Global Warming: A Geological Perspective

By John P. Bluemle

Editor's note: This article was summarized from "Rate and Magnitude of Past Global Climate Changes," which was published in *Environmental Geosciences*, volume 6, number 2, 1999, pages 63-75. The authors are John P. Bluemle (State Geologist of North Dakota), Joseph M. Sabel (geologist with the U.S. Coast Guard in Oakland, CA) and Wibjörn Karlén (Professor of Physical Geography at the University of Stockholm, Sweden). In the *Environmental Geosciences* article, more than 70 peer-reviewed reports are cited.

This article (slightly modified) also appeared in the Fall, 1999 issue of *Arizona Geology* (Vol. 29, No. 3). It benefitted greatly as a result of the efforts of Dr. Larry Fellows, State Geologist of Arizona, who summarized the original article from *Environmental Geosciences*.

The average surface temperature of Earth is increasing. Continued increase could cause profound impacts on Earth and its inhabitants (Figure 1).

Figure 1. Many glaciers in North America and Scandinavia, including the two in this photograph (Isfallsglaciären and Storglaciären in the Tarfala Valley in Sweden), have receded since the early eighteenth century. Note the distance between the frontal moraines (arrows) and the ice. If global warming continues, glaciers and ice caps may melt, sea level may rise, and many population centers could be submerged. There would likely be an increase in icebergs, which would endanger maritime commerce. The list of possible effects of continued global warming is long and uncertain.

The average surface temperature increased from the mid-1880s until about 1940, declined until about 1980, and has been increasing since then (Figure 2). Some believe that the current warming rate is unusually high, is being caused by the burning of fossil fuels that produce carbon dioxide (CO_2), creating a "greenhouse effect," and can be slowed or even reversed. To evaluate the significance of the current warming, one must compare it with temperatures and variations that occurred prior to human activities. If the current warming is greater than that in the past, human activities may be a cause. If temperatures and variations in the past were comparable to or larger than the current warming, however, human activities may not be significant.

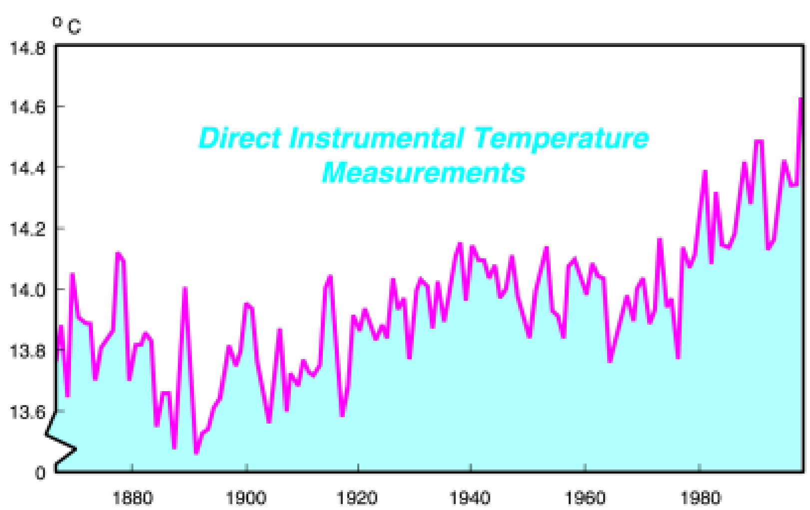

Figure 2. Direct instrumental temperature measurements show that the average temperature at Earth's surface increased from 13.8° in 1866 to 14.6° in 1998. Note that the temperature increased from about 1885 until 1940, decreased until about 1978, and has been increasing since then. Modified from a graph provided by the Goddard Institute for Space Studies. Art work by Peter Carrao, Graphics Artist with the Arizona Geological Survey.

Two colleagues and I reviewed published articles to compare past temperatures and variations with the current warming. Much research has been done on this subject in the past 30 years, especially the last decade. Scientists have completed investigations in widely distributed parts of the world and used varied methods to interpret past temperatures and changes. Independent research has been done on topics such as glacial advance and retreat, ice cores, pollen distribution, lichen growth, tree rings, sediment layers in glacial lakes, sediment on the sea floor, the composition of sea shells and corals, and the composition of cave deposits. Information about past temperatures, variations, and trends is summarized in this article.

Temperature variations during the Ice Age. The global temperature declined at least 10°C during the Ice Age (Pleistocene Epoch), which began two to three million years ago. In addition, the temperature cooled 15° - 20°C in central Europe in the 55 million years or so that preceded the Pleistocene (Figure 3).

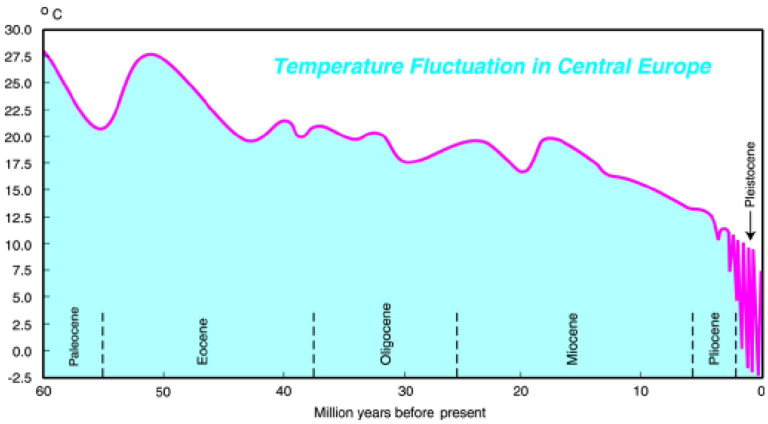

Figure 3. Temperature fluctuation (mean annual temperatures) in central Europe during the past 60 million years. Except for a peak about 50 million years ago, temperatures decreased about 15°C prior to the Pleistocene Epoch, which began about 3 million years ago. At that time, glacial conditions began and temperatures fluctuated widely, ranging from full glacial to interglacial conditions. The modern condition is approximately +4 to +5 degrees Celsius. This graph is modified and adapted from B. G. Anderson and H. W. Borns, 1997, The ice age world: Oslo, Scandinavian University Press. Art work by Peter Carrao, Graphics Artist with the Arizona Geological Survey.

Extensive continental glaciation took place in North America and northern Europe during the Pleistocene. Ice sheets advanced and retreated repeatedly, reaching as far south as the Missouri and Ohio Rivers in the United States. At least six major glacial advances and retreats occurred in North Dakota. Each major glacial and interglacial episode lasted about 100,000 to 200,000 years, during which the temperature decreased roughly 10°C during glaciation and increased by a comparable amount during the subsequent interglacial period.

Studies of ice cores from Greenland indicate that temperatures there rose and fell abruptly during the Pleistocene. On two occasions between 135,000 and 110,000 years before present (BP), temperatures dropped from 2°C warmer than they are today to 5°C cooler in less than a few centuries. In one instance the temperature dropped 14°C in a decade and returned to its former level 70 years later.

During the most-recent (Wisconsinan) glacial maximum, between 20,000 and 14,000 years BP, glacial ice covered about 27 percent of the Earth's land surface. During that time, sea level was about 130 meters lower than it is today. Sea level rose to current levels when the ice melted. Only about ten percent of the land surface is covered by ice today.

The present volume of the earth's glacier ice, if it were totally melted, represents 80 meters in sea-level rise. From minimum (during the interglacial epoch) to maximum (the height of the most-recent glaciation) volume of glacier ice on the continents, sea level has a range of about 200 meters. For example, during the last glacial maximum, about 20,000 years ago, sea level is estimated to have been 120 meters lower that it is today. During the peak of the last interglacial epoch, about 125,000 years ago, sea level was about 6 meters higher than it is today (and even then not nearly all of the ice was melted). During an even warmer interval 3 million years ago, sea level was approximately 25 to 50 meters higher than it is today.

The most recent interglacial age. We are living in the most recent of many interglacial ages. Geologists call it the Holocene Epoch. Frequent and rapid climate fluctuations have occurred throughout the Holocene, which began about 13,000 - 10,000 years BP and includes all of recorded history. Ice core studies show that, about 9,500 years ago, temperatures in Greenland changed from warmer than today to full glacial severity within 100 years. All of the glacial ice in North Dakota had probably melted by 8,000 years BP; the Scandinavian ice sheet had almost completely disintegrated before about 7,000 years BP. The last remnants of the once huge Laurentide ice sheet in the Hudson Bay region (the ice sheet that had once covered most of North Dakota) had melted by 5,000 years BP.

Temperatures have fluctuated rapidly during the last 2,000 years, although not to the extent they did during the Pleistocene interglacial periods. A time of relatively warm temperatures, the Medieval Warm Period (Figure 4), is well documented in Europe and the western hemisphere between about 1,100 and 600 years ago (900 - 1400 AD). It was followed immediately by a period of cooling from about 600 years ago until 200 years ago (1400 - 1800 AD) that included a particularly cold interval, the Little Ice Age, between 400 and 250 years BP (1600 - 1750 AD).

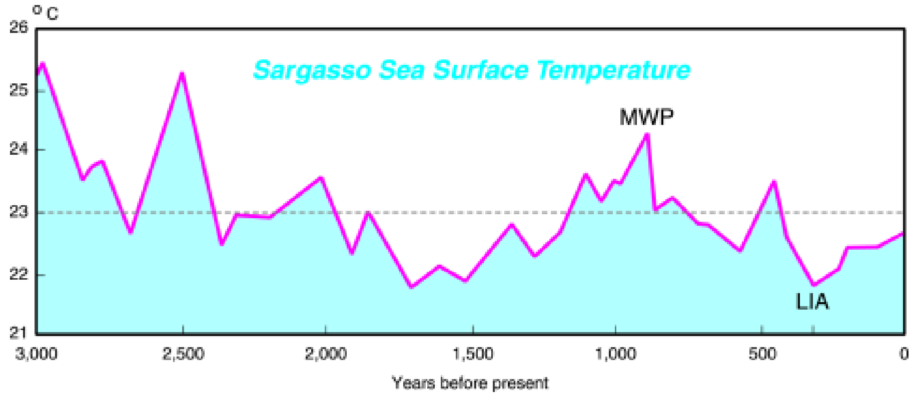

Figure 4. This graph shows the Sargasso Sea surface temperature, which was derived from oxygen isotope ratios. This is an indicator of evaporation and, therefore, a proxy for sea-surface temperature. The Sargasso Sea is a two-million-square-mile body of water in the North Atlantic Ocean that lies roughly between the West Indies and the Azores from approximately 20° - 35° N. It is relatively static through its vertical column so that potential interference from mixing with other water masses and sediment sources is minimal. The isotopic ratios are derived from biotic debris that has precipitated onto the sea floor. Wide and abrupt variations in temperature are indicted. The relative temperature variations of the Little Ice Age (LIA) and the Medieval Warm Period (MWP) are prominently recorded in the data. Note that the temperature has been increasing since about 300 years before present (1700 A.D.). The horizontal line is the average temperature for the 3000-year period shown on the graph (we are currently still slightly below that temperature). Graph is modified from Keigwin, L. D., 1966, The Little Ice Age and Medieval Warming Period in the Sargasso Sea: Science, v. 274, p. 1504 - 1508. Art work by Peter Carrao, Graphics Artist with the Arizona Geological Survey.

The entirety of Holocene climatic history can be characterized as a sequence of 10 or more global-scale "little ice ages," fairly irregularly spaced, each lasting a few centuries, and separated by global warming events.

Direct instrumental measurements. Direct instrumental measurements indicate that the average temperature at the Earth's surface increased about 0.8°C from1866 until 1998 (Figure 2). During this same time, the concentration of CO_2 in the atmosphere increased from 280 to 353 parts per million volume. Because this period of time very nearly coincides with the industrial revolution, the supposition arose that the warming was caused by human activities. Most of the warming, however, took place before most of the CO_2 increase occurred. Statistical analyses of the climate record since 1860 show that significant interannual and interdecadal variability occurred. This suggests that the warming had causes other than an increase in greenhouse gases alone.

The current increase in temperatures recorded by direct measurements may be part of a longer-term warming trend that began after the Little Ice Age and before the Industrial Epoch. Many poorly understood factors influence atmospheric CO_2 concentrations. For example, the current increase follows a 300-year warming trend, during which temperatures have been recovering from the Little Ice Age. The observed increases in CO_2 are of a magnitude that can be explained by oceans giving off gases naturally as temperatures rise.

Conclusions. A review of research on past temperatures and variations led us to the following conclusions:

1. Climate is in continual flux: the average annual temperature is usually either rising or falling and the temperature is never static for a long period of time.

2. Observed climatic changes occurred over widespread areas, probably on the global scale.

3. Climate changes must be judged against the natural climatic variability that occurs on a comparable time scale. The Little Ice Age, Medieval Warm Period, and similar events are part of this natural variability. These events correspond to global changes of 1° - 2°C.

4. Global temperatures appear to be rising, irrespective of any human influence, as Earth continues to emerge from the Little Ice Age. If the temperature increase during the past 130 years reflects recovery from the Little Ice Age, it is not unreasonable to expect the temperature to rise another 2 to 2.5 degrees Celsius to a level comparable to that of the Medieval Warm Period about 800 years ago. The Holocene Epoch, as a whole, has been a remarkably stable period with few extremes of either rising or falling temperatures, as were common during Pleistocene glacial and interglacial periods. Nevertheless, the Holocene has been, and still is, a time of fluctuating climate.

5. Climatic changes measured during the last 100 years are not unique or even unusual when compared with the frequency, rate, and magnitude of changes that have taken place since the beginning of the Holocene Epoch. Recent fluctuations in temperature, both upward and downward, are well within the limits observed in nature prior to human influence.