Arbaminch Water Technology Institute
Faculty of Meteorology and Hydrology

Climate change: Impact, adaptation &Mitigation

Course code: MHF1303.

Course credit: 6

Target group: UG3_MHS

Instructor: *Gizachew K*

Palaeo climate

Lecture Note3:

- Palaeo Climate conditions
- Palaeo Climatic Methods
- Palaeo Climate Modelling
- What Caused the Ice Ages?
- Climate models
- Climate scenarios

Palaeo Climate

- Paleoclimate science has made significant advances since the 1970s,
- when a primary focus was on the origin of the ice ages,
- the possibility of an imminent future ice age,
- and the first explorations of the so-called Little Ice Age and Medieval Warm Period.
- What is the need of learning the paleo climate?

Cont.

- U.S. Geological Survey (USGS) researchers are at the forefront of Palaeo climate research, the **study of past climates.**

- With their unique skills and perspective, only geologists have the tools necessary to delve into the distant past (long before instrumental records were collected)
- in order to better understand **global environmental conditions** that were very different from today's conditions.

- **Paleo climatologists** are geologists who study past climates to answer questions about what the Earth was like in the past and to enable projections, plans, and preparations for the future.

- An idealized spectrum of atmospheric variability at a mid-latitude location is given in Figure 2.2 of (Saltzmann, 2002)

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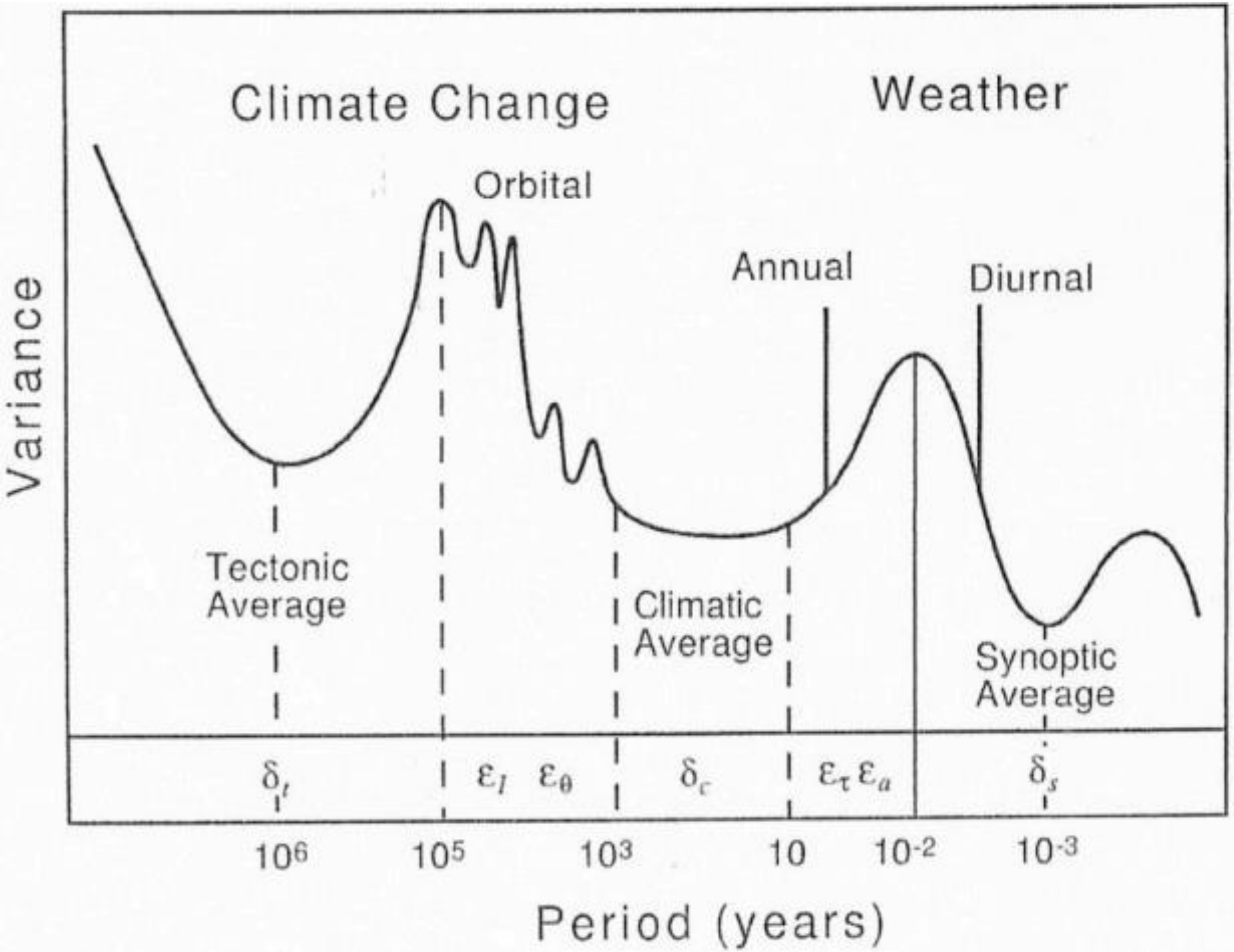

Climate Change
Weather
Orbital
Annual
Diurnal
Variance
Tectonic Average
Climatic Average
Synoptic Average
δt
ε1 εθ
δc
ετ εa
δs
10^6
10^5
10^3
10
10^-2
10^-3
Period (years)

- Figure 2.2 Hypothetical, highly idealized, spectrum of atmospheric thermal variance at a middle age of the Earth.
- δ_s, δ_c and δ_t denotes the Synoptic, climatic and tectonic averages and ε_t, ε_τ, ε_J denotes the approximate response times for the atmosphere.

➢ The state of the climate system has been changing continuously throughout the Earth’s history.

Cont.

- Atmospheric phenomena shorter than a month, including the diurnal cycle, mesoscale systems, cyclones,

- Decadal to century time scales during which the ocean plays a big role variability at periods greater than 10,000 years strongly associated with **planetary ice mass variations.**

Cont.

- It is important to note that the temperature of the Earth's atmosphere and surface is such that all three phases of water are present.

- The climate system hovers near the freezing point of water, allowing relatively slow but
- major fluctuations in the proportions of surface ice to liquid water involving only small perturbations of the global energy cycle.

Paleoclimate: The Last Billion Years

- Little is known about the climate previous to 1 billion years ago, except that life did exist, and that liquid water was on the surface of the Earth.
- Note that the time span of the Earth's history is divided (from the largest to smallest sub-division) into
- **Eons, Eras, Periods, Ages, and Epochs**
- Figure3. Diagram showing the major geologic ages [rom Crowley (1983)].

Cont.

EON	ERA	PERIOD	AGE (millions of years)	EPOCH	MAJOR GEOLOGICAL AND PALEONTOLOGICAL EVENTS	
Phanerozoic	Cenozoic	Quaternary	.01	Holocene	Himalayan Mountain-building	Age of Mammals
			2	Pleistocene		
		Tertiary	5	Pliocene		
			26	Miocene	Alpine Mountain-building	
			37	Oligocene		
			53	Eocene		
			65	Paleocene		
	Mesozoic	Cretaceous	136		First stages of Rocky Mountains	Age of Dinosaurs
		Jurassic	190		Breakup of Pangaea – opening of Atlantic	
		Triassic	225			
	Paleozoic	Permian	280		Final assembly of Pangaea	
		Carboni-ferous: Pennsylvanian	320	Consolidation of continents to form super-continent of Pangaea	Extensive coal formation	
		Carboni-ferous: Mississippian	345			
		Devonian	395			
		Silurian	430		First land plants	
		Ordovician	500		Primitive fish	
		Cambrian	570		First abundant shelled invertebrates	
	Precambrian	Proterozoic	2300		Abundant iron formations	
			2800		Major gold deposits	
		Archean	4600		Earliest known life (~3500)	
			4700		Oldest rock (~3800)	
					Formation of Earth	

- The climate has been cold enough for **ice sheets** to form during at least three periods over the past billion years:

- During the pre-Cambrian Era (600 **My**, where **My** = million years ago)
- During the late-Paleozoic (300 **My**)
- During the late-Cenozoic (last several million years)
- Note that we are still technically in the late Cenozoic ice age

- A well-studied **warm period** of non-glacial climate occurring between ice ages was the **middle Cretaceous** (120 – 90 **My**). (My stands for Million years)
- Since very little ice existed, sea level was about 100 m higher than now, so oceans flooded about 20% of the continental areas now above water.
- This period was substantially warmer than the current period, and large carbon deposits (including the major oil deposits) were laid down during this period.

Cont.

- The end of the Cretaceous Period and the beginning of the Tertiary Period is marked by the "K-T" boundary.

- About 75% of the total number of living species (including **dinosaurs**) became extinct.
- Chemical analysis of the earth's crust in layers where the K-T boundary is well marked indicate high iridium content, indicative of an impact by a large meteorite or comet

The Last 50 Million Years

- The continents moved away from Antarctica.
- The southern ocean circulation became circumpolar and deep waters cooled by more than 10 degrees.
- Glaciers developed over Antarctica, and ice volume increased until about 5 My.
- The current NH polar ice sheets first appeared about 3 My.
- Overall the trend in last 50 to 100 My was for the climate to cool from the middle Cretaceous warm climate to the current Quaternary ice age.

The Last Two Million Years

- This period is characterized by large amount of land ice, which advanced and retreated in both hemispheres simultaneously
- Before about 700,000 years ago, the ice advanced and retreated on a time scale of about 41,000 years.
- However, during the last 700,000 years the swings in ice cover have had a longer time scale, about 100,000 years.

The last 150,000 years

- About 125,000 years ago the amount of land ice reached a **minimum**, comparable to today's inter-glacial conditions
- Between 125,000 years ago and the present, the amount of glaciation reached a maximum about 20,000 years ago
- **Sea-ice** around Antarctica was greatly expanded
- Ocean temperatures cooled a great deal in the North Atlantic, but less in the tropics.

The Last 10,000 Years

- ➢ The global climate has warmed:
- The Early Holocene (10,000 to 5,500 years ago) was warmer than today's climate
- Minor advances of mountain glaciers were seen in the periods about 5300 years ago.
- The latter period is called the Little Ice Age (1250-1850 AD).
- In the intervening years (~900-1200 AD) the climate was warmer.

✓ These are all about the palaeoclimatic record in chronological order, from oldest to youngest.

Palaeoclimatic Methods

- **Methods – Observations of Forcing and Response**

✓ How is Past Climate Forcings Known?

- Time series of astronomically driven insolation change are well known and can be calculated from celestial mechanics.
- The methods behind reconstructions of past solar and volcanic forcing continue to improve, although important uncertainties still exist.

✓ How are Past Changes in Global Atmospheric Composition Known?

Cont.

- Perhaps one of the most important aspects of modern paleoclimatology is that it is possible to derive time series of atmospheric trace gases and aerosols for the period from about 650 kyr to the present from air trapped in polar ice and from the ice itself.
- As is common in palaeoclimatic studies of the Late Quaternary, the quality of forcing and response series are verified against recent (i.e., post-1950) measurements made by direct instrumental sampling.

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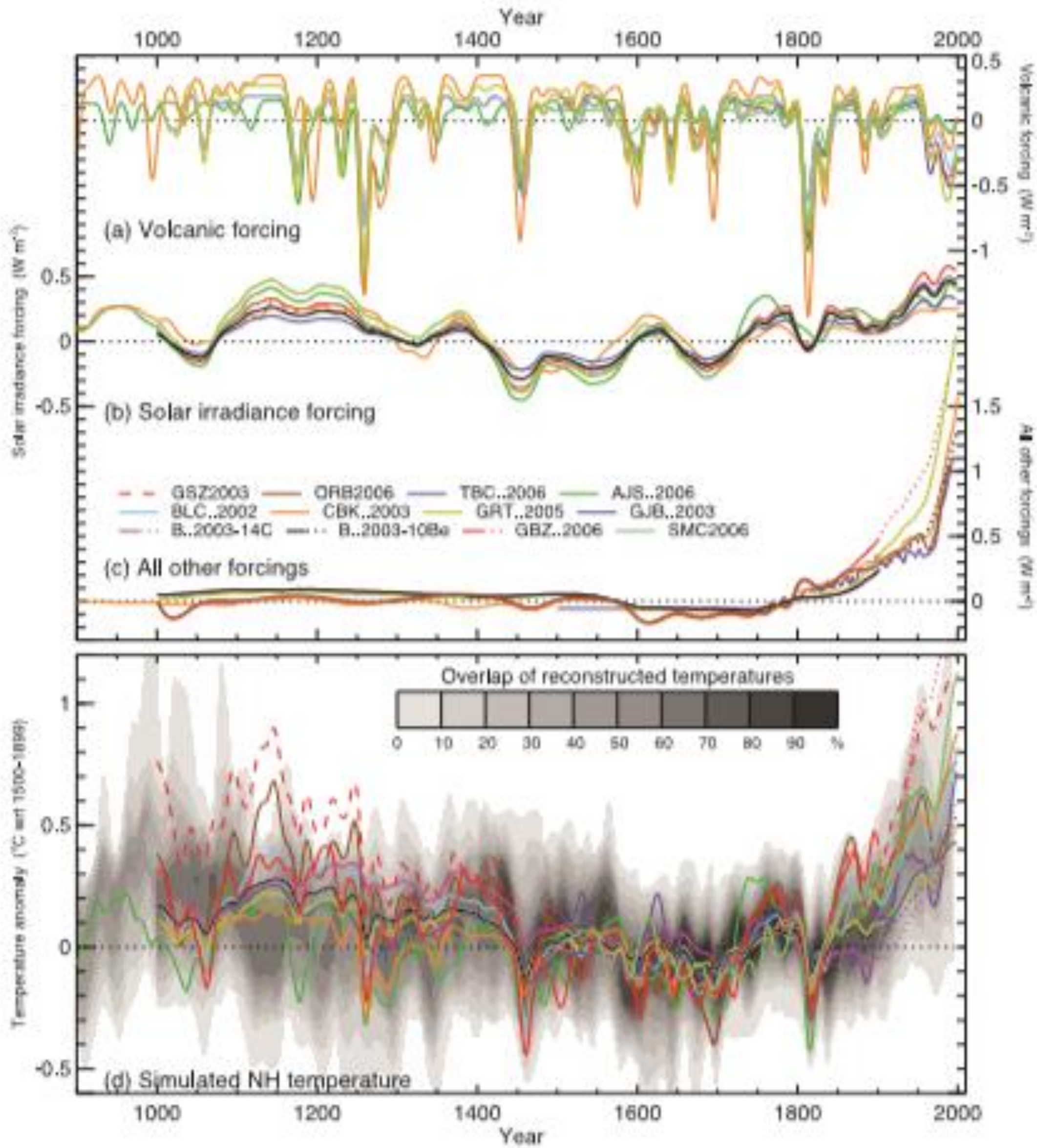


Figure: RF and simulated temperatures during the last 1.1 kyr.

- Global mean radiative forcing (W m–2) used to drive climate model simulations due to (a) volcanic activity, (b) solar irradiance variations and (c) all other forcings (which vary between models, but always include greenhouse gases, and, except for those with dotted lines after 1900, tropospheric sulphate aerosols).
- (d) Annual mean NH temperature (°C) simulated under the range of forcings shown in (a) to (c), compared with the concentration of overlapping NH temperature reconstructions (shown by grey shading).

➢ Methods – Paleoclimate Modelling

- ➢ Climate models are used to simulate episodes of past climate (e.g., the Last Glacial Maximum, the last interglacial period or abrupt climate events) to help understand the mechanisms of past climate changes.
- ➢ Models are key to testing physical hypotheses,
- such as the Milankovitch theory quantitatively.
- Models allow the linkage of cause and effect in past climate change to be investigated.

Cont.

- Models also help to fill the gap between the local and global scale in paleoclimate,

- as palaeoclimatic information is often sparse, patchy and seasonal.
- For example, long ice core records show a strong correlation between local temperature in Antarctica and the globally mixed gases CO2 and methane,
- but the causal connections between these variables are best explored with the help of models.

- Developing a quantitative understanding of mechanisms is the most effective way to learn from past climate for the future,
- since there are probably no direct analogues of the future in the past.
- At the same time, paleoclimate reconstructions offer the possibility of testing climate models,
- particularly if the climate forcing can be appropriately specified, and the response is sufficiently well constrained.

Cont.

- For earlier climates (i.e., before the current 'Holocene' interglacial), forcing and responses cover a much larger range,

- but data are more sparse and uncertain,
- whereas for recent millennia more records are available, but forcing and response are much smaller.

The Pre-Quaternary Climates

- What is the relationship b/n Co_2 and Temperature in this Time Period?

- Pre-Quaternary climates prior to 2.6 Ma were mostly warmer than today and associated with higher Co_2 levels.
- In that sense, they have certain similarities with the anticipated future climate change (although the global biology and geography were increasingly different further back in time).
- In general, they verify that warmer climates are to be expected with **increased greenhouse gases concentrations**.

Glacial-Interglacial Variability and Dynamics

- ➢ Climate Forcings and Responses Over Glacial-Interglacial Cycles.

- Palaeoclimatic records document a sequence of glacial interglacial cycles covering the last 740 kyr in ice cores several million years in deep oceanic sediments.
- The last 430 kyr, which are the best documented, are characterized by 100-kyr glacial-interglacial cycles of very large amplitude, as well as large climate changes corresponding to other orbital periods.

Cont.

- There is evidence for longer interglacial periods between 430 and 740 ka, but these were apparently colder than the typical interglacial of the latest Quaternary.
- The Holocene, the latest of these interglacial, extends to the present.
- The ice core record indicates that greenhouse gases co-varied with Antarctic temperature over glacial-interglacial cycles,
- suggesting a close link between natural atmospheric greenhouse gas variations and temperature.

What Caused the Ice Ages and Other Important Climate Changes Before the Industrial Era?

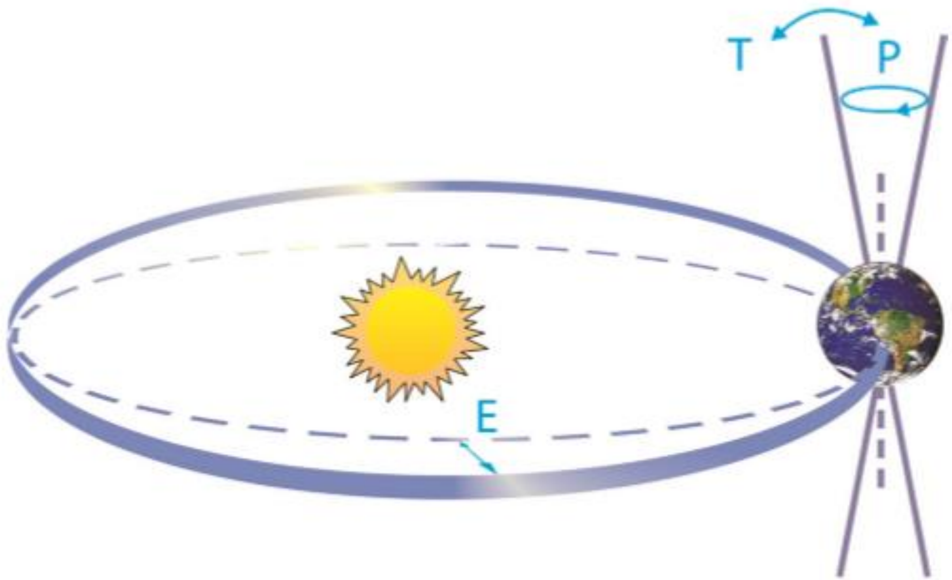
- Climate on Earth has changed on all time scales, including long before human activity could have played a role.

- Great progress has been made in understanding the causes and mechanisms of these climate changes.

- Changes in Earth's radiation balance were the principal driver of past climate changes, but the causes of such changes are varied.

- For each case – be it the Ice Ages, the warmth at the time of the dinosaurs or the fluctuations of the past millennium – the specific causes must be established individually.

- In many cases, this can now be done with good confidence, and many past climate changes can be reproduced with quantitative models.



- Figure . Schematic of the Earth's orbital changes (Milankovitch cycles) that drive the ice age cycles.

- ‘T’ denotes changes in the tilt (or obliquity) of the Earth’s axis,
- ‘E’ denotes changes in the eccentricity of the orbit (due to variations in the minor axis of the ellipse), and
- ‘P’ denotes precession, that is, changes in the direction of the axis tilt at a given point of the orbit.
- Source: Rahmstorf and Schellnhuber (2006).

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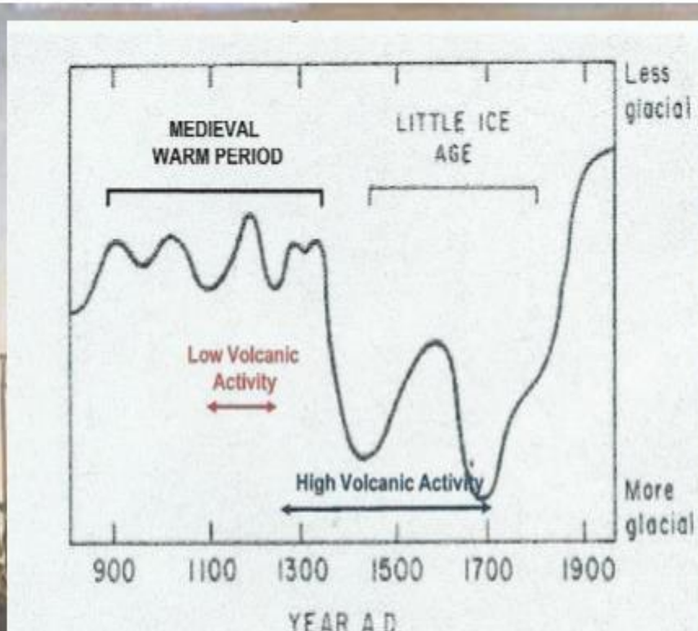
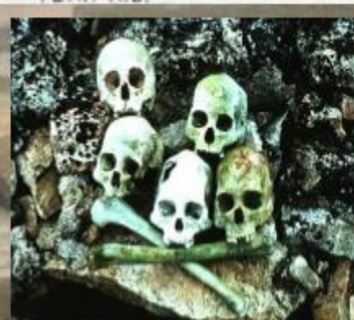
Non-periodic changes: the little ice age





- Generally global climate is determined by the radiation balance of the planet.
- There are three fundamental ways the Earth’s radiation balance can change, thereby causing a climate change:

1. Changing the incoming solar radiation

- (e.g., by changes in the Earth’s orbit or in the Sun itself), 2.Changing the fraction of solar radiation that is reflected (this fraction is called the albedo

- it can be changed, for example, by changes in cloud cover, small particles called aerosols or land cover), and

3. Altering the longwave energy radiated back to space

- (e.g., by changes in greenhouse gas concentrations).

The climate system

Components of the climate system

- The climate system can be divided into five components.
- **Atmosphere**: Gaseous part above the Earth's surface including traces amounts of other gaseous, liquid and solid substances
- Weather, radiation balance, formation of clouds and precipitation, atmospheric flow, reservoir of natural and anthropogenic trace gases, transport of heat, water vapour, tracers, dust and aerosols.

- **Hydrosphere**: All forms of water above and below the Earth's surface.
- This includes the whole ocean and the global water cycle after precipitation has reached the Earth's surface.
- Global distribution and changes of the inflow into the different ocean basins, transport of ocean water masses, transport of heat and tracers in the ocean, exchange of water vapour and other gases between ocean and atmosphere, most important reservoir of carbon with fast turnover.

Cont.

- **Cryosphere**:
- All forms of ice in the climate system, including inland ice masses, ice shelves, sea ice, glaciers and permafrost.
- Long-term water reserves, changes of the radiation balance of the Earth surface, influence on the salinity in critical regions of the ocean.

Cont.

- **Land Surface**: Solid Earth.
- Position of the continents as a determining factor of the climatic zones and the ocean currents,
- Changes in sea level, transformation of short-wave to long-wave radiation,
- Reflectivity of the Earth's surface (sand different from rock, or other forms), reservoir of dust, transfer of momentum and energy.

Cont.

- **Biosphere**: Organic cover of the land masses (vegetation, soil) and marine organisms.
- Determines the exchange of carbon between the different reservoirs, and hence
- The concentration of CO_2 in the atmosphere, as well as the balances of many other gases, and therefore also the radiation budget.

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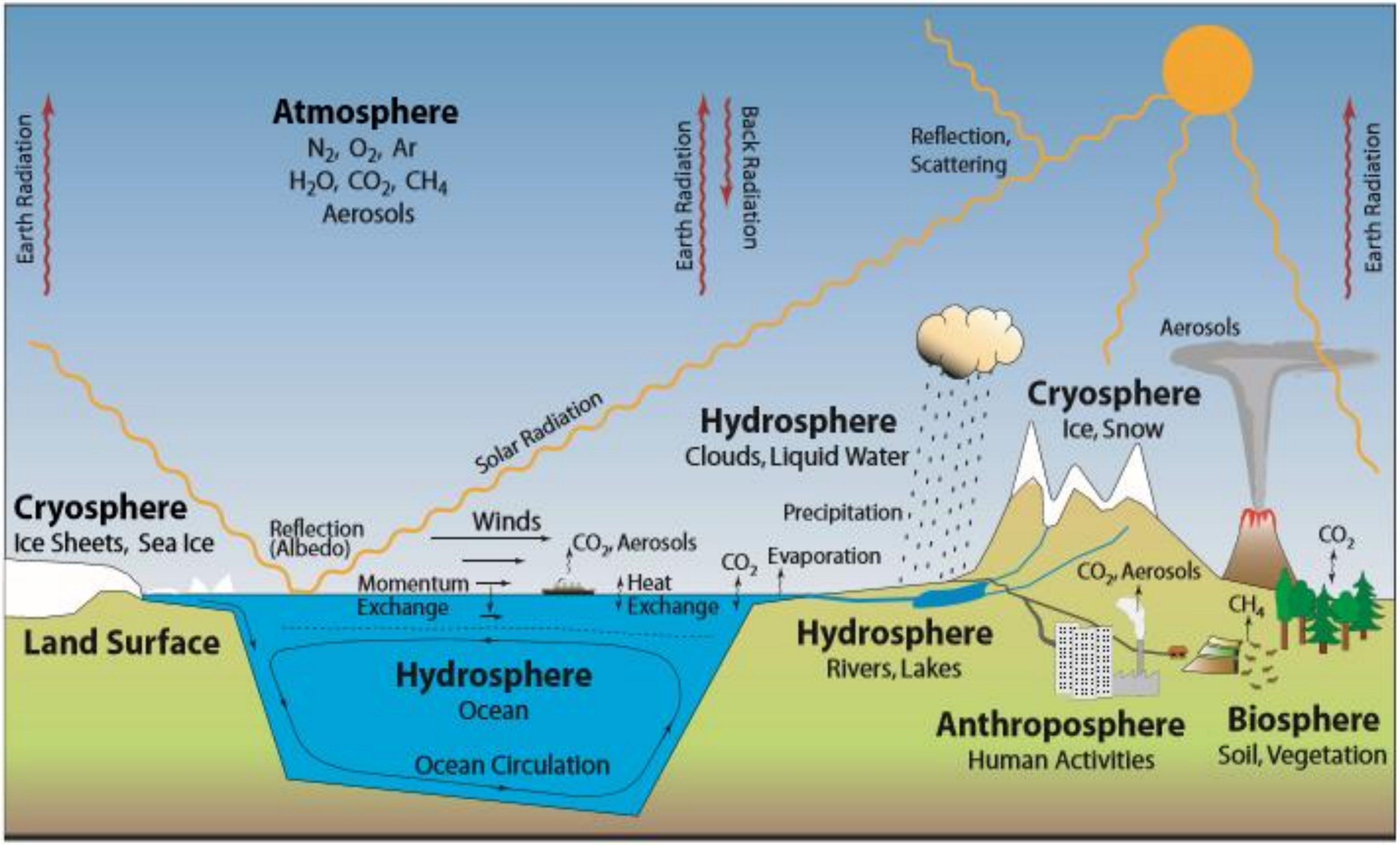

- Figure2.4. The most important components and associated processes of the climate system on a global scale

Climate models

- **Global climate models (GCMs**) are complex, computer based, mathematical representations of the Earth's climate based on fundamental scientific principles.
- Many different climate processes are represented in the global climate models. Precipitation, wind, cloudiness, the ocean currents, air and water temperatures, the amount and type of vegetation , the concentration of greenhouse gases (GHGs) and

Cont.

- atmospheric aerosols (fine particles)
- These and other Global climate models are the principal tools used by climate scientists to quantitatively explore potential future climates, globally and regionally(IPCC 2013).
- **GCMs** are the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations.

Purpose and limitations of climate modelling

- Climate models are simplified descriptions of complex processes within the climate system.
- They are used for the quantitative testing of hypotheses regarding the mechanisms of climate change,
- as well as for the interpretation of instrumental data from paleo-data from various archives.

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- Climate models are essential for the operational prediction of the economically important ENSO-phenomenon and other climate modes.
- A further important motivation for the development and application of climate models remains the aim to assess future climate change.

Cont.

- Global Climate Models (GCMs) are used to simulate the present climate in order to estimate future climatic change at global scales.
- **Global Climate Models** (GCMs) precipitation scenarios are often characterized by biases and coarse resolution that limit their direct application for basin level hydrological modeling (IPCC 2013).

Cont.

- Simulation of the 20th century to quantify the link between increases in atmospheric CO_2 concentrations and changes in temperature.
- Given that the most important driving factors of the radiation balance are known, the effect of increasing CO_2 concentrations on the annual mean atmospheric temperature and other variables can be estimated.

Climate scenarios

- **Climate scenarios** are plausible representations of future climate conditions (temperature, precipitation and other climatological phenomena).
- These scenarios provide plausible descriptions of how the future might unfold in several key areas—socioeconomic, technological and environmental conditions, emissions of greenhouse gases and aerosols, and climate (Moss et al. 2010).

Cont.

- Table2.1 History of Climate Scenarios (Source Bjornaes, C. 2015).

Year	Name	Used in IPCC report
1990	SA90	First Assessment report
1992	IS92	Second Assessments Report
2000	SRES-Special Report	Third and Fourth Assessment Report
	On emission Scenario	
2009	RCP-Representative	Fifth Assessment Report
	Concentration Pathway	

Thank

You

For

Attention

Paleoclimate