EARTHQUEST

Changes in Time in the Temperature of the Earth

Natural variability in the climate system is most often visualized in terms of the average temperature of the atmosphere near the surface of the earth, ideally for the planet as a whole. Continuous records of surface temperature sampled sufficiently over the globe to allow reconstructions of global or hemispheric averages reach back but about a hundred years, although histories of about twice that span are available for specific stations where the longest records were kept.

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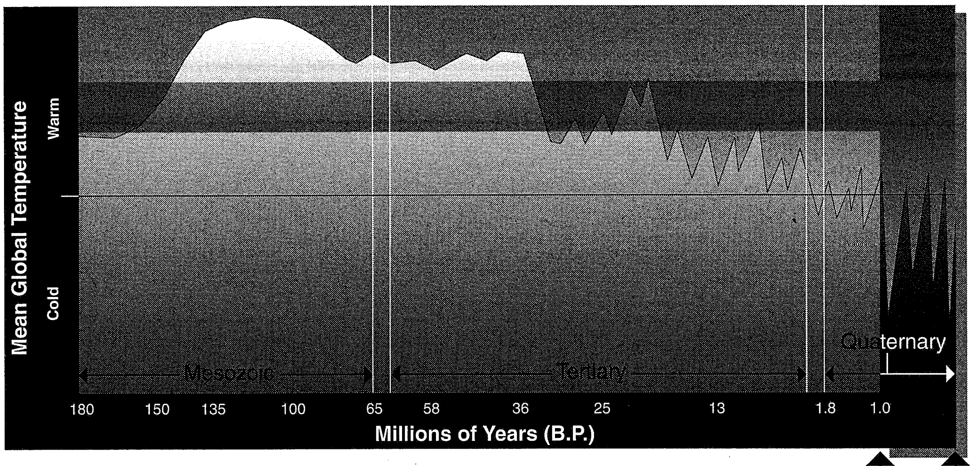

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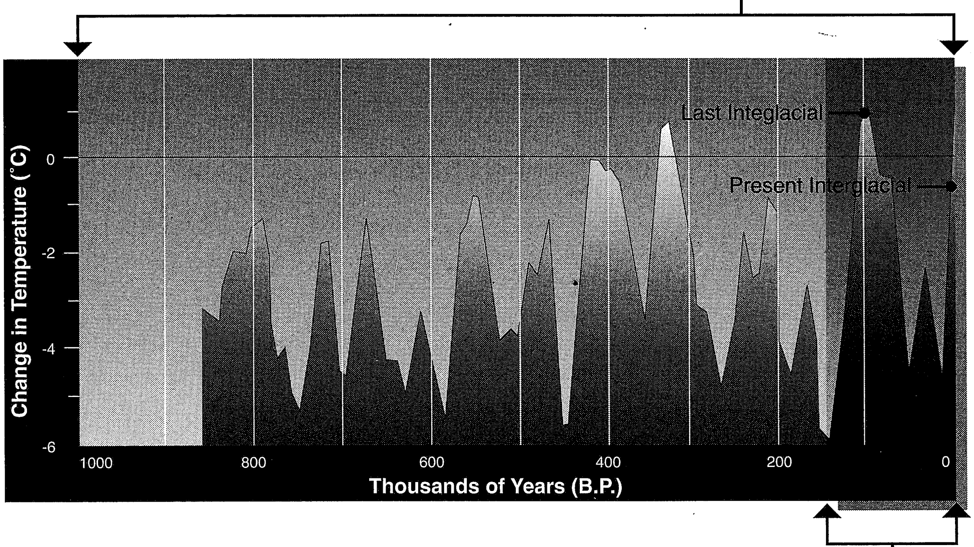

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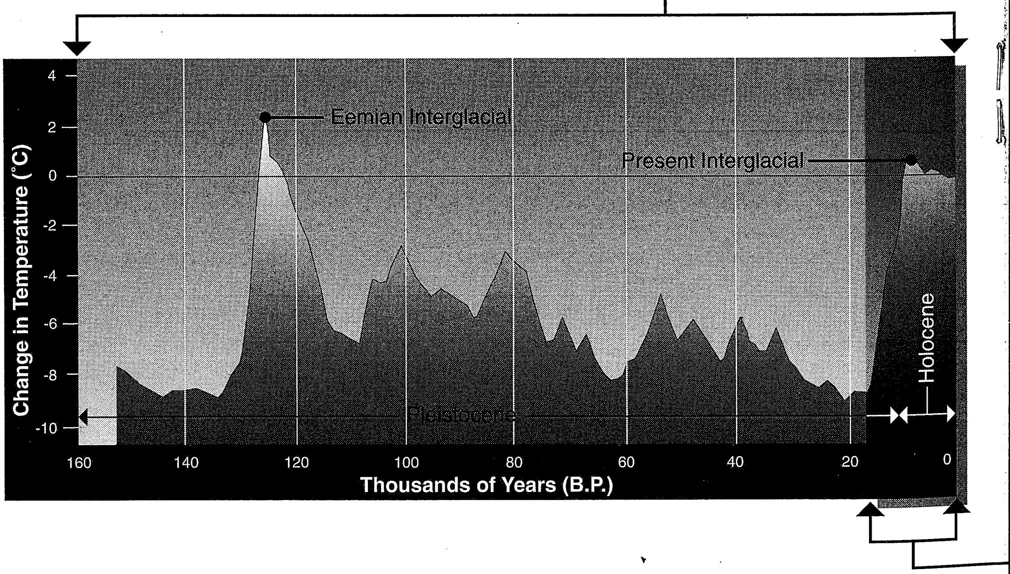
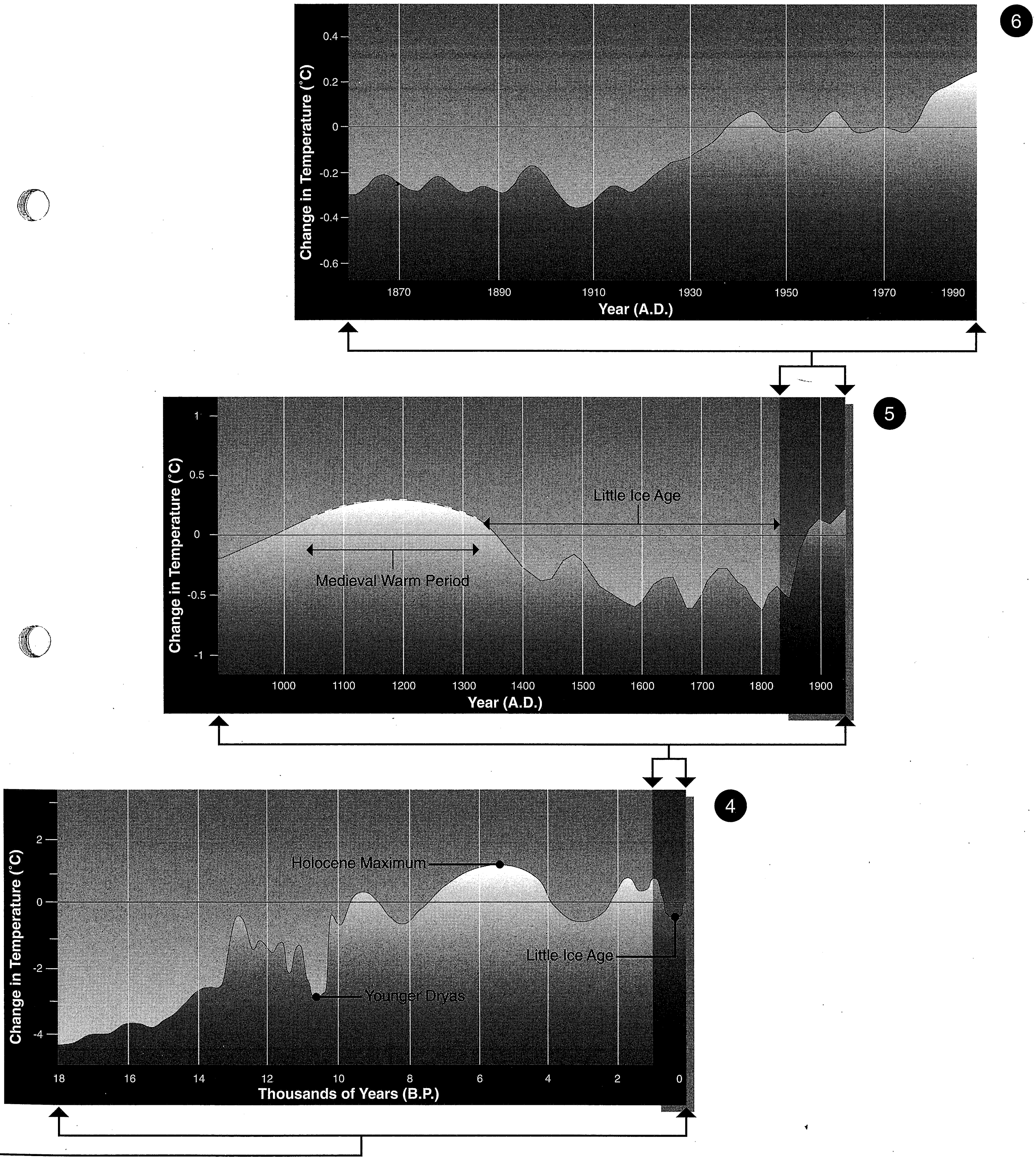


Reconstructions of the longer history of past variations of surface temperature are obtained through the chemical analyses of dated sediments of various kinds, and as such are themselves regionally or even site specific. One of the challenges of global change research is to improve upon what is known of past changes in temperature of the earth as a function of space and time.

A compilation representative of what is known today is shown in this set of graphs, which portray a sampling of estimated surface temperatures through the last 180 million years of earth history.

They are arranged counterclockwise from upper left in ever more recent eras and with greater and greater expansion of the time scale, as through a zoom lens. The shaded portion of each of the first five graphs is expanded in the graph following it. Temperatures shown are in degrees Celsius (1°C = about 2°F), in most cases as a departure from the mean value at the turn of the present century of about 15°C (59°F). The vertical scale varies, expanding about 15 times between the first and last figures.



1 Mean global temperature through the last 180 million years, derived from oxygen isotope analyses of various marine and terrestrial deposits (from L.A. Frakes, *Climates Through Geologic Time,* Elsevier, Amsterdam, 1979). The present (ca. 1900) condition, for reference, is shown as a horizontal line. Of note are (1) a global cooling trend since the time of the Cretaceous, when global surface temperatures were 8–10°C warmer than today, and (2) the onset of a continuing series of deeper, periodic glacial/interglacial oscillations in the latest, Quaternary period. Also shown (dark band) is the range of modeled surface temperature based on a doubling of atmospheric CO_2, projecting an increase from present values of about 2–5°C (from T.J. Crowley, *Journal of Climate 3,* 1282–1292, 1990). Note that a different linear time scale is used for each of the three geologic divisions.

2 Surface temperature through the last 850,000 years, derived from measurements of the ratio of ^{16}O to ^{18}O in fossil plankton which had settled to the sea floor and were recovered in a deep-sea core from the equatorial Pacific Ocean (from N.J. Shackleton and N. Opdyke, *Quaternary Research 3,* 39–55, 1973). The changes mainly reflect variations in global ice volume; the scale used here was added to show schematically the probable associated changes in global average surface temperature, based on a model-derived difference of 4–6°C between full glacial and full interglacial conditions (from W.C. Clark, *Carbon Dioxide Review,* Oxford University Press, New York, 1982). The reference line at 15°C corresponds to surface temperatures of the modern era. The glacial/interglacial oscillations, characteristic of the Pleistocene epoch, are now thought to be induced by periodic variations in the orbit of the earth and in its axis of inclination (the Milankovitch effect), which act together to bring about systematic changes in the seasonal distribution of sunlight over the surface of the planet.

3 Air temperature over Antarctica, expressed as a difference from the modern surface temperature value. These estimates are derived from hydrogen/deuterium ratios measured in an ice core from the Vostok station in Antarctica (from J. Jouzel et al., *Nature 329,* 403–408, 1987). Of note are the present (Holocene) and the preceding, somewhat warmer "Eemian" interglacial periods, each characterized by a rapid onset to an early interglacial maximum temperature, and a subsequent, slower decline. The glacial period between, called the Wisconsin glaciation in the Americas, is itself characterized by significant variations in temperature that fall systematically to a coldest extreme (maximum glaciation) about 20,000 years before the present (B.P.).

4 Variations in surface temperature, estimated from a variety of sources, principally isotope ratios from Greenland ice cores, for the last 18,000 years. The onset and subsequent character of the present interglacial or Holocene epoch are depicted. Of note are century-scale oscillations in temperature, identified in the Greenland record and in certain European lakes, during the period of deglaciation between about 15,000 and 10,000 years B.P., and a broad Holocene maximum about 5000–6000 years B.P., when summer temperatures may have been 1–2°C warmer than the present era. At these expanded scales, the temperature excursions depicted in this and the subsequent graph are the most conjectural of the set (modified from J.T. Houghton et al., *Climate Change: The IPCC Assessment,* Cambridge University Press, Cambridge, 1990).

5 Variations in surface air temperature estimated from a variety of sources, including temperature-sensitive tree growth indices and written records and accounts of various kinds, largely from western Europe and eastern North America. Of note is a possible protracted global warming through the Medieval period, when surface temperatures may have averaged about 0.3°C warmer than the A.D. 1900 reference. It was followed by a longer period of much colder conditions, loosely termed the Little Ice Age, when the estimated global mean temperature may have fallen about 0.6°C below the reference norm, reflecting global temperatures almost 1°C lower than the values attained during the middle of the current century (modified from J.T. Houghton et al., 1990).

6 Globally averaged, direct measurements of the combine[illegible] a surface temperature and air temperature over the land, s[illegible]wn in this case relative to 1951–80. A stepped warming of about 0.6°C is evident, qualified in the consensus 1990 IPCC Report as 0.3–0.6°C to reflect uncertainties in the data used (from J.T. Houghton et al., 1990).

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