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Guide to the Science of Climate Change in the 21st Century

Chapter 13
Paleoclimatology

David H. Manz
PhD., P. Eng., AOE, FCAE
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13.1 Introduction

Paleoclimatology is the study of the history of Earth's climate. Planet Earth as it exists today is the legacy of the forces which formed it over the previous billions of years. Earth's age is estimated to be 4.54 billion years. The geologic time periods are shown in Figure 13.1. The present period dating from the end of the last ice is known as the Holocene and is only twelve thousand years long. The period of Earth's history in which humans appear to be having the dominant impact on planet Earth is being called the Anthropocene. It has been argued that the Anthropocene is at best only a few thousand years long though it is argued that it is essentially the same as the Holocene, or maybe, less than a century long.

The changes in Earth's climate over the decades, centuries and millennia are of particular interest to those who study the science of climate change (Chapter 2, History of the Scientific Study of Climate Change). They were able to identify the impacts of climate change, the forces that were active in the climate change processes, when the processes were active, and the duration the processes were active (For example the Ice Ages and the Little Ice Age). From their work insight is gained into the nature of the climate changing forces that Earth is presently experiencing. The information gained helps guide scientific thinking and provides a perspective of how the significant climate change currently being experienced or forecast is or might be. (An excellent reference on paleoclimatology is a book authored by Summerhayes titled Paleoclimatology - from Snowball Earth to the Anthropocene.)

Paleoclimatology relies on being able to discover and study past climate changes and examine the factors which determined them. This is only possible with the use of proxy sources of information. The proxy techniques are based on sound scientific knowledge and all of our knowledge of Earth's geological past can be attributed to their use. It is important to know that proxy sources of past climate information exist and to be confident that they are providing reliable information.

Information on past climate changes have resulted in the discovery and understanding of a variety of climate change phenomena, clearly driven by natural forcings, that have significantly impacted human history. These include the ice ages, the results of which we are living with, the warming period which marked the end of the last ice age, (the Holocene), ENSO phenomena and what is known as the Little Ice Age to name a few. As a result of the science of paleoclimatology it is possible to put current human activities into perspective. The debate over whether anthropogenic caused forcings are presently dominating Earth climate changes compared to natural forcings is over. Current climate change is being driven by humans. What is not known is how significant these changes might be.

Colin P. Summerhayes in the book titled Paleoclimatology from Snowball Earth to the Anthropocene provides a detailed scientific/ technical description of the changing climate of Earth over the past 800 million years.

A book written by Peter Brannen titled The Ends of the World provides a readable scientifically informed description of the evolution of life on Earth and the circumstances that resulted in its extinction and reforming - five times since life on Earth first began.

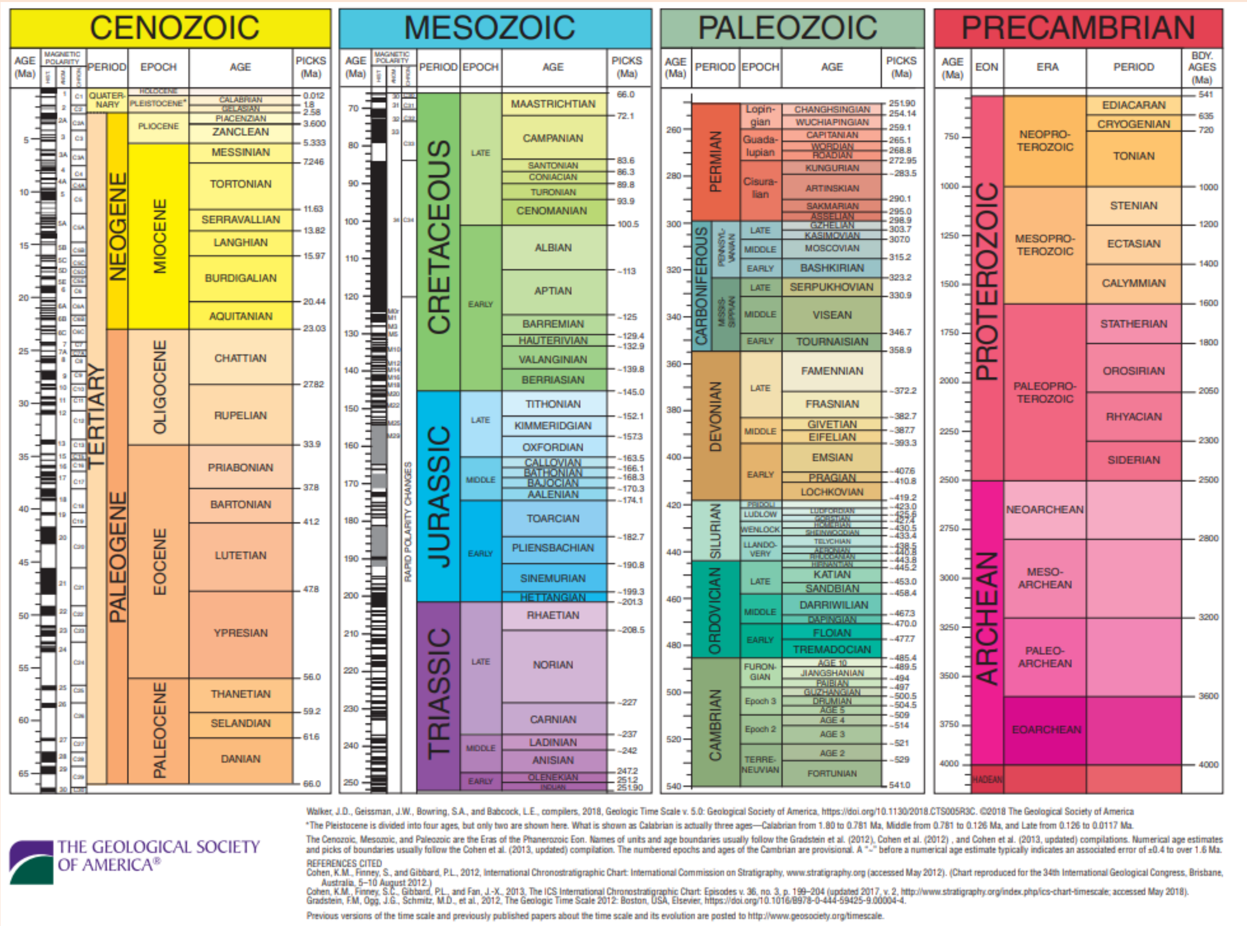


Figure 13.1 Geologic time scale V. 5.0 as prepared by the Geologic Society of America. https://www.geosociety.org/GSA/Education_Careers/Geologic_Time_Scale/GSA/timescale/home.aspx

13.2 Variation of Earth's temperature over last 500 million years.

Figure 13.2 shows a graph illustrating how Earth's temperature has varied over the last 500 million years and Figure 13.3 shows a graph illustrating how Earth's temperature has varied over the last 65 million years. Figure 13.4 shows a graph illustrating how Earth's temperature has varied over the Holocene period.

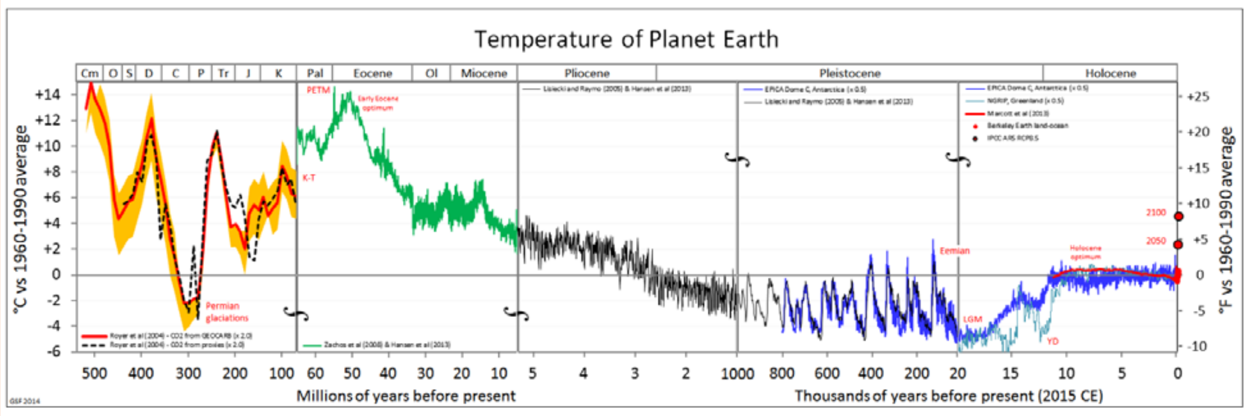
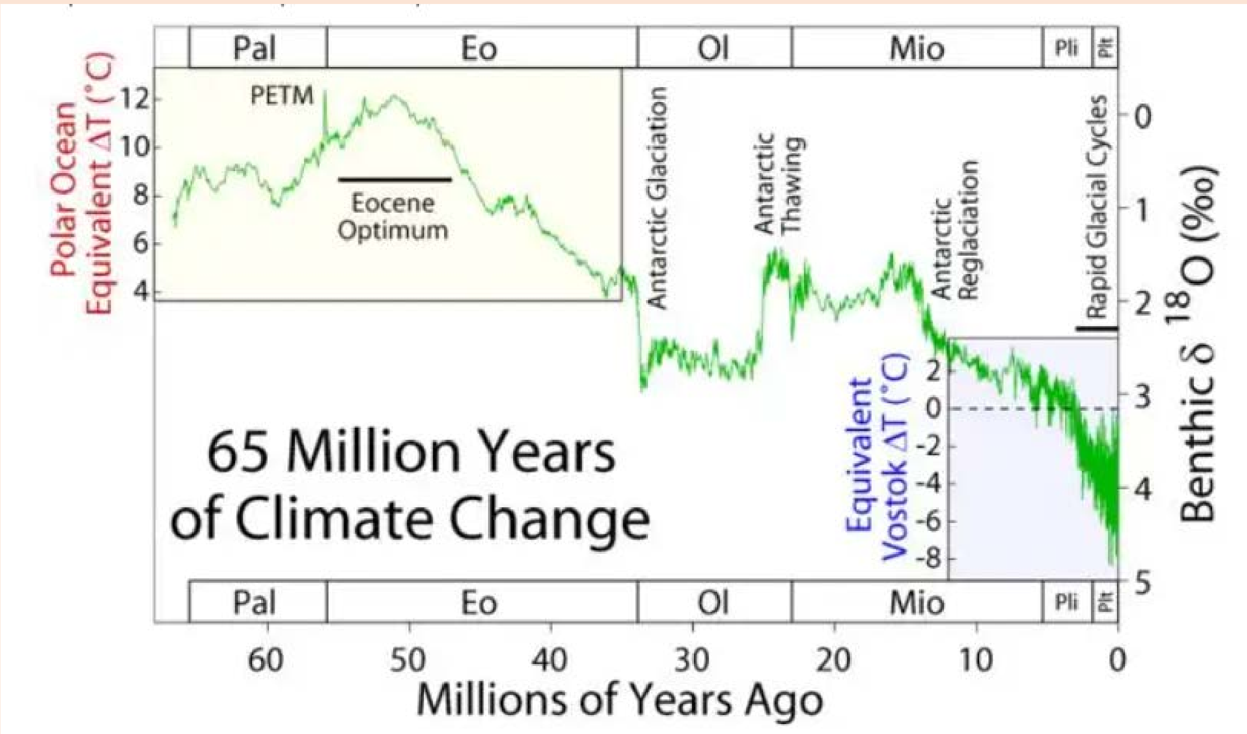


Figure 13.2 Variation of Earth's temperature over last 500 million years
http://en.wikipedia.org/wiki/Paleoclimatology



The Paleocene-Eocene Thermal Maximum
(Image: Robert A. Rohde, Global Warming Art)

Figure 13.3 Variation of Earth's temperature over last 65 million years.

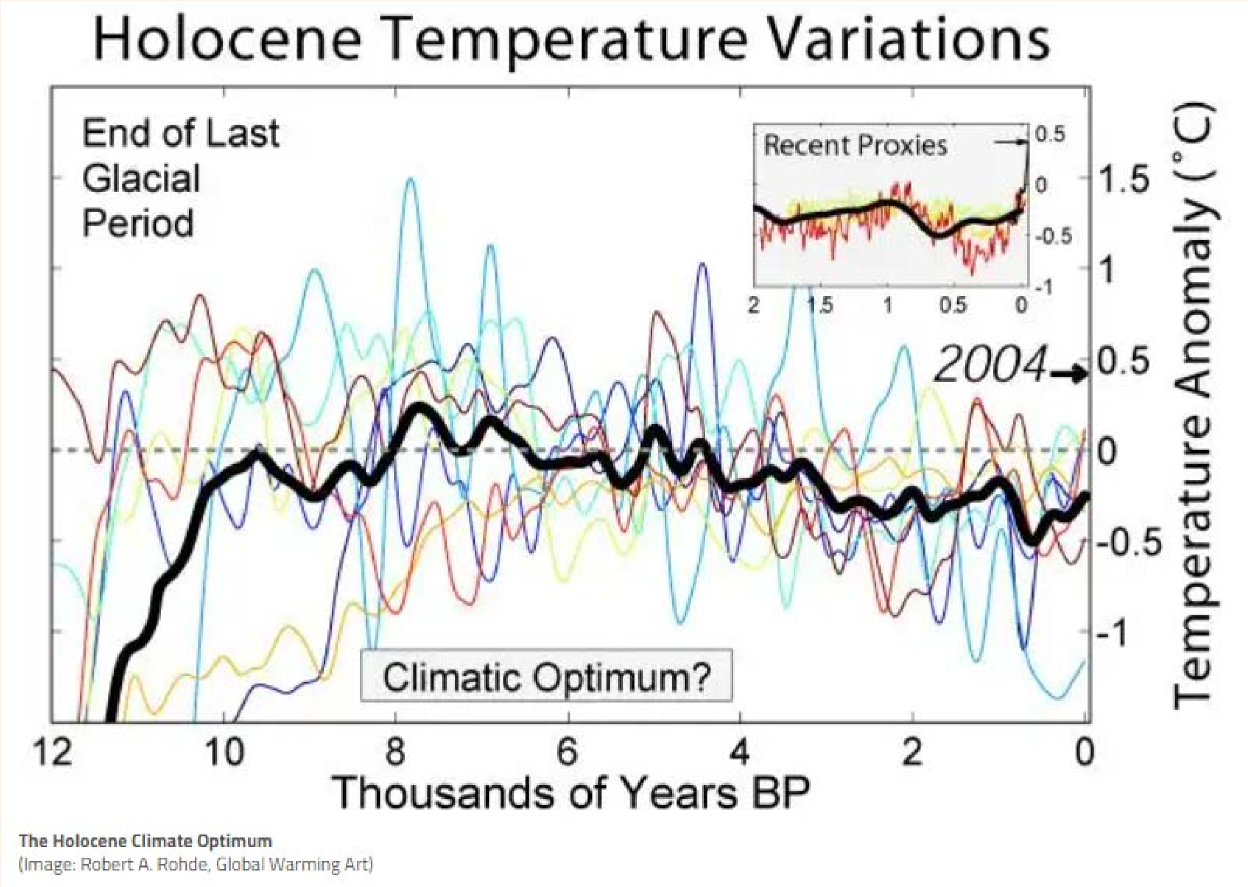


Figure 13.4 Variation of Earth's temperature over last 12,000 years
http://en.wikipedia.org/wiki/Paleoclimatology

Figure 13.5 shows a graph of global average temperature over the past two thousand years. Figure 13.6 shows a graph of global average temperature since 1850. Temperature data acquired since 1850 is known as the instrumental temperature record or instrumental period.

Direct climate observations on a global scale, that are considered reliable, have only been available for the past one hundred and twenty years or even less.

Its only in the last thirty years that global observations which are spatially and temporally comprehensive, have become available with the aid of satellites and the ability to manage the information being collected.

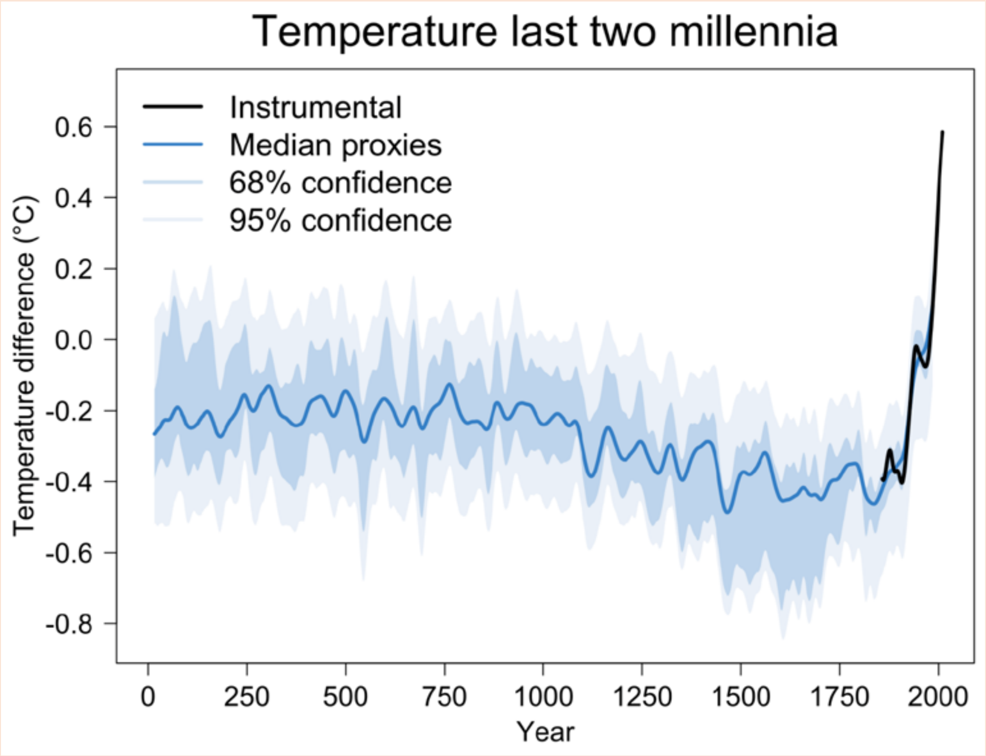


Figure 13.5 Variation of Earth's temperature over last two thousand years.

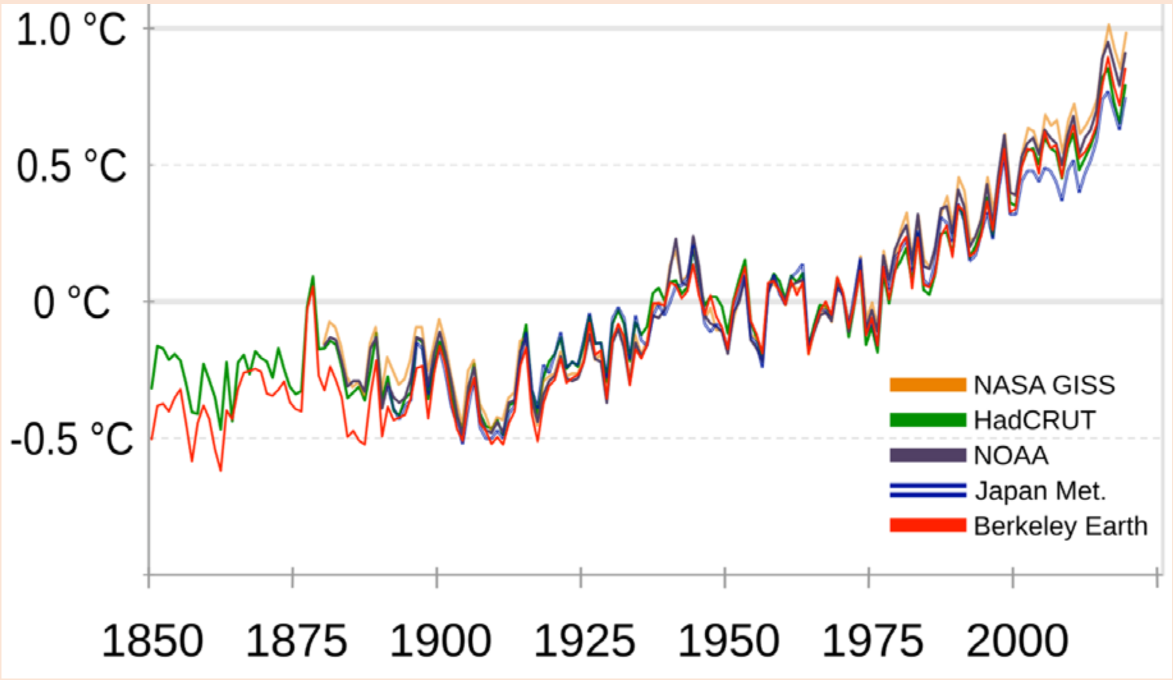


Figure 13.6 Global average temperature change – 1850 to present.

13.3 Climatic data obtained from proxy sources

Proxy sources, known as proxies, are used when direct measurement of climatic data, typically temperature and precipitation, are unavailable. A very good review of proxy information may be found in https://interactive.carbonbrief.org/how-proxy-data-reveals-climate-of-earths-distant-past/?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210331&utm_medium=email&utm_source=Revue%20Daily . A list of the more common paleoclimate proxies and the information that can be obtained/ extracted is shown in Table 13.1.

Table 13.2 provides a partial list of proxies that provide only age and no additional climate information or only climate information.

Proxy	Sampling Interval (minimum)	Temporal Scope (order: yr.)	Temperature	Precipitation or Water Balance	Chemical composition (air or water)	Biomass or vegetation	Volcanic eruptions	Sea Level	Solar Activity
Historical Records	Day/hr	$\sim 10^3$	x	x	x	x	x	x	x
Tree Rings	Yr/season	$\sim 10^4$	x	x	0	x	x	0	x
Lake Sediments	Yr to 20 yr	$\sim 10^4 - 10^6$	x	x	0	x	x	0	0
Corals	Yr	$\sim 10^4$	x	x	x	0	0	x	0
Ice Cores - Antarctica Greenland	Yr	$\sim 5 \times 10^5$	x	x	x	x	x	0	x
Ice Cores - Ice Caps	Yr	$\sim 2 \times 10^3$	x	x	x	x	x	0	x
Speleothems	100 yr	$\sim 5 \times 10^5$	x	x	x	0	0	0	0
Loess	100 yr	$\sim 10^6$	0	x	0	x	0	0	0
Boreholes	200 yr	$\sim 2 \times 10^3$	x	0	0	0	0	0	0
Marine Sediments	500 yr	$\sim 10^7$	x	x	x	x	x	x	0
Geomorphic Features	100 yr	$\sim 10^6$	x	x	0	0	x	x	0

Table 13.1 Partial list of paleoclimatic proxies and the information that can be obtained/ extracted. These proxies provide age and climate information.

Proxy	Precision	Information Obtained
Pollen	20 yr	Type of vegetation. Temperature and precipitation can be inferred.
Water Isotopes O^{16} and O^{18}	n/a	Temperature
Stomatal Density	n/a	Carbon dioxide
Carbon 14	yr	Age and solar activity
Beryllium 10 and 7	yr	Solar activity
Radiometric Dating	$\sim 10^6$	Age
Anecdotal	month	Age, temperature, precipitation.

Table 13.2 Partial list of paleoclimatic proxies and the information that can be obtained/ extracted. These proxies provide age **or** climate information but not both.

13.3.1 Historical records

Historical records are actual records of Earth's temperature and as such might not seem to be a proxy. However, until the last few decades it would be difficult to argue that the entire temperature profile of the Earth was actually measured so global temperature must be determined using 'spotty' information, in both the geographical and collection period, which then must be considered a proxy of actual global measurements.

Historical records would be equivalent to what is known as the instrumentation period that started in 1850. There is a consensus as to the record of Earth's temperature since 1880 as evaluated by the NASA Climate 365 project where four international science institutions made independent judgements about whether the year was warmer or cooler than average https://climate.nasa.gov/climate_resources/9/graphic-earths-temperature-record/. The participating institutions were NASA Goddard Institute for Space Studies, Met Office Hadley Centre/ Climatic Research Unit, NOAA National Climatic Data Centre and Japanese Meteorological Agency. The graph shown in Figure 13.6 clearly illustrates close agreement between these institutions - from 1880 to present.

13.3.2 Tree rings

Climate conditions influence tree growth, patterns in tree-ring thickness, density and isotropic composition reflect variations in regional climate. In temperate climates where there is a distinct growing season trees generally produce one ring a year distinguishable by a denser thinner ring thickness during slow growing period for each year as shown in Figure 13.7. Trees can grow to be hundreds and thousands of years old. Ideally, tree ring information from one tree can be used to calibrate tree rings from another older tree in the same region providing there is some overlap in the tree ring history, Figure 13.8 and the tree ring record can be extended back in time several thousand years.   Individual rings may be sampled to obtain information on the environmental conditions in which the trees were growing.

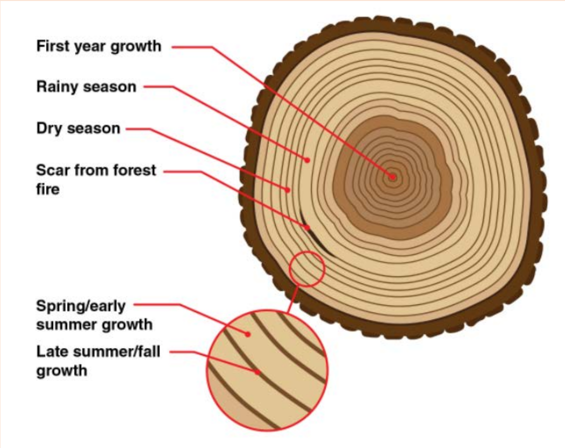


Figure 13.7 Tree ring dating.

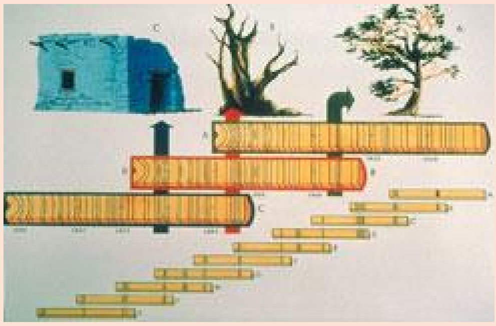


Figure 13.8 Extending tree ring dating using multiple sources of wood from same region.

13.3.3 Lake sediments

Vertical cores are obtained of the sediment layers without disturbing them during the drilling and extraction process. The contents may include fossils, chemicals and different types of mineral deposits which can be used to describe salinity, temperature, ice cover, oxygen levels, nutrient levels, origin of the sediment, and volcanic eruption histories. Size and shape of sediment particles determine if the sediment was transported, how far it was transported, and how energetic the transportation environment was. (Large particles are deposited in very turbulent conditions and small particles in very still conditions.) Pollen and fossils of plants and animals provide information on the climatic environment at the time they were deposited.

13.3.4 Corals

Corals build their skeletons from calcium carbonate extracted from sea water. The carbonate contains isotopes of oxygen and trace metals that can be used to determine the temperature of the water in which the coral grew. The density of the calcium carbonate skeletons changes as the water temperature, light and nutrient conditions change giving coral skeletons formed in the summer a different density than those formed in winter. The seasonal variations in density produce growth rings similar to trees which allow dating to an exact year and season. See Figures 13.9 and 13.10.

Figure 13.9 Sampling a coral.

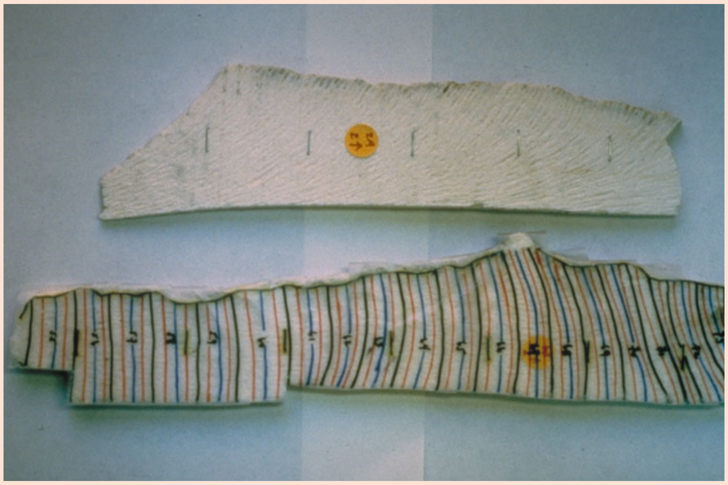


Figure 13.10 Annular rings on a coral.

13.3.5 Ice cores – Antarctica and Greenland https://icecores.org/about-ice-cores

Ice core records taken from Antarctica and Greenland ice sheets allow us to go back in time (approximately 800,000 years) to determine accumulation rate, air temperature (global climate), biology (pollen) and air chemistry including greenhouse gases. Ice cores show layers of particulate deposit such as volcanic ash, carbon deposits and dust. Figures 13.12 (a), (b) and (c) show deep ice core drilling in progress, coring equipment and core storage. Figure 13.13 show samples of ice core taken from different depths illustrating how the cores change.

(a) (b) (c)

Figure 13.11 (a), (b) and (c) Deep ice core drilling, coring equipment and core storage.

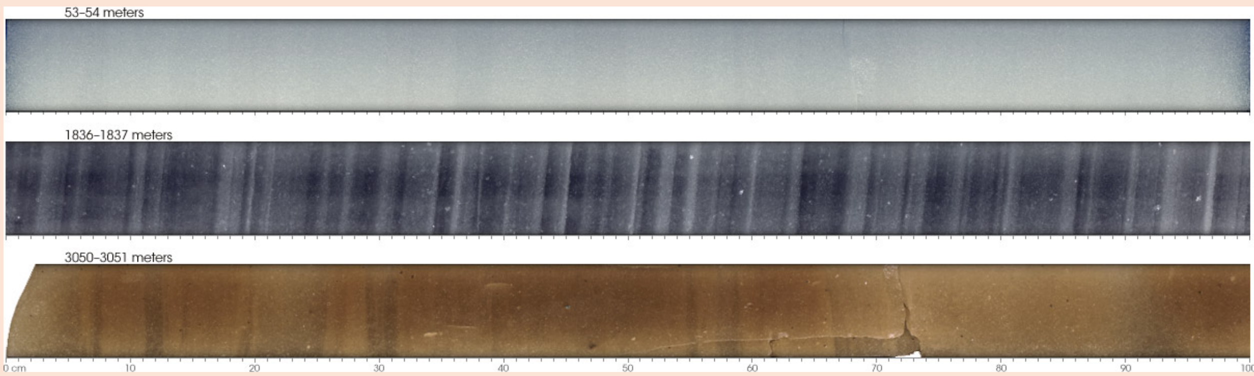


Figure 13.12 Examples of ice core from different depths.

13.3.6 Ice cores – icecaps https://icecores.org/about-ice-cores
Ice cores are taken from icecaps around the world can be used to determine similar kinds of information taken from the deep cores in Antarctica and Greenland; that is, accumulation rate, air temperature (global climate), biology (pollen) and air chemistry including greenhouse gases. Similarly, the ice cores will show layers of particulate deposits such as volcanic ash, carbon deposits and dust. The advantage of taking ice cores from icecaps is that they provide information of regional interest. Care must be taken to be sure that the icecap is not mobile and is unaffected by local climate conditions such as melting that would confuse the information record. See Figures 13.13(a) and (b).

(a)

(b)

Figure 13.13 (a) and (b) Shallow ice core drilling.

13.3.7 Speleothems

These are mineral formations in caves resulting from mineral-rich water originating in the ground above the cave depositing solid material to form stalactites, stalagmites and flowstone. The amount of material deposited will depend on how much ground water dripped into the cave. The layers in the speleothem can be dated using such techniques as radiometric dating. Ground water levels can be inferred from speleothem growth. Records from several caves are required to use this information to estimate how climate has changed. See Figures 13.14 (a), (b) and (c).

(a)

(b)

(c)

Figures 13.14 (a), (b) and (c) Stalactites, stalagmite and cross-section.

13.3.8 Loess https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/loess-eolian-dust

Loess and Eolian dust refer to silt-sized material deposited on the Earth surface by winds. Extensive loess deposits formed during the Ice Ages in areas bordering large, continental glaciers. These deposits provide some of the most dramatic examples of changes in climate and the effect of processes that shape the landscape. Successive layers are often analyzed to provide a history of the winds and surface processes through time. See Figures 13.15 and 13.16.

Figure 13.15 Loess deposit.

Figure 13.16 Wind blowing dust that will eventually form a loess deposit.

13.3.9 Boreholes

Borehole temperatures are used as temperature proxies. Temperature measurements are taken at different depths down the borehole at the time the borehole is drilled. The temperatures will approximate the surface temperature at a time corresponding to the time it would take for the surface temperature to reach that depth (heat transfer through the ground). The estimates are broadly comparable to the instrumental record – varying from a few decades in periods no longer than one hundred years ago. Accuracy decreases to a few centuries for periods six hundred or more years ago. Figure 13.17 shows typical borehole drilling equipment and Figure 13.18 shows where borehole temperature measurements have been taken worldwide.

Figure 13.17 Typical borehole drilling equipment.

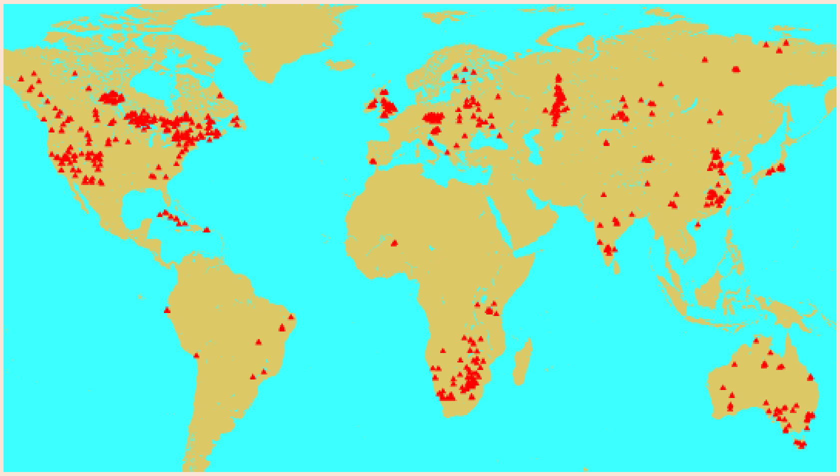


Figure 13.18 Boreholes where temperature measurement has been taken worldwide.

13.3.10 Marine sediments

Marine sediment is, any deposit of insoluble material, primarily rock and soil particles, transported from land areas to the ocean by wind, ice, and rivers, as well as the remains of marine organisms, products of submarine volcanism, chemical precipitates from seawater, and materials from outer space (e.g., meteorites) that accumulate on the seafloor.
https://www.britannica.com/science/marine-sediment Figure 13.20 shows the marine sampling ship and equipment and sediment cores being extracted and examined.

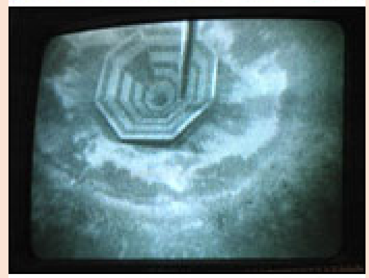


Figure 13.19 Marine sediment sampling ship, drilling equipment and sediment cores being extracted and examined.

13.3.11 Geomorphic features

Geomorphological systems include all of the land forming processes that together determine land form development. Recognizing that geomorphic features are a direct consequence of the climates that helped form them and knowing the nature of the environment the climate may produce; it is logical to interpret existing geomorphic systems in such a way as to predict the nature of the past climates that formed them. This is common practice in the field of glacial geomorphology where existing land forms and deposits are related to past glacial activity and melt processes and indirectly the climate conditions at the time. It is interesting to note that Louis Agassiz developed his theory of the ice ages based on exactly this kind of approach (see Chapter 2 History of the Scientific Study of Climate Change).

Recently developed geomorphic features beg answers to the question as to what happened to cause this. Geomorphic features of interest might be land and drainage erosion, vegetation changes, sediment deposits and more. Answers may include comments on precipitation, temperature and human activity.

13.3.12 Pollen

All flowering plants produce pollen grains unique in shape to the type of plants from which they came. Pollen grains are well preserved in sediment layers in the bottom of a pond, lake or ocean. Analysis of the pollen grains indicates what kind of plants were growing at the time the sediment was deposited. From this knowledge, inferences about the climate can be made by using present knowledge about modern and historical distributions of plants in relation to climate. It is possible to obtain records of changes in vegetation going back, hundreds, thousands and even millions of years.

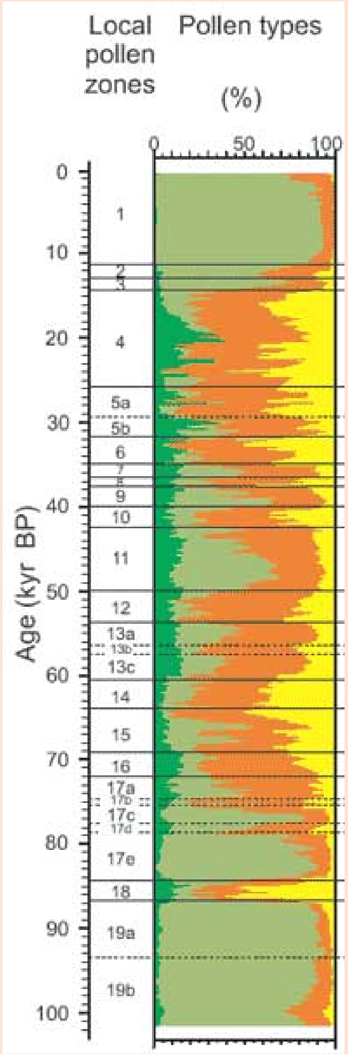


Figure 13.20 Bar graph illustrating relationship between pollen types and corresponding age illustrating beginning of the Holocene period.

13.3.13 Oxygen isotopes and hydrogen isotopes

An interesting aspect of water is that it may occur in several molecular forms depending on the isotope of oxygen or type of hydrogen atoms that form it. (See Figure 13.22) Oxygen has two isotopes, oxygen sixteen, O^{16}, the most common form, and oxygen eighteen, O^{18}, that has two extra neutrons. Water that is formed with O^{16} has a molecular weight of eighteen. Water that is formed with O^{18} has a molecular weight of twenty. Ocean water contains both types of water and there is a fixed ratio of the amount water formed with oxygen sixteen to water formed with oxygen eighteen. Water formed with oxygen eighteen is heavier and so requires more energy to evaporate (and releases more energy when it condenses). Water samples containing more of the heavier water indicates that the temperature of the water source and climate were warmer. Less heavy water indicates the temperature of the water source and the climate was cooler. Water molecules formed with isotopes of hydrogen H^2, deuterium, (also found naturally in water) will also produce heavier water and behave in a similar manner.

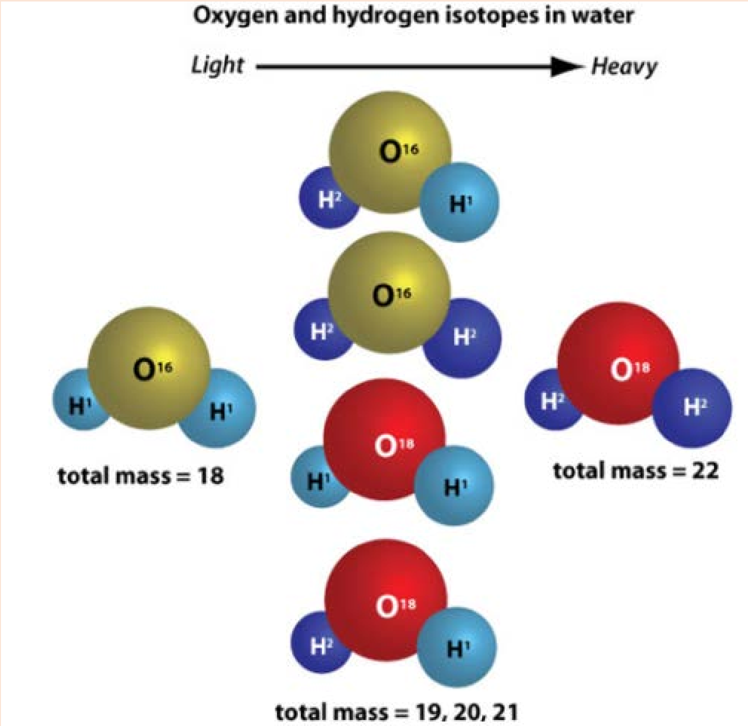


Figure 13.21 Oxygen and hydrogen isotopes in water.

13.3.14 Stomatal density (Stomata Density Index, SDI)

- Stomata control the cycling of water and carbon dioxide between plants and the atmosphere.
- SDI is the number of stomata on the surface of a leaf (typically the leaf).
- In a controlled environment (temperature, light type, duration and intensity, moisture conditions (soil and atmospheric), etc.) healthy plants will respond to increases in the concentration of CO_2 in the atmosphere by reducing the SDI on its leaves.
- The relationship between SDI and the concentration of CO_2 will vary with species of plant.

- The relationship between the concentration of CO_2 and SDI appears to be strong to some upper limit in the concentration of CO_2. This varies with plant species.
- Well preserved accumulations of plant leaves have been found in bog environments in Europe and North America. The accumulations have occurred over several hundreds of years. The preservation of the leaves is sufficiently good that the SDI can be determined.
- The suggestion has been made the SDI of the leaves in layers which are able to be accurately dated, can be used to estimate the concentration of CO_2 in the atmosphere and even be used to correct the concentration of CO_2 in the atmosphere determined from ice core measurements.
- The scientific community is in general disagreement with the use of the SDI of leaves in the bog environments for estimation of atmospheric CO_2 because of the numerous other factors which also determine the SDI. SDI is not used as a proxy to estimate atmospheric CO_2 in paleo-climates.
- The estimates of the concentration of atmospheric CO_2 from ice core data is considered to be quite accurate and may be used to evaluate the SDI determinations.

Figure 13.22 Photograph of stomata.

13.2.15 Radiocarbon or Carbon-14 dating

This is a method for determining the age of an object containing organic material using the properties of carbon-14, C^{14}. The C^{14} forms part of the carbon dioxide which is taken up by plants and animals that eat plants. When the plant or animal dies it stops exchanging carbon with its environment after which the C^{14} it contains begins to decrease as it undergoes radioactive decay. By measuring the amount of C^{14}, information is provided which can be used to determine when the plant or animal died. The half-life of C^{14} is approximately 5,730 years and oldest dates that can be reliably estimated are 50,000 years ago. The C^{14} content of a sample is measured and compared to a standard to determine the age.

13.3.16 Beryllium 10 and 7

Beryllium 10 and 7, Be^{10} and Be^{7}, can be used to reconstruct solar activity, sunspot number and cosmic ray intensity.

13.3.17 Radiometric dating or radioactive dating

Radiometric dating relies on the properties of isotopes with very long half-lives such as uranium-238, uranium-235 and potassium-40 each of which have a half-life of more than a million years. Dating is typically performed on the layers of volcanic ash that the subject material lies between.

13.3.18 Leaf wax

Leaf wax is preserved in sediment and uses isotope analysis similar to that used in the study of ice cores. The utility of this proxy technique is being able to extract appropriate sediment cores which capture and preserve the time at which the sediment was deposited. An example of its application is the dating of period of the green Sahara, https://advances.sciencemag.org/content/3/1/e1601503 .   Details of how the leaf was proxy works and is used may be found in a paper published by Science Daily, https://www.sciencedaily.com/releases/2018/03/180302090955.htm, Watts Up with That, https://wattsupwiththat.com/2018/03/02/a-new-but-unbelievable-climate-proxy-plant-leaf-wax/, Copernicus, https://cp.copernicus.org/articles/14/1607/2018/cp-14-1607-2018.pdf, and Caltech, http://web.gps.caltech.edu/~als/research/dh_paleoclimate_records.html.

13.3.19 Anecdotal and ad hoc historical data

Historical records of weather and climate conditions found in ship logs, farmers' records, diaries, newspaper accounts and any other kind of written record.

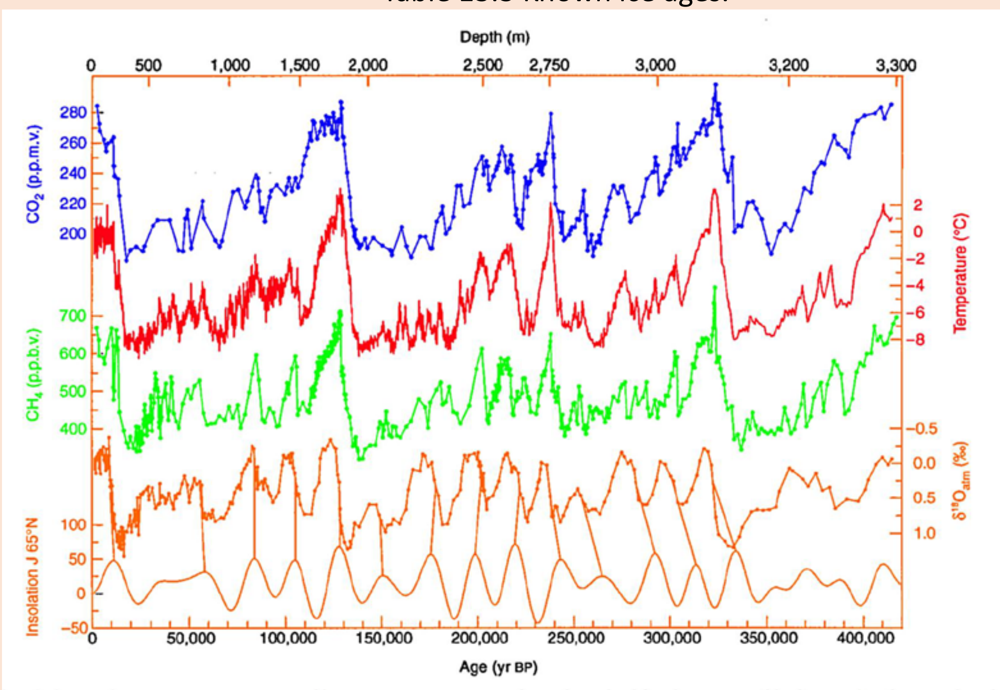
13.4 Ice ages

Ice ages, also called a glacial period, are periods of time when the temperature of the Earth's surface and atmosphere decreased sufficiently to allow the development of glaciers and thick ice sheets that covered vast areas of land in both the northern and southern hemispheres. Earth has experienced at least six major ice ages over the past three billion years. These are listed in Table 13.3.   Ice ages are separated by warm periods during which there are no glaciers or ice sheets. (During an ice age some part of the planet must be continuously covered by ice.)

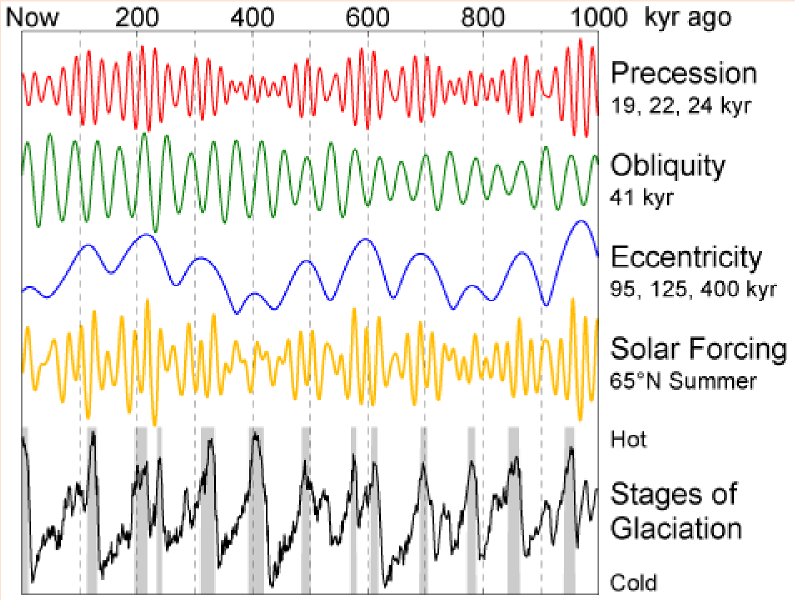
The most recent ice age is known as the Quaternary glaciation which started 2.58 million years ago.   Within the Quaternary glaciation are periods of cold climate also known glaciations (or 'ice ages' within the ice age) and periods of warm climate known as interglacials. Figure 13.23 (a) shows a graph of the stages of glaciation as observed in the ice core data from Vostok, Antarctica research station and Figure 13.23 (b) which shows a graph of the stages of glaciation predicted by the Milankovitch Cycles. The match between observed and predicted is very good. At the peak of the recent glaciation, approximately 18,000 years ago, the ice grew to more than 3,600 metres thick as sheets spread across Canada, Scandinavia, Russia and South America and sea levels decreased by more than 122 metres. Figure 13.24 illustrates areas of land and sea ice for most recent glaciation. The Earth is presently into an interglacial period known as the Holocene that began 11,700 years ago.

Name of ice age	Years BP (Ma)	Geological period	Era
Pongola	2900–2780[2]		Mesoarchean
Huron	2400–2100	Siderian Rhyacian	Paleoproterozoic
Sturt Marino Gaskiers Baykonur	715–680 650–635 580 547	Cryogenian Ediacaran	Neoproterozoic
Andean-Saharan (incl. Hirnantian and Late Ordovician glaciation)	450–420	Late Ordovician Silurian	Paleozoic
Karoo	360–260	Carboniferous Permian	Paleozoic
Late Cenozoic Ice Age (incl. Quaternary glaciation)	34–present	Late Paleogene Neogene Quaternary	Cenozoic

Table 13.3 Known ice ages.



(a)



(b)

Figure 13.23 (a) and (b) 420,000 years of ice core data from Vostok Antarctica research station and stages of glaciation over the past 1,000,000 years predicted by Milankovitch Cycles.

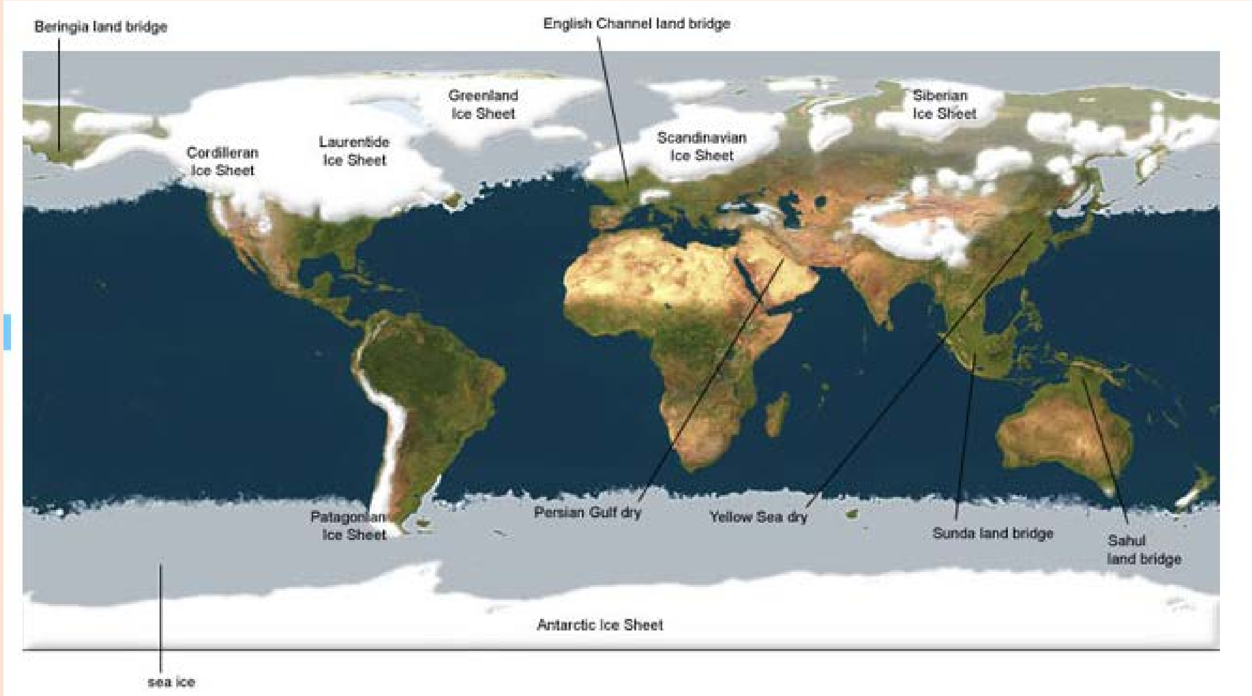


Figure 13.24 Areas of land and sea ice for most recent ice age. (Satellite imagemap, ETOPO2, http://www.planetaryvisions.com/Earth_texture_map.php?pid=4101)

The study of the last ice age through the window of ice cores and marine sediments provides a unique look at the dynamics of climate change over the past 800,000 years. While the data confirms the role of natural forces such as the Milankovitch cycles it also suggests the existence of new processes (Dansgaard-Oeschger events, Bond cycles and Heinrich events) that challenge explanation.

There is substantial additional deep and shallow ice core data from Greenland and Antarctica and from numerous ice caps from mountain ranges around the globe. (See https://en.wikipedia.org/wiki/List_of_ice_cores for a list of these projects.)

The Greenland and Antarctica cores provide substantial information on Earth's climate in the late Quaternary period (most recent ice age). Figure 13.25 shows a comparison of 800,000 years of ice core data from the European Project for Ice Coring in Antarctica (EPICA) and 420,000 years of ice core data from Vostok Antarctica research station. This information is well correlated with other proxy data for the Holocene period.

Data collected from ice cores include temperature, concentration of various gases, precipitation, solar activity, volcanic ash, pollen and other parameters. These data have proven very useful to validate and interpret other proxy information and helping to describe past regional and global climate changes that assist in the understanding of the science of present day and future climate change processes.

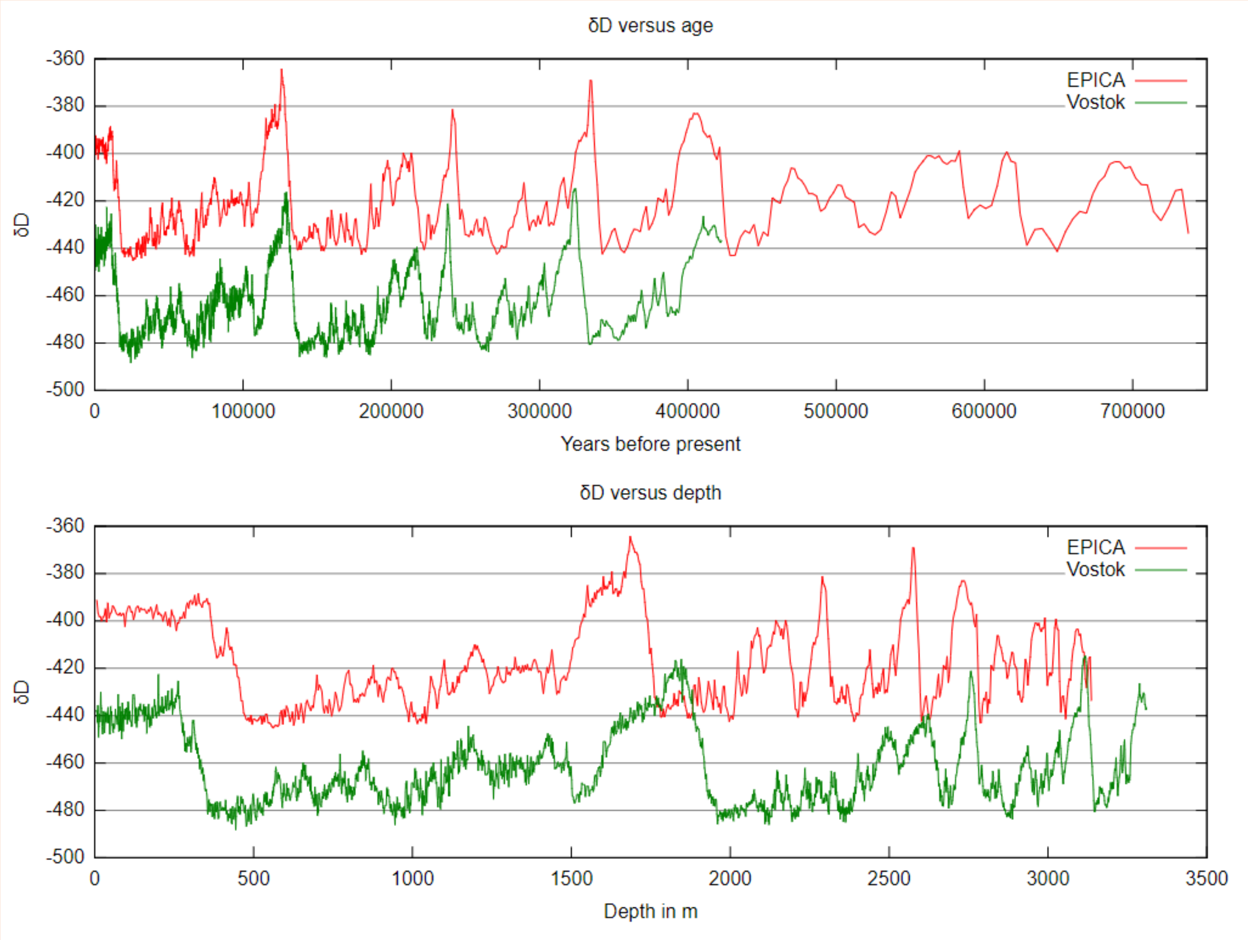


Figure 13.25 Comparison of 800,000 years of ice core data from the European Project for Ice Coring in Antarctica (EPICA) and 420,000 years of ice core data from Vostok Antarctica research station.

Figure 13.26 shows a graph of variations in temperature, atmospheric carbon dioxide and oxygen isotopes over the past three million years using an Earth system model of intermediate complexity (discussed in Chapter 17). The model results compared favourably with observed climate history which provided confidence in simulations. The authors conclude: "In the context of future climate change, our results imply that a failure to significantly reduce CO_2 emissions to comply with the Paris Agreement (discussed in Chapter 21) target of limiting global warming well below 2°C will not only bring Earth's climate away from Holocene-like conditions, but also push it beyond climatic conditions experienced during the entire current geological period." Note that the concentration of carbon dioxide in the atmosphere on November 22, 2020 was 413.59 ppm, (https://www.co2.earth/daily-co2) a concentration not seen in the past three million years.

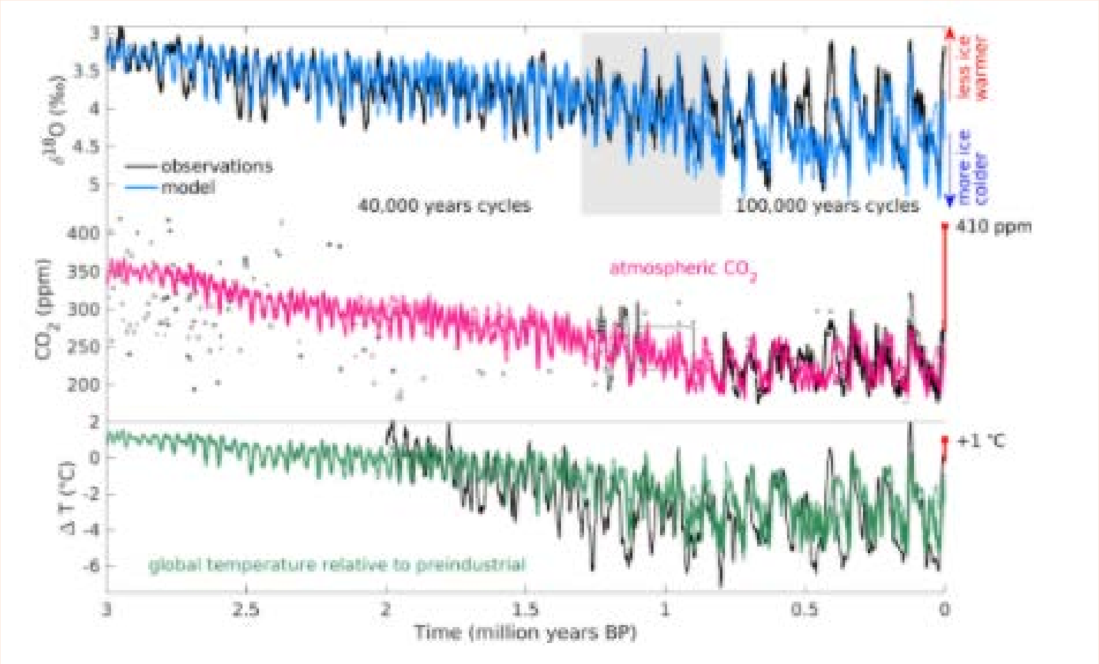


Figure 13.26 Temperature, carbon dioxide and oxygen isotope variation over the past three million years. http://www.realclimate.org/index.php/archives/2019/04/first-successful-model-simulation-of-the-past-3-million-years-of-climate-change/

13.5 Little Ice Age

The Little Ice Age, LIA, was not a true ice age. According to the IPCC it was a period of modest cooling in the Northern Hemisphere between 1300 and 1850 “consistent with estimates of naturally forced climate variability”. That said there is evidence that cooling effects occurred in the same time period throughout the world. (See Figure 13.27 which shows a graph of global temperature over the past two thousand years.) The principal reason for the interest in the LIA was the profound and well documented impact it had on northern European communities as described by a book by Brian Fagan, The Little Ice Age, How Climate Made History, 1300 – 1850.

From a climate science perspective, the interest in the LIA is the search for possible causes which have included orbital cycles, solar activity, volcanic activity and ocean circulation. Orbital cycles could contribute cooling at the rate of 0.02 °C per century so its influence is minimal. Solar activity as evidenced by the sun spot cycles and the impact of associated fluctuations in the Sun’s magnetic field on cosmic rays, cloud cover and cooling have been carefully examined by several reputable research efforts and found to be insignificant, (see section 11.2). Volcanic eruptions occurring shortly before the LIA and at several times during and near the end of the LIA are said to been the principle causes for short term temperature decrease or provided the initial forcing causing regional cooling and associated positive feedback which resulted in the long-term cooling reported to have occurred during the LIA. Changes in ocean circulation alone, including the thermohaline circulation, Gulf Stream and the Atlantic Meridional

Overturning Circulation, do not explain the LIA.   Recently published studies, using climate modelling techniques, have concluded that all of the factors are important since no individual factor can explain the phenomena.

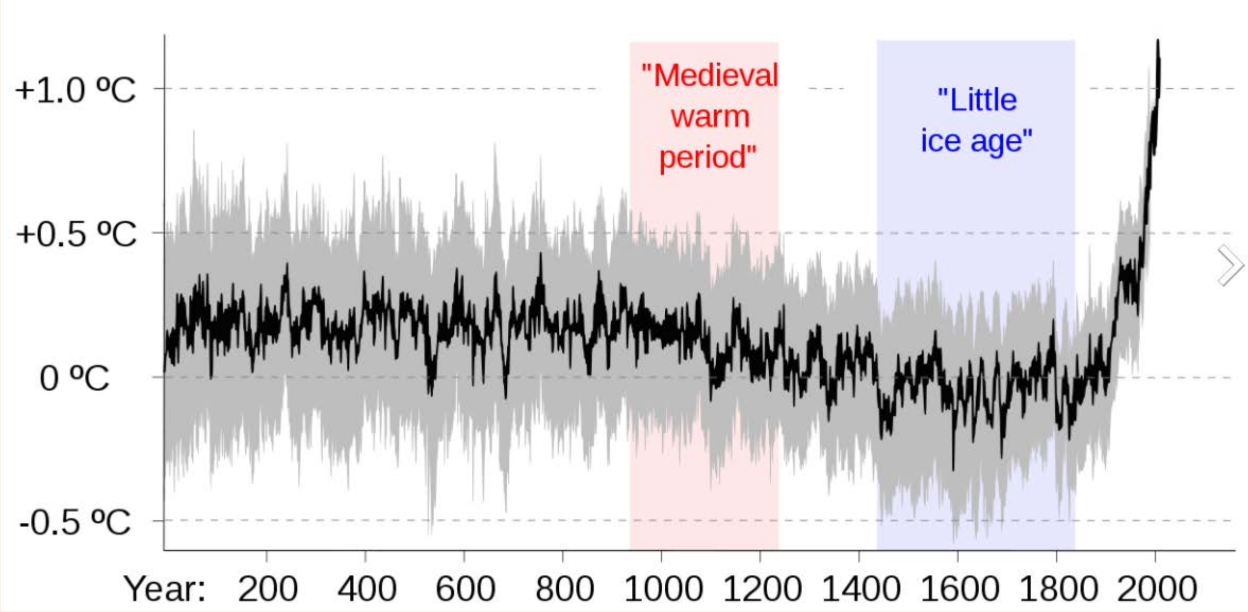


Figure 13.27 Global average temperature 0 – present highlighting the 'medieval warm period' and the 'little ice age'.
https://en.wikipedia.org/wiki/Little_Ice_Age#/media/File:2000+_year_global_temperature_including_Medieval_Warm_Period_and_Little_Ice_Age_-_Ed_Hawkins.svg

13.6 Information support

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