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A Long-Term Perspective on Climate Change

by Petr Chylek

During the last few decades our ability to observe the climate and to detect climate and temperature changes has increased considerably as a result of improved ground-based measurements as well as by development of global satellite-based observations. Most of us seem to be surprised that the climate is changing. A changing climate challenges our feeling of stability and security. We are trying to find the reason for climate "change" and whom we should blame for it. However, the climate was changing even before mankind produced the first mole of carbon dioxide; it was changing dramatically even before mankind arrived on earth.

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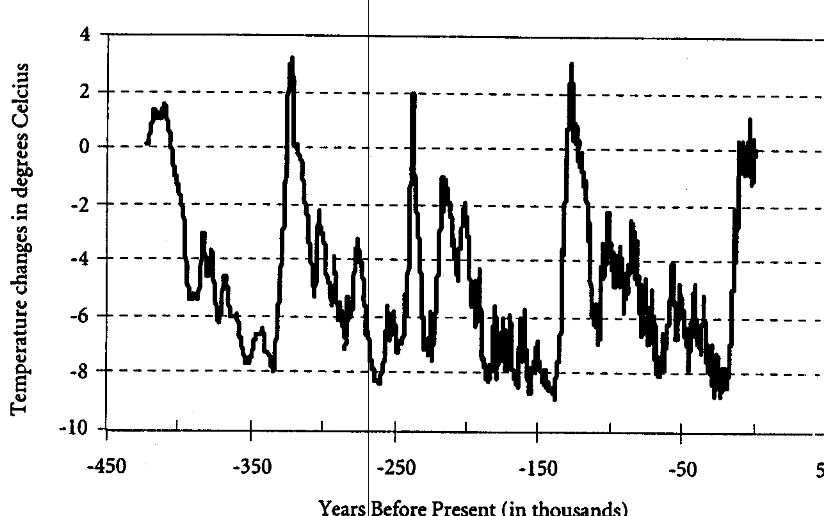
Ice ages and warm interglacial periods

The ice core records from Greenland and Antarctica provide one of the most reliable sources of information about the past climate. The longest and one of the most accurate records of past temperature change is available from the Vostok ice core (Petit *et al.*, 1999) in Antarctica. The fact that Greenland and Antarctic ice core results agree with each other, and with temperature records derived from ocean floor sediments and other climate indicators, suggests that the temperature changes observed in ice core records were global. Thus, the temperature record of the Vostok ice core can be considered to simulate global climate evolution.

Fig. 1 shows the atmospheric temperature changes (numerical data from Petit *et al.*, 1999) over the Vostok site for the last 420,000 years. The changes are displayed with respect to the current average temperature that determines a zero point on the vertical scale. There are several distinct peaks protruding considerably above the average. These peaks represent warm interglacial periods. The current warm period, called Holocene, started about 11,000 years ago. There were other warm periods around 130,000, 240,000, 320,000 and 420,000 years ago. These warm periods, similar to

Figure 1: Ice Ages and Warm Periods



The temperature record (about the last 420,000 years) from the Vostok ice core in Antarctica (numerical data from Petit et al., 1999) shows the climate oscillations between relatively short warm periods and longer lasting ice ages.

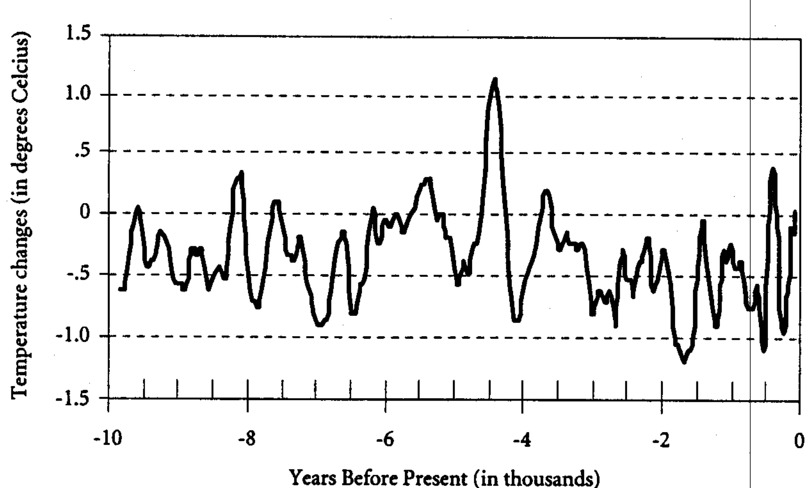
one we are living in right now, occupy only about 16 percent of the past 420,000 years. For most of the time, the Earth's climate was considerably colder and less hospitable to humans than it is today. In this sense we are living in an exceptional period of the Earth's climate history, in a pleasant warm period that has made the development of civilization and technology possible.

The Vostok ice core record (Petit *et al.*, 1999) also includes a record of atmospheric carbon dioxide (CO_2) concentrations. A challenging detail of the Vostok ice core record is that often the temperature changes first, followed later by changes in carbon dioxide (Fisher *et al.*, 1999). The changes in CO_2 lag behind changes in temperature. Consequently, changing carbon dioxide atmospheric concentration was not the cause of the past climate variation documented in the Vostok ice core.

Current warm climate

Our current, warm, interglacial period (the Holocene) started about 11,000 years ago. Figure 2 shows the Vostok temperature record (Petit *et el.*, 1999) for the last 10,000 years. Although the current temperature at the Vostok site is about 0.4 degrees C above the Holocene average, such a temperature is not uncommon. In the past, there were periods with even higher temperatures. The most distinct of these is a period of about 500 years between 4,000 and 5,000 years ago when temperatures were up to 1.5 degrees C above the Holocene average at the Vostok site. It is worth noting that there is no evidence that the West Antarctic ice cap collapsed or melted during this 500-year warm climate period. Although the current mass balance of the Antarctic ice sheet is subject to definite uncertainty, most of the reports indicate that the Antarctic ice sheet is currently growing. Similar warm periods are also recorded in ice core samples from Greenland, suggesting that the warming was not just local. Past warmer and drier periods also led to increased levels of forest fires, which are recorded in soot deposits in ice cores (Chylek *et al.*, 1992, 1995).

Figure 2: Last 10,000 Years

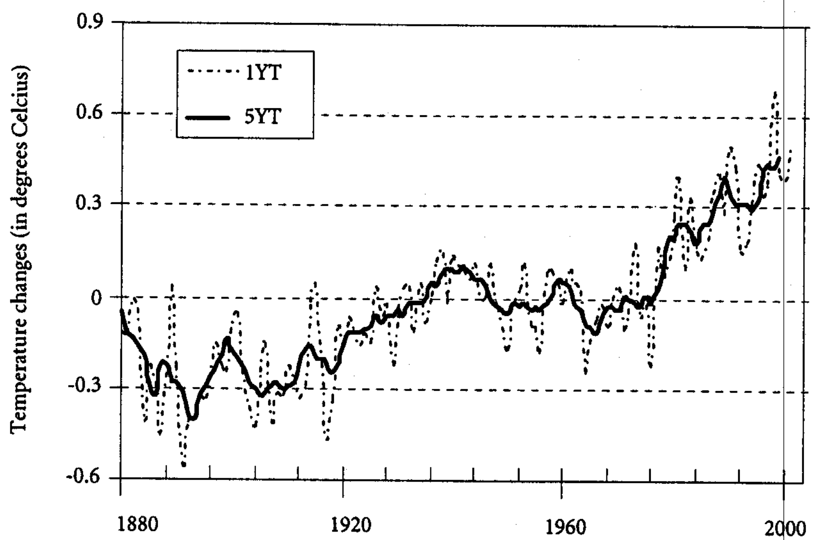


The Vostok ice core record of the temperature changes during the current warm period called Holocene (numerical data from Petit et al., 1999). About 4,500 years ago, the climate in Antarctica was considerably warmer than it is today for a period of over 500 years. In spite of that there is no evidence of any climate catastrophe (melting of ice sheets) taking place in this hot episode of climate evolution.

Instrumental temperature records

For the last 120 years, we have instrumental temperature records from meteorological stations distributed over several continents and a few observations from ships. Several research groups have tried to reconstruct the "global average" earth temperature from these measurements. Since the density of the stations is not uniform over land, and since there are very few observations over the ocean, the data need to be adjusted for this lack of homogeneity. The resulting "global average" depends on the way in which it is done. In addition, the environment at many stations has been changed over the decades from the growth of cities, the expansion of airports, and other environmental changes. The measured temperatures must be corrected to separate the effect of local environmental changes from the global climate change. Consequently, there are some differences between the results of individual research groups. As a typical example of the observed changes in global surface air temperature, figure 3 shows approximately the last 120 years of global average temperature as produced by the NASA Goddard Institute for Space Studies climate research group (Hansen *et al.*, 1999). Individual points represent annual global average temperature; the thick solid line is the five-year running average. The five-year averaging smoothes out annual variations and the long-term trend becomes more obvious.

Figure 3: Global Temperature Changes



Surface air temperature changes (annual data and 5 years running average) for the last about 120 years (numerical data from NASA GISS web site). The temperature rise started around the year 1890, when anthropogenic carbon dioxide production was negligible compared to present.

The observed warming is at the rate of 0.5 degree C per 100 years. There are two intervals during which considerable warming took place. The first warming period is from about 1890 till 1940. The second warming period starts around 1970 and lasts to the present. In between these two periods, a slight cooling occurred between 1940 and 1970.

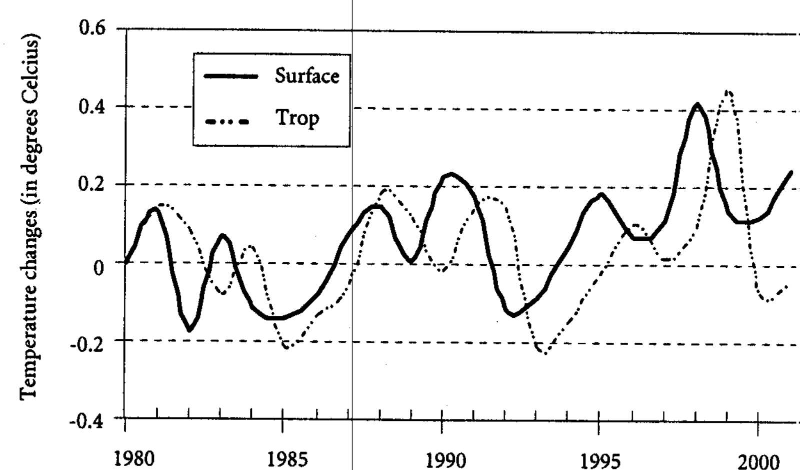
The warming between 1890 and 1940 cannot be blamed on carbon dioxide since its production, especially at the beginning of this period, was quite small. Most scientists agree that the changes in solar radiation are the most probable cause. Many blame the second warming period, from 1970 to the present on our production of carbon dioxide.

Satellite observations

As discussed in the previous section, the surface temperature record can be subject to various interpretations and criticism. The highest density of meteorological stations is in North America and Europe. Many fewer stations are spread over South America, Africa, and Asia. Over the oceans, which form about two-thirds of the earth's surface, the coverage is extremely poor. In addition, it is not always easy to separate the effect of changing local environments from global climate change in temperature measurements.

Recently, it has become apparent that satellite-based technology is the only feasible way to monitor global environmental and climate change. The microwave radiation emitted by the atmosphere is a sensitive function of the atmospheric temperature. This sensitivity can be used to measure the temperature of the atmosphere (Christy *et al.*, 2000). The satellite-based measurement of the temperature of the lower atmosphere (troposphere) has been available since late 1970s. Figure 4 compares the surface temperature records (NASA GISS site data) with the atmospheric temperatures deduced from the satellite

Figure 4: Surface and Tropospheric Temperature Changes



The annual global surface air temperature (data from NASA GISS web site) and tropospheric temperature derived from microwave satellite data (provided by John Christy). The average rate of temperature rise of 0.12 deg. C per decade for the surface air temperature is contrasted by almost no temperature change (a rate increase of 0.03 deg C per decade is within uncertainty of measurements and is not statistically significant) indicated by satellite observations.

microwave data (up-to-date data kindly provided by John Christy).

Although both the curves have a similar character, there is an essential difference between them. The overall trend of the surface temperature measurements shows the temperature increasing at the rate of 0.12 degree C per decade. On the other hand, the satellite measurements of atmospheric temperature indicate an increase at the rate of only 0.03 degree C per decade. Thus, the surface seems to be warming faster than the atmosphere.

How can we reconcile these different rates of warming between the surface and the atmosphere? We can, of course, argue, as some do, that either the surface or the satellite measurements, or both, are wrong. On the other hand, a lot of highly competent people put a lot of effort into both sets of data, and so we should not dismiss either set lightly. Is it possible that both sets are correct, and that the surface is really warming faster than the atmosphere? The IPCC (Intergovernmental Panel for Climate Change) 2000 report acknowledges the discrepancy between the surface and atmospheric temperature data that cannot be currently reconciled.

Current climate change

The General Circulation Models (GCMs) are complicated models of the atmosphere and oceans that are used for climate studies. The increasing concentration of carbon dioxide is generally considered to be the driving mechanism for current climate change. The GCMs suggest that the increasing atmospheric concentration of carbon dioxide or other greenhouse gases will heat the atmosphere at the same rate as the surface. On the other hand, if the warming is caused by factors other than greenhouse gases (for example the change of low-level cloudiness), then it is quite possible that the surface could warm faster than the atmosphere.

If we admit both sets of data as correct, then carbon dioxide should not be considered as a dominant force behind the current warming. Natural climate variability, changes in land use and the variability of solar radiation are a few factors that can affect the climate.

The sun can affect the climate by the variation of total solar radiation output, by changes in the UV radiation that affect the ozone layer, and by modifying the cloudiness through the variation of flux of cosmic rays reaching the earth's atmosphere. The current solar cycle is unusual in that it reached the solar maximum in the year 2000, but a second, unexpected peak in solar activity occurred again in late 2001 and early 2002. This double-peaked cycle keeps the sun close to its maximum activity for a longer time than usual, so should effect the earth's weather and climate. During enhanced solar activity, there is increased heating, especially of the tropical regions. This is just one example of how factors other than carbon dioxide do contribute to the current climate variability.

We are living in a rare period when the earth's temperature is pleasantly warm. Only 16 percent of the last 420,000 years had a climate as pleasant as it is today. Instrumental measurements suggest that the global average temperature increased by about 0.5 degree C over approximately the last 120 years. Some of this increase was very probably caused by increased atmospheric concentration of CO_2. However, how much of the increase can be ascribed to CO_2, to changes in solar activity, or to the natural variability of climate is uncertain. The fact that the temperature started to go up around 1890, when man-made production of CO_2 was negligible, indicates clearly that forces other than increasing CO_2 were responsible for the heating that occurred during the first half of the twentieth century. The fact that currently the surface air is warming faster than the atmosphere suggests that even in the post-1970 warming period, forces other than greenhouse gases are responsible for at least a considerable fraction of the observed warming. Thus, it is highly probable that global average temperature will go up and down in the coming years, decades, and centuries regardless of what we do.

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