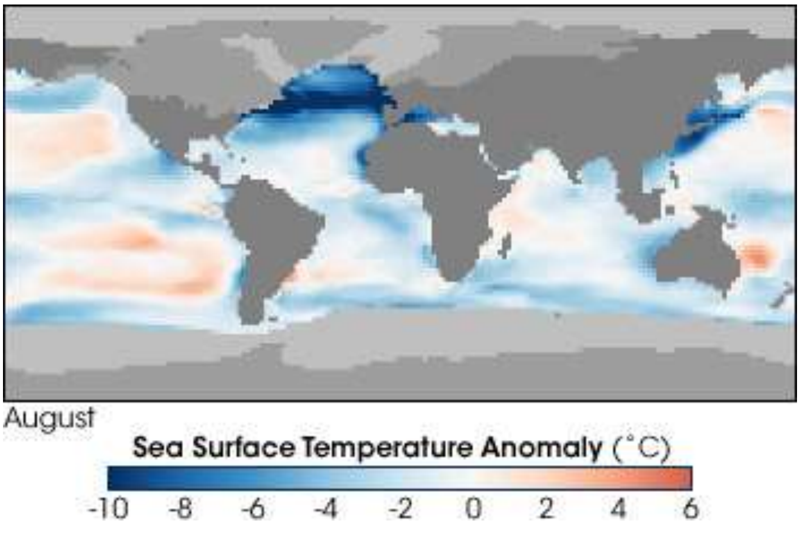
Lecture 8
The Science of Climate Change (I): Past Climates

KEY QUESTION:

Is climate variability a new phenomenon in Earth's history?

With the completion of this lecture, attached readings and tutorial, you should be able to understand the:
- Episodes of warming and cooling of Earth during the Quaternary period
- Evidence of past climate variability derived from proxy indicators through the study of ice and ocean cores

Lecture Outline



In a project called **Climate: Long-Range Investigation, Mapping, and Prediction** (CLIMAP) in the 1970s, researchers reconstructed the climate of the Earth about 20,000 years ago, during a time many refer to as the Ice Age. This map shows the difference in temperatures between then and now (blue areas were colder, red areas warmer). The most obvious feature is perhaps the presence of much colder water in the North Atlantic.

Ocean cores proved invaluable in this project. What are ocean cores and how did they help? What else do we know about Earth's climate in the past?

8.1 Climate Variability Is Nothing New

- Climate variability refers to variations in the mean state and other statistics such as standard deviations and the occurrence of extremes of the climate on all spatial and temporal scales beyond that of individual weather events. Climate variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing.
- Contemporary climate change in recent years is deemed as a global challenge, but it is important to note that climate variability itself is not a new phenomenon. Climate of the Earth has been varying over a long period of time.
- In this section of the syllabus, we shall first outline the **changes in global climatic patterns** as far back as 2.6 million years ago (mya). We then proceed to examine the **evidence** that suggest that these changes did occur (**Section 8.2**) and find out **why** these changes occur (**Lect. 9**).

- The Earth is more than 4.5 billion years old. This vast span of time is called *geologic time*. Geologists have divided the geologic time into a series of time intervals. Of most relevance to us is the time interval known as the **Quaternary Period**. The Quaternary period extends from 2.6 million years ago till present. There are two epochs within the Quaternary period - the Pleistocene and the Holocene.
    - The Pleistocene is the period of Earth's history covering approximately 2.6 million years ago until 11,700 years ago.
    - The second epoch of the Quaternary, the Holocene, is the last 11,700 years of earth's history.

- **Fig. 1** shows the **past climate variability** over the Quaternary Period.

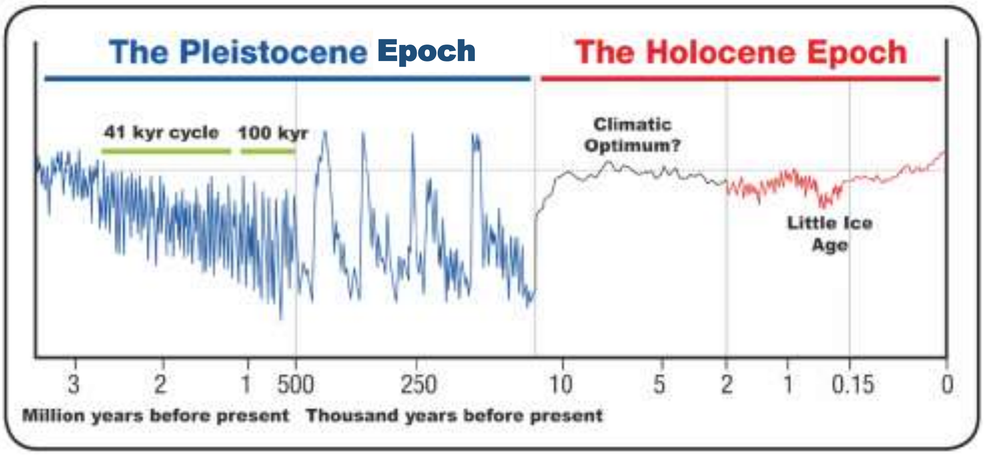


Fig. 1 Climate during the Quaternary Period

8.1.1 The Pleistocene

- Although sometimes called the Ice Age, the Pleistocene was not one long, uninterrupted deep freeze. Rather it was marked by a recurring cycle of **climate oscillations** or **changes in average temperature and rainfall**. Such oscillations or changes are referred to as *glacials* and *interglacials*.
  - **Glacials** – time during the Ice Age when ice sheets expanded, and average global climate was **colder** and drier than during the intervening interglacials (see next line). For example, the Maunder Minimum is marked by a period of significantly reduced sunspot activity, which correlates with cooler global temperatures. During this time, the sun's radiation output was lower, and this lack of solar activity is thought to have contributed to the cooling observed on Earth.
  - **Interglacials** – phase of **warmth** between glacials when the great ice sheets melt and retreat.
- During the long and cold periods, global temperatures were much lower, perhaps as much as 10°C in higher latitudes, and at least 5°C in the tropics. When the Pleistocene ended 11,700 years ago, temperatures were 4°C lower than present day.
- From **Fig. 1**, <u>note</u> in particular: the beginning of the decline in temperatures at around 2.6mya, the four major climatic fluctuations commencing 500,000ya (giving the 4 major glacial periods we also refer to as ice ages), and the relative stability of temperatures during the Holocene.

8.1.2 The Holocene

- This began 11,700 years ago (see **Fig. 1**), at the end of the last glacial period, when average temperatures increased rapidly by 6°C and have stayed at that higher level through to the present day, with oscillations limited to around 0.5 degrees centigrade. (<u>Note</u>: The Holocene period is considered by some to be an interglacial period, not the end of the Ice Age. This may help to explain the views of climate change deniers that we hear of today. See **Lect. 9** also.)
- The postglacial warming trend culminated in the so-called **Climatic Optimum** about 8000 to 5000 years ago, a time when the mean global temperature was somewhat higher (perhaps 1°C) than at present. (There is evidence that indicates that 6000 years ago, over most of Europe, July temperatures were about 2°C higher than now.)
- From **Fig. 1**, notice also that beginning 8000 years ago, the overall trend in temperatures is downward (approximately 0.75°C). That is until the onset of the industrial revolution, when temperatures again started to rise. The average global temperature has risen by a little more than 1°C since 1880. This is known as the **contemporary** phase of **climate change**(or **global warming** as is often referred to today).

8.2 Evidence of Past Climate Variability

- Instrumental records (from thermometers, rain gauges, etc.) only existed for the last 150 years. Hence, we have to rely on proxy indicators to know how climate has varied over the past 4.5 billion years or so.
- **Proxy indicators** are indirect evidence of past climate change. In the study of past climates, the information obtained from geological and biological records are proxy indicators – evidence

derived from sources other than human measurements. In the syllabus, you are required to understand evidence that is obtained from **ice cores** (see **Section 8.2.1**) and **ocean cores** (see **Section 8.2.2**).

8.2.1 Ice Core Records

- As snow accumulates on ice caps and sheets where temperature usually remains below freezing point year-round, it lays down a record of the environmental conditions at the time of its formation.
- Over time the snow, buried under further accumulations, is compacted to ice, preserving the climatic information. Ice-core (see **Fig. 2**) records are therefore important because **bubbles of air that were trapped in the ice** as it became compressed provide tiny '**time capsules**' of the atmosphere over time.
- Analysing microscopic air bubbles in ice cores helps to reveal past climates. Temperatures of the past is inferred from the **isotopic composition** of the water molecules released by melting the ice cores.
- However, generally the changes in gas concentration lag behind the temperature changes by 800 to 1000 years and thus might be regarded as a limitation of using ice cores records as an evidence of past climate change.

Fig. 2 An ice-core being drawn in the Antarctic and readied for analysis. A recent European project revealed a climate record for the last 800,000 years. It showed that the Earth experienced eight glacial cycles – each with a warm period and an ice age.

(a) Greenhouse gas concentrations

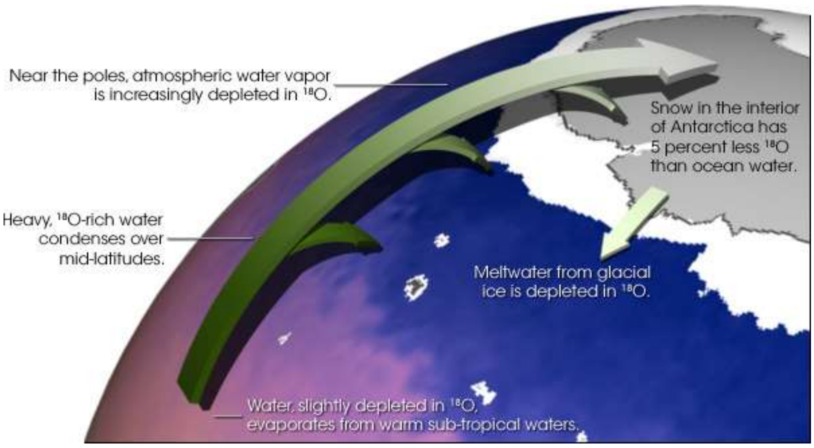
- The concentration of carbon dioxide and other trace gases like methane in these bubbles yields a long-term record of their varying levels in the air.
- **The higher the concentration of greenhouse gases, the warmer it was when the ice was formed, indicating interglacial period; whereas glacial periods coincide with reduced concentrations of these greenhouse gases.**

(b) Oxygen isotopes

- Water evaporates from the warm oceans in the tropics and are transported towards the poles where it gets deposited as snow and ice. Ice cores thus have different types of oxygen isotopes which acts as proxy indicator. Some of these isotopes are 'heavier' than others and this mass is determined by the number of neutrons the isotopes contain. Oxygen-18 (O18) (8 protons and 10 neutrons) is **heavier** than Oxygen-16 (O16) (containing 8 protons and 8 neutrons in each atomic nucleus). **Less Oxygen-18 and more Oxygen-16** in the polar ice core indicates glacial periods and **more Oxygen-18 and less Oxygen-16** indicates interglacial periods.

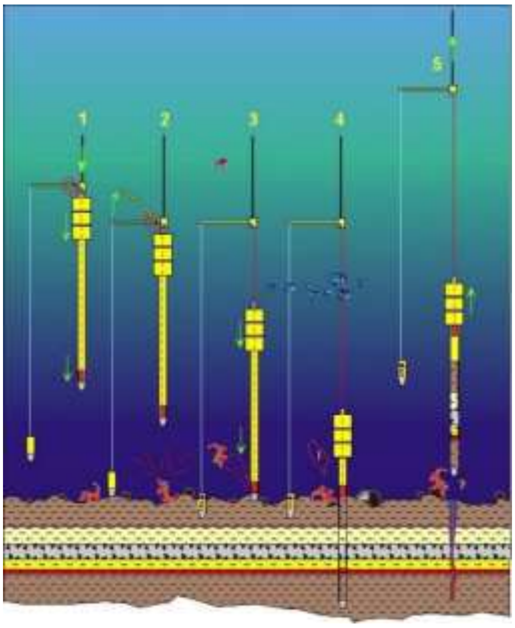
- **During glacial periods, there is less Oxygen-18 and more Oxygen-16 in the ice formed**. This is because **(1)** it takes more energy to evaporate the water molecules containing a heavy isotope from the surface of the ocean in the tropics **(2)** as the moist air is transported polewards and cools, the water molecules containing heavier isotopes are preferentially lost during the journey as precipitation.
- This ensured that only a low volume of O18 is left by the time ice is formed and descends at the poles (see **Fig. 3**). Water vapor gradually loses O18 as it travels from the equator to the poles. Because water molecules with heavy O18 isotopes in them condense more easily than normal water molecules, air becomes progressively depleted in O18 as it travels to high latitudes and becomes colder and drier. This way the snow that forms most glacial ice has less O18 indicating glacial period.
- By the above reasoning, during **interglacials** which are the warmer phases of climate, there is more sufficient energy to transport O18 towards the poles, resulting in **more Oxygen-18 and less Oxygen-16 in the ice formed**.

Fig. 3 Water vapor gradually loses Oxygen-18 as it travels from the equator to the poles.

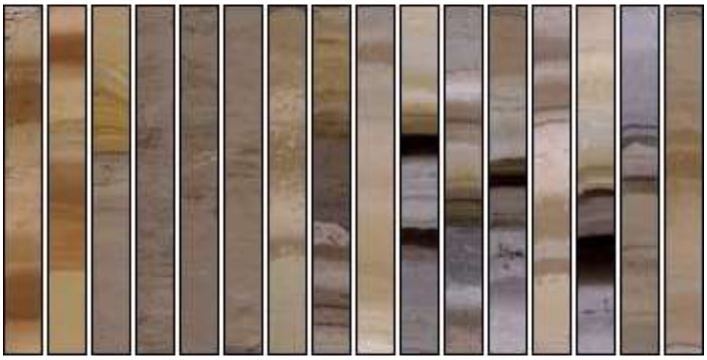


8.2.2 Ocean Core Records

- On the deep ocean floor, sediments have been accumulating relatively undisturbed for millions of years. These sediments are a mixture of land derived material and marine biogenic sediments.
- Scientists have been drilling into the ocean floor since the 1970s. They extract deep cores of material that has been deposited over very long periods.
- Much like ice cores are obtained (see **Section 8.2.1**), ocean core sampling involves collecting samples from the ocean floor using a corer to obtain a cylindrical piece of sediment (see **Figs 4 and 5**).
- The deposited materials included bones and shells of plankton and other animal life, made largely of calcium carbonate. The information contained in the shells is most important for determining past climates. The deeper layers belong to climates of a further past, and the upper layers are more recent.



(Fig. 4, Left) Illustration of the steps taken to obtain an ocean core sample.



(Fig. 5, Top) This image sequence shows the cross-section of a core drilled in the Mediterranean Sea. Sediment layers can be formed from dust, volcanic ash, river sediments, underwater mudslides, plant and animal skeletons, precipitated calcium carbonate, or salts left behind by an evaporated sea.

(a) Shells of marine microorganisms

- Studying the shells of the marine microorganisms or *foraminifera* that lived in the ocean water can tell researchers much about past climates.

Coil directions

- Among some modern and recent fossil species of planktonic *foraminifera*, the proportion of left- to right-coiled shells in a population appears to be temperature-dependent. Researchers have related the relative abundance of each *foraminifera* shell to ocean water temperature:
  - the left-coiled shells being dominant in cold, high northern latitudes; whereas
  - their right-coiled counterparts are found in more temperate or warmer environments.
- The findings led to the current understanding about coil directions and the dominant past climatic conditions under which they were formed (see **Fig. 6**):
  - If the shells coiled **left**, the ocean water temperature then was below 7°C, suggesting **glacial** periods; whereas
  - if the shells coiled **right**, the temperature was greater than 7°C, suggesting **interglacial** periods.
- Therefore, an examination of how the fossil coil directions vary throughout the ocean core profile will provide an indication of past climate variability.

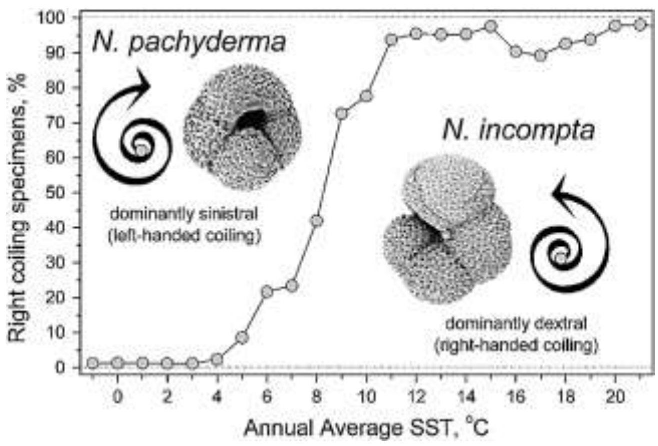


Fig. 6 Relationship between coil directions and ocean temperatures

Oxygen isotopes

- Ocean water has both isotopes of oxygen namely Oxygen-16 and Oxygen-18 and both are incorporated into the carbonate shells of *foraminifera* and bones of marine animals. If the ratio of Oxygen-18 to Oxygen-16 in the water is relatively high, it will be also high in the sea life living in that water.
- Thus, if glaciers are expanding during **glacial periods**, the **oceans** will have **relatively high Oxygen-18** to Oxygen-16 ratios, as more of the Oxygen-16 water is removed from the ocean (as it is lighter and evaporates more readily than Oxygen-18) and deposited as snow onto the growing ice sheets. When the organisms die, they sink to the ocean bottom, where their calcium carbonate is deposited. The ocean bottom thereby maintains a record of climate through the varying Oxygen-18 to Oxygen-16 ratios in its layers.

(b) Materials removed from land

- Ocean indicators of past climates come in the form of materials removed from land surfaces by glaciers, wind and water.
- **Rocks and sediments** can reveal where **glacier** erosion had taken place, where water warm enough to melt the glacier ice existed.
  - Glaciers erode large amounts of rocks and sediments as it moves along the valley floors. When they reach places with water warm enough to melt them, these sediments are dumped in the ocean, swept on currents to its final resting place and later show up in ocean sediment cores.
  - Glacial sediments have several distinctive characteristics that set them apart from other oceanic sediments, such as:
    - Composition and Texture
      - **Poor sorting**: Glacial sediments are typically poorly sorted, containing a wide range of grain sizes from clay to boulders. This contrasts with water-sorted deposits, which tend to be better sorted.
    - Geophysical Signatures
      - **Acoustic properties**: Glacial sediments often show distinct acoustic signatures in seismic profiles.
    - Sedimentation Rates and Timing
      - Glacial sediments often show higher sedimentation rates during glacial periods due to increased erosion from ice melt and iceberg discharge.
  - By combining these characteristics, researchers can distinguish glacial sediments from other oceanic deposits, providing insights into past ice sheet behavior and climatic changes.

- **Dust** in ocean cores can reveal weather patterns, especially **wind** conditions.
  - When the dust shows up in ocean cores, scientists can analyse its chemistry to determine where it came from.
  - The dust gives scientists a glimpse into how dry and dusty the climate may have been at a particular time. The dust's location on the ocean floor as well as the mineral content of the dust give scientists clues about where the dust came from and how it arrived on the ocean floor. For example, dust in the middle of the Pacific Ocean is more likely to have been carried on the wind (drier and cooler climate) than deposited by rivers (wetter and warmer climate).

8.3 Conclusion

In conclusion, the science of climate change provides a comprehensive exploration of past climate variability (series of glacial and interglacial periods), emphasising that climate fluctuations are not a new phenomenon. By examining the Pleistocene and Holocene epochs, the lecture highlights the natural cycles of warming and cooling that have shaped Earth's climate over millions of years. The use of ice core and ocean core records as proxy indicators provides robust evidence of these variations, offering valuable insights into the mechanisms driving past climate change.

While the historical perspective reinforces the long-term nature of climate variability, the lecture also underscores the distinctiveness of contemporary climate change. The rapid rise in global temperatures since the Industrial Revolution, in contrast to the relatively stable Holocene period, strongly suggests an unprecedented human influence. The document effectively differentiates between natural climatic oscillations and anthropogenic climate change, urging critical analysis of modern global warming trends.

Overall, this lecture equips students with a solid scientific foundation for understanding climate change, its historical context, and the evidence supporting it. However, future discussions should further explore the implications of contemporary climate change and potential mitigation strategies, bridging the gap between past climate studies and the urgent challenges of the present.