Is our climate changing?

# Warmer or Cooler?

**Prof. Leszek Marks is a Quaternary geologist specializing in geological mapping and the study of past and present glaciers. He devotes much time to popularizing a broader-minded approach to climate change issues**

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**Are the climate changes we are now witnessing really so extraordinary? Research on the Earth's climate system indicates that cyclic changes have been occurring for millions of years**

The weather and climate are natural phenomena that have an impact on our day-to-day lives. The actual beginning of climate change is not easy to pinpoint, although warming will cause cool weather to occur more rarely and warmer weather more often. In the geological past, climate change has been repeatedly more drastic than that seen at present, although developed human societies appeared on the Earth relatively recently, during a period of relatively stable climate. That is why the distinct, yet small changes of climate observed in recent years have sparked concern and brought the issue into the limelight.

The climate system is highly complex, driven by various phenomena that occur in the atmosphere, oceans, cryosphere (glaciers and permafrost), lithosphere (the Earth's crust), and biosphere. The individual elements of this system are linked together by numerous feedback loops that can stretch as long as millions of years, and are therefore hard to predict.

Simplifying things somewhat, we can say that the Earth's climate is shaped by the mutual interactions of its surface and atmosphere, above all in reaction to quite regular changes in the intensity of solar radiation. Climate changes occur in many cycles, running from decades up to millions of years - the longer ones usually triggered by extraterrestrial factors, the shorter ones by regional and local factors. This is compounded by the impact of other natural phenomena, which are not always fully understood.

## At the intersection of zones

The amount of solar radiation reaching the Earth's surface varies cyclically due to different variations in the Earth's orbit (the so-called *Milankovitch effects*): the eccentric cycle (running around 100,000 years) caused by the changing shape of the Earth's orbit around the Sun, the obliquity cycle (around 41,000 years) due to the fluctuation of the Earth's axial tilt, and the precession cycle (around 23,000 years on average) caused by the circling direction of the Earth's axis.

The most important terrestrial factor controlling both the weather and the climate are the oceanic currents. A powerful surface sea current forms in the equatorial zone of the Pacific and Indian Oceans, transporting a huge mass of warm water westward all the way to the North Atlantic. On the edge of the Arctic the waters of this current cool down and sink deeper, finding their way back via deep-sea currents. Such oceanic circulation leads to the redistribution of heat on the Earth, and the warmer lower atmospheric layers near the warm currents are conducive to maintaining milder climatic conditions in the surrounding land.

Climate changes can be identified in various ways, depending on the scale of the phenomenon, the remoteness in time, and the desired precision. They can be felt particularly

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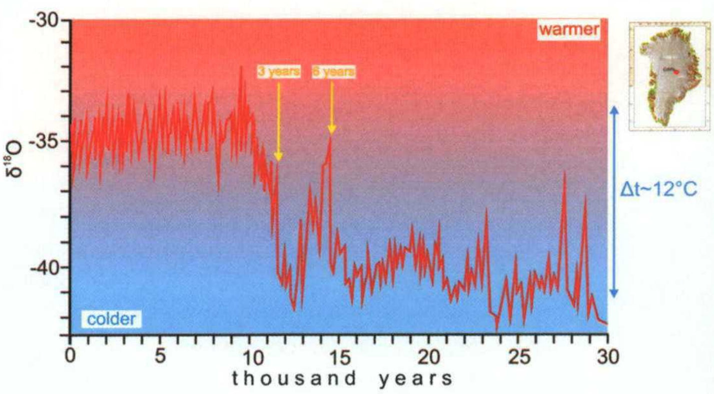


**The ratio of oxygen isotopes ($\delta^{18}O$) found in the GISP2 ice core record from Greenland points to sudden changes in temperature at the end of the Pleistocene ice age (from Broecker, 1997; significantly modified)**


**Climate change may cause the area covered by deserts to increase. Here: part of the Negev Desert in Israel**

acutely at the intersection of various climate zones. Long-term phenomena may have a very weakly perceivable impact, while those that are brief but intense may have a dominant effect. The consequences of past climate changes are recorded in sediments and organic remains, which can be interpreted based on various environmental indicators, among others as changes in glacial coverage and sea level, the distribution of vegetation zones, the borders of permanent snow, and the intensity of mass movements and erosion.

The world's first meteorological station was established in Bavaria (Germany) in 1781, and thus our records of basic instrumental readings only go back that far. Moreover, even the long-term data sets we do have are not fully self-comparable, because some come from meteorological stations once situated on the peripheries that have now ended up inside the centers of cities, which have become "urban heat islands."

## Deciphering history

To identify climate changes in the historical past, we can utilize the information contained in historical documents. In addition to direct weather descriptions, these also include the dates when harvesting has begun, when ports froze up and thawed, how long the growing cycle lasted, fluctuations in fishing catches and grain prices, and mentions of prayers for rain.

Worldwide changes in sea level are closely linked to changes in the amount of water stored in glaciers, accumulated during cooler periods and released during warmer ones. Over the past 100 years, the level of the world's oceans has raised by 1-2 mm per year on average, causing the flooding of low-lying coastlines and the destruction of coastal cliffs.

The Earth's ground surface is heated by solar radiation, which also has an impact on the temperature of deeper strata. While the intensity of this process is affected by the vegetation cover, changes in ground surface temperature over the past tens of thousands of years can still be inferred from geological data.

However, the most important source of geological information about climate changes over the past millions of years has been found in deep-sea deposits and ice cores obtained from drillings into the ice sheets of Greenland and Antarctica. One particularly important type of measurement is the ratio between $_{18}O$ and $_{16}O$ isotopes found in water molecules, the remains of sea organisms, and carbonate deposits. When sea water evaporates into the atmosphere, the lighter isotope finds it somewhat easier to evaporate - and the lower the temperature, the bigger this difference between isotopes. When water vapor reaches the world's cold regions, it gets stored away in permanent snow and glaciers. The result is that a larger share of the heavier isotope is found in seawater, a smaller proportion in glacial ice.

Variations in oxygen isotope proportions found in glacial ice indicate that temperature changes have been periodically and locally very rapid, even by as much as 5-7°C within a century. The composition of air bubbles trapped within glacial ice, in turn, has evidenced a close link between temperature changes over the past 800,000 years and increased quantities of greenhouse gases in the atmosphere.

Short-term climate changes may be the result of strong volcanic eruptions, when volcanic dust reaches up into the stratosphere and spreads within it. That inhibits solar radiation, and at the same time hampers the radiation of heat outward into space. For example, the eruption of the Laki volcano in Iceland in 1783 led to a significant temperature drop in the Northern Hemisphere, while the 1815 eruption of the Tambora volcano in Indonesia triggered such a significant worsening of weather in Europe that the following year was dubbed the "year without summer."

Greenhouse gases - chiefly water vapor, but also carbon dioxide, methane, nitrogen oxides, and ozone - are generated by many natural processes and in recent decades also as a side effect of human economic activity. Greenhouse gases allow a significant portion of solar radiation to reach the Earth, but limit the radiation of heat away from its surface. As a result, the average temperature on the Earth's surface is currently 15.5°C (without them it would be -18°C and life would not be able to exist in its current form). Changes in greenhouse gas concentrations in the atmosphere play a significant role in determining the climate. The main long-term factor affecting $CO_2$ content in the atmosphere is the water temperature in the oceans: $CO_2$ dissolves in ocean water, becomes chemically bound, and the resulting sediment settles on the ocean floor. It takes as long as 1,000 years before the $CO_2$ trapped on the bottom

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**One of the consequences of greater evaporation may be to increase the areas covered with glaciers and permanent snow in the polar zone. Here: Mt. Cook in the Southern Alps, New Zealand**

returns to surface waters. Increased ocean water temperature lowers the solubility of carbon dioxide and thereby releases it into the atmosphere.

## Forecasting changes

One key to forecasting climate changes lies in geological research, making it possible to distinguish between the rhythm of natural climate changes, extreme phenomena, and those caused by human activity. Such research identifies the prospects for future climate changes and explores the delicate balance between climate-determining factors. Even though the Earth's climate has predominantly been significantly warmer climate than today's, several significant periods of worldwide cooling are known to have occurred, when the continental ice cover stretched from the poles down to the subtropics. The most recent, Quaternary ice age began only about 3 million years ago. Small alterations in solar radiation occurring in 100,000 year cycles were enough to cause the ice sheets to grow or to shrink.

Over the past 100 million years the Earth's climate has cooled gradually (albeit not uniformly), and the quantity of greenhouse gases in the atmosphere has decreased. That trend now seems to have been reversed. However, there is no unequivocal evidence that this is a long-lasting trend or that it is exclusively caused by human activity. If the current climate change trend were to be sustained, within several hundred years (?) the Earth's climate would be reminiscent of the conditions that prevailed 5 million years ago. The temperature was then higher than at present and the atmospheric greenhouse gas content was significantly higher.

## Global cooling?

The forecasting of climate change is made possible by the study of climate evolution in the Earth's geological past. It is based on predicting the atmospheric circulation triggered by solar forcing. The other factors affecting the climate are so numerous that forecasts make the assumption that one of them begins to dominate. Two approaches are used in forecasting climate change. One of them is similar to weather forecasting and concerns the occurrence of specific climatic events of very limited duration, such as the El Niño

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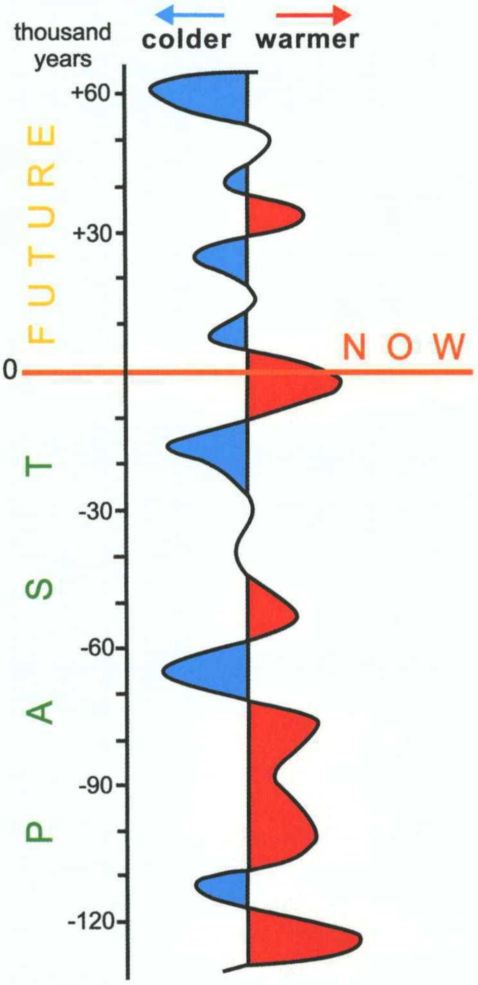


**Climate forecast for the next 60,000 years, based on changes in the intensity of solar radiation reaching the Earth's surface**

oscillation. The second type of forecasting involves calculating a statistical depiction of the climate, which means that the precise timing of climate events cannot be forecast, only the likelihood of their occurrence.

Overall, based on the expected changes in solar radiation caused by changes in the Earth's orbit, we can expect significant cooling to occur around 5,000, 24,000, and 40,000 years from now, and a cooling comparable to the latest Pleistocene glaciation to occur around 60,000 years from now. Small warming periods can be expected around 16,000, 31,000, and 50,000 years from now. ■

**Further reading:**

http://www.33igc.org - Lectures available as webcasts: Themes of the Day *Climate Change: Past, present, Future - How much is anthropogenic?* Friday 8 August 2008.

http://www.ipcc.ch - IPCC Fourth Assessment Report (AR4) *Climate Change 2007*.