overhead at 23.5° south, at the Tropic of Capricorn. It occurs around December 22.

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A Student Guide to

Climate and Weather

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A Student Guide to

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The Earth and the Sun

VOLUME 5

Angus M. Gunn

GREENWOOD

AN IMPRINT OF ABC-CLIO, LLC
Santa Barbara, California • Denver, Colorado • Oxford, England

Library of Congress Cataloging-in-Publication Data
Gunn, Angus M. (Angus Macleod), 1920-
A student guide to climate and weather / Angus M. Gunn.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-313-35568-4 (set: hardcover: alk. paper) — ISBN 978-0-313-35569-1 (set: ebook: alk. paper) — ISBN 978-0-313-35570-7 (v. 1: hardcover: alk paper) — ISBN 978-0-313-35571-4 (v. 1: ebook) — ISBN 978-0-313-35572-1 (v. 2: hardcover: alk paper) — ISBN 978-0-313-35573-8 (v. 2: ebook) — ISBN 978-0-313-35574-5 (v. 3: hardcover: alk paper) — ISBN 978-0-313-35575-2 (v. 3: ebook) — ISBN 978-0-313-35576-9 (v. 4: hardcover: alk paper) — ISBN 978-0-313-35577-6 (v. 4: ebook) — ISBN 978-0-313-35578-3 (v. 5: hardcover: alk paper) — ISBN 978-0-313-35579-0 (v. 5: ebook)
1. Climatology. 2. Meteorology. 3. Climatic changes—Effect of human beings on. I. Title.
QC861.3.G86 2010
551.5—dc22 2009042256

14 13 12 11 10 1 2 3 4 5

This book is also available on the World Wide Web as an eBook.
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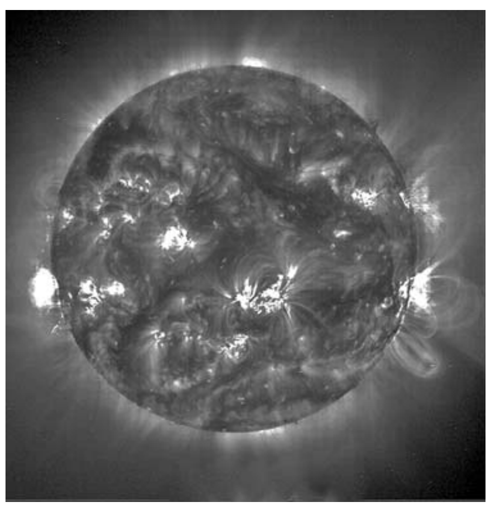
INTRODUCTION

This is Volume Five of a set of five books on weather and climate designed for schools and universities. These books are intended to provide two kinds of information: an understanding of the scientific processes at work in weather and climate, and an analysis of the ways in which weather and climate impact human life and the places where we live. The second of these goals is the more important of the two as there are a number of books in print dealing with the scientific processes involved in weather and climate, but few on how weather influences our lives. Beginning in the first volume with aspects of the subject that impinge on us daily, such as the unpredictable nature of weather, we go on in the second and third volumes to deal with characteristic global weather patterns, before moving, in the last two books, into more general themes such as global warming and earth-sun relationships. A list of reference materials will appear at the end of each book to assist in linking together the different aspects dealt with in individual volumes.

In this final volume we examine weather and climate in terms of the overall relationships between the earth and the sun. This will allow the content of the previous volumes, each of which focused on one aspect of the subject of climate and weather, to be seen in a larger context. The first two chapters focus on the sun and the earth as the two realities around which gather all of the information about weather and climate and the changes that are taking place in both. We are learning a lot of new things that explain the operation of the sun insofar as it affects our lives here, not only things from the past but also those that might develop in the future. As recently as late 2008, new reports appeared about the interstellar boundary, the general area of the universe that lies between the zone that is dominated by one star and the zone that relates to another one. It seems that dangerous radiation that normally stays outside the solar system—that is to say, the zone that is dominated by our sun—has been entering our solar system. Scientists expect to be able to identify this radiation if it approaches the earth and to keep it away from us.

The enormous size and heat output of our sun seem to get bigger and bigger as more and more satellites get close enough to take measurements. Its weight is more than that of all the planets in the solar system put together. For this reason, it is the center of gravity around which every planet orbits. Because it is so massively big and heavy, its weight alone is sufficient to create nuclear energy explosions at its center that are like the atom bombs we make on earth, but far, far, bigger. Furthermore, they continue to happen for millions and millions of years. Fortunately for us, the heat that is generated from these nuclear explosions and radiated out into space remains fairly constant over time. Some changes do occur in the amount of heat that is radiated, but their effects on the earth are manageable. One change that happens on average every eleven years is known as a sunspot cycle. It's a change that is so big that it can be seen on earth as dark spots on the face of the sun. The output of energy is slightly reduced during one of these cycles. They have fascinated scientists since the time of Galileo. Once, several hundred years ago, a sunspot cycle lasted for seventy years. That's a very long time, and living conditions were very unpleasant until it ended.

We know that the radiation emitted when a nuclear bomb explodes is very dangerous. People who unfortunately happened to



NASA's ultraviolet image of the sun. (NASA) be close to one when it went off were either killed or seriously harmed. What about the radiation that reaches the earth from the sun? Why does it not harm us? The answer is that there is an area near the top of our atmosphere, the ozone layer, that absorbs the dangerous part of the sun's radiation. The very high frequency radiation, ultraviolet rays, the ones that would seriously damage our bodies if they reached us, are absorbed by the ozone layer. Some years ago, it was discovered that dust and gases from industrial operations on earth were interfering with the ozone layer so that it did not stop all the radiation it should stop. New laws were introduced to control this damage, and all the countries of the world agreed to enforce these laws. The frequency ranges of the sun's rays that reach us at the surface of the earth are not dangerous. There are many other things that interfere with the amounts of solar radiation that reach the earth's surface, and we will consider them in Chapter Two, which discusses the earth's behavior as it rotates on its axis and as it orbits the sun once every year.

Although we rarely think about it, the speed of earth's movements through space is the result of the combination of a most extraordinary pair of events. It rotates at a thousand miles an hour and orbits at sixty-times that speed, 67,000 miles an hour. Why do we not feel any sense of moving at a great speed? The answer is that everything is moving: the whole earth, its atmosphere, oceans, land, and us. It's the same when you fly in an airplane, except for the times at takeoff and landing or any time when the plane's speed is changing. As long as the plane and all of its contents are moving at the same speed, there is little awareness of movement. Chapter Two describes the factors that determine the amount of sunlight that each part of the earth's surface receives. It also shows how latitudes near the equator receive more warmth, compared with the polar areas, and how the disparity between the two areas is resolved. The annual orbit through space around the sun that we all experience, even though we do not think of ourselves as astronauts, is not always exactly the same every year. Nothing in space is as precise as we would wish because the movements of objects like comets and asteroids exercise very small influences, through their gravity, on the paths of other planets or objects, including the earth.

EARTH AND OCEAN WATER CYCLES

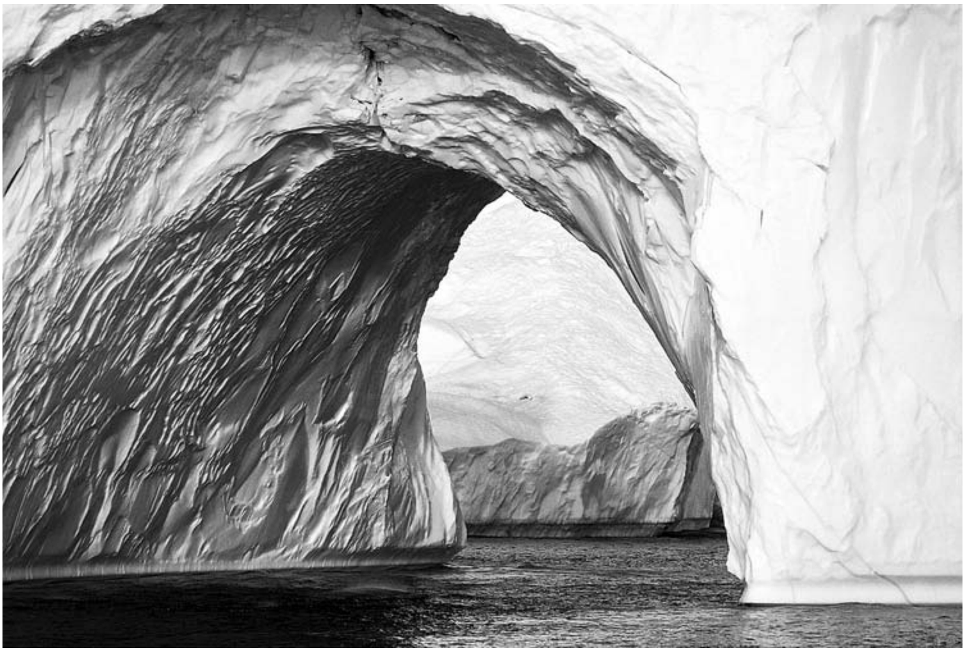
Before noting the many water cycles that operate in and below both continents and oceans, we need to be able to locate places accurately anywhere on earth. Chapter Three is devoted to this task. It is easy to make a map of any small place, such as a building or a small subdivision, because they seem to be on flat areas of land, even though we know that every place on the planet is part of a curved surface, part of the globe we call the earth. Thus, for small areas we can use the same method we use in school geometry, *x* and *y* coordinates, and in this way we can find the *x* coordinate and the *y* coordinate for a particular place, and therefore know exactly where the place is located. It is a very different matter when you have to identify the temperature of a place in Africa and compare it with the temperature of a place in Chicago in such a way that meteorologists will know immediately where each place is in relation to the other. This is the kind of information needed today, ever since we discovered that weather in one spot is often affected by weather anywhere and everywhere else on the planet. Chapter Three explains how a system based on lines of longitude and latitude enables us to identify accurately every place on earth. Furthermore, because of the system of global satellites now in place, the global positioning system (GPS), we can know instantly where a place is.

Chapters Four and Five deal with two important subjects, the water cycle and the problem of understanding and coping with places that lack sufficient water. The first of these two, the water cycle, describes the ongoing process of water evaporating, mainly from the ocean, as water vapor, rising high into the atmosphere until its temperature drops low enough for it to form clouds or fall as rain, and then to either be stored below ground or become runoff from the land back into the ocean. The amount of water that is involved in this cycle at any time is tiny, a very small part of the whole, but they cycle is continuous and so, over a year, the total volume is huge. The quantity involved in the water cycle has remained constant over long periods of time, and this is fortunate because water is a powerful greenhouse gas, much more powerful than carbon dioxide. However, because water vapor is in the atmosphere for only a short period of time, there is no buildup of its influence as there is with carbon dioxide. The heat exchanges that always occur when water changes to gas cool the earth's surface as latent heat is added to the water vapor. When precipitation occurs, this heat is restored to the atmosphere and the earth's surface.

The flow of rain into lakes and rivers on its way to the ocean is often interfered with by a variety of human activities, including irrigation for agriculture and damming of rivers for hydroelectricity. There is a parallel flow of water down into the earth through pores in soil and rock formations. In dry seasons of the year, it is from these underground resources that plants are able to obtain the water they require to stay alive. Some water seeps farther down and accumulates in large quantities over time where it can be absorbed by permeable layers of rock. This is known as groundwater, and millions of Americans in rural areas depend on it for their daily supply of fresh water. For the most part, this domestic use of groundwater has not been a problem, but other uses of the same resource for urban and agricultural applications are causing big problems in the southeast United States and in California, two areas of the United States that have often experienced shortages of rainfall. The problem arising from too much groundwater being withdrawn is that saltwater from the ocean seeps into the places from which fresh water was withdrawn. The saltwater damages agricultural land. In some parts of the world, groundwater gets trapped between two layers of impermeable rock, and over time an underground lake is built up. The pressure that develops, because the water cannot escape, makes it easy to access this source of water from the surface, once it is discovered. Some areas of the western United States tap into such underground lakes to secure a continuous flow of fresh water.

These cycles of water from the ocean to the atmosphere, within the atmosphere, and on and under the land were, until recently, considered to be the whole story of water as far as weather and climate are concerned. All of this changed over the past two or three decades as scientists discovered another cycle of water operating near the surface and deep down below the surface throughout the entire ocean system. It has been known for many years that currents on the ocean's surface, driven by the global wind systems, brought warmth from tropical areas to northern and southern colder regions of the globe, but the discovery of this other system, involving enormous volumes of water, brought new insights into the forces controlling weather and climate. The name for this newly discovered water cycle is the ocean conveyor belt, but, because it is powerfully influenced by its saltiness, it is given the name thermohaline circulation (THC). Meteorologists and specialists in several branches of climatology are now scrambling to find out all they can about the temperatures, pressures, and movements of water on and below the ocean's surface. Developments in the North Atlantic branch of the THC are affecting the world's climates in a new way as they combine with other events arising from global warming.

All of these new developments are described in Chapter Six. The most dramatic aspect of them is that the Gulf Stream, the branch of the THC that brings warmth to northwest Europe as well as to the eastern United States, has the most control over the world's climates, more than any other part of the THC. This information would be important at any time, because it influences the climate of the most developed part of the world, Europe and North America, raising the average temperatures in these two large regions by about 9°F. However, something is happening in the northernmost part of the Gulf Stream, something that no scientists expected would happen as fast as is being witnessed at the present time: sea ice and icebergs are melting at an alarming rate, and the ability of the Gulf Stream to continue flowing is threatened by these changes. There are questions being asked even about the Greenland ice cap, a mass of ice so big that it would raise sea levels by about three feet if it melted completely. It is clear now, from all that is happening in and around the Gulf Stream, that the oceans and the atmosphere form one interconnected system. We need to examine both, as well as the interactions between them, if we are to understand fully what is



A large iceberg, with a tunnel that is over 60 feet in diameter, from Greenland's western shore. (iStockPhoto.com)

happening in global weather and climate and if we are to succeed in reducing greenhouse gases in the atmosphere.

GLOBAL DROUGHTS, FLOODS, AND CLIMATES

Droughts and floods are among the costliest natural disasters we experience. With the problems associated with atmospheric carbon dioxide, they are likely to increase more rapidly than any other aspect of weather and climate. The details of this acceleration in global warming and climate change, based on data from the National Center for Atmospheric Research (NCAR), are given in Chapter Seven, along with illustrations of both floods and droughts from around the world. Two nations were singled out as examples of severe flooding: China and the United States, the latter because of the association of its biggest flood with volcanic activity.

The Sahel region of Africa will be briefly mentioned as a major drought location, one that has suffered from rainfall shortages for decades and, it seems, a part of Africa that is not likely to see much change in the next few decades. Why is there so little hope for this large region of drought that stretches across Africa from Senegal to Ethiopia, just south of the Sahara Desert? This region has a semiarid climate at the best of times, with a delicate ecological structure that manages to survive the dry spells as long as the human imprint is light. That imprint consists mostly of rearing cattle and goats.

For most of the people who live there, this is their sole livelihood. Many of them are nomadic. They move into the area when rainfall is adequate, and they often get caught in a season of drought because these dry spells arrive slowly and may stay for five or more years. One drought lasted from 1968 to 1974. Rainfall had been unusually heavy between 1950 and 1968, and new herders had moved into the region, often as a result of conflict in other places. In the worst phase of the six-year drought, more than five million cattle died and close to 100,000 people died from starvation and disease. When the rains returned, the soil and all vegetation had been so harmed that erosion set in, and huge areas of topsoil were washed away. In some ways, it was reminiscent of the Dust Bowl years of the United States, except that the poorly farmed soil was destroyed in the Sahel by water, not wind.

The impact of volcanic eruptions on weather and climate has been mentioned more than once in earlier volumes of this set, and more will be said about it later in this volume as we consider the more distant future. The Chapter Seven account of the impact of Mount Pinatubo's eruption on the devastating U.S. flood of 1993 was more than just another example of events of this type. It became a model that would be used again and again to forecast the possibility of another event like the 1993 one. This was accomplished by extensive research that followed the 1991 eruption, tracking the content of dust and debris in the atmosphere over a period of three years, and recording the temperature differences throughout the globe at the same time. Furthermore, although the Mount Pinatubo eruption was extremely powerful and destructive, the model that emerged was usable and was employed for subsequent eruptions of different strengths. It represents a significant advance in forecasting the influence, at least in the northern hemisphere, of future volcanic eruptions.

Modeling the Mount Pinatubo Eruption

In scientific work today, once a certain amount of experimental work is done, a model is designed to represent what has been discovered. The model is then used to predict outcomes in future similar situations. If it proves to be successful in several outcomes, it becomes an important tool for scientists everywhere. Things that occur in the atmosphere are extremely complex, and frequently models of climatic events have to be redesigned before they are dependable for widespread use. The expected worldwide impact of Mount Pinatubo's eruption of 1991 was modeled at the time of the eruption, in the hope that what was known about events of this kind would enable scientists to predict the outcomes. This model used the Earth Radiation Budget Satellite to provide a detailed profile of the evolution and dispersion of the aerosols from the eruption over a period of three years. The result was that the temperature of the surface air globally was predicted to be reduced in those three years by the same amount as would have occurred if humans had doubled their output of carbon dioxide into the atmosphere over the same three years. As a result, it proved to be a very valuable model, one that could be employed again and again in measuring the impact of volcanic eruptions on global warming and climate change.

THE EARTH'S FUTURE WEATHER AND CLIMATE

The content of the five books in this set deals mostly with events that occurred within human history, that is to say, within the last few thousand years. Some references have been made to events in the distant past, such as the ice ages, and we have learned a great deal from the ice cores that documented past climates. Now, in the final chapter of Volume Five, some perspective needs to be added regarding future developments that we know from our research will certainly come, even though we do not know when. Chief among those future certainties are what is known as super-eruptions, those that emit more than 125 cubic miles of volcanic rock. The Toba eruption in Indonesia, referred to in Volume One and elsewhere, was one of these super-eruptions. It happened long ago, at the time of the last ice age, and destroyed most of what was at that time the area we now know as the contiguous United States. There have been other super-eruptions more recent than Toba: one in New Zealand and one in Italy. Others have come from more ancient times. There is no doubt that the earth will experience more of these massive eruptions at some time in the future.

There is nothing in our history that could adequately prepare us for super-eruptions, but we can learn a lot from less destructive events. The 1912 eruption of Novarupta in Alaska, sometimes referred to as the Katmai eruption, was the biggest on earth in the twentieth century. Fortunately there were very few people living in the area around Mount Katmai and there was very little industrial activity at that time. No humans lost their lives. Scientists have recently assessed the potential destruction and disruption that would likely occur if a similar eruption were to arrive today. A glimpse of this scenario came a few years ago when a minor eruption took place near Mount Katmai just as a jumbo plane was approaching Anchorage and about to land. The ash from the volcano clogged its engines and they stalled. With less than five thousand feet of air space available, the pilot turned out to sea and began a slow glide, hoping that fresh air would clear the engines; fortunately it did, at less than one thousand feet, and the pilot was able to fly to a nearby airport. Present predictions, given the level of development that characterizes the Anchorage region, pose quite a challenge. The whole state's economy would stop instantly. The U.S. Geological Survey (USGS) has painted the following grim scenario:

> Clinics would be overwhelmed by people with eye, throat, and lung damage. Building ventilation systems would have to be closed to outside air. Ash entering computers, bankcard machines, and other electronic equipment would cause them to break down. Automobile, snowmobile, and boat engines would also be damaged. Airports, including Anchorage, which handles the largest amount of air cargo of any airport in the United States and is a refueling stop for many

The devastation caused by the Novarupta, or Katmai, volcanic eruption of 1912, the largest 20th-century eruption anywhere on earth. (Library of Congress)

trans-Pacific flights, would be closed until runways could be cleared of ash. To avoid the ash cloud, aircraft would have to be diverted around most of Alaska, Canada, and the Northern United States, seriously disrupting national and international commerce.

INSURING AGAINST AN UNKNOWN FUTURE

The idea of insuring against an unknown future seems to make no sense. How can anyone take out insurance against a future risk unless we know what the risks will be and what financial costs might be incurred? From one point of view, thinking about insuring against an unknown event makes no sense if our thinking is based on guesswork. A good deal of this kind of thinking took place for the first half of the twentieth century regarding hurricane damage in the United States. People took out standard insurance against total or partial destruction of their homes or injury to any of the family members, but they paid little attention to developments that were taking place over time in and around the locations of their homes. Some of these developments included the following: greater knowledge of the frequency of hurricanes (although there is no precise knowledge of when powerful hurricanes will arrive, we do know now the cyclical patterns they take, and we can plan accordingly); huge increases in land values along coastal areas as more and more people decide to live there (as a result, damage to the environment and collateral damage to neighboring homes need to be taken into account when deciding insurance premiums); and growth in the number and density of cities.

This last-mentioned one was the reason for a wake-up call to all who lived in hurricane-prone locations when Hurricane Andrew hit the built-up area of Miami and caused $30 billion of damage. Prior to that event, all through the first half of the twentieth century, there was often no insurance coverage for powerful storms, even though some had caused damage amounting to $300 million. Comparisons were quickly made between Andrew's $30 billion loss and the totals for all hurricanes that had come before 1950. Even the huge amount of destruction caused by the 1900 Galveston hurricane only added up to $30 million. Some changes in insurance had taken place before Andrew, but in every case the amount was far below the value of the destruction caused. Owners of property damaged or destroyed by Hurricane Andrew had insurance coverage for about half the damage done. Everyone knew that higher amounts would have to be included to cover urban incidents, yet two years later, less than a third of the $44 billion costs of the Northridge earthquake, in another dense urban area, was covered by insurance.

CHAPTER 1

The Sun, the Earth's Energy Source

The solar system consists of planets, comets, and asteroids, all of which orbit the sun, the center of the system. The sun's mass is a thousand times greater than that of all the planets that orbit it. It would take more than a hundred earths to reach across the sun from one side to the other, and it would require more than a millions earths to fill the sun's interior. This huge star that we call the sun is more than 90 million miles away. Its outer temperatures are higher than 10,000°F, so we would probably not want it to be much closer. The planets that are closer to the sun experience much higher temperatures than we would welcome. The energy that radiates outward to us from the sun is created deep within it, where both the pressure of the sun's weight and the much higher temperature cause nuclear fusion, the same type of event that occurs on earth in a much smaller way in nuclear reactors. Throughout the four or five billion years of its existence, the sun has been able to maintain a fairly constant output of radiant energy, and it will continue to do so for many millions more. One exception to this constancy is the sunspot cycle.

Sunspots are darker areas on the surface of the sun. They are so big that they can be seen from earth even without a telescope. They are darker because they represent locations that are a bit colder than the rest of the sun's surface, and they appear about every eleven years on average, sometimes as early as every nine years and at other times every 13 years. The sun's output of radiant energy is a little weaker during these sunspot cycles, and people everywhere must adjust to the lower amount of heat during these cycles. Sunspot cycles may last for years, and they usually have their maxima and minima within the cycle. Once, as we know now from historical records, there was a period of time when the low temperatures lasted for a very long time, from 1645 to 1715. That's a very long period of colder weather. Historians wondered whether human activity was greatly affected by such a long sunspot cycle. Certainly one very important series of conflicts occurred in that time, the civil wars in England that ended with the elected parliament having greater power than the king. In the year 2007, there was another discovery by a historian of musical instruments.

This historian had been puzzled for a long time about the fine tonal quality of the violins made by the Italian Stradivari. He knew that the wood used by this man was the same wood used by other makers of violins, yet the violins made by Stradivari were consistently superior to all others. As this historian of musical instruments studied the life of

The tonal quality of a Stradivarius violin is due to the close-knit arrangement of the annual growth rings in the wood used by the maker of the violin, a condition in the parent trees caused by extended periods of very low temperatures. (Seanyu/ Dreamstime.com)

Stradivari, he noticed that he had lived between 1666 and 1737, dates that were close to those of the cold period. He spoke with experts in trees and was told that they grew very slowly during the years after 1645. That bit of information gave him the clue he needed. Because the trees grew slowly, their annual rings of growth were much closer together. These trees were selected by Stradivari for making violins. The historian compared the tonal quality of violins that had been made at warmer periods of time in the past, and he found that the fine-grained wood used by Stradivari was the secret that gave his violins the superior tonal quality.

THE SUN'S ENERGY RECEIVED BY THE EARTH

Energy usually travels by conduction or convection. These are the two ways with which we are familiar for transferring energy from place to place, and both require a material substance such as water or rock to do their work. The electromagnetic wave energy that the earth receives from the sun is transferred by another method, that of radiation. Thus energy passes from the sun to the earth through the vacuum of empty space. The very-short-wave, high-energy x-rays that would damage life

Where Does Space Begin?

Most of our weather events occur within the troposphere, the area of the atmosphere that extends upward from the surface of the earth for approximately 12 miles. Beyond this area lie the strata we call stratosphere and mesosphere. In both of these layers, air gets thinner and thinner with height. Traditionally, in the United States, when 50 miles above earth was reached, all higher regions were regarded as part of space. Not everyone agrees with this definition because there are no specific data that would distinguish 50 miles from, say, 62 miles, a height that was selected by the International Aeronautical Federation as the threshold of space. The main reason for the different opinions relates to finding a height at which the friction with air will be so small that it can be ignored when figuring out the amount of energy needed for satellites. The choice of more than two hundred miles by the designers of the International Space Station is an indication of how diverse the range of opinions is.

if they reached the earth's surface are, fortunately, absorbed by the atmosphere well above our heads. Additionally, in the stratosphere, the ozone absorbs the ultraviolet rays that would endanger health if they reached low elevations. Some of the remaining energy that comes down through the atmosphere is absorbed by particles of matter and clouds. The remainder that reaches the earth's surface usually comprises the light waves and those around radio frequencies. As this energy reaches the surface of the earth, it is absorbed by material things such as soil and water. As this happens, the earth's surface gets warm and then radiates some of this warmth upward in the form of heat energy, or infrared waves, which in turn heat the atmosphere.

There is an important principle about energy that always applies, in whatever form the energy exists: it can never be destroyed; it can only be changed from one form to another. The sun's energy as it enters our atmosphere is interfered with in a number of ways, as has just been explained, so the amount that reaches the surface of the earth is less than the amount that arrived at the outer limits of the atmosphere. Then, as heat energy is radiated from the earth into space, some of it is sent back to the earth by clouds and particles in the air. All of these different activities can be examined and, through experimental work, calculated to find their energy values. These calculations were listed in some detail in Volume Two of this series of books, and they show conclusively that the total energy value of all that arrives from the sun is matched by the total energy value of all that is radiated back into space. It is because of this that the earth has been able to maintain for millions of years a level of warmth that, despite variations from time to time, remains favorable for human and other life. It must be added that this longstanding stability is now being threatened, as we saw in Volume Four, by global warming and climate change.

Thus far, we have looked at the state of things on the earth's surface. What happens in the atmosphere as warm air and water vapor, evaporated from the oceans as a result of warm air over and on the

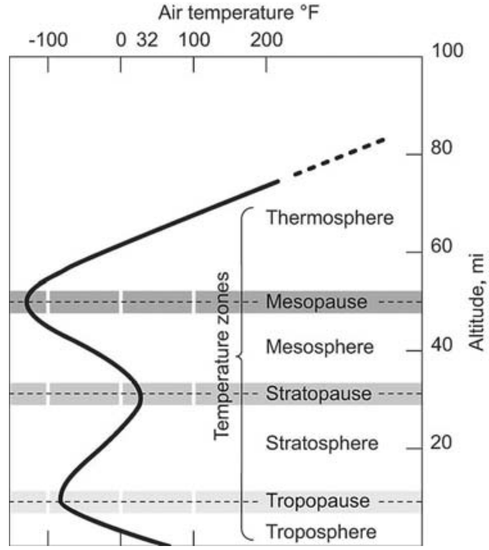


Figure 1-1 Changes in atmospheric temperatures with height. (ABC-CLIO)

water, move upward? First, heat is lost from the earth's surface when water becomes water vapor. Later, when the water vapor forms clouds, the atmosphere gains that latent heat that the earth lost during evaporation. Heat, rising from the earth's surface, warms the atmosphere. The warmer air is forced upward as cooler air from higher up sinks down and helps to form a convection loop. Distance from the source of heat (that is, the earth's surface) causes a progressive drop in temperature throughout the troposphere, the part of the atmosphere that is of most interest to humans because most storms and cloud formations are found in it. Beyond 16 miles of elevation, as air enters the stratosphere, temperatures begin to increase and continue increasing until the mesosphere, where temperatures once again drop with altitude. The additional warmth in the stratosphere is caused by absorption of ultraviolet radiation by the ozone layer.

GLOBAL DISTRIBUTION OF THE SUN'S ENERGY

The amount of energy received at the surface of the earth is not the same at all places around the world. Although the amount that reaches the surface is approximately the same everywhere, the amount of heating that takes place as the sun's energy is absorbed varies greatly. The reason for this comes from the angle at which the sun's rays, technically known as insolation, strike the earth. At the equator during solstices, the times when the sun's rays are directly above the equator at noon and therefore perpendicular to it, the area impacted is minimal in size, and the amount of absorption is therefore at a maximum. The farther away from the equator that a place is at noon on a solstice, the greater will be the size of the area impacted, and therefore the smaller

What Are Solstices and Equinoxes?

For some parts of the year, the North Pole and areas near it are tilted away from the sun, and at other times of the year, they are tilted toward the sun. It is when this northern area has the maximum amount of daylight or nighttime that we get the solstices, a word that is based on the Latin for "sun standing still." It gets that name because of the way these maxima moments happen in the course of the earth's movements. As amounts of light or darkness reach their maxima, there is a moment when things begin to change to the opposite direction, and this "standing still" moment is the solstice. On December 22 comes the darkest moment, and on June 21 the brightest moment. Halfway between these two important moments, there are two times when the lengths of daylight and nighttime are exactly equal. These are the equinoxes, again a term borrowed from Latin words, this time meaning "equal nights." The equinoxes occur on March 21 and September 22. All of the above relates to the northern hemisphere. If we were thinking of Australia or New Zealand or South Africa, the dates of the equinoxes would be reversed, as would the dates of the solstices; their darkest moment occurs around June 21, and their brightest around December 22.

the amount of absorption of insolation per unit area. The proportions of areas impacted at times other than equinoxes will similarly be varied, with the places nearest the equator always getting the greatest amount of warming. In summary, the higher the latitude, the greater the area over which the solar beam is spread on the earth's surface; thus, the amount of insolation received on each unit area decreases progressively from the equator to the poles.

If the differences in heating were the only thing determining the distribution of warmth throughout the world, the air heated at the equator would rise and flow in one direction toward the poles. There it would sink down as it cooled and flow back to the equator at ground level in the opposite direction to complete the convection circulation.

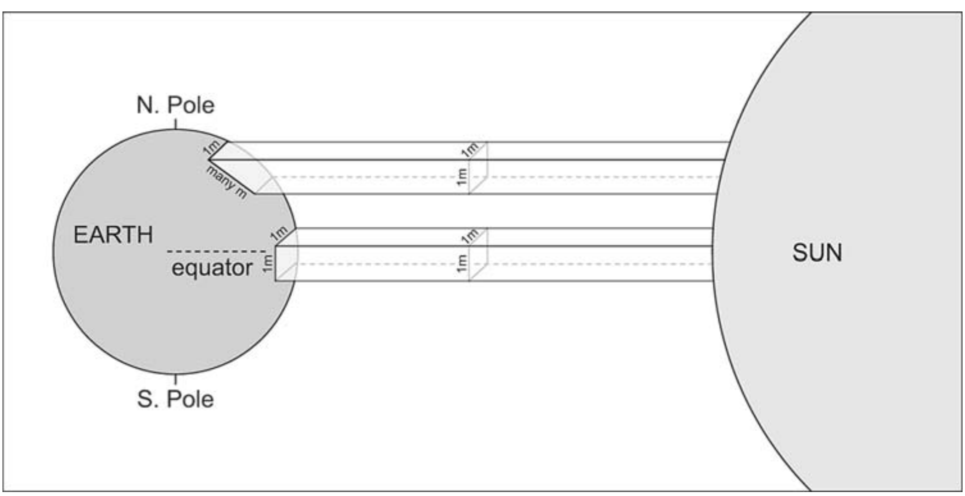


Figure 1-2 The amount of heat at any place depends on the angle of the sun's rays striking it. (ABC-CLIO)

Air movements behave just like those of water because both are substances that respond to the laws of physics: warm air or warm water moves upward in its setting, and cold moves down. In a simple scenario like the one suggested here, pressure would be greatest at the poles and least at the equator. The reality of what happens as warmth is distributed is quite different due to two additional factors: the rotation of the earth, and the locations of the continents. The earth's rotation affects the direction that air flows as it moves toward the poles; the air is moved to the right as it travels northward. It is easy to test this out experimentally by trying to draw a line from one point to another on a sheet of paper as the paper is rotated beneath you. Before the moving air gets halfway to the north, it has turned so much to the right that it has become a west-to-east wind instead of a south-north one.

The air has cooled and continues to cool at this stage, so most of it sinks to ground level to flow back southward. A small amount continues northward, much of it air that was added along the way, until it reaches the sixtieth parallel, where it sinks and returns southward at ground level just as the air did before it reached the fortieth parallel. In these ways, two high-pressure areas, the results of cooler air sinking at 35° north and 60° north, create two banks of high pressure all around the globe. This is the first difference between the idealized pattern and the real one. The second difference relates to the presence of continents. They disrupt the otherwise predictable flow of warm air from the equator northward. They add additional warmth in summer to air that moves over land, because air heats more quickly than water. The continents remove heat, making the air colder, in winter under the same conditions. The result is a series of high-pressure air masses, each independent of its neighbor, around the globe at 35° north and at 60° north. Some of these are over the ocean and others are over land. They are identified by the characteristics of the surfaces below them. These are the air masses that shape most of the mid-latitude cyclones that constitute the weather of North America. They are explained in detail in Volume Two.

CHAPTER 2

The Earth's Rotation, Revolution, Orbit, and Seasons

In Chapter One, we examined the behavior of the sun, the one source of energy for almost everything in the solar system, including every form of life on earth. In this chapter, we will do the same for the earth's behavior, its rotation and its orbit, and how these affect us. For most of human history, people risked their lives to say that the earth was round and not flat and that it moved around the sun, not the other way round as society's leaders kept insisting for more than a thousand years. Even as recently as 1544, Gerard Mercator, designer of the world-famous map that bears his name, was threatened with death for making a map that offended the Roman Catholic Church's interpretation of a particular part of the Bible. People seemed to have forgotten that Eratosthenes, director of the Great Library of Alexandria, Egypt, knew quite a lot about the earth and the sun as far back as 200 BC and had measured the earth's circumference at that time by an interesting experiment based on shadows cast by the sun.

Eratosthenes discovered that the sun's shadow at noon disappeared every year around June 21 at a place in the south of his country located very close to the line that we now call the Tropic of Cancer. We know that the reason for the sun's shadow disappearing on that particular date is that the sun is then directly overhead on that line of latitude. We call it summer solstice, a name based on the Latin words for "sun standing still," so named because the sun appears to stop its northward movement on the solstice before moving southward. Eratosthenes then discovered that in Alexandria, where he lived, the sun, unlike the place on the Tropic of Cancer, cast a shadow at the solstice. He was able to measure the angle made by this shadow from a vertical object of known height. It turned out to be seven and one fifth degrees. He figured that the shadow was caused by the spherical shape of the earth, so he took the portion of 360 degrees represented by the seven and one fifth and multiplied it by the distance from Alexandria to the place on the Tropic of Cancer to get an answer close to 25,000 miles.

The answer he got was very close to the more precise one of 24,860 miles that we now have for the circumference of the earth, a remarkable achievement given that he had none of the accurate modern instruments. As we examine the earth and its movements today, in spite of all that we have discovered about it, there are some things that we do not yet know. In this chapter, we look at the two movements of our planet that go on all the time: its rotation on its axis

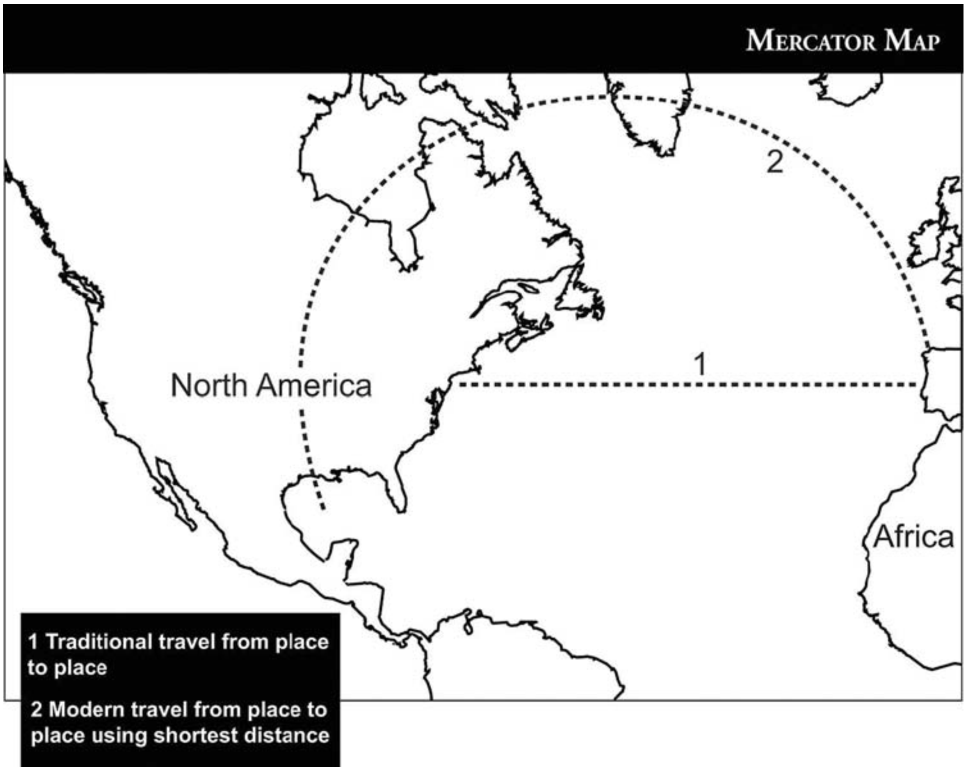


Figure 2-1 This map is part of the Mercator Map, used by sailors for centuries because any straight line on it gives the correct compass direction to follow in order to reach a destination. Going from place to place at sea, following a compass direction, was used even before the time of Mercator, because little was known about the globe or places outside of Europe. Columbus used this method and only strayed from it in order to be helped by trade winds. Today, with our knowledge of the shape of the earth, we know that the shortest distance between two points is not the compass direction and that the Northwest Passage is the shortest distance from some places in Europe to places in Asia. (ABC-CLIO)

and its orbit around the sun. Rotation refers to the spinning of the planet on its axis, which occurs at a speed of a little over a thousand miles an hour. It's a bit slower at certain places on the globe, but still very fast. If you ever tried moving at that speed in a car, and I hope you do not try, you would be very conscious of what was going on, even if all the windows were closed. Why, then, are we able to stand on the ground, out of doors, without feeling any sense of speed? The answer is because everything is moving at the same speed all the time.

You could compare it to the experience of flying in a plane or traveling on a train: once the vehicle reaches a steady speed, and there are no interfering noises such as bumps or uneven tracks, you do not feel the speed of motion except when you slow down or speed up. The earth makes one complete rotation every 24 hours. That is why you see the sun rise and set once a day. Because the earth's circumference is approximately 24,900 miles, it has to travel at 1,000 mph to circumnavigate the globe in a day. Now consider the earth's movement around the sun. That takes a bit longer. The distance is more than 90 million miles, as the crow flies, but the earth does not travel like a crow. Instead it takes an elliptical path, very much more than 90 million miles, and it completes the trip in one year. To do that it moves along at about 67,000 mph, 67 times faster than it rotates, and it takes its atmosphere with it so that you and I can breathe easily in space.

THE EARTH'S ORBIT AROUND THE SUN

The annual orbit of the earth around the sun takes a little over 365 days. It's not a circular orbit but rather an oval or elliptical one. As a result, two additional variables become involved in climate and weather: the earth's distance from the sun, and therefore the amount of energy reaching us, varies throughout the year; and the angle at which the sun's rays hit us also varies from the patterns we might imagine from looking at different parts of the globe. In fact, the earth, in the course of its full-year odyssey, wobbles a bit, although fortunately not enough to change the average conditions on earth from year to year. One influence of these tiny wobbles is seen in the small changes that have to be made in the times of arrival of solstices and equinoxes. Many researchers have studied these small variations that appear in the course of the earth's orbits, and it is remarkable that the changes are so small over long periods of time. There are so many things that could go wrong in the course of a year and cause changes in the earth's seasons. One of these might be the approach of an asteroid whose gravity would alter the earth's course a little even though it might be very far away and represent no direct risk to life on earth.

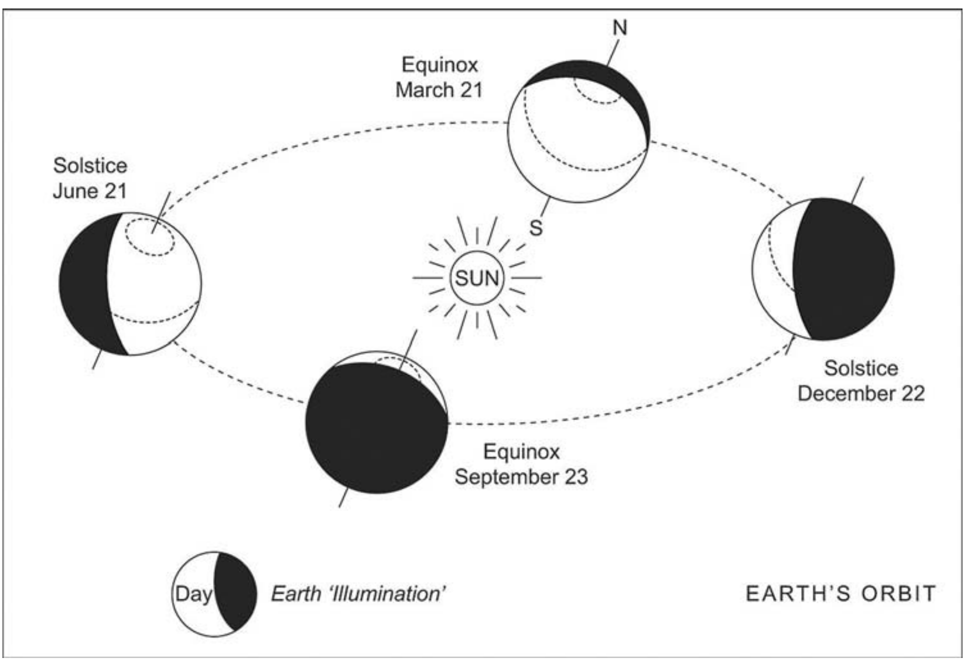


Figure 2-2 Areas of the earth illuminated by the sun as the earth orbits the sun. (ABC-CLIO)

The closest that the earth comes to the sun occurs in early January. It is then about 92 million miles away. The farthest comes early in July, when it is 95 million miles away. To be able to visualize what an orbit looks like, you have to imagine a huge flat surface with the sun in the middle and the earth moving on that surface with its axis tilted 23.5 degrees away from the vertical. It is this tilt that causes the earth's seasons, and very small changes in its angle can make big differences in the kind of weather we get in particular seasons. Although it is true that the tiny wobbles that occur make little difference to the weather we experience as we fly around the sun, occasionally, over long periods of time, bigger changes happen in the tilt. We do not know why they happen, but scientists have discovered how to determine when they will come, so that we can be prepared for them.

Fortunately, the amount of time between these changes is huge. They are many thousands of years apart, so it is easy to forget about them unless you happen to be living when one of them comes along. That happened to some who lived about 11,000 years ago. They coincided with one of these rare events, the one that only comes every 41,000 years. The tilt changed by one and a half degrees. This was all that was needed to make summer a wintertime for everyone, and also to make winter much warmer than normal. Snow and ice remained on mountains and in higher latitudes all year round. From this particular episode, and from one or two others that were identified by studying ice cores from Greenland, scientists decided that it was the cool summers, especially those that persisted for more than a year, that had triggered an ice age. Even summers that were only slightly cooler than normal had this effect. As we have seen in other aspects of weather and climate, the whole system is interdependent, and every element is affected by what happens to any one.

Cool summers in the northern hemisphere, where most of the earth's land areas are located, are particularly sensitive to an event like the one that occurred 11,000 years ago. Land heats up more quickly than water and also cools more quickly than water. If snow stays longer on mountain areas because the land becomes cooler, then more of the solar radiation is reflected back into space and additional cooling takes place on the ground. Increasingly, scientists are convinced that the tilt's move at distant times in the past was responsible for initiating an ice age. We know that these ice ages wax and wane over time and that other things such as volcanic eruptions play a part in these events. The alteration in the tilt's angle is just one contributor to these great sequences of ice. We also know that the northern hemisphere experienced more of them than did the southern hemisphere. There is another uncertainty about earth's orbits for which we do not have an exact explanation because it relates to the time billions of years ago when the earth first began to take shape. The uncertainty is that the earth is always moving through space at right angles to the line of sight from the earth to the sun. This is why the sun cannot pull it in a straight line toward itself by force of gravity.

THE FOUR SEASONS

The tilt of the earth's axis at 23.5 degrees, as it orbits the sun elliptically, determines the four seasons, as has already been noted. The first attempts to translate this into major divisions of the earth led to five zones based on the assumption that latitude was the main determinant of climate in any place. Thus arose the polar zones, the temperate zones, and the tropical zone, each defined by a temperature that was related to typical plant growth within the region. The north and south polar zones were defined as places where the warmest month did not rise above 50°F, because at this temperature there are few trees. Nowadays we have to note that polar areas are warming, and therefore this defining temperature may no longer be useful. The boundary between the tropical and the temperate zones was defined by the temperature 64.4°F for the coldest month because, at this temperature, tropical plants do not grow very well. When we mark these temperatures as lines on a map of the world, we call each line an isotherm, meaning a line that represents one specific temperature at every place on the line.

The Arctic Circle is one of the major circles of latitude that mark maps of the earth. It is approximately 66.5° north of the equator, and it represents the southern limit of the polar day, that is, the southernmost line of latitude on which a person can see the sun in summer for a full 24 hours. In winter it is the same line that marks the limit of a full 24 hours of darkness. Because of dust and other particles that cause refraction of the sun's rays, and also because the sun is a disk and not a point, these limits of visibility or darkness vary by as much as

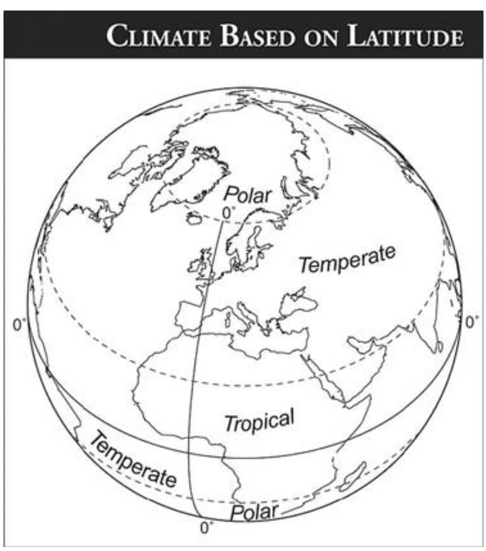


Figure 2-3 In earlier times, even before the discovery of all the global land areas, there was an assumption that temperature was determined by latitude only. This view persisted into the 19th century. (ABC-CLIO)

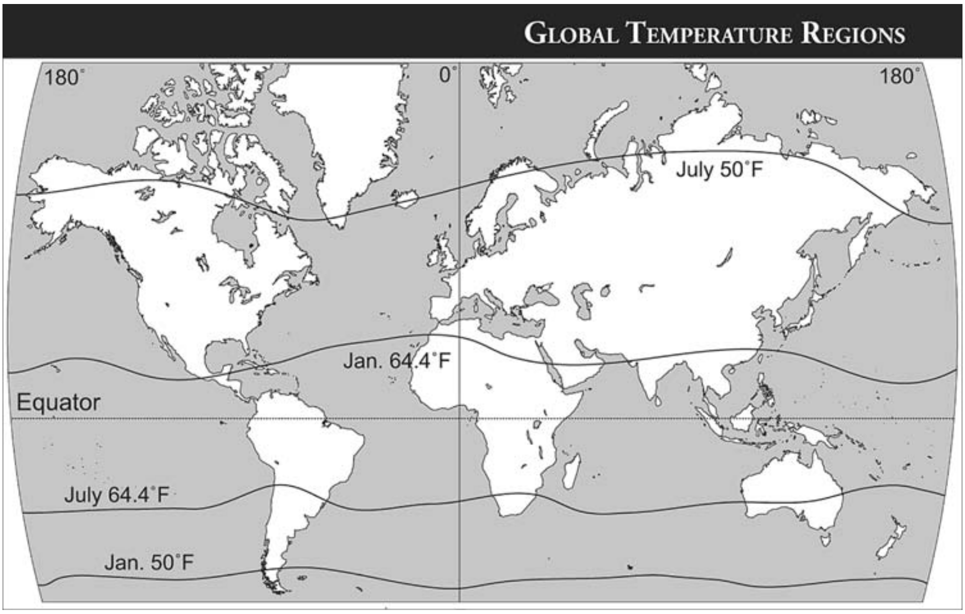


Figure 2-4 Using the same criteria employed in the older concept of climatic regions—50°F for the warmest month and 64.4°F for the coldest month—this map illustrates what we know now about temperature regions. These categories are opposite, in terms of time of year, south of the equator. (ABC-CLIO)

two degrees of latitude. In addition, as has already been mentioned, the tilt of the earth's axis that is the cause of these limits also varies. One of the unexpected outcomes of the earth's orbit is that North America and Europe experience their coldest weather when the earth is closest to the sun, and their warmest weather when the earth is at its farthest point from the sun. The idea that latitude determined the temperature anywhere on earth persisted for centuries, simply because there was very little data to contradict this assumption.

Today we have a great number and variety of observations of temperature, precipitation, and atmospheric conditions generally. The U.S. Weather Bureau prepares a detailed weather map of Asia, North America, and Europe every day. Data is constantly received from satellites that send photographs of cloud patterns back to earth. Special instruments within the satellites measure the flows of energy away from different parts of the earth. The instruments used for this kind of measurement are sensitive to heat, or infrared radiation, rather than light. Banks of computers assemble almost limitless quantities of data, all of which are used to support or correct the models that climatologists designed from previous sources of information. With all of this wealth of information, it is easy to redraw the map of the world's zones. This revision can be seen in Figure 2-4 where the same isotherms as those used in Figure 2-3 are repeated—but they are no longer straight lines. One of the biggest changes in the isotherms, compared with those in the older map of zones, comes from our understanding of the different rates of heating that occur with land as compared with water. This has already been described in relation to the way that such differences may have been the triggers that initiated ice ages in the distant past.

Keep in mind the relevance of the tilt of 23.5 degrees in the earth's axis as it proceeds on its orbit, technically named the ecliptic. We see again and again how the 23.5 degrees determines many of the important seasonal boundaries on earth. The two factors that determine how much energy a place receives from the sun are the angle at which the sun's rays strike the surface and the length of time the location is exposed to the rays. The second one means that the amount of energy received is approximately the same at all points at any given latitude. From these two considerations, and from the determination of the amount of solar energy at different latitudes, we can see that the vertical rays of the sun move throughout the year between 23.5° north to 23.5° south. They are never directly overhead beyond these latitudes. The March equinox marks the beginning of the spring season in the northern hemisphere. It is the time when the sun is directly over the equator. The sun is again directly over the equator at the September equinox, marking the beginning of the fall season in the northern hemisphere.

We can measure the length of the year and therefore of the seasons either from equinox to equinox or from solstice to solstice. This is the method we employ in the calendars we use today. It is often referred to as the tropical year, and it represents a complete cycle of seasons. Some places use the time between two successive occasions when the earth is at its closest to the sun as the definition of a year. Although the solstices represent the high points of the summer and winter seasons, they do not represent the warmest or coldest days. This is because temperature depends not only on the amount of heat the atmosphere receives from the sun, but also on the amount of heat it loses due to the absorption of this heat by the ground and ocean. It is not until the ground and oceans absorb enough heat to reach equilibrium with the temperature of the atmosphere that we feel the coldest days of winter or hottest days of summer.

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CHAPTER 3

Finding a Place on Earth

Until the twentieth century, weather and climate data were local events, transmitted from place to place only to inform travelers and business people who might be interested, but not used extensively by meteorologists elsewhere as they predicted local and regional weather. In the United States, early systems of communication were in use from coast to coast before 1900 because scientists knew that weather patterns frequently moved across the country from west to east, and it was therefore essential for people in New York to know what was happening in California. The rest of the world was considered irrelevant to local weather right up to the middle of the twentieth century, when there was greater understanding of the atmosphere and its worldwide interactions that so often affect weather everywhere. Demand soon arose for accurate knowledge of weather conditions everywhere. Implicit in that demand was the need for precise information on any place on earth, information that could be transmitted to meteorologists in any other place.

With the advent of satellites, computers, the digital world, and the numerous means of communications of the modern world, all that had to be added were maps that identified exactly the location of any place on earth, and a method for any other place on earth to get that information instantly. Weather satellites, weather balloons, and radar installations that frequently used responders in ocean areas provided constant flows of information about weather conditions everywhere. It is not very easy to make a world map that will accurately tell the exact location of every place on earth. This is because maps are flat and the world is round. You can prove this principle for yourself by taking a sheet of paper and trying to make it fit exactly over a globe without having to crinkle some parts of it.

To solve the problem of making the perfect map for weather information, map designers began with the standard grid of x and y geometrical coordinates that architects use when laying out a plan for a community. They then asked themselves how they could make a similar geometrical grid that would fit a curved surface, that is to say, one that would fit the globe of the earth (even though the shape of the earth is not exactly a globe). They began with a grid of latitudes, circular lines around the earth that are easy to identify, starting with the equator as the zero line of latitude. Navigators from earliest times have been able to fix latitudes, using a sextant to determine the elevation of

For most of history, captains used the sextant to find a ship's latitude. (Bettmann/Corbis)

the sun at high noon, or at night the elevation of a star of known movements such as the North Star. The elevation is the angle between the horizon and the bottom of the celestial object. The navigator would then use historical tables that matched elevation with date to give the latitude. In this way, two sets of ninety degrees of latitude were fixed, north and south from the equator to the poles.

It was a much bigger problem to fix longitude of places on earth. It was easy enough on land because the earth's circumference was known and, once a starting line was fixed, 15-degree lines, known as longitudes, could be marked east and west at appropriate distances from the starting line all the way to the 180-degree line on the opposite side of the globe. The difficulty of finding some longitudes arose as navigators found themselves in the middle of vast stretches of ocean. Although they could approximate where they should be by what is called dead reckoning, or measuring distances from knowing the ship's speed, that method was not accurate enough. The key to a solution lay with having a clock that could maintain accuracy at sea. On land, navigators had discovered that for every 15 degrees they traveled east or west there was one hour of difference in the noon-hour time. They wondered how to use that knowledge at sea.

Scientists for centuries tried to make a watch that would stand up under the rigor of ship movements at sea. Any instrument that depended on a pendulum could not be used. Galileo was the first to try, but his attempt failed. It was near the end of the eighteenth century before the problem was solved. Captain Cook demonstrated the reliability of a new watch when he used it on his third voyage to the south Pacific. The lines of longitude could be placed in position once accurate clocks were available. The line from the North Pole to the South Pole that passes through London, England, was taken as zero longitude, and the whole earth was marked out from there. A problem arose when Magellan, the first sailor to travel around the world, arrived

The International Date Line

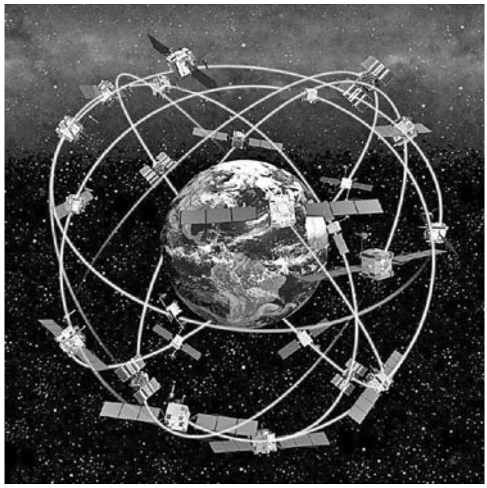
We know that the date does not change if we fly from San Francisco to New York or from New York to Paris. But what happens if we fly in the opposite direction to Japan or China? Will the date be the same? The first people to sail around the world from Europe, under their captain, Ferdinand Magellan, around southern South America and all across the Pacific, were careful to change their date every day when the sun came up. However, when they got back to England, they had a surprise. They had lost a whole day. What happened? They did not have accurate clocks in Magellan's time, so they were not able to tell exactly how many degrees of longitude they had passed through. At 180 degrees of longitude west, people traveling west are 12 hours earlier than noon at Greenwich, but those traveling east from Greenwich are 12 hours later than noon at Greenwich.

If travelers were to continue westward beyond the 180-degree line, changing time by one hour for every 15 degrees, they would end up at Greenwich a day earlier because their clocks would have gone backward by 24 hours. People traveling eastward would end up at Greenwich, if they circumnavigated the globe, an extra day late, because they would have moved their clocks ahead by 24 hours. To solve this problem, the nations of the world agreed to establish a rule for everyone crossing the line of 180 degrees longitude. They called this line the International Date Line (IDL), and everyone moving westward would add one day to their calendar, while those traveling eastward would subtract one day from their calendars. By so doing, everyone would end up at Greenwich, assuming that that was their destination, at exactly the same time and date that they would find there. Clocks and calendars would be correct for any other place on earth as long as the rule about crossing the IDL is remembered.

back in Europe having lost a day on his calendar. He did not have an accurate clock, as none were available in his day, but the daily count could be made. The reason for the problem was later seen in the fact that Magellan lost an hour every time he moved fifteen degrees to the west. To solve the difficulty, the International Date Line was invented. It runs north and south, and every ship gains or loses one day as it crosses this line, depending on which direction the ship is moving.

THE GLOBAL SATELLITE NAVIGATION SYSTEM

Once the lines of latitude and longitude are known, and places in between them can be identified by fractional parts of one degree such as minutes and seconds, every location on the globe can be described by a number. The next question that comes up is this: if we know the weather at one of these places, how can people in other parts of the world get that information immediately? This is where the Global Positioning System (GPS) comes in. The U.S. military, in the post–World War Two years, developed and implemented this satellite network as a military navigation system, but soon opened it up to everybody else. It consists of 27 satellites that fly high above the earth, about 12,000 miles up, along with three extra ones in case of failures. The heart of this system is the GPS receiver, because it decides what, when, and how information is needed. It is therefore essential that



Global positioning system (GPS). (NOAA)

every receiver, anywhere on earth, must be able to receive at all times, by unobstructed radiation, whatever information is needed. For this reason there are at least four satellites always visible in the sky from any point. By visible is meant that they communicate in a direct line of transmission to the receiver.

The receiver's job is to locate four or more of the satellite transmitters, figure out the distance of each one from the receiver, and then do some calculations. Sometimes, several transmitters may be in one satellite. This is not the extraordinary problem that it sounds like when you first hear it. In this digital age, all the person at the receiver needs to do is enter, from a list, a reference number for each of the four, and then another reference number for the place where the receiver is located. Immediately the desired information appears on his screen. The technical name for the calculations that are made is triangulation, or trilateralism if four or more satellites are involved. You can visualize what is happening in all the calculations, since the way they work in GPS is exactly the same way they would work on earth, whether with three places or more. If you are standing beside a highway and you find out from a passing driver that you are 550 miles from town X, and also discover from another driver that you are 400 miles from town Y, you can draw circles to represent these two distances and wait for someone to give you one more measure, this one from another place. The first two give you two possible answers, at the two points where the circles cross each other. The third circle coincides with one of these two, giving you the answer you need, namely your exact one and only location on the earth.

There are thousands of civil users of GPS all over the world, some direct users at receiver stations, most of the others users of users, that is to say, linked via smaller receivers in some way so that the same provision of information is available to them. Coded signals are provided for each user, whether directly from satellites or from another receiver, providing position, speed of movement, and time. A GPS receiver can be so small that it is easy to install it on an individual or in an important package so that the whereabouts of the person or package is available to another person at all times. One of the most widely employed uses of GPS receivers is in private cars: using a road data bank, a route calculation module, and the GPS receiver, the driver is provided with a map in the dashboard that has the highway, or street, being traveled highlighted with an arrow or icon. This arrow or icon moves along the road marked on the map, keeping in step with the car's speed at all times. Of much greater importance to the subject of this chapter is the ability of GPS to collect information from a known location and relay it to any or all other locations. Once a GPS location is linked to information from meteorologists, the data the meteorologists are reporting can be relayed to weather stations around the world.

CHAPTER 4

The Water Cycle

The water cycle, frequently referred to as the hydrologic cycle, is a continuous movement of water on, above, and below the surface of the earth. It has no beginning or end. Water can be found in different states: water vapor, liquid, dew, ice, or cloud. The total amount of water on earth has remained constant over time. More than 97 percent of it is in the earth's oceans, more than 2 percent is stored in ice sheets and glaciers, and most of the remaining 1 percent is in lakes and rivers. The whole water cycle involves only a tiny fraction of earth's water, not more than 1 percent of the whole, yet the total volume of water in that 1 percent is huge: it has been estimated at more than 20 times the total amount of water in all the Great Lakes. A major factor in water's influence over weather and climate relates to the energy exchanges that occur when it changes state. When water changes to water vapor, for example, it extracts energy from its environment, making the environment cooler while water vapor gets warmer. When water vapor changes back to water, this energy, known as latent energy, is released back into the environment, making it warmer. Similar exchanges of latent energy occur in other transformations.

Water Ice and Water Vapor

Water can exist in three different states: liquid as water, solid as ice, and gaseous as water vapor. Each has its own properties. Furthermore, changes from one state to another require the transfer of heat energy. One of the simplest examples of differences in properties can be seen in the density of water compared with ice. The former is denser than ice and hence, once a pond freezes and ice is formed, the ice, because it is less dense, floats on the surface. The terms used to describe the changes that occur are as follows: ice melts to form water, water freezes to form ice, water evaporates to form water vapor, and water vapor, when it cools, condenses into water. The terms used for direct changes from solid to vapor and vice versa are less familiar: sublimation is the term used when ice changes directly into water vapor without first becoming water, and deposition is used to describe changes from water vapor to solid ice crystals without first becoming water.

Latent heat is often described as "hidden heat," and it comes from the motions of molecules as a substance changes its state. It is an extremely important aspect of our environment because it operates at different scales, from evaporating a cup of water into water vapor to moving thousands of tons of water from equatorial regions to polar ones. Warm winds blowing across an ocean can evaporate huge volumes of water into water vapor and, in the process, draw heat from the ocean and store it as latent heat in the water vapor. Later, by condensation, the water vapor may be released in colder places, warming them by releasing its latent heat.

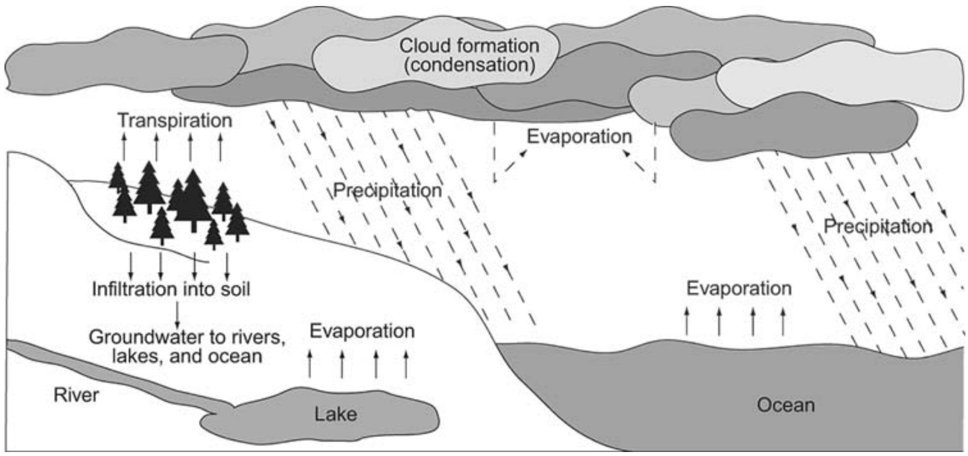


Figure 4-1 The global water cycle. (ABC-CLIO)

In fact, any change of state with water involves energy exchanges. Water can go from solid ice directly to water vapor and also from water vapor directly to ice or ice pellets or overnight frost. Latent heat is transferred in all of these. From solid to liquid, liquid to water vapor, or solid to water vapor, heat is withdrawn from the surrounding environment and stored as latent heat in the molecules of the new state. When changes go the other way, this heat is released. The water cycle is often seen as having two parts. It starts as the transfer of water from the earth into the atmosphere as water vapor. With its added warmth, this water vapor moves into the atmosphere and is carried globally by wind systems, thereby distributing water vapor around the world. The second part begins with cooling as the humid air reaches its dew point and precipitation begins. Rivers and underground flows of groundwater are the agencies of transportation to carry the water back to its main source, the oceans.

THE WATER CYCLE BEGINS

The cycle begins as the sun heats the surface of the earth and evaporates water to become warm water vapor. As this happens, the environment is cooled. We see this multifaceted process in different locations, in moisture rising from a newly plowed field, in mist ascending from streets when sunshine follows rain, or in tiny puddles drying up. Underground water, known as groundwater, is drawn up to the surface by the roots of plants and released into the atmosphere by transpiration. That means direct transfer of moisture into water vapor from the pores of leaves, rather like the perspiration we experience when we are physically active. This movement of water out of plants is something you can feel if you are in a forest on a hot day. More than all other

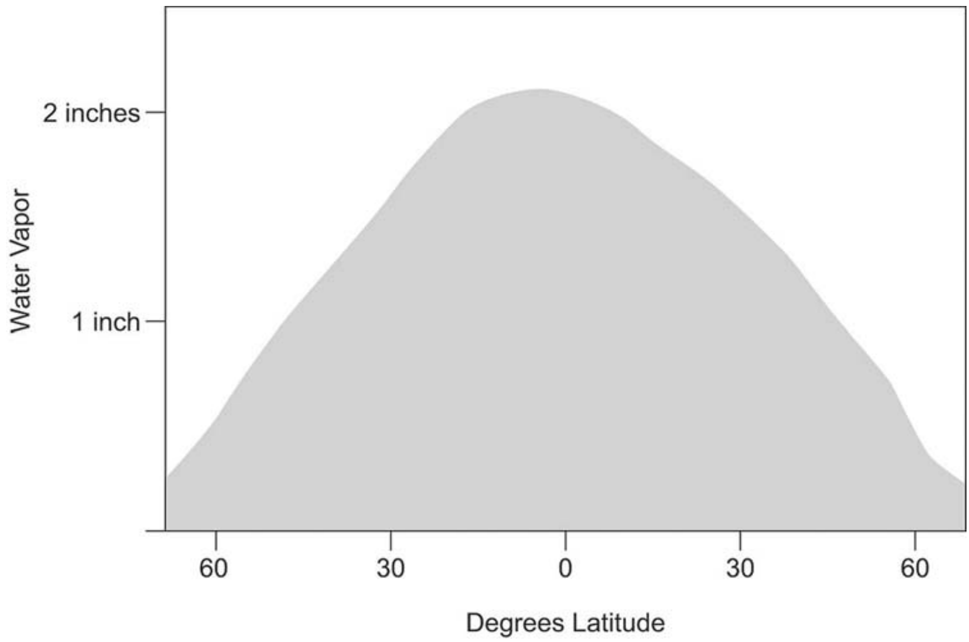


Figure 4-2 The higher the temperature, the greater the amount of moisture the atmosphere can hold. (ABC-CLIO)

places from which water is evaporated, the vast stretches of oceans are the main sources.

Water vapor is carried upward into the atmosphere and moved around in the global circulation of air that was described in Chapter One. As water evaporates, the molecules in the vapor exert a pressure, and this adds to the pressures from other gases that already exist. Once this pressure from water vapor matches the pressure existing in the water from which it came, all evaporation activity stops. This is called saturation vapor pressure, so named because the air is now saturated and can hold no more water vapor. As temperatures increase, the capacity of the air to hold more moisture increases. A diagram of water vapor pressure matched against latitude illustrates this ability of the air to hold more moisture as its temperature increases. The closer air is to the equator, the warmer the atmosphere is, and therefore the more water vapor it can retain.

Relative humidity is the term we use to describe the amount of water vapor in the atmosphere at any given time. It is represented as a fraction that relates the amount of water vapor in the air at any given time compared with the maximum possible amount that the air could carry. If the relative humidity is very high, it does not matter whether the actual temperature is high or low, we feel a bit uncomfortable, especially if we are active in a game or physical activity, because perspiration tends to stick to our skin. The reason, of course, is that the high relative humidity prevents any more moisture from evaporating into the atmosphere. We sometimes say, under these conditions, that the air is sticky.

PRECIPITATION STORAGE AND RUNOFF

Water is cooled when it rises in the atmosphere, not because of the influence of cooler surrounding temperatures, but because of the lower pressure at higher altitudes. Lower pressure always occurs when air rises into higher elevations. A basic law of physics informs us that lower pressure always means lower temperature; this law can easily be tested by the reactions of a bicycle tire as pressure is increased on it. The more air you pump into a tire, the warmer it gets; the reverse action always leads to lower temperature. Thus, air moving over mountains causes lower pressure, as does heating of parts of the ground so that hot air bubbles rise. Lower pressure is also the result of air mass encounters, as cold air forces warm air upward. The result is condensation, water vapor changing into water in the form of clouds, rain, snow, fog, or ice pellets.

Some precipitation falls as snow and can accumulate as ice caps and glaciers, which can store frozen water for a long time. Most precipitation falls back into the oceans or onto land, where, due to gravity, the precipitation flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, where stream flow moves water toward the oceans. Runoff and groundwater seepage accumulate and are stored as fresh water in lakes. Not all runoff flows into rivers. Much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes layers of permeable rock that store water. Over time, water continues to flow, much of it into the oceans, where the water cycle starts all over again.

Water vapor must have a surface on which to condense, and such are found in the tiny particles of salt or industrial dust that prevailing winds are able to keep aloft in the air. Simple experiments can demonstrate the necessity of having these minute molecules before precipitation can happen. Place a jar over a saucer of water and heat the saucer with a lamp. Leave the lamp on until evaporation stops, that is to say, until the level of the water stops falling, then turn off the lamp and observe that water has formed on the sides of the jar because the jar cooled more quickly than

Atmospheric Pressure Change with Height

Air at the surface of the earth is subjected to the pressure of a whole ocean of air, stretching upward for more than a dozen miles. This huge heap of air exerts a pressure of 15 pounds on every square inch of the earth's surface. Why doesn't all that pressure squash us? The answer is because we have air inside our bodies too, and that air balances out the pressure outside so that we stay firm and do not get squished. If you travel in a plane and the air pressure is reduced a little bit in the cabin, you feel it in your ears. The same thing happens if you go up a mountain. Because the pressure that air exerts is based on its huge volume, you would expect this pressure to decrease as you go up higher and higher in elevation because there is less and less weight of air on top of you. That is exactly what happens, and, because there is less pressure at higher elevations, the air is cooler, and so it continues to rise much slower than it would if it were near the ground.

the air inside it. How do I know that the water vapor condensed on particles, even though I cannot see them? The answer can be found by repeating the experiment with filtered water, water that has no tiny bits of solids in it, and then heat it as before. This time it will be obvious that no condensation takes place even if the relative humidity is at 100 percent, the level that normally always causes precipitation. Depending on how perfect the filtering was done, it will be evident now that, even if relative humidity reaches 400 percent, no water vapor will condense.

Where are the largest amounts of the fresh water that falls as precipitation stored on earth? The answer is in the ice masses of Greenland and Antarctica. Billions of cubic miles of fresh water have accumulated in these two centers over time, and some experts suggest that icebergs from either of these locations could be towed to places on earth that have extreme shortages of water. The costs of doing something like this are very high, and perhaps that is why the only country that seriously thought of doing it was Saudi Arabia, the global capital of oil. With present concerns over global warming and climate change, there is widespread concern about the possibility of these fresh water centers melting. If that were to happen, ocean levels would rise by more than 100 feet. There is another location where large volumes of fresh water are stored, in underground aquifers, layers of permeable rock that store water, often referred to as groundwater. They are usually the only source of fresh water for rural communities all across the United States as well as being a principal source of water for many farming areas. They have given rise to some major national problems. Some of these problems, as they affected the U.S. southeast and California, are described in the Introduction to this volume.

INTERFERENCE WITH THE WATER CYCLE

In numerous ways, human activities interfere with the natural cycle of water, some beneficently, others harmfully. More than a quarter of all the fresh water that falls as precipitation ends up as groundwater, and more than 250 million U.S. citizens depend on groundwater for daily needs. More will be said about this in the next chapter. The reference in the Introduction to this volume to the use of groundwater, particularly in California, is one of the biggest and most controversial examples of using groundwater. No other state has so large a portion of its fresh water withdrawn from this resource. Excessive exploitation of groundwater led to a subsidence of the San Joaquin Valley by one foot on average, and by as much as 30 feet in some places. As a result, seawater invaded the groundwater territory because there was insufficient pressure within the aquifer to prevent this from happening. On a smaller scale, in the coastal areas of the state of Georgia, a similar invasion of seawater occurred because people had been withdrawing too much groundwater.

The water cycle has a long history. For millions of years, it has operated on the land and shaped it into forms that reflect the influence of

Area in India flooded due to heavy seasonal rains. (AP/Wide World Photos)

gravity and the nature of the rocks and soils over which the water flows. Humans entered these lands and selected places that were suitable for whatever type of work and life they anticipated. The courses of streams were altered and dams were built to serve the newcomers, and for a long time it mattered little what they did because the total number of alterations to the landscape were few. It has only been in modern times that the dangers associated with large-scale interference with the water cycle have received adequate attention. In many cases, the damage had been done and was irreversible by the time the problem received attention. Land use changes have interfered with the runoff characteristics of watersheds in India, a country that depends heavily on the monsoon rains. Diversions, storage dams, irrigation schemes, and inter-basin transfers by humans have altered river flows and thus the onset, duration, and destructive power of the floods they experience today.

The enormous scale of deforestation all over the world, especially in southeast Asia and parts of Africa and South America, has probably been the single most destructive interference with the water cycle, simply because of the high volume of trees that were and are being removed. Even in those few places where new trees are planted, the destruction is still massive because new trees cannot do the work of absorbing the volumes of water that older ones can do. In deforestation there are few, if any, redeeming values. Old-growth trees not only prevent flooding, but they also are a key to reducing the global warming and climate change problem because they withdrawing carbon dioxide from the atmosphere. In most cases, the reasons for deforestation are to make room for intensive agriculture of the monoculture kind, or for dairy or stock farming, both of which rob the soil surface of its natural nutrients.

CHAPTER 5

Water Balance or Water Budget

In the previous chapter, we noted the importance of groundwater and the great harm that can be done if too much of it is withdrawn for human use. This chapter will deal with calculating whether enough water is available at any place in the course of the water cycle, not just for human needs in agriculture and in homes, but also for the plant and vegetation life on which we depend. To find out whether water input and water output is well-balanced, so that all vital needs are met, we examine water quantities just as a banker would examine financial quantities as he checks to see if money coming in is balanced with expenditures. Water income, water outgo, and water in storage at a given place are recorded on graphs representing the balance or the budget of water for that place. Plants, unlike us, are more concerned with moistness than with quantities of water, and moistness depends on

Transpiration is the direct transfer of water into the atmosphere from the leaf pores of plants. (Clearviews/Dreamstime.com) two things: the amount of water coming in and the amount of evaporation that is taking place. For many plants, a perfect water balance occurs when the supply of water is just sufficient to keep the soil moist. Any different level of supply represents either a water deficiency or a water surplus.

In the United States, for the most part, people tend to take the supply of fresh water for granted, because there is usually a surplus from the water cycle in most places. Only when there is a period of drought, as happened in the western states during the Dust Bowl years of the 1930s, do we give special attention to it. Most of us live in cities where water is always available from taps, so there is little need or ability to sort out where it all comes from. In the different books of this series on weather and climate, most of our study of water is focused on its role in the atmosphere, because of the pervasive influence it exercises there on weather. However, as far as our use of fresh water is concerned, it is what happens when water reaches ground level that matters most. Is it available in places where we can use it? Will it flow away back to the ocean, or will it replenish lakes and reservoirs? Of most importance to us is whether or not it will seep into the soil to restore groundwater supplies and also to support plant life. If rainfall is very light, most of the water may evaporate back into the atmosphere. If precipitation is heavy, much of the water will enter the soil and provide moisture for plants.

WATER INFILTRATION AND ARTESIAN WELLS

As water is added to the earth's surface, it moves downward through the surface soil at varying rates, depending on the nature of the ground beneath, until it reaches the bedrock. The penetration is through spaces between soil particles, usually referred to as pore spaces. If the soil is mostly clay, the pores are small and the rate of infiltration is slow. If the soil is sand, the pore spaces are much larger and water accordingly moves down faster. Bare ground is a poor conductor of water; under conditions of average rainfall, it tends to harden so that water runs off rather than penetrating downward. That is why farmers and gardeners make sure that plants cover the soil surface as often as possible so that their leaves absorb the impact of raindrops, allowing soil pores to remain open for rain to move into the ground. Often, in order to maintain easy access into the ground for rain, when the surface happens to be bare during winter, farmers will cover the bare surface with layers of straw or similar substances to serve as substitutes for growing plants.

Some water, as it infiltrates downward, is retained in place by surface tension and attraction between molecules, important features of the nature of water. These small quantities, called capillary water, prove to be essential to the survival of plants in very dry regions of the world because they can be absorbed into plant roots in times of drought. When rain returns, these capillaries are replenished and kept for future

Pumping water from a large aquifer into a storage tank in northwest India. (AP/Wide World Photos)

possible use while the rest of the incoming water continues downward until it reaches an impervious layer. The top of this layer is known as the water table, and it is above this layer that water accumulates to form groundwater resources. During the time of year when the input of rain exceeds the amounts withdrawn through evaporation and by plants, the water table increases in volume. At times, in humid climates, it may rise high enough to release water into neighboring streams. Whether it is located in a humid climate or in a dry one, it is here in the groundwater zone that great care must be exercised in withdrawing water for agriculture or domestic use. Charts that show the amounts of groundwater available during different seasons are essential tools to keep such withdrawals in balance.

If a layer of highly permeable material, such as sandstone, is located within the groundwater zone, large quantities of water can be stored there because its pore spaces are large, and this resource often remains in place semi-permanently, providing exceptional quantities of fresh water that can be withdrawn to the surface. The name aquifer is given to such formations, and often they extend horizontally below ground for hundreds of miles. If an aquifer is located between two layers of bedrock, pressure builds up as more and more water accumulates within it. When a hole is drilled from above to withdraw water from such an aquifer, there is no need to pump up water because the pressure that had built up releases the water. An aquifer of this kind is known as an artesian well, and, if it happens to be located in a region of moderate or high rainfall, it could provide a continuous flow of water at the surface.

EVAPORATION AND TRANSPIRATION

About two thirds of the precipitation received by the land is returned to the atmosphere by the combined processes of evaporation from the soil and transpiration through the pores of plants. The term evapotranspiration is used to define this double action. The evaporation process is the same as the one we can see on a hot day after rain as small areas of water slowly disappear from the ground. Transpiration is the movement of water from the ground through plant roots to their leaves, from the pores of which the water moves into the atmosphere as water vapor. The transpiration process can be observed in an experiment: place a plastic bag tightly around a green plant and leave it overnight. The next morning, observe the moisture that transpired on the sides of the plastic. To measure the amount of water involved, take a second plant. Weigh both plants, leaving one open to the air above and the other covered with plastic as before. The next day, weigh both plants and compare the changes in weights.

During evapotranspiration, water changes from liquid to vapor, and we know that such changes require energy; in particular, energy is withdrawn from the plant's environment and added to the water vapor as latent heat. As a result, the main factor controlling the rate of evaporation is the amount of energy available. Thus, in tropical areas of the world or in hot deserts, we would expect to see high rates of evaporation. If rainfall in these places is low, this high rate of evaporation may not be a benefit unless it happens to coincide with months of good rainfall. If we look at two maps of the world, one showing temperatures and the other places that have the highest rates of evapotranspiration, we end up with a very close correlation between the two maps. However, in this example, the places with highest rates of evapotranspiration are also places that have substantial amounts of rainfall, so we can conclude that the highest rates of evapotranspiration will likely occur where temperatures are highest.

Calculating the actual amount of moisture that reaches the atmosphere is thus a function of temperature and rainfall regime. Temperature determines what is possible, and we use the term PE to define this potential evapotranspiration. AE is the term that defines what is transferred into the air in particular areas, the actual evapotranspiration, and the data we need to illustrate this has to be found experimentally in places around the nation. Fortunately, much of this work has already been done, and tables of PE and AE are now available. The essential implication of the difference between PE and AE is the monthly provision of moisture, whether it is sufficient to make PE a reality and, if not, how irrigation or some other method may make up the difference. The water budget data listed in Table 5.1 come from a place in northern Wisconsin. They are typical of places in the northern areas of Midwest states.

If we assume that the amount of moisture available in the soil represents four inches of depth, during those months when P is greater

TABLE 5-1 Water Budget Data for a Place in Northern Wisconsin

	January	February	March	April	May	June	July
Precipitation	0.9	0.8	1.0	1.5	2.2	2.8	3.6
Potential Evapotranspiration	0	0	0	0.6	2.5	4.2	5.0

	August	September	October	November	December
Precipitation	2.8	3.4	2.5	1.6	1.0
Potential Evapotranspiration	4.2	2.8	1.3	0	0

than PE, then we can figure out for each month of the year when AE differs from PE and therefore when supplementary quantities of water are needed.

The only months in this example in which the incoming precipitation is less than what is needed for PE are April, May, June, July, and August. April has a shortage of 0.9 inches so, because there are the equivalent of four inches of rain already in the soil, 0.9 can be taken from that resource to make PE possible. The same can be done for May, June, and July, by which time all of the four inches of soil moisture is used up, leaving August as a deficit month, one that falls short of PE demands by1.4 inches. This is the only month where AE evapotranspiration occurs instead of PE.

This place in northern Wisconsin is typical of many all around it. Throughout the winter, soil and air temperatures are low, plants are dormant, and loss of moisture from the ground is slight. Snow frequently accumulates on higher slopes, and incoming precipitation seeps into soil, streams, and lakes. By late winter or early spring, melting snow adds water to streams and saturates the soil, ensuring that the average amount of water in reserve will remain at the level of four inches for some time.

Antarctica, the Coldest Climate

The climate of Antarctica is the coldest on earth. The lowest temperature ever recorded on earth was –128.6°F at Vostok, a Russian research station in Antarctica. Antarctica is also extremely dry, with an average of two inches of rain per year, making it technically a desert. At the beginning of the twentieth century, Antarctic explorers were finding out for the first time what conditions were like. On most parts of the continent, the snow never melts. It is eventually compressed to become the glacial ice that makes up the continent's ice sheet. Weather fronts rarely penetrate far into the continent. Around the sides of the ice sheet, cold winds sweep down off the ice caps in chinook-type winds at speeds of 150 miles per hour. Our present understanding of this continent's weather and climate has unlocked many of the difficulties we had in understanding conditions elsewhere around the world. Knowing more about Antarctica also helped us take action to stop the erosion of the ozone layer in the upper atmosphere, the layer that protects us from the lethal ultraviolet rays of the sun. When trouble with this layer takes place, we see it first in the atmosphere high above Antarctica.

Much of Saudi Arabia's water for agriculture is taken from the ocean through desalination plants. This photo shows a tomato field. (Corbis)

As warmer weather approaches, high amounts of energy input from the sun, coupled with increased evapotranspiration, reduce the amount of soil water available. There comes a time when all of it is used up in maintaining the PE levels that represent ideal conditions for plant health. In the case of the place for which the above data applies, the time of moisture shortage arrives in August and is gone by September.

The circulation and distribution of the world's water often leaves many places short of water. We have not yet found economic ways of resolving these shortages. Many different approaches have been tried to distribute water more effectively on the surface of the earth, but not one has been universally successful in the sense that it applies to any country. In Saudi Arabia, fresh water is processed from seawater on quite a large scale to meet the needs of that arid country, something that is possible there because of its oil wealth, but that is impractical for most other nations. On smaller scales, other efforts have been made, such as reducing evaporation from reservoirs by placing covers on them. Coastal nations have sometimes been encouraged to tow icebergs from Greenland or Antarctica and melt them. No nation has attempted this. As different places cope with the problem, the local water budget is a convenient model to help them account for their income, storage, and outgo of water. Using this method, a value is obtained for deficit or surplus of water during every month of the year.

Water may be stored in the soil as capillary water in the root zone or as gravity water at lower levels. It is removed from the land mainly through evaporation and transpiration, processes that are now together represented by the word evapotranspiration. Two thirds of the precipitation reaching land goes back into the atmosphere by this means. The other third leaves the land as runoff from surface or underground streams. Water on and in the land is a vital part of the water cycle. It involves many processes and movements of water between each of its three physical states, liquid, solid, and gas. Although more precipitation falls on the oceans than on the land, the most important circuit for water, as far as its value for humanity is concerned, is as follows: from the ocean to the atmosphere by evaporation; from the atmosphere to the earth's surface by condensation and precipitation; from soil to the atmosphere by evapotranspiration; and again to the earth's surface by precipitation.

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CHAPTER 6

Global Weather and the Oceans

Our understanding of the powerful role that is played by oceans in the global weather and climate system is constantly expanding as research fields add additional knowledge. Little thought was given to the relationship between global weather patterns and ocean currents until the 1960s. It was assumed that the atmosphere and the world's oceans operated as two unrelated systems. The first breakthrough came in the late 1960s when deep ocean studies, inspired by the U.S. military need to follow the movements of Soviet submarines, discovered the mid-ocean trenches from which magma emerged to create a world network of tectonic plates. These plates, in turn, cast new light on volcanic eruptions all over the world, strong polluters of the atmosphere, as we have seen in earlier books in this series. Different sea surface temperature regimes around the mid-ocean ridges came to be known as additional influences on the atmosphere.

The U.S. National Aeronautics and Space Administration (NASA) and the French government launched a new research satellite on June 20, 2008, from Vandenberg Air Force Base in California. This satellite is designed to chart sea levels all over the globe. The results will be used as a measure of the increases in global warming and climate change. Precise measurements from this mission will update existing knowledge of global and regional sea-level changes. It will also make possible more accurate weather, ocean, and climate forecasts. For example, measurements of sea-surface height reveal the

Weather Satellites

The first weather satellite was sent aloft in April 1960. Within a few years, many more were added, providing daily coverage of global weather patterns. Some were geostationary, appearing to be in a fixed position over the equator because they traveled at the same speed as the rotational speed of the earth. They provided pictures of half the earth every 30 minutes. Still later, specialized satellites were sent up, each dealing with one or two features: for example, one of these might deal with temperatures only, those at all levels of the atmosphere from the satellite to the surface of the earth plus temperatures at the surface of both the land and the ocean. Some of the other features of the environment that are now being recorded from above include the extent of polar snow and ice, the wind and wave patterns at sea, the condition of vegetation from polar regions to the equator, global pollution, and changes in the ozone layer.

Artist's impression of the Ocean Surface Topography Mission satellite, Jason-2, measuring variations in the world's oceans. (NASA/JPL-Caltech)

speed and direction of ocean currents and tell us how much of the sun's energy is stored in the ocean. The satellite has a lifetime of three years, and scientists are confident that it will complete its work within that time. The U.S. National Academy of Sciences (NAS) is concerned about our lack of knowledge of the world's oceans and urges scientists to expand research on this aspect of the global environment.

The NAS sees the need to be prepared for any and all developments in the oceanic system. That means being able to predict what could happen and when. To that end, we need the oceanic equivalent of our land-based meteorological instrument network. Such a network would begin to reveal climate-influencing oceanic processes that have hitherto been beyond our ability to grasp. These instruments, monitoring critical present-day conditions, can be coupled with computer modeling to project how the earth's climate system might react in the future. In one of its reports in 2008, the NAS made reference to what it called, and titled the report, "Abrupt Climate Change: Inevitable Surprises," based on the evidence of past events of this kind. In the opinion of the NAS, unexpected climate changes may be inevitable, but it is not inevitable that we be surprised or ill-prepared to cope with them. In this chapter, we will examine aspects of the ocean that affect our daily lives and those that relate to understanding better the ocean-atmosphere system.

BIOLOGICAL CHANGES IN THE OCEAN

An oceanographer from Oregon State University, studying relationships between climate and the global activity of ocean plants called phytoplankton, pointed out early in 2008 that phytoplankton are of tremendous importance to humans because their photosynthesis yields oxygen for us to breathe and they are the base of the ocean food webs that support global fisheries. Despite their microscopic size, the ocean phytoplankton are responsible for about half of the photosynthesis on earth, a process that removes carbon dioxide from the atmosphere and converts it into organic carbon to fuel nearly every ocean ecosystem. With the aid of satellites, phytoplankton are being tracked, and the results cause concern. The amount of photosynthesis going on is dropping, mainly due to warming temperatures and increasing amounts of carbon dioxide.

The ocean absorbs about half of all the carbon dioxide produced by human activities, and it does this mainly in the cold regions because carbon dioxide dissolves easily into cold water. When carbon dioxide reacts with water, it forms carbonic acid and releases more hydrogen ions into the sea. This leads to increasing amounts of acidity and, as hydrogen ions bind with carbonate ions, animals such as hard corals and certain mollusks and plankton are deprived of the raw material they need for their calcium carbonate shells and skeletons. Models predict that cold-water corals may lose 70 percent of their habitat by 2100, with some waters becoming corrosive as early as 2020. The increase in acidity makes it more and more difficult for ocean water to absorb

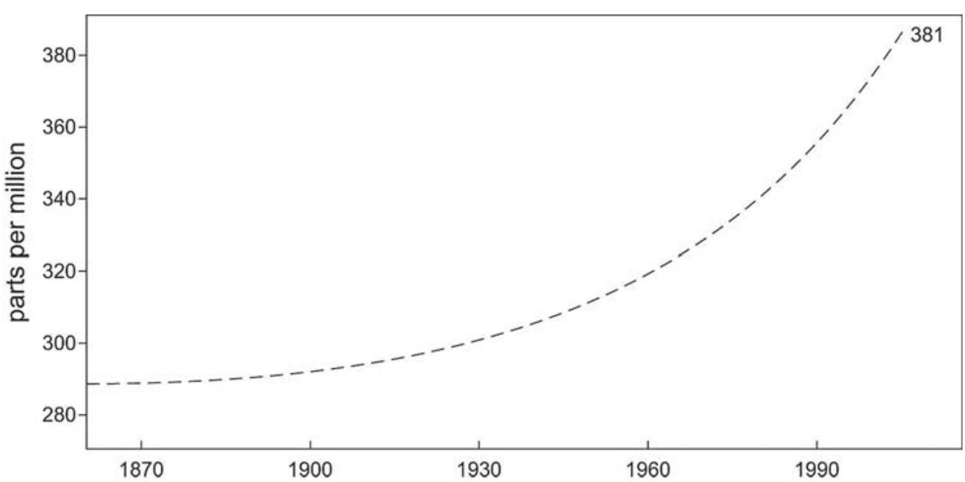


Figure 6-1 Growth of carbon dioxide in the atmosphere over time. (ABC-CLIO)

An emergency hospital room in Peru during a cholera outbreak in 2004. (Centers for Disease Control and Prevention)

carbon dioxide, with the result that the atmosphere will receive more than it is already absorbing.

An event in the ocean off the Peruvian coast in the early 1990s caused a cholera outbreak that killed thousands of Peruvians. Biologists have been reminding us of this event ever since because of its connection to global warming and climate change. Temperature changes in the ocean near Peru are well-known because of the periodic El Niño and La Niña events. Apparently, at the beginning of the 1990s, there was an unusually high rise in the ocean temperature. As a result, an explosive amount of growth occurred in phytoplankton, creating disease outbreaks that killed many Peruvians. It was this link with high ocean temperatures that convinced biologists to issue warnings of the likely increase in waterborne diseases all over the world, in lakes as well as in oceans, as temperatures increase due to global warming. Their warnings are focused on large U.S. cities because of their ancient sewer systems.

New York, Washington, and Chicago are among the many U.S. cities where sewer systems were originally designed to carry storm water and sewage in the same pipes. These systems have not been upgraded. They are like many other aspects of the nation's infrastructure, buried underground and invisible, likely to be ignored until events force authorities to give attention to them. Heavy rainfall is generally recognized as concomitant with global warming, and the U.S. Environmental Protection Agency has already linked the heavy rainfall of the years 1950 to 1990 to half of the country's waterborne diseases. One example of the problem of the old sewer systems was evident in Chicago, early in the fall of 2008, when unusually heavy, persistent rainfall forced authorities to release runoff water and raw sewage into Lake Michigan in order to prevent urban flooding.

POSSIBLE FAILURE OF THE THERMOHALINE CIRCULATION

The oceans influence the world's weather and climate by storing solar energy and distributing it around the planet through ocean currents, including surface wind-driven currents, those that operate just beneath the surface, and the deep-water flows that return cold water back to the equator. The ocean conveyor belt, also known as the thermohaline circulation (THC), is the agent that does most of this work. It is a continuous flow of water that moves through all the major oceans and touches Antarctica and the areas near the North Pole. Only in the past two or three decades has it received intense study, as the role of oceans has been seen as more and more significant in affecting the growth of global warming. Questions are coming from many places as research unveils more and more data about the THC, particularly data about the enormous amount of water that flows through this circuit.

It is known from fossil evidence and computer models that, in the past, the earth's climate has changed dramatically, often within short periods of time. It is also known that the earth's complex, dynamic system has more than one mode of operation, each producing different climatic patterns that have sensitive thresholds. If one of these thresholds is pushed hard in a particular direction, the system can jump quickly from one stable system of operation to a completely different one. These data from the past have been compared to flipping a switch and turning on a light. Why is all this being discussed now? Why are questions such as the following one coming from scientists like James Hansen of

Oceanic Pressure Change with Depth

Water in the ocean does not compress into smaller space as air does, because it is not a gas. Hence the weight that water would press on you if you were down deep under water, say in a submarine, would be based on how deep you were, and this pressure would not decrease with depth in the way air pressure does with height. This pressure would only be on the submarine. You, inside, would still be living in the same air pressure you experienced at the surface. Thus the submarine would be under a pressure equal to the weight of all the water above it plus the weight of the air on top of the water. The weight of the air on the submarine has been calculated and found to be the same as three extra feet of water. Because of the great weight that steadily increases on any object that goes deeper and deeper into the ocean, the materials used in the building of, say, a submarine, must be extremely strong. Furthermore, because the pressure reaches extremely great levels by the time a vessel is one or two miles down, not many have ever been designed to reach these depths with people inside them. Yet we know that many forms of life live and move around at depths of ten or more miles down in the darkness that exists at those depths.

NASA's Goddard Institute for Space Studies: Are we ignoring the ocean's role in climate change? The answer lies in the THC. Scientists have so far identified this agency as the only mechanism that could induce large, global, abrupt climate changes. It alone has the power to create a swift reorganization of the ocean currents circulating the entire globe. These currents, collectively known as the THC, distribute vast quantities of heat around the planet, thus governing the earth's climate.

Something quite new is happening in the THC. That's why the questions are coming now. The oceans and the atmosphere have for a long time been inseparably interlinked in the earth's climate system, but our present knowledge of ocean dynamics does not match our knowledge of atmospheric processes. This essential role of the oceans is too often neglected in our calculations. Is this why we may have missed something very big? In an important paper published in 2002 in the scientific journal *Nature*, oceanographers monitoring and analyzing conditions in the North Atlantic concluded that it had been adding fresh water at an extraordinary rate, continuously, for the past 40 years, and even faster since 1900. The data in *Nature* revealed that the seas feeding the North Atlantic had become less salty to depths of 10,000 feet. This was the largest and most dramatic oceanic change ever measured by modern instruments. At some point, fresh water may begin to pile up at the surface of the North Atlantic. If that were to happen, the THC would slow down or cease operating.

To understand the seriousness of this development, we need to look first at the global links between the North Atlantic branch of the THC and the rest of the world, because they seem to be more important than any other branch of the THC, and then at the events that have been developing over the past decade on land and sea in the Arctic. The equatorial sun warms the ocean surface and enhances evaporation in the tropics. This leaves the tropical ocean saltier. The Gulf Stream, a limb of the ocean conveyor belt, carries an enormous volume of heat-laden, salty water up the east coast of the United States, and then northeast toward Europe. What has been happening since 2000 in this branch of the THC has caught every scientist by surprise. The western Pacific Ocean, which is a major source of heat for the ocean and atmosphere, has warmed in the past century. Meanwhile, the eastern Pacific Ocean has not warmed as fast because of the interference from El Niño episodes, which keep the waters off Peru much cooler.

James Hansen of NASA's Goddard Institute for Space Studies and his colleagues suggest that the temperature differences between the western and eastern Pacific may affect weather patterns around the world. Changes in ocean circulation or water properties can disrupt the THC on a global scale. This oceanic heat pump is an important mechanism for reducing equator-to-pole temperature differences. It moderates the earth's climate, particularly in the North Atlantic region. Its circulation increases the volume of warmer waters in the Gulf Stream by about 50 percent. At colder northern latitudes, the ocean releases this heat to the atmosphere and warms North Atlantic regions by as much as 9°F. However, as has already been mentioned, the THC has slowed and shut down several times in the past. This shutdown reduced the delivery of heat to the North Atlantic and caused extensive cooling throughout the region. It may have triggered one of the ice ages. One leading scientist has called the THC the weak point in the whole ocean-atmosphere climate system.

The tropical saltier water that is taken northward, to form the Gulf Stream in due course, is heavily dependent on its salt. As it moves farther and farther northward, it gets colder, and therefore heavier, so the combined effect of colder, heavier, saltier, water becomes the key component in creating a return flow for the THC back to tropical waters. The heavier water sinks down into deep water in the region around Greenland and Iceland and travels southward at a deep level of the ocean. If this cold, salty, North Atlantic water did not sink, then this part of the THC, a part that happens to be a primary force driving the whole, global, thermohaline circulation, could slacken and even cease. Computer models, simulating ocean-atmosphere climate dynamics, show that, if this were to happen and the Gulf Stream stopped, the North Atlantic region would cool by as much as 9°F. It would produce winters twice as cold as the worst winters on record in the eastern United States over the past century. Furthermore, if such were to happen, it would persist for many decades.

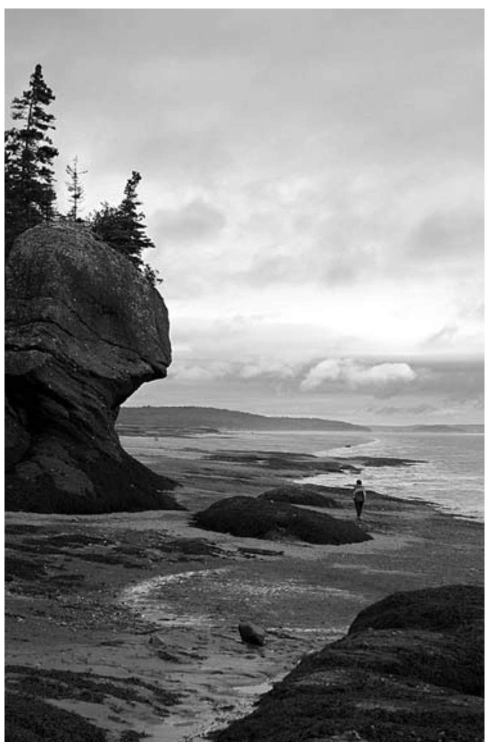
All of this overview begins to make sense when we look at present events in the Arctic. The huge increase of fresh water in the Arctic rivers that has already been reported is one element that will reduce the saltiness of the Gulf Stream and therefore the speed of the return flow. However, far beyond this factor, another development has steadily been both increasing the temperature of the Gulf Stream at its northernmost extremity and, simultaneously, adding fresh water from another source. This development is the rapid melting of sea ice and icebergs throughout the Arctic. The reasons for this were explained in detail in earlier volumes of this series, and were discussed in detail in Volume Four. The fact of this development is the scary part because of its influence throughout the planet. So fast has the rising temperature and rate of melting been taking place over the past decade that more than a dozen expert scientists were completely surprised.

At what threshold will the Gulf Stream branch of the THC stop? We do not know, but we do know that measurements taken of its speed, since 1990, show a measurable slowing down each year. New ocean-based instruments will reveal more of the ocean's essential, but poorly understood, role in the ocean-atmosphere system. Revealing insights from the past behavior of the earth's complex climate system tell us quite a lot about its sensitivity to small changes in any part of the whole. Abrupt THC-induced climate transitions could generate severe winters in the North Atlantic region. A bad winter or two bring inconveniences that societies can adapt to, but a persistent string of severe winters, lasting for decades, can cause unpredictable social disasters. Developing nations are especially vulnerable to the social and economic impacts of abrupt climate changes.

ALTERNATIVE ENERGIES FROM THE OCEAN

Reference has already been made to the use of wave and tidal energy as sources of what we have come to call green energy, that is to say, energy that does not add more carbon dioxide to the atmosphere. Unlike new land-based sources, where the transportation of energy to consumers poses many costs and legal problems as transmission lines are built above or below ground, ocean sources are readily accessible to the main population centers. They are likely to be valuable in our efforts to reduce the amounts of atmospheric carbon dioxide. The potential for generation of tidal hydroelectricity all over the world has already been described. Because of its proximity to major North American cities and because its tidal ranges are so big, the Bay of Fundy tidal site, in Canada, is already under development. Less familiar is the potential for green energy production from the ocean's temperature differentials.

All over the world, there is a huge difference between the surface ocean temperatures and those at depths of a few thousand feet or more. This difference is greatest in tropical areas because the sun's rays warm the ocean's surface layers to a greater temperature. Thus, a considerable difference of temperature can be found within a few thousand feet of depth in lower latitudes, a very important cost consideration when installing pipes from the surface. From cost considerations such as these, Hawaii has been a favored location for many years to explore the eco-



The Bay of Fundy in New Brunswick, Canada, has the world's highest tides. (Cybernesco/Dreamstime.com) nomic feasibility of using this source of energy. Once a temperature difference exists in any place on earth, whether between the indoors and outdoors of a home or between two lines of latitude, energy can be generated from this difference. Hawaii has been working on ocean thermal energy conversion (OTEC) for many years. Heat is drawn from the warmest surface area of the ocean and transformed into a vapor that can generate energy. It is then cooled by water drawn from deeper in the ocean. As part of the operation, cold seawater is pumped into the OTEC building for air conditioning.

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CHAPTER 7

Global Drought and Flood Areas

We tend to focus on temperatures in discussions about global warming and climate change, and this is right as far as it goes because many of the hazards evolving from the presence of carbon dioxide in the atmosphere are a direct result of rising temperatures. The Arctic melting of sea ice with all of its consequences is one major hazard that has already raised serious questions about future climates in Europe and eastern North America. However, moisture is a double hazard. It can increase rainfall in areas that already have high rainfall, and there may be increased droughts in places that are already very dry. The reason is that moisture in the atmosphere is already the most powerful greenhouse gas, although only a minor consideration because of its short time of residence aloft. If temperatures increase, then the atmosphere can hold more moisture, and so world patterns of rainfall will change. We now have a lot of information about the parts of the world that have been experiencing different amounts of moisture.

On an overall scale, the percentage of land affected by serious drought has more than doubled since the 1970s, as reported by researchers at the National Center for Atmospheric Research (NCAR). Areas affected include much of Europe and Asia, western and southern Africa, and eastern Australia. The definition used for

Measuring Weather and Climate Patterns

The U.S. Weather Service, along with similar agencies from other countries, has built up extensive data banks of weather and climate from both present conditions and those from the past. All of this information that they have and freely provide is given in well-defined categories: they include daily, monthly, and yearly averages; maximum and minimum daily temperatures and amounts of rainfall; and records of exceptional periods of time that departed from the average. When people want to know what summer will be like in a particular country, perhaps because they intend to go there, it is from data banks like these that they get the information they want. There is no other generally available source of information on weather and climate that they can turn to, yet we know that average conditions are not what matters to us at any given time, nor what we remember over time. It is the exceptional, the extreme, that creates our memories of weather in particular places, so it is important that extremes as well as averages be included in records of weather and climate. It is interesting that native Hawaiians have four different words for rain, covering conditions from light rain to floods. The different terms help to emphasize that the annual average might range from ten inches in one place to five hundred inches in another.

dryness over this period of time was a doubling of the lack of moisture in sample areas. The growth of carbon dioxide in the atmosphere, and therefore higher temperatures at ground level, over these 30 or more years is already an accepted fact with the IPCC, the scientists at NCAR have concluded that the changes they documented are due to these carbon dioxide changes. They also know from their research that average global levels of rainfall increased, as we would expect. There are disparities in the distribution of these changes around the world since the 1970s: most of the northern hemisphere was drier, while the United States, particularly the area west of the Mississippi, had increases in rainfall.

One disturbing conclusion from the NCAR researchers is that droughts and floods will increase faster than changes in average climate conditions. This follows from what has just been said about the double influence of rising ground temperatures, but there are implications that must be faced. Changes in the amounts of water reaching particular places throughout the past few centuries have been the costliest of all disasters in terms of numbers of deaths. For this reason, above all others, it is vital to monitor regularly, and predict probability of major weather events, in all areas that are presently being affected. In this connection, one area was singled out by NCAR because it has a history of droughts. That was the Sahel region of Africa, a territory that stretches all across the continent south of the Sahara Desert. It has a low rainfall regime most of the time, and it has been experiencing El Niño more frequently since the 1970s, causing additional reductions in precipitation.

Poor agricultural land during the 1973 drought in West Africa's Sahel region. (Library of Congress)

DROUGHTS AND FLOODS

China is a county that is rarely free from either floods or droughts. The name "River of Sorrow" is given to one of its rivers, the Huang He, because of the history of floods and droughts in its valley. It is sometimes called the Yellow River because of the color of the soils it carries. Because of its size as the world's most populous nation, and because of its history of flooding and droughts, China will be the focus of a large part of the first two sections of this chapter. In 2007, a drought in the area through which the Yellow River flows left more than two million people without sufficient drinking water. The drought has led to loss of arable land and livestock. Two and a half million people have been left without sufficient drinking water, and more than 25 million acres of arable land had to be abandoned. There is a continuing problem of water shortage in the northern regions of China, so much so that the central government is planning to divert some water from the Yangtze River to the north.

Iraq, like several other Middle East nations, is another country that suffers from water shortages. Our focus on the conflict in that country tends to distract us from the agricultural life of the people; agriculture is for many their only source of livelihood. In 2008, drought and sandstorms were frequent. This is not a new experience. These dry spells come frequently. In 2008, it meant the loss of much of the wheat crop, the country's principal food source. When there is an exceptionally dry year, as was 2008, dry conditions tend to persist for several

Sowing seed on parched land south of Baghdad, Iraq, during a drought in 2008. (AP/Wide World Photos) years, and this poses an additional strain on farmers to retain seed grain for the future. More than 30 years ago, when Saddam Hussein was vice president of Iraq and relations with the United States were good, the United States donated huge quantities of seed grain to help the country cope with several years of drought. In Appendix B, there is an NOAA list of the twentieth century's weather and climate global disasters, and this list includes many droughts and floods.

We in North America are familiar with floods and the damage they cause, but we often forget about droughts. The Dust Bowl years of the 1930s were a series of events that affected the entire nation, and they are remembered and recounted in the books that were written about them. However, droughts are a continuing problem in the United States, and they are costly. In 1998, for example, there was an extensive drought that cost the nation more than $40 billion, a figure that exceeded the costs of other better-known tragedies such as Hurricane Andrew in 1992, the Mississippi River floods of 1993, and the San Francisco earthquake of 1989. NOAA is well aware of the challenge of dry spells in parts of the country and of the costs they carry. To make sure that no one is caught off guard, this agency of government has a Web site on which daily accounts are posted for any low-moisture areas.

CHINA'S WORST FLOOD

In 1887, China experienced its worst flood ever. The Huang He overtopped its banks in Henan Province and caused widespread destruction and deaths. The dikes on both sides of the river were built to prevent river overflows, because such flooding would destroy the farmlands, the only source of livelihood for the peasants who own and work the farms. From time to time, however, a sudden heavy rainfall can make the river overtop these dikes and flood the neighboring farms. That is what happened in 1887 when the worst flood in Chinese history occurred. Five thousand square miles were inundated. Eleven large towns and hundreds of villages were destroyed. Close to one million people lost their lives, and an additional two million became homeless. Along its extensive course, the Huang He travels through territory where the yellow loess soil is dominant. This soil is easily eroded and then transported by the river. From time to time the amount of soil that builds up in the bed of the river raises the level of the river. A sudden rainfall can then push the river to overtop its levees, and flooding occurs.

In the list of the greatest weather events of the twentieth century, prepared by the staff of NOAA, in Appendix B, you will find a large number of major Chinese floods. The Huang He is the principal location for this tragic history of floods. Historically, after each flooding, the levees are raised to ensure that the next big rainfall will not allow the river to burst its banks. As a result of these successive increases in the height of the levees, the river flows across the farmland at a high elevation above the surrounding territory. Thus, when a flood occurs, thousands of square miles are flooded and hundreds of thousands of people are drowned. The process by which a catastrophic flood occurs in this region is tied to both the amount of silt and the height of the dikes. Throughout most of its history, the Huang He was never dredged, so there was always a slow buildup in the level of the river compared with the surrounding land.

Earthen dikes supported by stones were built on the sides of the river and periodically raised to higher levels as the river rose so that river water was always kept below the overtop level. Thus, in the thousands of years over which farming has been carried out beside the river, the overall picture was of a river flowing along at a high level above the adjacent land. When a river overtopped its banks, the damage caused was enormous because of the advantage of height. The kinetic energy of the water as it left the river enabled it to wash away large segments of the dikes. The overflow of water then continued until it reached the lowest point in the broken dikes. It took some time for the water to drop to this level, and then the hard manual work of rebuilding the dikes had to be undertaken. As a precaution against flooding, people had to watch the weather and the level of water in the river. As soon as the latter reached too high a level, an army of people was supposed to rush to the scene and raise the level of the dikes.

It was not always possible to identify the right moment to do this or to get people in place in time to do the needed corrective work. In 1887, there had been heavy rain right through the latter part of summer and into the month of September. On September 28, a major collapse of dikes took place unexpectedly, and water began to spill all over the land on both sides. The province of Henan where this happened has an average elevation above sea level of six hundred feet, very different from the mountainous regions from which the Yellow River originates. Henan is close to the sea and close to the mouth of the Yellow River, and is often referred to as the North China Plain. Immediately after the break in the dikes, the alarm was sounded, and a large number of people rushed quickly to the river in the hope of repairing the breaches. Before they could reach the river, the breaks had expanded to more than two thousand feet in length. There was little they could do. Many of them then tried to run or walk upstream in order to reach a level above that of the flooded area, but they were caught in the fast-moving volume of water and drowned.

The breaches in the dikes took place near the city of Zhengzhou, and within an hour a lake as big as Lake Ontario had formed on the adjacent plain. People from the city attempted to reach as many victims as they could by rowing around in small boats. Some of the peasants were able to reach terraces that were slightly higher than the water level, and there they waited for someone to reach them. Others desperately tried to stay alive by clinging to straw barrows. The overall temperature is quite low in that region by the end of September, and on the day of the tragedy there was a strong wind that made everyone feel cold. It was slow work for the small boats as they tried to go from terrace to terrace and take people to safety. Often there would be as many as a hundred families on one terrace. Some homes were still erect though underwater, and survivors stood on these as long as they could before either hunger or cold took over and they lost their lives. Here and there an old tall tree was standing, and people of all ages were seen clinging to branches in the hope that help would arrive. One family, knowing that it had no chance of surviving, placed a baby on top of a chest along with some food and a piece of paper with its name, and this chest stayed afloat long enough for the child to be rescued.

There was very little organization or resources for the rescue work. Foreign missionary societies shared their meager food supplies with survivors, but this did little for the starving thousands. One report described them as thousands of people all around, stunned and hungry, crying out for food. Efforts by individuals and government agencies continued unabated all through the winter months. It took a lot of time because there was so little organization in China at that time for dealing with emergencies. When the water finally stopped, residents saw a plain on which there lay a heap of loess mud about eight feet deep. As it dried out, the whole region looked like the Sahara Desert rather than the green fertile plain that had been there a few days before. People unfamiliar with life around the Yellow River often wonder why peasants insist on living and working in such dangerous areas. The same people also wonder why peasants live and work very close to volcanoes. The answer in both instances is the same: it is there that the best soils for farming are found.

The cleanup of the farm fields and the rebuilding of the dikes had to be undertaken immediately despite the approaching cold weather of winter. Farm work in this part of China is a year-round activity. Furthermore, the danger of a new flood would increase once the warmer weather of the following year came around. Every person was familiar with the routine for dike repair. Thousands of tons of earth had to be moved in wheelbarrows and, in the process of both removing the mud from their farms and rebuilding the dikes, almost all of it had to be passed from place to place by hand buckets. The stones needed for the work had to be carried in ox carts from places as far away as a hundred miles.

Thousands of feet of damaged dike were subject to constant crumbling and, when wet, the silt facing was so slippery that workers were sliding to their deaths in the river below. From the top of the dike the river may be 40 feet below, so it is easy to imagine the amount of work that had to be done to build up the dikes to prevent any further breaches. The site of operations for the repair work may have been more than 40 feet high, and everywhere the surface was wet and slippery. It was early 1889 before the dikes were finally completed. By that time, the spread of disease had added its troubles to all that had been experienced from the flood and the famine.

VOLCANIC ERUPTIONS' IMPACT ON FLOODING

The Mississippi River drainage basin is one of the largest in the world and the largest in North America. Floods have been a constant feature of it since historical records began to be kept, about two hundred years ago. In the early part of that period, perhaps because states' rights have always been a top priority in the political life of America, floods on the Mississippi were regarded as the responsibilities of the states affected, despite the obvious fact that no state could control conditions upriver in other states. That set of arrangements changed after 1927, when a massive flood occurred. It began when heavy rains pounded the central basin of the Mississippi in the summer of 1926. By September, the Mississippi's tributaries in Kansas and Iowa were swollen to capacity. On New Year's Day 1927, the Cumberland River at Nashville topped levees at 56.2 feet. The Mississippi River broke out of its levee system in 145 places and flooded 27,000 square miles. The area was inundated up to a depth of 30 feet. The flood caused more than $400 million in damages and killed 246 people in seven states. Arkansas was hardest hit, with 14 percent of its territory covered by floodwaters. By May 1927, the Mississippi River below Memphis, Tennessee, had reached a width of 60 miles.

The Flood Control Act of 1928 brought the problem of Mississippi floods under joint federal and state control. About 1,800 miles of levees

The Mississippi River flooding in 1927. (NOAA) and floodwalls were built along the river's course, and floodways were provided to divert water into storage areas or into the Gulf of Mexico. For a time it seemed that these measures were a solution to the problem of repeated flooding, but subsequent floods proved that there was no single set of solutions to Mississippi River flooding. The flood of 1993 was far bigger and more destructive that the 1927 one. It was among the most costly and devastating ever to have occurred in the United States, with $15 billion in damages, an area of flooding that was about 750 miles in length and 500 miles in width, with a total flood area of 500,000 square miles. Some locations on the Mississippi River flooded for almost 200 days, while flooding of locations on the Missouri neared 100 days. On the Mississippi, Grafton, Illinois, recorded flooding for 195 days; Clarksville, Missouri, for 187 days; Winfield, Missouri, for 183 days; Hannibal, Missouri, for 174 days; and Quincy, Illinois, for 152 days. The Missouri River was above flood stage for 62 days in Jefferson City, Missouri.

This flood was among the most costly and devastating ever to occur in the United States, with $15 billion in damages. It was the worst such U.S. disaster since the Great Mississippi Flood of 1927, as measured by duration, square miles inundated, persons displaced, crop and property damage, and number of record river levels. Within days of the end of this tragedy, questions were being asked about adequate levees and warning systems. People wondered why meteorologists and engineers were unable to predict the possibility of an event of this scale. It was known by the fall of 1992 that soil moisture levels were higher than usual, but that had often been observed in other years. During the winter, the upper reaches of the river received an unusually heavy amount of snow and, in the following spring and early summer, there were long periods of persistent storms and heavy rainfall, quite a different regime compared with the experiences of previous years. The river was reaching flood stage at several locations.

Unknown to all who were concerned with water levels and meteorological conditions in the upper reaches of the Mississippi was one event that had profound influence on the big flood. It was a volcanic eruption far away in the Philippines. Unfortunately, in 1993, there was little widespread acquaintance with the impact of volcanic eruptions on temperature and rainfall patterns, particularly those that erupt in tropical regions. In June 1991, the second-largest volcanic eruption of the twentieth century occurred in the Philippines, northwest of the capital city Manila. Up to 800 people were killed and 100,000 became homeless. Mount Pinatubo had erupted, and millions of tons of sulfur dioxide were discharged into the atmosphere. The cloud of dust and debris cut off much of the incoming solar radiation and disrupted weather cycles. The eruption plume reached high into the atmosphere within two hours, attaining an altitude of 21 miles and spreading outward over an area of 250 miles.

Polar Impacts on the Ozone Layer

Chlorofluorocarbons, or CFCs, which are widely used in spray cans, are so destructive of the ozone layer that an international conference was called in 1987 in Montreal, Canada, at which about 24 developed nations agreed to stop producing CFCs and find some alternatives that might serve in their place. Within ten years, stratospheric measurements showed a marked decrease in the amounts of CFCs reaching the ozone layer.

More recently discovered, however, are natural enemies of the ozone layer. Prominent among these natural enemies are what have come to be known as polar vortexes, especially the Antarctic vortex. In winter, the clouds that spin around the Antarctic pole in a vortex block out much of the sun's rays, with the result that the spinning air gets very cold, creating tiny ice crystals to which chemical molecules attach themselves and form compounds. In the early 1990s, during the warmer conditions in spring and summer, measurements in the highest reaches of the air over the Antarctic revealed holes in the ozone layer, clearly the result of some compounds that had formed there. (One of these compounds was found to be chlorine oxide, the one that had been associated with the CFCs; clearly not all of the CFCs had been removed from circulation by the beginning of the 1990s.)

The Arctic vortex, in most years, is less effective than the Antarctic one in shutting out sunlight and thus lowering the temperature. However, in the years 1993, 1996, and 1999, significant ozone holes appeared in the Arctic vortex as well, so it must be assumed that this location too needs to be regularly observed in the future. Quite apart from the polar areas, central Canada and central Russia have recently experienced increased levels of ozone, as much as 10 percent more than elsewhere in the atmosphere reaching the surface of the earth.

This eruption was the largest disturbance of the stratosphere since the eruption of Krakatoa in 1883. The aerosol cloud spread around the earth within a two-week period and covered the planet within a year. During 1992 and 1993, the damaged area of the ozone layer over Antarctica reached an unprecedented size as tiny particles from Mount Pinatubo interfered with the process that protects us from ultraviolet radiation. In later years, more normal conditions were restored to the ozone layer, and ever since that date the high altitude over Antarctica has remained as the best place to check on the condition of this important protective layer. The cloud over the earth reduced global temperatures. In 1992 and 1993, the average temperature in the northern hemisphere was reduced by 2°F, and the entire planet was cooled by almost the same amount. It was this cooling of the northern hemisphere in 1992 and 1993 that disrupted weather patterns over the upper Mississippi, raising rainfall amounts and dropping temperatures.

In many other parts of the United States, 1992 was the coldest and wettest in more than 70 years. Clearly the main cause of the massive 1993 flooding was the Mount Pinatubo eruption. Other parts of the world were affected by this eruption too, in addition to Antarctica. The Sahel region of Africa, frequently subjected to droughts, experienced another dry spell during 1992 and 1993, and scientists were convinced that Mount Pinatubo was the cause. Over the years that followed the

1993 flood, scientists developed a model of all that had happened as a result of the eruption. They then later tested it out with other volcanic eruptions so that it is now a valuable tool for testing the impact of eruptions in the future. More details of this model are given in the Introduction to this volume of the series. It has increased attention on the potentially damaging influence of volcanoes on weather and climate. In particular, it demonstrated that this one eruption changed atmospheric conditions to a greater extent than either the El Niño event that was active in the western United States in 1993 or the quantities of carbon dioxide that were added to the atmosphere in 1992 and 1993.

CHAPTER 8

Endangered Environments Changing Climatic Regions

Throughout the world, either as a result of trends in global warming or because of human interference with the land surface, many areas of the world are under threat. Before we examine traditional patterns of global regions and the future challenges they will face, we need to look at some present environmental disruptions. In Nepal, a small independent country in the lower reaches of the Himalayas that recently underwent a major political change when the monarchy was overthrown and replaced by a parliamentary system, is now facing new social problems because of the shrinking of glaciers. The rising atmospheric temperatures from global warming have cut back severely on the volume of melt water on which the villagers in the western part of the country depend for irrigation.

Communist revolutionaries had been exploiting this problem, because the government had promised help but it had not arrived, so unrest and anti-government protests increased. Large numbers of villagers left their traditional villages and moved south, close to the Indian border, where they hoped to find better opportunities for survival. The land in that part of the country is relatively flat compared with the land farther north, and in the 1990s about a fifth of Nepal's population lived there. This population has now risen to half of the nation's total because of the failure of the irrigation system. In another part of Asia, in Indonesia, a country that is far bigger and far wealthier than Nepal, a different environmental problem surfaced, one caused by human activity in Europe.

The European Union, a group of many countries with a total population in the hundreds of millions, passed a law that required every car and truck to switch from 100 percent gasoline to part gasoline and part biofuel by the year 2010. This was a move intended to help reduce the amount of carbon dioxide being sent up into the atmosphere, something that most nations of the world would consider to be a good move. However, the quantities of biofuel needed to meet the requirements of this new law are very great, and Europe does not have sufficient agricultural land to produce it. They searched for a place that could provide what was needed, and they were able to persuade Indonesia to help them. This nation has vast stretches of forests that are vital to the lifestyles of its native people, but potentially rich sources of income if the trees are removed.

Greenpeace activists with masks and fake chainsaws protesting Indonesia's huge deforestation projects. (AP/Wide World Photos)

The temptation to respond to Europe's appeal as well as those from other countries resulted in huge-scale removal of forests, so that the rich volcanic soil beneath, in this tropical country, could be used for palm oil plantations. It was a sad decision for many reasons: it offended the native people and caused social unrest, it removed the trees that would have been excellent carbon sinks to absorb carbon dioxide, and it led to a poor form of agriculture, monoculture, a type of farming that over time robs soil of its fertility. As a result of its decision and the large-scale deforestation that followed, including extensive stretches of fires as forests were burned down, Indonesia became the third-biggest emitter of greenhouse gases, behind only the United States and China.

Europe never intended to cause all this damage in Indonesia, but these unintended consequences come when humans do not fully understand the outcomes from their decisions. There is new interest on the part of five northern nations, Canada, Denmark, Norway, the United States, and Russia, to claim territory around the North Pole as more and more open water appears in the wake of sea ice melting. These nations know that different mineral resources in the Arctic seabed are now accessible, and they are thinking about reaching them. There is potential for international crises among these nations as research and mapping reveal the nature of these resources. There is also potential for environmental damage from unintended consequences, because we now know that ocean currents in this part of the world profoundly affect the entire global weather and climate system.

There is one other area of the globe where droughts are frequent and where new instances of this problem are surfacing again. It is the eastern part of North Africa, Ethiopia and southern Sudan and the whole Sahel region along the southern border of the Sahara Desert. Decreasing food supplies among increasing populations throughout this area have already set off major migrations, creating social tensions and conflicts. A 2008 United Nations report predicted a 70 percent reduction in food supplies over coming years, and the authors of this report pointed out that, in northern Africa, it is not the scarcity of resources that is the greatest concern of authorities. It is the accelerated rate of change that matters most.

THE KÖPPEN GROUP OF REGIONS

Meteorologists divide the world into regions for purposes of documenting information about weather and climate. Over many years they have used a system based on temperature and moisture, the easiest criteria to measure and the two main elements affecting conditions at any time on the ground and in the atmosphere. The system used is known by the name Köppen. It consists of five regions of the world, identified by the five letters A, B, C, D, and E, and defined as follows:

A. Tropical moist, with all months having average temperatures above 64.4°F.

B. Dry with deficient precipitation during most of the year.

C. Moist, mid-latitude climates with mild winters, average temperatures between 26.6°F and 64.4°F and at least one month averaging above 50°F.

D. Moist, mid-latitude climates with cold winters and average temperatures under 26.6°F and the warmest month averaging at least 50°F.

E. Polar climates with extremely cold winters and summers.

Within all five of these regions there are subregions, each of which is defined by a lowercase letter as follows, and the more detailed climatic maps delineate the boundaries of these subregions within the bigger areas:

- An a subregion has the warmest month above 71.6°F.
- A b subregion has the warmest month below 71.6°F.
- An f subregion is a moist one with adequate precipitation in all months and with no dry season.
- A w subregion has a dry season in winter.

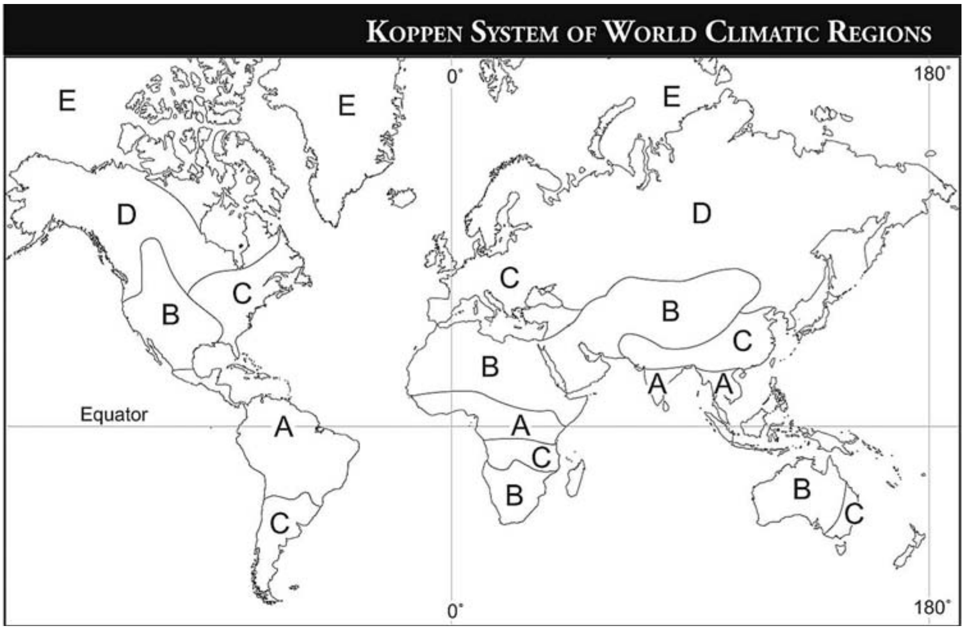

Figure 8-1 The main categories, A, B, C, D, and E, of the Köppen system of world climatic regions. The system of climate regions is based on the main types of vegetation found within an area. (ABC-CLIO)

- An s subregion has a dry season in summer.
- An m subregion describes a rainforest, and it only applies to the A climatic region.

In the rest of this section of the chapter we will examine the temperature and precipitation statistics of several places around the world, for each month of the year in each one, and then check these figures against the standards set by Köppen for his regions.

Akassa, Nigeria, is four degrees north of the equator and has a climatic subregion classification of Af. Its temperature and precipitation data are shown in Table 8.1. Check these against the Köppen categories:

TABLE 8-1 Temperature and Precipitation Data for Akassa, Nigeria

	January	February	March	April	May	June	July
Temperature in Fahrenheit	78	79	80	80	79	77	76
Precipitation in Inches	3	7	10	9	17	19	10

	August	September	October	November	December
Temperature in Fahrenheit	76	76	77	78	79
Precipitation in Inches	9	19	25	11	7

TABLE 8-2 Temperature and Precipitation Data for Palermo, Italy

	January	February	March	April	May	June	July
Temperature in Fahrenheit	51	52	55	58	64	71	76
Precipitation in Inches	3	3	3	2	1	1	0

	August	September	October	November	December
Temperature in Fahrenheit	77	73	67	59	53
Precipitation in Inches	0	2	3	3	4

This is a very wet and hot climate. Visitors often talk of it as the place of rain, rain, rain, all the time, so that clothes and bedding get damp and uncomfortable because with so much moisture the atmosphere is saturated and no evaporation is taking place. Mornings in such a place can be warm and pleasant, but soon after noon the rain begins to fall, and it continues for many hours.

Palermo, Italy, is 38 degrees north of the equator and has a subregion classification of Cs. Check the following against the Köppen classifications:

This subregion is often described by the word Mediterranean because so many places around the Mediterranean Sea have this classification. It is a very pleasant place in which to live. The temperatures are pleasant all year round, and there is plenty of sunshine in winter in spite of that season being the time of maximum rainfall. Southern California has this type of climate, and that is why it is such a popular location for visitors and residents alike.

Peoria, Illinois, is 41 degrees north of the equator and has a subregion classification of Dfa. Check the following against the Köppen classifications:

TABLE 8-3 Temperature and Precipitation Data for Peoria, Illinois

	January	February	March	April	May	June	July
Temperature in Fahrenheit	24	28	40	51	62	71	75
Precipitation in Inches	2	2	3	3	4	4	4

	August	September	October	November	December
Temperature in Fahrenheit	73	65	53	39	28
Precipitation in Inches	3	4	2	2	2

Early visitors to Illinois often commented on the appearance of the general landscape. The sense of solitude that they felt was profound, a feeling of endless prairie, with nothing in sight but infinite sky and grass.

IPCC FINDINGS AND THE FUTURE

The scientific consensus of the IPCC, in its comprehensive fourth assessment published in 2007, is that precipitation will increase in all regions, but in subtropical land areas, where dry conditions are already widespread, precipitation will decrease throughout the twenty-first century. Drought is expected to be greatest near the northern and southern margins of the subtropics. These areas include much of the Mediterranean, southern Africa, southern Australia, and the southwestern United States. It seems clear that the regions defined by Köppen will change a lot in this century, even as they have done in the past. Annual precipitation amounts are expected to increase near the equator and in higher altitudes. All of these projections are based on the assumption that nothing significant will be done to halt the increase in carbon dioxide in the atmosphere. Everyone hopes that much will be done and, therefore, that these dire predictions will not become future realities.

Using the predictions of the 2007 report, average global temperatures are expected to rise by 5 °F. This is a serious change for the world's environment. It is known that increased precipitation means accelerated global warming, because more moisture means more greenhouse gas in the atmosphere. Alongside this development, the reduction of moisture in those areas that presently lack adequate moisture could lead to social unrest and new waves of people moving to new locations. What the IPCC did not do, of course, was address in any detail the likelihood of action being taken by different countries to reduce atmospheric levels of carbon dioxide. Uncertainties persist regarding the amounts of action that will be taken. For a time, optimism centered on the Kyoto Protocol as one means of reducing carbon dioxide but, after the 2007 planning conference to replace Kyoto, little hope remained for success there.

One area of research findings has only recently been added to our ability to project the future. It is the influence of aerosols. These tiny particles that are suspended in the atmosphere come from fuel combustion and other human activities. Some aerosols worsen the problem of global warming; others, such as liquid sulfate molecules, can cool the earth's surface. In summary, historical data give strong support to the IPCC conclusions. Average northern hemisphere temperatures during the second half of the twentieth century were generally regarded as higher than during any other 50-year period over the last 500 years. Over the past decade, there have been no new breakthroughs affecting the science of climate change. The IPCC's findings have largely been confirmed, and we have refined what we already know: the global climate is warming, humans are playing a role, and we can expect further warming of a few degrees in this century if we do not reduce our emissions of greenhouse gases.

INSURANCE NEEDED FOR WEATHER DISASTERS

Preparation for the unknown, in relation to insurance coverage, is not just an interest of the buyer of insurance. Surprisingly, it is the insurance companies that are in the forefront of thinking about insurance in the future. This industry must know what it can undertake to pay, and hence it must provide leadership to society in planning for unknown futures. For example, following the great fire of New York in 1835, it was difficult to assess the values of the places that were destroyed because there was no map of the area that showed either the materials installed in each location or their values. The result of that event was the production in 1950 of the first New York maps for fire underwriting. These maps showed types of construction, materials used, where combustible materials were stored, and where the nearest fire extinguishing equipment was located.

As a step in the same direction as the insurance companies had taken, the National Climatic Data Center of the U.S. Department of Commerce recently took notice of the disturbing trend in the costs associated with weather-related disasters. This organization issued a list of the billion-dollar weather disasters that occurred within the continental United States during a 25-year period from the late twentieth century to the early part of the twenty-first century. The dollar values for each time period were adjusted to what they would have been had they occurred in 2007, the last year for all the cases. Altogether, the various billion-dollar events for the 25-year period added up to approximately $600 billion. For convenience of comparison, this total and the totals for the different groups described in the following will be taken to the nearest whole figure.

The statistics were taken from a wide variety of sources and represent the estimated total costs of the disasters in terms of dollars and lives that would not have been incurred had the event not taken place. Insured and uninsured losses are included in the damage estimates, and direct plus indirect deaths are included in fatality totals. Indirect deaths mean those closely related to the event, those that would not have occurred apart from the disaster. Economic costs are included for long-lasting events such as droughts. For the first five years studied, 1980 to 1985, total costs were $23 billion; as already noted, these totals were adjusted to 2007 equivalent values. The dominant cost features of this period related to storms, flooding, and droughts; about two thirds of all costs related to these. An El Niño sequence in 1982 represented a good deal of the flooding costs, in northwest states, California, and along the Gulf of Mexico, but an even greater share of the dominant costs came

Damage from Hurricane Hugo on a street in Charleston, South Carolina, 1989. (AP/Wide World Photos)

from three hurricanes in 1983 and 1985. The third cost category lay in the severe freezes that affected the fruit industry in Florida during 1983 and 1985.

For the years 1986 to 1990, costs reached $100 billion in 2007 dollars, with two thirds of this total being related to heat waves and droughts in 1986 to 1989. The central and eastern United States, because of their high productivity, were hit the hardest when, in 1988, a severe summer drought destroyed extensive areas of agriculture and industries related to agriculture. The other areas that suffered agricultural losses from drought were the southeastern United States in 1986 and the northern plains in 1989. Other high costs in this period were due to Hurricane Hugo, 1989, over Puerto Rico and North Carolina, and an extended series of torrential rains in 1990 that caused river flooding in four states, Texas, Oklahoma, Louisiana, and Arkansas. Costs in the years 1991 to 1995 were related mainly to two events, Hurricane Andrew in 1992 and the Midwest Flood of 1993. The total for the five-year period was $122 billion, and these two events contributed $88 billion of this total. Hurricane Andrew has already been referred to in these volumes because it represented a new level of damage in the entire history of U.S. hurricanes, $40 billion. It was the first big hurricane to hit a dense urban area, and it focused attention ever afterward on the great risks of hurricanes in similar locations.

The 1993 floods on the Mississippi-Missouri system were, like Hurricane Andrew, a national shock. Mississippi floods were familiar tragedies throughout U.S. history, and everyone thought that, after the worst flood ever to that time, in 1927, when new safety regulations were put in place and many new levees were installed, the age of massive floods was past. Furthermore, circumstances in 1993 convinced meteorologists that there was little likelihood of a flood in that year. All the indications predicted a year of normal rainfall. No one gave thought at that time to the influence of a major volcanic eruption on rainfall regimes. Later it was discovered that a volcanic eruption in 1991 was the main cause of the 1993 floods. Californian fires, although in total amounting to much less than the bigger events of this period, still accounted for $6 billion of costs in the years 1991, 1993, and 1994. Similarly, the severe ice storms of 1994 amounted to $8 billion and affected ten states, all the way from Mississippi to Virginia. Hurricanes accounted for the other billions of costs and, within that category, Hurricane Opal of 1995 must be singled out: it added $4 billion to the total of costs and caused major damage through flooding, storm surges, and winds to five states.

The total cost figure for the years 1996 to 2000 was $80 billion, with the years 1996 and 1997 being dominated by flooding that added up to a quarter of the total. About $7 billion was caused by Hurricane Fran's behavior in 1996 when it stalled over North Carolina and Virginia and deposited ten inches of rain in the course of one day. Extensive agricultural areas were destroyed by this concentrated amount of rain. Flooding through periods of heavy rain and snowmelts explain the other costs in those years. In 1998, a heat wave and a lengthy period of drought extending from Texas and Oklahoma to the Carolinas accounted for the costliest single event of 1998. It added $12 billion to the total. The other significantly costly event of 1998 was Hurricane Georges. It added $8 billion to the total for this period. This storm caused a good deal of flooding as it hit Puerto Rico, Florida, and the Gulf coasts of Louisiana, Mississippi, and Alabama, with total rainfalls over a two-day stretch of more than 20 inches. The remainder of this five-year period was dominated, as far as costs are concerned, by the destructive activities of Hurricane Floyd in 1999. Its heavy rains, as much as 20 inches over two days, flooded 13 states, with the heaviest rains falling in North and South Carolina.

In the last group, which covers seven years, about half of the total costs for the whole period 1980 to 2007 was incurred, about $300 billion, and close to half of that total came from Hurricane Katrina, the hurricane that demolished New Orleans, or perhaps we should say caused the flood that destroyed this city. The real problem with New Orleans was not the strength of the hurricane that reached it. It had survived bigger hurricanes at other times. The substandard levees caused most of the damage when they failed and let the city be flooded. Many of the residents could not get their insurance companies to honor the insurance claims for damages because their plans were designed for protection from hurricanes, and the insurance companies insisted that the city was destroyed by flooding, not the hurricane. Additionally, in this period of time, there were several powerful hurricanes that caused extensive flooding and together added $40 billion of costs, including Tropical Storm Allison in 2001, and the following in 2004: Hurricane Jeanne, Hurricane Ivan, and Hurricane Frances. There is also the story of widespread drought in 2006 that must be added, almost reminiscent of Dust Bowl days, when as many as 20 states suffered from extremely low rainfall; this added $7 billion of costs to the total.

All of these costs point the way to a much more sophisticated method of assessing risks before insurance premiums can responsibly be identified. Again, it is the work of insurance companies that we have to depend on if we are to plan for insurance against future weather disasters efficiently. More recently, toward the end of the twentieth century, insurance companies have gone far beyond maps in refining data for underwriting: experts have constructed digitized data banks linked to maps, covering all aspects of a particular place. Still more recently, given the interlocking nature of the elements involved in a modern disaster, they have created scale models of places, such as windstorm models, so that their clients can assess risks with greater precision.

CHAPTER 9

Volume Five Review

This Volume Five, the last in our set of books on weather and climate, is organized around major themes relating to the sun and the earth and the variety of systems that link them together. This overview structure will make it easy to relate the specialized themes of the other books to one another. One chapter is devoted to finding places anywhere on earth, using a special grid of longitude and latitude lines. This has become particularly important now that we know, in much clearer detail, that all weather and climate events are interrelated. Thus, meteorologists frequently need to know what is happening in a place in Europe when forecasting weather for New York State, and such information can be relayed by satellite once we know the exact locations of places on earth.

A good deal of content in Chapters Four and Five deal with water, including the familiar water cycle of evaporation, precipitation, and runoff. The discussion goes beyond that system to other water cycles. These include the cycles of infiltration through soil and deeper layers to be stored as capillary water for plants, groundwater for trees and for human use in rural areas, and, in specialized areas, as artesian wells. Beyond all of these, and beyond the cycles of water along the surface of oceans, Chapter Six describes the role of the thermohaline circulation, a flow of massive amounts of water that scientists have only recently recognized as the master key to understanding the role of oceans in weather and climate events. The final chapter deals with climatic regions of the world and how they are changing.

IMPORTANT TERMS

Ultraviolet rays

Groundwater

Thermohaline circulation

Sahel region

Water cycle

Köppen regions

Gulf Stream

Short-wave energy

Infrared energy

Insolation

Infiltration

Gerard Mercator

Tropics

Solstice

Equinox

Ice cores

Transpiration

Impermeable rocks

Relative humidity

Annual orbit

QUESTIONS

How does the ozone layer protect our health?

How does warm equatorial air reach colder places?

How do we locate a place anywhere on earth?

What are sunspots?

What makes the sun hot?

Where is the earth's coldest place?

What is an artesian well?

Where does space begin?

What is the biggest object in the solar system?

What caused China's worst flood?

WEB SITE FOR FURTHER STUDY

The Web site http://www.srh.noaa.gov/jetstream is an educational service of the U.S. National Weather Service designed to expand our understanding of many aspects of weather and climate. This service introduces itself in the following way:

> Welcome to JetStream, the National Weather Service Online Weather School. This site is designed to help people who are interested in learning about weather and weather safety. The information is arranged by subject; beginning with global and large scale weather patterns followed by lessons on air masses, wind patterns, cloud formations, thunderstorms, lightning, hail, damaging winds, tornados, tropical storms, cyclones and flooding. Interspersed in JetStream are "Learning Lessons" which can be used to enhance the educational experience.

Appendix A: Important Dates in Weather and Climate History

1238 The hottest and driest summer of the millennium in England.

1281 A North Sea storm surge hit the Netherlands in January, flooding large tracts of land and drowning 60,000 people.

1421 Worst North Sea storm surge hit the Netherlands in November, causing the deaths of 100,000 people.

1586 England's first colony in America, established on Roanoke in 1585, had to be abandoned because of severe weather.

1737 The second-deadliest Asian cyclone in recorded history killed 300,000.

1772 The biggest U.S. snowfall (before official records began) occurred in January, when three feet fell in the Washington-Baltimore area. It has been called the Washington-Jefferson snowstorm because it was recorded in both of their diaries.

1780 A hurricane traveled the length of the Windward Islands chain in the Caribbean in October, with St. Lucia and St. Vincent the worst affected, causing the deaths of 24,000 residents.

1791 Cuba was hit in June with a powerful hurricane that took three thousand lives.

1816 The year that was called "the year without a summer." In Savannah, Georgia, the Fourth of July had a high temperature of 46°F. Because it was so cold across the eastern United States, crops were ruined. Snow fell in June, heaviest in New England, with snow drifts of 18 inches. It was the same story in Canada and in Europe. These changes in weather were attributed to the 1815 eruption of Mount Tambora in Indonesia.

1824 In St. Petersburg, Russia, in November, a powerful storm from the Baltic Sea brought a storm surge into the Sea of Finland that swept inland, flooding the Imperial Capital and its palace and drowning 570.

1831 The Caribbean island of Barbados experienced its worst hurricane, which destroyed thousands of buildings and killed 1,500, representing 2 percent of the island's total population

1840 The second-deadliest tornado in U.S. history, Natchez, killed 317.

1870 U.S. Weather Bureau was founded and placed under the office of the Secretary of War.

1881 The third-deadliest Asian cyclone of all time, the Haiphong Typhoon in Vietnam, killed 300,000.

1887 San Francisco's greatest snowfall came in February, with a total of four inches in the downtown area.

1888 The Blizzard of 1888 affected the eastern United States in March. Over four feet of snow fell in the Albany and Troy areas of northeastern New

York state. More than 400 people lost their lives, mainly due to exposure to strong winds and cold temperatures.

1896 The third-deadliest tornado in U.S. history, St. Louis, killed 255.

1899 In February a cold wave caused a massive east coast blizzard and induced bitter cold temperatures across two-thirds of the United States. It was the only occasion that saw true blizzard conditions in the state of Florida.

1900 The second-deadliest Atlantic cyclone in U.S. history, Galveston, hit in September, killing 12,000.

1913 The highest U.S. temperature on record was recorded in Death Valley, California, on July 10, at 134°F.

1913 Several tornadoes hit southwest England and central Wales on October 27.

1921 On September 10, Thrall, Texas, experienced the greatest U.S. 24-hour rainfall on record up to that date. The total was 38.2 inches.

1922 A community in Libya, Africa, on September 13, claimed the world record for the highest temperature of 136.4°F.

1925 The deadliest tornado in U.S. history, Tri-State, killed 689.

1934 On April 12, Mount Washington, New Hampshire, experienced a gust of wind at 231 mph, accepted as the U.S. record for the highest wind speed.

1936 The fourth-deadliest tornado in U.S. history, Tupelo, killed 216.

1940 The U.S. Weather Bureau moved to the U.S. Department of Commerce.

1947 At Snag in the Yukon Territory of Canada, on February 3, the temperature was –81.4°F. This is the lowest on record for all of North America.

1949 In October Guatemala experienced a week of heavy rain from a stalled tropical cyclone. The results were flash floods and mudslides and a death toll of 40,000.

1952 From December 2 to December 6, London, England, experienced its deadliest weather disaster, the great smog that paralyzed the city, stopping all traffic and almost all pedestrian movements, and killed 6,000.

1953 The worst North Sea storm surge of modern times hit the Netherlands and southeastern England on January 31, killing more than 2,000.

1954 In Qazvin, Iran, a violent thunderstorm over the Elburz mountains triggered a flash flood over this city, killing 10,000.

1959 Due to an unusually wet summer monsoon season the Yellow River in northern China overflowed its banks and caused the deaths of an estimated two million people, the highest death toll ever for a meteorological disaster.

1963 The third-deadliest Atlantic cyclone in U.S. history, Flora, hit Haiti and Cuba in October, killing 8,000.

1964 At Oymyakon, Siberia, Russia, in February, the lowest temperature for the northern hemisphere was registered at –96°F

1964 Karachi, Pakistan, in December, experienced a major tropical cyclone that took the lives of 10,000.

1970 The deadliest Asian cyclone of all time, the Great Bhola of Bangladesh, killed 550,000.

1974 A tropical cyclone hit Darwin, Australia, on December 25, killing 65.

1975 The eighth-deadliest Asian cyclone of all time, the Super Typhoon Nina, hit China, killing 170,000.

1983 In Vostok, Antarctica, on July 12, the world's lowest temperature of –138.6°F was recorded.

1992 Hurricane Andrew, the United States' costliest meteorological disaster, swept across Dade County in August with devastating results.

1993 Missouri–Mississippi flooding, greatest U.S. flood of the century.

2005 Hurricane Katrina, costliest storm in U.S. history.

2008 The tenth-deadliest Asian cyclone of all time, Nargis, hit Myanmar, killing 140,000.

U.S. WEATHER AND CLIMATE FROM AD 1000 TO 2000

There are no written records for the first half of this millennium, so there are no details of actual weather conditions. However, there is a huge amount of archeological, botanical, and zoological evidence available, and we can construct from them a picture of the prevailing conditions at different periods of time. At the beginning of the last millennium, both in the United States and throughout Europe, warm weather was widespread, and this continued for the first two centuries, from 1000 to 1200.

The overall regime of warmth was accompanied with abundant, reliable rainfall across the Great Plains, giving rise to extensive wooded areas, the kind of landscape that remained unique to this time period of 1000 to 1200. This was also the time when a large population could be sustained in heartland America. One place in southern Illinois had 50,000 inhabitants between 1100 and 1200. All of this changed in the early years of the thirteenth century; by its first decade, what is now the United States became much colder and drier. The warm and moist air masses from the Gulf Stream were replaced by a strengthening that developed in the westerly flow across the continent. Within the following 40 years the woodlands had retreated from the U.S. Interior, and the Great Plains became grasslands, the habitat of the buffalo that would become, at a later time, so familiar to early European explorers.

Native American populations declined as a result of the change in climate. Settlements were abandoned, and people migrated westward and southward. It was a similar story farther to the north, where the first Europeans had settled for a long time during the warm period on the island of Newfoundland in Canada. By the fourteenth century, they had to abandon their North American settlement as well as those they had founded in Greenland and Iceland. Most of the United States remained cold for the long period that came to be known as the Little Ice Age. The first English colony that was established on an island off the coast of Virginia had to be abandoned within a year due to low temperatures. An overall warming trend, one that affected all of the United States, began to arrive toward the end of the nineteenth century, but it did not become a settled pattern until the second half of the twentieth century.

EVOLUTION OF CLIMATE CHANGE CONCERNS

1970s For much of this decade, mainly because evidence of global cooling had been experienced over the previous three decades, scientific interests and publications focused on the prospect of a return to ice-age conditions.

1980 A report to the president of the United States from the Federal Council on Environmental Quality pointed out that human-caused climate change as a result of greenhouse gas emissions would probably be evident to all within the following 20 years.

1988 The World Meteorological Organization and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC).

1993 The scientific journal *Nature* published the findings of the scientists who had extracted a two-mile ice core from the Greenland ice sheet in order to identify climatic conditions 12,000 years ago. These scientists were astonished at both the rapidity and extent of the climate changes they identified, in particular the 1,300-year cold snap that appeared relatively suddenly. This period of time is often called the Younger Dryas after an Arctic flower.

1997 The scientific journal *Science* published an article that identified the slowdown in recent years of the Gulf Stream as a development that closely resembles the rapid changes in the Younger Dryas time.

2005 The Kyoto Protocol, a set of obligations related to the IPCC, came into force in February, and many developed countries agreed to follow its prescriptions. These related to reductions in levels of greenhouse gases by a specific date.

2007 The Norwegian Nobel Committee awarded the Nobel Peace Prize in two equal parts, to the IPCC and Albert Arnold (Al) Gore Jr., for their efforts to build up and disseminate greater knowledge about manmade climate change and to lay the foundations for the measures that are needed to counteract such change.

Appendix B: Some Extreme Global Weather Events

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as well as Appendix C, which focuses specifically on U.S. extremes, is to provide a larger context to which the individual references can be linked. When it comes to global extremes, the nations of Asia still dominate. Again and again, even after a century of improved methods of protection from tropical cyclones and interior floods, weather events are far more severe in Asia than we are accustomed to in North America. Numbers of casualties and the extent of environmental damage are often huge. One reason for this is the high terrain that borders nations such as Bangladesh and Vietnam; another is that the Pacific Ocean is much bigger than the Atlantic, and storms reach the Asian mainland with huge volumes of moisture after moving across great stretches of water.

The two biggest nations of Asia in terms of population are China and India, and they epitomize two extremes of weather: flooding in China and drought in India. The extremes of flooding in China are described in Volumes 1 and 2, and the drought problems of India are explained in some detail in Volume 3. The China flood of 1931, described next, was by far the most extreme in centuries, and the drought that hit India in 1900, along with the accompanying famine and starvation, was the worst of the entire twentieth century. Extremes of tropical cyclones, just like floods and droughts, are usually greatest in Asian countries, but occasionally other parts of the world experience exceptional storms. The two examples included here are of this character, Hurricane Mitch of Central America and Cyclone Wanda of Australia. The fifth extreme event included here took place in the Sahel of Africa, selected because it is an area that experienced so many droughts in the twentieth century that the United Nations set up a special task force to study the problem and identify the causes.

CHINA FLOOD, 1931

In the United States it is easy to think of hurricanes and tornadoes as the causes of more deaths than other weather events. In fact, in the United States, and to a far greater extent in Asia, floods cause far more deaths. In China, in particular, there is a tragic history associated with flooding, and Chapter 5 of Volume 1 shows this in the tragic story of

the great 1887 flood. The 1931 flood went far beyond the 1887 one in terms of deaths and damage. Nothing equal to it had happened in China in centuries of experiences of flooding. It began during the summer months, and the worst flooding occurred on the Yangtze River, although the heavy rains and rapid snow melt affected many other rivers in central China at the same time. About 51 million people were affected, representing a quarter of the nation's population at that time.

The U.S. National Oceanic and Atmospheric Association (NOAA) considered this 1931 event the most extreme weather-related disaster of the twentieth century, possibly the deadliest natural disaster ever recorded. The number of deaths was approximately four million, not all due to drowning. In 1931 China was still predominantly a rural society, and people earned their livelihood from agriculture. There was no national organization that could provide emergency food supplies, so, as water destroyed their food crops, mostly rice, people had nothing to eat beyond the supplies they might have saved from previous crops. Thus many died from hunger. Many others became infected with deadly diseases from polluted water. The causal factors that led up to this tragedy were a combination of extended droughts, from 1928 to 1930, followed by an equally protracted period of heavy rain. In winter much of the precipitation fell as snow, and in the following spring, the thaw added quantities of water to the rainfall, greatly increasing the volume of water in the rivers.

Rainfall persisted throughout the summer months and, in July alone, the area on the Yangtze River near the capital of that time, Nanjing, was hit with seven tropical cyclones, each of which added substantially to the amount of water in the rivers. Normally this part of China experiences about two tropical cyclones a year. By July of 1931, Nanjing had become an island in a massive flooded area. The high-water mark on the Yangtze reached 53 feet above normal by the middle of August. The immediate cause of flooding in China is nearly always a result of failure of the levees. Historically these are built of sods, so they offer little resistance to a sudden rise in the level of the river, especially if the rise in river flow occurs on a downward slope. These levees get built up over time to compensate for the rise in elevation of the riverbed, as more and more silt is deposited in it, so the river runs at an elevation above the surrounding plain.

Thus, as soon as a breach occurs in a levee, the rapid flow of water through the opening quickly expands the opening and increases the volume of water escaping into the lower land below. Toward the end of August the water flowing through the Grand Canal near the mouth of the Yangtze washed away the supporting dikes and drowned 200,000 people. In modern China the ancient forms of levees and dikes have been replaced in critical areas of the country by protective walls of concrete so that the enormous tragedies of the past will not be repeated. Additionally, hydroelectricity is being produced in many locations on rivers, and the dams serve as control points to prevent overtopping during sudden increases in river flows. The huge undertaking to dam the Yangtze River in order to secure much greater amounts of hydroelectricity provides protection from flooding all along the river.

HURRICANE MITCH, 1998

Deadly tropical cyclones frequently strike coastal areas along the Bay of Bengal, causing enormous loss of life and extensive environmental destruction. The Bangladesh cyclone of 1970 that is described in Volume Three of this series was the nation's greatest disaster of the twentieth century. Winds coupled with a storm surge killed between 300,000 and 500,000 people. The tropical cyclones we experience in North America, which we call hurricanes, do not generally reach these levels of destruction, but occasionally there are extreme examples of deadly hurricanes. Hurricane Mitch of 1998 was one of these. It was a late-season arrival, forming in the western Caribbean in October and moving westward over the mountainous areas of Central America. This storm weakened as it reached Honduras. Perhaps because it arrived late in the season, it did not have the strength to continue westward after reaching Honduras so it stalled over that country.

Hurricanes that travel across the warm waters of the Caribbean carry large amounts of water, and this volume of moisture is usually spread over an extensive area of land when precipitation takes place and the storm moves along. It is a very different story when a hurricane operating in the warm waters of latitude 15° north stalls over land, and especially when it stalls over mountainous land, as Mitch did. It unleashed precipitation amounts estimated as high as 75 inches. The resulting floods devastated the entire infrastructure of Honduras and also severely impacted other countries in the Central American region. The final estimated death toll was 11,000, the greatest loss of life from a tropical system in the western hemisphere since 1780. The fact that this was an estimated death toll tells us a lot about the level of development, and preparedness for hurricanes, in the countries affected.

Extensive wind damage and devastating floods occurred all over Honduras, particularly on the northern seaboard and in the Bay Islands that are located off the northern coast. Approximately 1.4 million persons were left homeless, more than 92 bridges were damaged or destroyed, and nearly 70 percent of crops were lost. The U.S. Geological Survey was called to help assess and map the damage and to provide technical help with landslide mitigation. Fortunately, the recent date of this hurricane makes possible the use of techniques to accurately assess the extent of the damage and provide expert help in recovery.

INDIAN DROUGHT, 1900

In contrast to the famines that occur in China due to the country's frequent floods, the Indian famines are caused by the absence of rain. The monsoon is the name given to the annual arrival of massive amounts of rain that reach land after traveling thousands of miles across the warm waters of the Indian Ocean. It is the greatest weather event in the world for two reasons: it travels over an area of water greater than

that of any other weather system, and it affects a bigger population than is ever affected by another single series of rainfalls. This main weather event of the year begins with rain arriving in early summer in the south of the country and often continuing unabated for weeks before dying down. It is common for rivers to overflow and communities to be flooded, but no one objects because this summer rain is the lifeblood of the whole nation. Even today, most of India is still a rural, agricultural society. In 1900 everyone depended on what could be grown in order to survive and, in this hot tropical climate, every crop depended on rain.

India has a second monsoon that arrives in the fall of each year. It is quite different from the summer one because it travels south over dry land and so carries much less moisture. If we think of India together with the large mass of continental land that lies north of it in the Himalayas, China, and Siberia, the enormity of these two annual events can be visualized. In summer, because land heats up much quicker than water, the air that had been circulating over long stretches of warm ocean water, and that therefore carries large quantities of moisture, is attracted toward the low-pressure areas over land. As it rises over higher ground water is precipitated, and the summer rains begin. People talk about it as rain, rain, and rain again; clothes damp, bed linen damp, walls damp, food damp, everything damp. Rain hammers a tattoo on corrugated iron roofs, tears up roads, and smashes down vegetation. The opposite movement of air happens in the fall as the land cools below sea temperatures, and a reverse flow of air takes place. It is the summer rains that are always the focus of interest. They sustain crops, especially rice, for the hundreds of millions of Indians. Billions of rice seedlings are in the fertilized, prepared plots of land in May or early in June awaiting the arrival of the monsoon.

What happens if it fails to arrive at the time the weather forecasters gave? In 1900 forecasting the exact date of arrival involved quite a bit of guesswork. There were few weather stations serving the land areas, and nothing on the ocean except reports from passing ships. A primitive form of statistical prediction operated. That is to say, forecasters knew that, on average, the monsoon would arrive within ten days of the middle of June, so they used whatever data they had to fix a date within that timeframe. However, even if the statistical average proved to be true for 30 years, the elders in Indian communities knew that occasionally there were huge exceptions. They knew of the terrible years of 1768, 1769, and 1770, when inadequate rain arrived and ten million people died. Somehow these anomalies had been forgotten in the year 1900. There had been exceptionally low amounts of rain in 1899 and again in 1900. Because of the possibilities of weak monsoons, farmers had been in the habit of storing some grain each year as a kind of insurance against a famine, but for some reason this had not been done before 1899 and 1900.

Severe shortages of rice were reported all over southern India in 1899 and over the rest of the country a year later. Unlike modern times

in India, in which food reserves are on hand to cope with disasters like this one of 1900, there was nothing that could be done for the farmers who had inadequate amounts of rice. A certain amount of sharing was done within communities, but the overall picture deteriorated into widespread famine by the fall of 1900. Disease and a breakdown in social order followed. There were many deaths. Subsequently it was discovered that there had been low levels of rain in the monsoons of 1896 and 1897, and these conditions led to the inability of farmers to put some grain aside as a reserve for emergencies. The British colonial authorities of the time paid no attention to these failures in the monsoons. They were only concerned with securing their quota of rice in order to satisfy their superiors. The final tally of deaths from famine and disease ranged from two million to ten million. The uncertainty about the numbers is a sad commentary on the failure of the colonial power to look after the people over whom they ruled.

AUSTRALIAN CYCLONE WANDA, 1974

Australia is quite well acquainted with extremes of climate. It has a very large desert area, and its location in a tropical zone means it gets the full effect of the unexpected heavy rains and high temperatures that are commonplace in that part of the world. During the summer of 1974 there happened to be one of the wettest seasons that Australia had ever known. The climatic variation called La Niina had been one of the most extreme of the entire twentieth century. As result of both of these conditions, rainfall was torrential and continuous through most of January 1974, as the inter-tropical zone settled over northern Australia. On January 25 of the same year, Cyclone Wanda moved over the interior of Queensland and New South Wales, dumping more than 12 inches of rain in 24 hours over a very wide area. As a result, because the summer rains had completely saturated the ground, massive flooding occurred on all the nearby river systems.

The city of Brisbane was the worst hit. It had not experienced a major flood for more than 70 years, and few suspected that anything like this would ever happen. After the last occasion when a major flood had hit the city, in 1893, very strict regulations were established for building on areas below a certain elevation. These restrictions were laid out for the parts of the city that would be at risk in the event of a major flood. Sadly, these regulations were not maintained for one reason or another, and subdivisions were allowed to develop on the areas on which no homes or other buildings were to be built. It is a story that is similar to what we have seen in the aftermath of the San Francisco earthquake, where areas that should never have been built on were once again rebuilt. Throughout Brisbane on January 25 there was a general failure of disaster warnings. There was no central authority that was able to receive details on the amount of flooding that occurred in different areas, so that local flooding in key areas was never reported to the authorities. About 70 percent of the

residents who were questioned afterward about the flood said that they had received no official warning.

January 25, 1974, the peak of the damage caused by Wanda, will be remembered as the worst floods in Australian history. Flooding covered an area slightly larger than the entire drainage basin of the Mississippi River. It reached from the dry interior at Alice Springs all the way to the Pacific Ocean, and from the extreme north of the country to the areas around Sydney, including the Murray River system. Military airplanes had to be used to supply isolated towns that were cut off by the floodwaters with emergency food for both humans and animals. In Brisbane, all bridges across the Brisbane River were damaged or destroyed, and 35 people drowned. At its height, the river broke its banks and ran through the central business district of the city. Water levels peaked at 20 feet by January 29. In one of the subdivisions 1,200 homes were destroyed. Overall, 20,000 people were left homeless. There was no adequate relief organization at this time, and about half of the victims depended on church contacts and a large number of volunteers for the help they did receive. By the end of January much of Australia, normally the dry continent, was submerged in water. Crops were destroyed, and there were outbreaks of disease.

Major flooding like this is so rare in Australia that the disasters of January 1974 are unique in the history of the country. In the aftermath, thoughts were concentrated on appropriate action that would prevent future disasters. Almost immediately the Queensland Government introduced a series of flood mitigation measures that expanded earlier ones. The experience was a wake-up call for Australia.

SAHELIAN DROUGHTS

This region, which stretches for three thousand miles across Africa south of the Sahara Desert, from Senegal at the Atlantic Ocean to Eritrea at the Red Sea, is a focus for all the world in the study of drought. It is an extreme example of aridity because of the extent and persistence of the droughts that overwhelm it. From 1968 to 1973 most of the region suffered from lack of rain, and the Sahelian Office at the United Nations created a special unit in 1973 to investigate the causes and recommend ways of coping with droughts. Occasionally the whole world becomes aware of the deadly nature of these times of aridity when international aid efforts are launched. One of these efforts is described in Chapter Six of Volume One: half a billion dollars was raised by Live Aid to help Ethiopia cope with a famine that had already taken the lives of 300,000 people. Overall, in the Sahel as a whole, between the 1960s and 1980s, famines took the lives of a million people, and many millions more were affected.

The 50 million people of the Sahel pursue different livelihoods. These include agriculture, livestock herding, fishing, and short- and

long-distance trading. Farming is almost entirely reliant on three months of summer rainfall, except for places that happen to be near a major river such as the Niger. Researchers from The United Nations, as they examine the region's economic fragility, recognize that the vast majority of the population is dependent on some form of rain-fed agriculture, including pastures for animal production. Three major droughts have occurred this century, in 1910–16, 1941–45, and a long period of below average rainfall that began in the late 1960s and continued, with some interruptions, into the 1980s. Absolute minimum rainfall levels were recorded at many stations in 1983 and 1984. The period of poor rainfall in the 1970s was particularly hard for many Sahelian farmers and pastoralists. An estimated 100,000 died from it.

Sahelian droughts and their effects have been studied extensively since the 1970s as part of the international response to this environmental emergency. It is only since 2000, however, that the long-term impacts of the famines of the 1970s have become evident. Those events provoked a rethinking of the links between population growth, drought, and sociopolitical change, and also helped to refocus development policy away from expensive and unsuccessful interventions toward more considerate strategies targeted at boosting local capacities. A complicating factor was increases in migration and international trade. Food distribution in famine situations by donors and governments has not been successful, despite the establishment of national cereals boards in most Sahelian nations, and the construction of roads into more remote rural areas. Rural residents still have to pay for government grain, and not all households are able to pay.

Originally it was believed that the problems in the Sahel were caused by humans overusing natural resources through overgrazing, deforestation, and poor land management. The expansion of farming and herding into marginal areas was said to have produced a spiral of changes, in which reduced vegetation caused reduced rainfall, producing further decreases in vegetation and thence a further reduction in rainfall. The series of Sahelian studies and climate modeling carried out by an agency of the NOAA over some years, and published in 2005, present a very different story: the problems are caused by changing sea surface temperatures that, in turn, were created by greenhouse gases and atmospheric aerosols from volcanic eruptions. In other words, global warming and climate change are the primary villains. The NOAA studies also point out that these human-induced changes in sea temperature could lead to a substantial reduction in the Sahel's rainfall in the course of this century.

Appendix C: Some Extreme U.S. Weather Events

In the volumes of this set extremes of weather are mentioned or, in some places, described in detail. The purpose of this appendix, as with Appendix B, is to provide a larger context to which the individual references can be linked. This list of U.S. extremes begins with two volcanic eruptions, one from Alaska, the biggest that occurred anywhere on earth during the twentieth century, and one from Washington State, the biggest ever within the contiguous United States. They are reminders of the unpredictable element brought by volcanic eruptions to the ongoing changes occurring in our atmosphere. Volume 1 describes the role of volcanic eruptions in considerable detail, with regard to their influences both now and in the future.

The other three extreme events included in this appendix are two extremes of temperature, cold and hot, and one of the most violent hurricanes of modern times, Camille of 1969. The extreme of heat is interesting because it arrived in the midst of widespread talk about global warming and climate change and is a reminder that the addition of carbon dioxide to the atmosphere has different effects in different places. In this instance, the high heat of the year 2006 is almost identical to that of the year 1936, the time of the Dust Bowl. The years 2006 and 1936 were the two hottest of the twentieth century.

MOUNT KATMAI, ALASKA, 1912

Katmai was the biggest eruption of the twentieth century anywhere on earth. A volume of volcanic ash greater than the amount from all other volcanic eruptions in Alaska was ejected, and it devastated every place within miles of the source. It created the Katmai Caldera and the Valley of Ten Thousand Smokes. Volcanic ash devastated areas hundreds of miles away. Within four hours of the initial eruption, ash had reached Kodiak, lying one hundred miles to the southeast, and by the end of the event, both Vancouver, British Columbia, and Seattle, Washington, were showered with sulfurous ash. The cloud produced by the eruption had reached Virginia by June 7. Ten days later, it had reached North Africa.

Kodiak suffered greatly during the three-day eruption. Ash and sulfurous smoke caused a slew of health problems ranging from respiratory illness to sore eyes. Additionally, the eruption rendered Kodiak's water

supply undrinkable, disrupted radio communications, and destroyed many buildings, some of which burned and others of which collapsed under the weight of mountains of ash.

As a result of the Katmai disaster, several villages were abandoned forever. Additionally, the eruption caused untold environmental havoc, and many animals, ranging from bears to birds, died of starvation. Aquatic organisms were also affected where waters were shallow and became choked with ash. This devastated local salmon fisheries for years.

Despite the fact that the eruption was so close to the continental United States and comparable in magnitude to that of Krakatau of 1883, it was hardly known at the time because Mount Katmai was so remote from the world's main population centers.

Almost a hundred years after it happened, researchers are still paying attention to Katmai because it is near the Arctic Circle, and its impact on global climate appears to be quite different from that of volcanoes in lower latitudes. Unlike eruptions in the tropics, the aerosols emitted by Arctic volcanoes tend to stay at high latitudes, because the stratosphere's average circulation is poleward from the equator. As a result, these particles remain effectively "bottled up" in the Arctic, dispersing into the rest of the earth's atmosphere only very gradually. Professor Alan Robock of Rutgers University has argued that this trapping of aerosols in the Arctic has an unexpected side effect: the weakening of the Indian monsoon. Robock reached these conclusions using complex calculations; however, the basic concept is that cooling in the northern hemisphere caused by the Katmai eruption set in motion a chain of events ultimately affecting air flow over the Himalayas and thus rainfall in south Asia.

To check his results, Robock and colleagues have been examining weather and river flow data from Asia, India, and Africa from 1913, the year after Katmai. They have also investigated the consequences of other high-latitude eruptions in the last few centuries. The fact that the stratosphere in high latitudes is shallower than at the tropics means that even small eruptions near the North Pole may deposit more aerosols than bigger events in the tropics. Furthermore, they would remain in circulation longer, as happened with Katmai. Indians will need to keep an eye on future Arctic eruptions.

It is unlikely that another eruption on the scale of Katmai will occur in the same region in the foreseeable future. However, volcanologists have confirmed that at least seven Katmai-scale eruptions have occurred over the last four millenia within a five-hundred-mile radius of the city of Anchorage, Alaska, so such a recurrence is far from outside the realm of possibility.

MOUNT ST. HELENS, WASHINGTON, 1980

The eruption of Mount St. Helens was the largest ever in the history of the contiguous United States. It had a VEI of 5. Mount St. Helens is the

youngest of the Cascades' volcanic peaks, and the explosion of 1980 is just the most recent of the many intermittent eruptions that took place over the past 40,000 years. Pumice and ash from these past events now cover large areas of the Pacific Northwest. From the 1950s onward, the mountain was intensively monitored, perhaps to a greater degree than any other. Days before the fateful event of Sunday May 18, 1980, there were many signs of impending danger, but no one was quite prepared for what finally happened. It all seemed to take place in seconds. Seattle's air traffic control tower tracked the mass of ash and rocks hurtling out of the mountain and concluded that it was traveling at close to 300 mph. The earthquake that triggered the explosion measured 5.1 on the Richter scale, but the energy released might be more accurately defined as the equivalent of thousands of Hiroshima-size bombs.

An avalanche of mud, rock, and ice roared down the mountainside, and the ash cloud rose as high as 54,000 feet. What had moments before been a beautiful 9,000-foot-high peak was reduced to a 7,500-foot decapitated mountain. Ash high in the atmosphere drifted eastward across the country, covering the ground everywhere it went with a layer of ash and blocking out sunlight in several communities near the mountain. Two hundred square miles of forest was flattened. Mudflows rushed westward down river valleys toward the Columbia River, blocking the navigation channel for ships with logs and mud for a distance of ten miles. It was estimated that 57 people lost their lives on that first day.

A Boeing 737 jet flying from Reno, Nevada, to Vancouver, Canada, at six thousand feet, was 40 miles south of Mount St. Helens when the mountain exploded. The pilot saw the explosion and swung away from his course, a path that would have taken him directly over the eruption, escaping in so doing a dirty gray cloud that was rising quickly to meet him. His 737 rocked in the air from the shock of the explosion as if it were a ship at sea. Fortunately his flight had been delayed for 30 minutes at Reno, or all 122 passengers plus crew would have been added to the list of deaths for May 18. The earthquake that triggered the event was not an unusual event in a region that experiences frequent earthquakes of this strength and stronger ones, but the scale of the eruption was a very different matter. It was a rare event even in historical time. Volcanic eruptions are identified by a volcanic eruption index number (VEI) based on the volume and speed of the rock and ash that is ejected. The index is numbered similarly to the Richter scale, each number representing ten times the volume of the one immediately below it, and one tenth that of the next number above it.

For this event of VEI 5, a volume of eruption greater than any other in the contiguous United States, one has to go back into earlier times to find a meaningful comparison. Vesuvius in the year 79 or Krakatau in 1883 each had VEIs of 6, or they were ten times more powerful than Mount St. Helens. Volcanoes in the Cascade Range are fairly new in geological time. A few date back several million years. Mount St. Helens is one of the youngest. Much of its visible cone was

formed within the last thousand years. It was frequently active during that time, and because of that geologists were convinced that a major eruption would occur sometime in the twentieth century. Further evidence in support of that expectation came more recently when it was found that the mountain had been more active and more violent over the past few thousand years than any other volcanic mountain in the contiguous United States. From the evidence in ash deposits across the western Cordillera, it is clear that some of these older eruptions must have had VEIs of 6.

The most recent well-documented eruption, prior to 1980, occurred in 1842. Eyewitness accounts from that time described seeing vast columns of smoke and fire. Ash from that time was subsequently located at The Dalles in Oregon, about 65 miles away. Fireworks continued intermittently over a 15-year period. Then came a three-year lull followed by a lot of activity in the year 1857. After that date the volcano seemed to have slept for the 123 years before 1980. The moment of eruption on May 18 of that year was indelibly etched in many memories. David Johnston, the expert geologist from the U.S. Geological Service who was monitoring the mountain on the morning of the explosion, talked to news reporters early on that day. He described Mount St. Helens as a keg of dynamite with a lit fuse whose length you do not know. He was well aware of the risks of being so close to the summit, but he stayed there right up to the moment of the eruption. He told the reporters that it was extremely dangerous to stand where they were at that time. "If the mountain explodes," he told them before they left, "we would all die." Soon afterward they heard his final words as he yelled into his radio, "Vancouver, Vancouver, this is it!"

A family watched their dream $100,000 home smashed and washed down the chocolate-brown Toutle River. A couple on a camping and fishing trip on the same river tried to grab their camping gear when they heard the explosion, but quickly saw there was no time to escape in their car. They were thrown into the water and carried along in a mass of mud, logs, and rocks, grimly clinging to one log. They were lucky. The log was shunted sideways out of the main stream. Some time later, a helicopter picked them up. A television cameraman a kilometer and a half from the base of the mountain filming the event saw the mass of mud and debris heading for him. He dropped everything, got into his car, and drove madly to keep ahead of destruction. He was able to stay ahead of it.

Farther east, travelers were stranded in numerous small communities, altogether 10,000 of them in three states. One couple driving west from Spokane saw the black oncoming cloud. Soon they could only inch along the highway at less than eight kilometers per hour. They abandoned their car and joined the other stranded ones. Everywhere around, trains, buses, airplanes, and cars came to a stop. Walking was the only thing that worked. Digging out from under the ash was yet another hazard. It proved to be as hard as getting around it. For some time people wore masks of whatever material they could find for fear of toxic fumes.

As is common in volcanic eruptions, the magma that had risen and caused the explosion left the inner chamber empty for a time until new magma moved up from below. The interior dome then began to grow until pressure rose to a level that caused another eruption. Several of these subsequent eruptions came in May, June, July, August, and October of 1980. By 1983 the dome had grown to six hundred feet and the crater in which it sat was two miles in diameter, waiting for the moment of the next event, and meanwhile continuing to grow.

How can volcanic eruptions and earthquakes be predicted? The answer remains elusive, but experience from Mount St. Helens shows us some of the things that can be done. As mentioned earlier in this chapter, this mountain received more monitoring since the 1950s than almost any other, and the small number of people who were killed is largely due to this, as well as to the actions that were taken in the months before May 18, 1980. The first earthquake in Mount St. Helens struck on March 20, 1980, and immediately afterward seismologists met with local authorities to warn of the danger ahead and make some preliminary plans.

One week later steam and ash exploded from the summit of the volcano, and this was followed by several minor eruptions over the following weeks. As these eruptions became more frequent, public authorities closed off the area around the mountain, causing heated opposition from the general public. Later they lowered the water level in the Swift Dam reservoir to minimize damage from mudflows. Still closer to the time of the eruption, the governor of Washington declared a state of emergency in order to use the National Guard to staff the roadways. So angry were some over the closure that they found ways of circumventing the law by using little-known roads and footpaths to gain access. Some, including Harry Truman, a veteran resident of the mountain, refused to leave their homes on the north side and died.

ARCTIC OUTBREAK, 1989

America's coldest spell of the century arrived in December 1989. In the South, New Orleans experienced 64 consecutive hours at or below 32°F and a total of 81 out of 82 hours below freezing. A total of 15 hours were below 15°F, with the lowest reading of 11°F on the morning of December 23. A low of 8°F was recorded at Baton Rouge. Snow and sleet paralyzed transportation systems in New Orleans, and there were a hundred fires in the city, a result of inadequate heating systems. The greatest impact was on breakage of water pipes in homes and businesses. Five weather-related deaths occurred in the area during this rare Arctic outbreak.

The story was similar in the Midwest: it was the coldest day of the season for south central Nebraska and north central Kansas, and most locations experienced subzero temperatures. This Arctic outbreak peaked around December 15 and continued for about ten days. Low temperature records were broken throughout the United States. Nothing comparable

is found in weather records until we go back to 1899, when a similar chill occurred. The events in both of these years were quite similar: both were fast-moving, very powerful Arctic outbreaks that stretched across most of the United States and reached into Mexico and Florida.

GREAT HEAT WAVE, 2006

In 2006, from June 1 to August 31, as summer is defined by the National Climatic Data Center, the United States experienced its greatest heat wave in 70 years. The average temperature across the country was 74.5°F, based on readings from hundreds of weather stations. It was the second-hottest summer temperature since the government started to keep records in 1895. The only comparable heat wave was in 1936. At the 2006 peak, temperatures greater than 100°F covered the Great Plains, Midwest, South, and much of the Northeast. The year 1936 is a reminder of the Dust Bowl years that are described in Volume One.

With air conditioning being quite limited in its coverage in 1936, many people were forced to sleep in their yards or in parks. The death toll was high, estimated at about 50,000 total. The heat was especially deadly in large Midwestern cities such as St. Louis, Minneapolis, and Detroit. The total number of deaths from a heat wave is rarely given out by media for various reasons: deaths from heat are silent killers, they do not cause visible destruction where they occur, and causes of deaths are difficult to identify.

HURRICANE CAMILLE, 1969

Camille was one of only three hurricanes in the history of the United States to make landfall as a Category 5. It was an extreme hurricane, one of the most violent storms of the twentieth century. It arrived from western Cuba on August 14 and entered the warm waters of the Gulf, reaching Bay St. Louis on the evening of August 17 with sustained wind speeds of 190 mph. It almost totally destroyed the Mississippi coast. Before it left the mainland United States it had caused the deaths of more than 250 people and injured 8,900, and destroyed 6,000 homes and damaged 14,000. The total costs of the destruction it caused were in excess of a billion dollars. Millions of Gulf coast residents were made aware of the strength of the storm before nightfall on August 17. Before the storm reached Bay St. Louis, about 200,000 residents had fled the coastal areas into sheltered places.

As the storm moved across the coast in darkness, homes, motels, apartments, restaurants, and other buildings were swept off their foundations and deposited in mountains of rubble. It was the same for almost everything movable and for much, such as trees, that was not. Camille maintained its hurricane strength for ten hours. On the morning after

the storm, thousands searched among the wreckage for anything that might have been left. There was no semblance of normal life in the region around New Orleans for days, but fortunately the levees around the city were not affected because the storm was centered a few miles to the east. About 15,000 people were left homeless. There was no water, food, or fuel. The storm had wiped out all means of communication, and roads, bridges, airports, and even railways were impassable or destroyed. Gulfport Hospital had closed down and evacuated all of its patients to hospitals farther inland.

Adding to the devastated landscape was a serious vermin problem. There were thousands of dead animals of all kinds, and insects and rodents had quickly overrun the stricken area to feed on these and on the rotting food. Rattlesnakes, fire ants, and rats bit dozens of victims who were sifting through the rubble. In an attempt to control the ants, low-flying planes roared up and down the Mississippi coast, dropping quantities of mirex. At the time of Camille this product was not considered dangerous to humans, but eight years later the U.S. Environmental Protection Agency banned it as a possible carcinogen. President Nixon sent a thousand troops to help, and the state governor declared a state of emergency in order to control crime. Using federal troops and state police, all roads leading into the area where the eye had crossed the coast were sealed off. Military and local police imposed a curfew. The first problem to overcome was the thousands of dead farm animals, pets, and wildlife. Camille's incredible 25-foot storm surge had drowned thousands of animals. Heavy equipment was brought in to bury these thousands of animals.

The National Hurricane Center took note of Camille's weather data because of the unusual ferocity of this storm. The lowest barometric pressure recorded on land during the evening of August 17 was 26.85 inches. That was at Bay Saint Louis. This was the second-lowest barometric pressure ever measured in the United States. Only the 1935 Labor Day hurricane produced a lower pressure in the middle keys. That figure was 26.35 inches. The highest tidal surge ever recorded in the United States belongs to Camille. It was officially recorded as 22.6 feet above mean sea level, but high-water marks on buildings, still clearly visible long after the storm had passed, showed water heights of 25 feet. Camille moved inland and then gradually weakened to a tropical depression over northern Mississippi on August 19. It had picked up a lot of moisture over the Gulf of Mexico, and this led to torrential rain over the mountains of Virginia. In eight hours, 28 inches of rain fell on Nelson County, an amount that more than tripled the state's 24-hour record, which had been set in 1942 and has not been broken since. In other parts of the state, 14 inches came down during the night. Afterward, Camille turned eastward to emerge into the Atlantic near Virginia Beach on August 20.

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Appendix D: Measuring Weather and Climate Events

MEASUREMENT CONVERSIONS

1 inch equals 2.54 centimeters

1 centimeter equals 0.39 inches

1 meter equals 3.28 feet

1 kilometer equals 0.62 miles

1 square meter equals 10.76 square feet

1 square kilometer equals 0.39 square miles

1 hectare equals 2.47 acres

1 cubic meter equals 35.31 cubic feet

1 cubic kilometer equals 0.24 cubic miles

1 degree Fahrenheit equals 9/5 degree Celsius plus 32

1 degree Celsius equals 5/9 degree Fahrenheit minus 32

FUJITA F AND EF SCALES FOR TORNADOES

The F scale was created by Japanese American meteorologist Tetsuya Fujita in 1951 to classify tornadoes.

F0 40–72 mph (light)

F1 73–112 mph (moderate)

F2 113–157 mph (significant)

F3 158–206 mph (severe)

F4 207–260 mph (devastating)

F5 261–318 mph (incredible)

Half of all tornadoes worldwide are F1 or less. Only 1 percent of all are F5.

Over the years, the F scale has revealed weaknesses: (1) too much reliance on the estimated wind speeds, and (2) oversimplification of the

damage description. Fujita recognized that improvement was necessary. When the committee met to develop the enhanced Fujita scale, one point was made very clear: it must continue to support and maintain the original tornado database; in other words, there must be some conformity to the F scale that is listed in the database.

F Scale

F0 40–72 mph

F1 73–112 mph

F2 113–157 mph

F3 158–207 mph

F4 208–260 mph

F5 261–318 mph

EF Scale

EF0 65–85 mph

EF1 86–110 mph

EF2 111–135 mph

EF3 136–165 mph

EF4 166–200 mph

EF5 Over 200 mph

SAFFIR-SIMPSON SCALE FOR HURRICANES

Developed in the later 1960s by Herbert Saffir to quantify potential wind damage from hurricanes, and expanded in the early 1970s by Robert Simpson, director of the National Hurricane Center, the Saffir-Simpson scale is used to measure hurricane strength. Wind speed is the determining factor in the scale, but storm surges caused by wind are highly dependent on the slope of the continental shelf and the shape of the coastline.

Category 1 74–95 mph (minimal)

Category 2 96–110 mph (moderate)

Category 3 111–130 mph (extensive)

Category 4 131–155 mph (extreme)

Category 5 155 mph or more (catastrophic)

VOLCANIC EXPLOSIVITY INDEX (VEI)

To compare the magnitudes of volcanic eruptions, scientists have developed a volcanic explosivity index (VEI) in which each level is ten times as powerful as the previous level. The index measures eruptions on a scale of 0 to 8. The VEI of any eruption is based on the volume of rocks and ash that is emitted. A VEI of 1 could represent a Hawaiian eruption, a gentle oozing of lava with no violent activity; a VEI of 8, a very rare event, would apply to Toba, an Indonesian eruption of gigantic proportions that occurred 74,000 years ago. Krakatau of 1883 had a VEI of 6. Mount St. Helens of 1980 had a VEI of 5.

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GLOSSARY

absorption of radiation. Transfer of electromagnetic energy into heat energy.

adiabatic process. Temperature change in a gas or in air due to compression or expansion. No heat is gained or lost from the outside in the process.

advection fog. A fog that develops when condensation occurs within moist air close to the earth's surface.

acid rain. The presence of acidic elements in rain that tend to destroy plants and trees.

aerosols. Tiny substances in the atmosphere, so small that the slightest movement of air keeps them aloft.

air. The mixture of gases that make up our atmosphere.

air mass. A large body of air that has defined temperature and humidity characteristics. It may extend over thousands of square miles and be miles in depth.

air pollution. A harmful substance put into the atmosphere from the earth

albedo. The amount of solar radiation that is reflected by a part of the earth's surface, usually expressed as a percentage.

alcohol thermometer. *See* thermometer.

anemometer. An instrument for showing wind speed.

Antarctic Circle. The parallel of latitude at 66.5° south.

anthropogenic. Caused by human activities.

anticyclone. High pressure mass of air with winds circulating clockwise in the northern hemisphere or counterclockwise in the southern hemisphere.

Arctic Circle. The parallel of latitude at 66.5° north.

Arctic front. The zone of interaction between polar and Arctic air masses.

armada. A Spanish word meaning a very large group of warships.

Asian cyclone. A tropical cyclone or typhoon that occurs in Asia. *See* typhoon.

atmosphere. The gaseous envelope surrounding the earth, mostly consisting of nitrogen and oxygen, concentrated within an area 30 miles above the earth.

atmospheric pressure. The force exerted by the weight of the atmosphere on an area.

aurora borealis. Lights visible near the North Pole, caused by interaction between the sun's radiation and molecules in the earth's atmosphere.

automatic weather stations. Weather stations, often at sea, that record and transmit data to a central location for weather forecasting.

barometer. An instrument for measuring atmospheric pressure.

biosphere. The part of the earth system that contains all living things, in or on the land, in the atmosphere, and in or on the oceans.

blizzard. Violent winter storm that lasts for several hours or longer.

caldera. A steep-sided circular depression in the ground, the end result of a volcanic eruption.

carbon dioxide. Gas that is a byproduct of burning fossil fuels or biomass. It also occurs naturally.

Celsius scale. A temperature scale in which the freezing point of water is zero degrees and the boiling point is one hundred degrees.

Chinook wind. A very dry wind that flows down the eastern side of the Rocky Mountains.

chlorofluorocarbons (CFCs). Compounds used in refrigerators, aerosol products, and solvents. Now banned in many products because of their harmful influence on the earth's ozone layer.

climate. The average pattern of weather in a given area over a long period of time.

climate classification. Division of the earth's climates into a system of regions, each defined by specific climatic elements.

climograph. A graph that shows the monthly totals for two climatic variables such as temperature and precipitation.

cirrus cloud. A high-level cloud, stringy and layered.

cloud. A suspended concentration of water or ice particles.

cloud base. The lowest elevation where cloud particles such as water droplets or ice crystals can be observed.

cold front. At the boundary between two air masses of different temperatures and humidities, the cold front is the heavier of the two, so it pushes the warm air mass upward.

colony. A territory owned and administered by a colonial power, usually a European power.

condensation. A physical process in which water vapor is changed into a liquid, that may take the form of a cloud, fog, or dew.

condensation nucleus. A tiny substance in the atmosphere on which water vapor condenses to form a drop of water.

convection. Transference of heat in a gas or liquid by upward movement of the heated and therefore less dense part.

Coriolis effect. A force caused by the earth's rotation that turns air movements to the right in the northern hemisphere and to the left in the southern hemisphere.

cumulonimbus. A heavy and dense cloud with a substantial vertical component.

cumulus cloud. A cloud made up of a rising mass of air that can be found at any level in the lower atmosphere.

cyclone. An area of low atmospheric pressure with inwardly rotating winds.

D-Day. The day selected to launch a massive attack by sea from Britain to France near the end of World War Two.

depression. An area of the atmosphere in which sea-level pressures are lower than those of the surrounding region, often the early stage of a middle-latitude cyclone.

desert. An ecosystem with less than four inches of rain a year.

dew. Water that has condensed on things near the ground.

dew point temperature. The temperature at which a mass of air holds its maximum amount of water vapor.

diurnal. Daily.

doldrums. A belt of calm seas near the equator.

doppler radio. A radar tracking system that enables a meteorologist to determine the speed of a moving object.

downburst. Violent and damaging downdraft associated with a severe thunderstorm.

drought. When an area experiences rainfall levels significantly below normal.

dust storm. A heavy mass of dust in a disturbed air mass.

El Niño. The fluctuating warm temperatures of the equatorial Pacific Ocean that affect global circulation of air.

energy balance. Globally, the total energy input from the sun equals the total energy output.

equator. The parallel of latitude that is midway between the North and South Poles.

equinox. The moment in time when the sun is directly overhead at the equator.

evaporation. The change of a liquid into a gas.

eye of tropical cyclone. The clear and calm area inside the rotating wall of convective clouds.

Fahrenheit scale. A temperature scale where the freezing point of water is 32 degrees and the boiling point is 212 degrees.

fall equinox. When the sun is overhead at the equator in autumn. It occurs around September 23.

fertilizers. Substances added to soil to make it more fertile.

flash flood. A flood caused by heavy rainfall within a short period of time.

flood. A stream that overtops its banks and covers the surrounding area.

flood stage. A particular level on a stream at which flooding occurs.

fog. A cloud at ground level.

forecast. A prediction about future weather conditions.

frost. Small ice crystals that form on or near the ground when temperatures are below freezing.

Fujita scale. The method used for calculating the strength of tornadoes.

global energy balance. The balancing of solar short-wave incoming energy with outgoing long-wave energy from the earth

global warming. An overall increase in the earth's average surface temperature.

greenhouse effect. Absorption of long-wave radiation, especially by water vapor and carbon dioxide, and reflection of heat back to earth to raise ground level temperatures.

greenhouse gases. Atmospheric gases that absorb and reflect long-wave radiation, causing the greenhouse effect. The two most important gases of this type are water vapor and carbon dioxide.

green revolution. The use of new quick-ripening, high-yield plants for use in developing countries.

guerilla-type attacks. The use of individual soldiers or small groups of soldiers to carry out raids on enemy positions.

Gulf Stream. The warm ocean current that flows northward along the east coast of the United States.

hailstorm. Pellets of ice falling from thunderclouds.

heat island. An area within an urban zone that has higher temperatures than those of the surrounding areas.

Himalayas. A mountain chain on the border between India and China.

humidity. The amount of water vapor in an air mass, measured as a percentage of the maximum that it could carry.

hurricane. A North Atlantic or Caribbean tropical cyclone.

ice age. A geological period in which ice sheets covered much of North America.

iceberg. A mass of floating ice.

Indian monsoon. *See* monsoon.

insolation. The technical term for the energy that reaches the earth from the sun.

irrigation. Water that is taken to fields from ponds or streams.

isobar. A line on a weather map connecting places that have the same atmospheric pressure.

jet streams. High-speed air flows about 15 miles above the earth, usually running from west to east.

L'Anse Aux Meadows. A Heritage site on the island of Newfoundland where the first Europeans to reach North America lived.

La Niña. The fluctuating cold temperatures of the equatorial Pacific Ocean that affect global circulation of air.

latent heat. Energy being absorbed from the air during changes from water to water vapor and released to the surrounding air during changes back from water vapor to water.

levees. Embankments to prevent rivers from flooding.

mercury thermometer. *See* thermometer.

meteorologist. A person who understands, studies, and predicts weather conditions.

microburst. A very narrow downburst.

monsoon. A persistent seasonal wind with a change in direction from season to season, usually associated with the wind patterns to and from the Asian interior in relation to the Indian Ocean.

NOAA. U.S. National Oceanic and Atmospheric Administration.

nor'easter. An extra-tropical storm along the coasts of Atlantic Canada and from Maine to New York, frequently referred to by this name because its winds come from the northeast.

Norwegian school of meteorology. The group of meteorologists who discovered and used air mass theory in forecasting the weather.

Northwest Passage. The north shore of Canada, the shortest sea route to Asia from Europe, now no longer permanently covered by ice.

ocean conveyor belt. Another name for the thermohaline-driven global ocean current.

ozone. A gas in the higher reaches of the atmosphere, created both naturally and through photochemical reactions, that absorbs ultraviolet radiation from the sun, an activity that is vital to the preservation of life on earth.

ozone layer. A region of the stratosphere stretching from about eight miles to 25 miles above the earth that contains large concentrations of naturally occurring ozone.

permafrost. Permanently frozen areas of the earth's surface.

pesticides. Chemical substances used to destroy insects or other organisms that are harmful to growing crops.

photosynthesis. The process by which plants take carbon dioxide from the air and release oxygen into the air.

polar front. The front between cold polar air masses and warm tropical air masses.

precipitation. A general term for different forms of water that may either be falling from or held in suspension in the air. Included in this term are rain, drizzle, snow, hail, and ice pellets.

rain gauge. Instrument for measuring the amount of rain that has fallen.

relative humidity. *See* humidity.

Rossby waves. Planetary waves in the atmospheric westerly circulation, characterized by great length and amplitude.

Sahel. The dry southern part of the Sahara Desert.

Santa Ana winds. Hot and dry winds that come from the interior desert regions of California and pass over the coast mountains to reach the Pacific Ocean.

sensible heat. Heat that can be measured by a thermometer.

sleet. A mixture of snow and rain.

smog. Fog combined with smoke, a common problem in large cities.

solar constant. The intensity of solar radiation on one unit of area when it is at right angles to the incoming sun's rays.

spring equinox. When the sun is overhead at the equator in the spring. It occurs around March 21.

statistical average. A calculation made by adding a collection of numbers and then dividing the answer by the total number of individual items in the collection.

Stevenson screen. A shelter for housing such weather measuring instruments as thermometers.

storm surge. The temporary increase in the height of the sea at a particular location due to a hurricane or a strong wind.

stratosphere. The part of the atmosphere above the troposphere, from about eight to 30 miles above the earth.

sublimation. The change of ice directly to water vapor or vice versa without passing through the liquid phase.

subsolar point. A place where the sun's rays are perpendicular to the earth's surface.

summer monsoon. Inflow of air from the Indian Ocean toward the continental Asian low-pressure center.

summer solstice. When the sun is overhead at 23.5° north, at the Tropic of Cancer. It occurs around September 23.

tar sands. The rich oil-bearing sands of northern Alberta, Canada.

thermometer. An instrument that measures temperature by using the properties of either alcohol or mercury as they respond to heating.

thunderstorm. Sudden electrical discharges, usually from convective clouds such as cumulonimbus, followed by lightning, thunder, and rain.

Tibetan Plateau. The highest extensive elevation of land north of the Himalayas.

tornado. A violent rotating storm of small diameter, a twister, usually appearing as a funnel cloud extending from the base of a cumulonimbus to the ground.

tornado F5. The most destructive type of tornado.

tornado outbreak. A succession of powerful tornadoes occurring within a short period of time.

trade winds. Winds that blow from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.

tropopause. The boundary between the troposphere and the stratosphere.

troposphere. The lowest part of the atmosphere, extending upward from the earth for about seven miles.

trough. A layer of the atmosphere with low pressure.

typhoon. A tropical cyclone occurring in the western Pacific Ocean.

urban heat island. An area at the center of a city where temperatures are higher than they are in the surrounding areas.

volcanic eruptions. The ejections of masses of lava and other material from a volcano.

warm front. The transition zone between warm and cold air masses. The warm front is the lighter of the two, so it is pushed upward by the cold air mass.

water vapor. Water when it is in gaseous form.

wave cyclone. A mid-latitude cyclone, usually originating at the polar front.

westerlies. Winds from the west between the latitudes 35° north and 65° south.

wind chill. A temperature based on actual temperature and wind strength. It indicates the cooling effect of wind on exposed parts of the body.

winter monsoon. Outflow of continental air from the Siberian high to southeast Asia and the Indian Ocean.

winter solstice. When the sun is overhead at 23.5° south, at the Tropic of Capricorn. It occurs around December 22.

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