Climate in perspective: how does present day climate differ from climates in the past?

Testimony of

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before

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Introduction

My name is Raymond Bradley. I am the Head of the Department of Geosciences, and Director of the Climate System Research Center, at the University of Massachusetts, Amherst. My research interests are in climate variations during the last century and how these compare with variations over longer periods. This involves studying both instrumental records of climate, and paleo-records -- natural phenomena that have in some way registered past changes of climate in their structure (for example, tree rings, ice cores, lake sediments, banded corals etc). Using such "proxies" of climate enables the short instrumental record to be extended back in time, so it can be placed in a longer-term perspective. Like other witnesses here, I have served on many national and international committees related to climate variability. Most recently I was Chairman of the Past Global Changes Project of the International Geosphere Biosphere Programme (IGBP-PAGES), a member of the National Research Council Panel on Climate Variability on Decade-to-Century Time Scales, and I have been contributing author to all of the

Intergovernmental Panel on Climate Change (IPCC) scientific assessment activities. I have written or edited 8 books and numerous articles on climatic change.

We are living in unusual times. The climate of the twentieth century climate was dominated by universal warming; almost all parts of the earth had temperatures at the end of the century that were higher than when it began. At the same time, the concentration of greenhouse gases in the atmosphere increased to levels that were higher than at any time in *at least* the last 420,000 years. **These observations are incontrovertible.** Global warming is real and the levels of greenhouse gases (such as carbon dioxide) are now 35-40% higher than they were in the middle of the 19th century. This change in greenhouse gas concentration is largely the result of fossil fuel combustion. What is less certain is whether the observed global warming is due entirely to the build-up of greenhouse gases, or to other "natural" factors, or to a combination of both. Here I provide a longer-term perspective on the issue by focusing on the evolution of climate in the centuries and millennia leading up to the 20^{th} century. Such a perspective encompasses the period before large-scale contamination of the global atmosphere and global-scale changes in land-surface conditions. By studying both the record of past climate variability and factors that may have caused climate to change ("forcing factors"), we can establish how the climate system varied under "natural" conditions, *before* human effects became significant on a global scale. Although there is considerable uncertainty about the rate and magnitude of any future warming which may occur as a result of human activities, one thing is not in dispute: any human-induced changes in climate will be superimposed on a background of natural climatic variations. Hence, in order to understand future climatic changes, it is necessary to have an understanding of how and why climates have varied in the past. Of particular relevance are climatic variations of the last few centuries leading up to the recent warming trends observed in instrumental records.

For most parts of the world, instrumental records of climate rarely span more than a century. We thus have a very limited perspective on climate variability and its relationship to potentially important forcing factors. To obtain a longer perspective requires reliance on climate-dependent natural phenomena that have preserved, in some way, a record of past climate. The most important of these are tree rings, ice cores, banded corals, varved lake and marine sediments, as well as historical records of past weather conditions (see Appendix 1). In recent studies we have assembled the best of these records to produce a global picture of how temperature has changed over the last 1000 years (Figure 1). It is worth noting that it is not sufficient to select one or two records; an extensive network is needed to obtain a global assessment. Just as listening to one instrument would not capture the full beauty of a symphony, so one can not hope to say anything meaningful about global climatic change by using data from only one site.

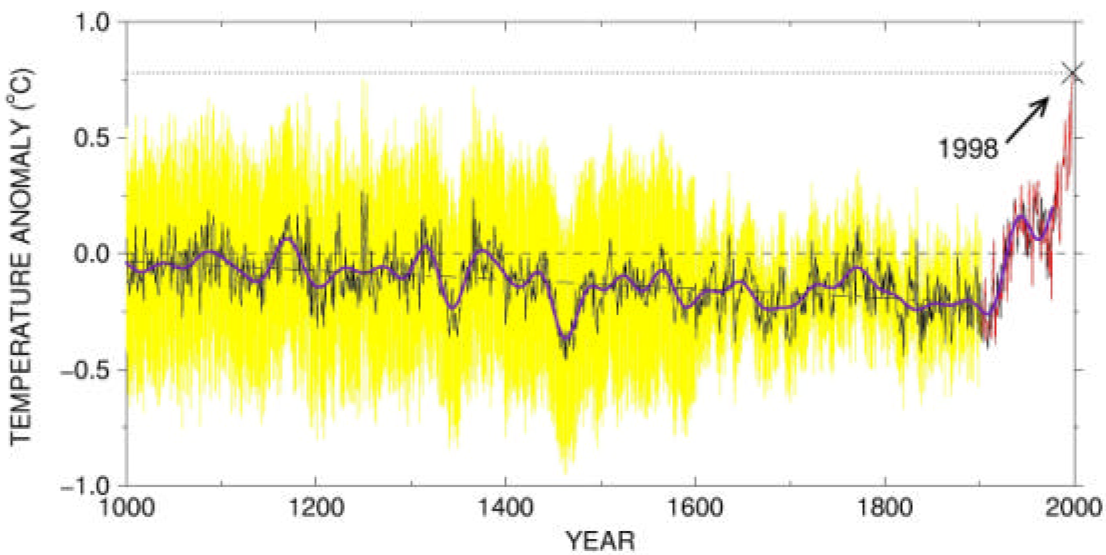

Figure 1. Mean annual temperatures for the northern hemisphere since A.D. 1000. Values are shown as anomalies from the average for 1902-1980 (from M.E. Mann, R.S. Bradley and M.K. Hughes, 1999: *Geophysical Research Letters*, v.26, p.759-762).

In spite of the uncertainties that such a global reconstruction entails, the reconstructed record (of mean annual temperature for the northern hemisphere) shows that temperatures slowly declined over the millennium, with especially cold conditions in the 15th, 17th and 19th centuries. This colder period is generally referred to as the “Little Ice Age”, when glaciers advanced in most mountainous regions of the world. However, the downward trend changed abruptly to a strong warming trend early in the 20th century and *this rate of warming was unprecedented in the last 1000 years*. The warming continued through the 1990s making that decade the warmest in *at least* 1000 years; indeed, 1998 was arguably the warmest year of the millennium, and 1999 was only slightly cooler.

What can this longer perspective on temperature tell us about natural climate variability? By comparing it with the records of factors that may have affected temperature, it is apparent that variations of solar irradiance (the total energy emitted by the sun), major explosive eruptions and perhaps changes in the position of the earth in relation to the sun (slight orbital variations) were responsible for much of the variability of temperatures leading up to the 20th century. However, these “natural” effects were completely overwhelmed in the 20th century by the increasing effect of greenhouse gases. Human effects on climate system variability now appear to dominate over natural factors. If variations in “natural” forcings in the future are similar to those of the last millennium, it is unlikely that they will be of great importance since climatic changes will be mainly affected by anthropogenic (human-induced) increases in greenhouse gases.

What significance does the paleo-record of temperature have for future climate? An important conclusion from our long-term climate studies is that until the second half of the 20th century, temperatures generally remained within 0.5°C (~1°F) of the average for 1902-1980 (the arbitrary baseline we used in our studies). The latest IPCC model-based projections of future climate point to a temperature increase of 0.6 to 2.2°C (~1 to 4°F) above 1990 levels by 2050. Clearly, these estimates have large uncertainties, but it is important to note that even the lowest value would be far beyond the range of temperatures in the last millennium. If these estimates are even close to being correct, we are heading into uncharted waters relative to the climate of the last 1000 years.

Why should we be concerned about global contamination of the atmosphere and future changes in climate? Earlier, I noted that the levels of two important greenhouse gases (carbon dioxide and methane) were now higher than at any time in the last 420,000 years (Figure 2). In fact, this conclusion is based on measurements from the longest ice core record available (from the Russian Vostok station in Antarctica) but it is likely that

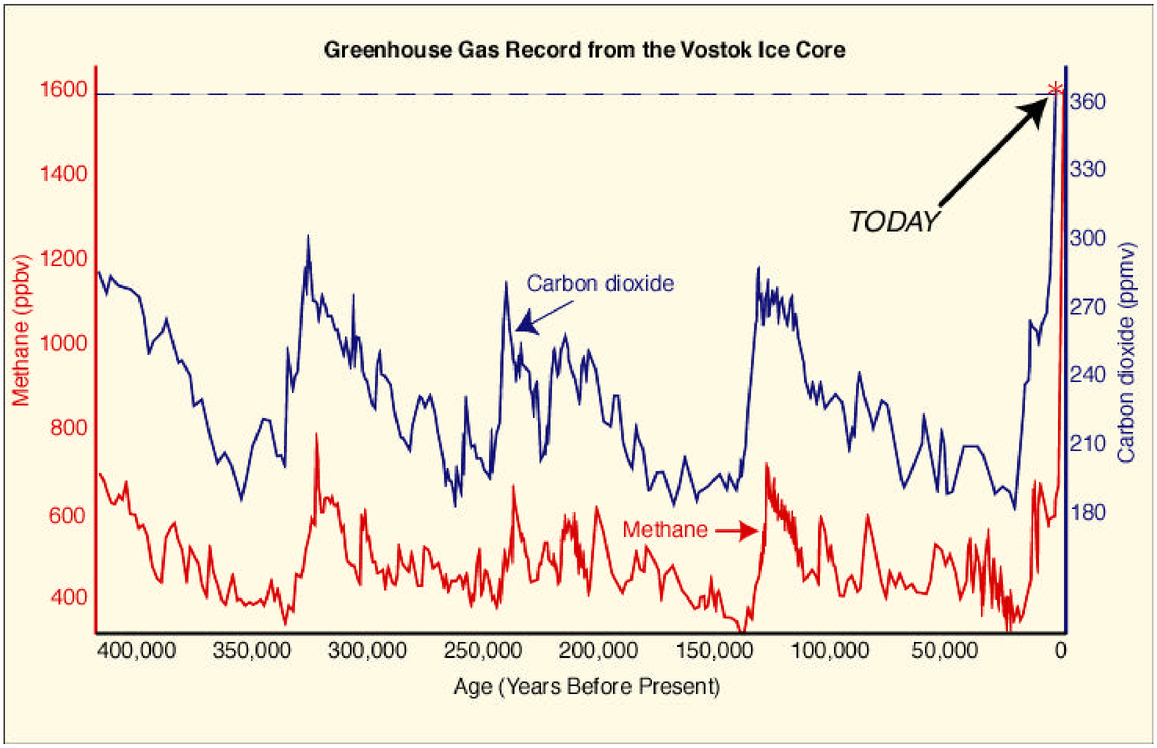

Figure 2. Changes in atmospheric carbon dioxide and methane levels in the atmosphere over the last 420,000 years (from gas bubbles trapped in an ice core, from Vostok, Antarctica)

current levels are higher than at any time for several million years. To put this in perspective, recall that it was only 10,000 years ago that human society first developed agriculture, and 120,000 years ago sabre-toothed tigers roamed what is now Trafalgar Square. Yet carbon dioxide levels have risen from fairly steady background levels (~270ppmv) to present day levels (370ppmv) in a little over a century. This rate of change has no parallel in the historical past, just as temperatures recorded in the late 20th century were unprecedented. Most of the change in CO_2 and other greenhouse gases resulted from the growth of world population and the insatiable demand for fossil fuel-based energy. Given that world population will almost certainly double within the lifetime of those currently in kindergarden, unless something is done to curb the use of fossil fuel consumption, it seems very likely that significant changes in climate will occur in the near future.

Should we be concerned that the climate may change significantly in the future?

Here I have focused exclusively on changes in temperature, but temperature change is only one component of our overall climate system. Changes in temperature are associated with variations in rainfall and the amounts of snow, shifts in storm tracks and hurricanes etc. From the record of past climate, we know that a relatively small overall change in global temperature can have significant environmental effects. The "Little Ice Age" was characterized by dramatic changes in ice cover in mountain regions throughout the world. But historical records from lowland areas of Europe also document more extensive snow cover, longer periods when rivers and lakes were frozen over and frequent cold, wet summers, with disastrous consequences for agriculture, leading to social disruption and political upheavals. Such changes all occurred with an overall change in average hemispheric temperature of less than 1°F. Of course, in trying to anticipate the effects of future climate change, we are looking at the consequences of warmer, not colder conditions but the implication is the same --- even a small shift in average global or hemispheric temperature, with its associated changes in atmospheric circulation, rainfall patterns etc, can be highly disruptive to society. We have seen many examples of such anomalies in recent decades, yet temperatures, though warm, were nowhere near the levels that may be reached later in this century. These include extremes in rainfall, leading to catastrophic flooding in some areas, and droughts, exceptional wildfires and historically low lake levels elsewhere, as well as an increase in windstorms and other weather-related disasters. Unusual weather events are becoming less uncommon, impacting agriculture, transportation and commercial activity. Of course, such disasters have always occurred to some extent, but the frequency of extremes has increased in recent years throughout the world, leading major insurance companies to express grave concerns about their exposure to these unprecedented risks (note that these risks are *in addition* to the costs due to increased development). Munich Re, one of the world's largest re-insurance firms recently reported:

"*1999 fits exactly into the long-term pattern of increasing losses from natural catastrophes…insured losses came to $22bn. This is the second highest figure ever recorded…windstorms were responsible for 80% of the insured losses while earthquakes accounted for 10%, floods 6%, and other events like forest fires, frost, and heat waves* *around 4%…In view of the fact that the signs of climate change and all its related effects are becoming more and more discernible…if…meteorological extremes like torrential rain, windstorms, and heat waves continue to increase and the rise in sea level accelerates, many regions of the world will be in immediate danger…*"

Can we be certain that future climate will involve unprecedented risks? Some argue that processes within the climate system will act to compensate for the effects of higher greenhouse gas levels (so-called negative feedback effects). According to this scenario, these feedbacks will help maintain the climatic *status quo* enabling us to continue to contaminate the atmosphere *ad infinitum*. There is a small chance that such critics are right, in which case it would be safe to do nothing. But they may be completely wrong, and indeed the scientific consensus is that they are wrong. Political decisions inevitably involve assessing risk and weighing the consequences of action versus inaction. Just as Congress must decide if the (perhaps small) risk of a rogue nation launching a nuclear missile at the United States (resulting in a catastrophe) is worth avoiding by spending large sums of money on a space defense system, so it must weigh the potentially catastrophic environmental and commercial consequences of future global warming against the costs of curbing fossil fuel consumption to reduce these risks. Scientists cannot provide Congress with a *certain* forecast of the future and as research on global warming continues, our understanding will undoubtedly change. But the picture at present is that we are indeed living in climatically unusual times, and that the future is likely to be even more unusual.

Appendix 1.

Tree ring data include both ring width and ring density variations. Records are available from all continental areas (except Antarctica) though most series are from outside the tropical regions. High latitude and high altitude trees generally provide estimates of past temperature; trees in dry regions generally provide estimates of past precipitation, though even in wetter areas, records of rainfall changes can sometimes be obtained.

Ice cores provide many records of past climate but changes in oxygen isotopes in the ice, accumulation rate and (summer) melt conditions are of primary interest in examining recent centuries. In polar regions oxygen isotopes are generally considered to be an indicator of annual temperature. Other useful climate indicators include the fraction of a core containing 'melt features' (produced by the re-freezing of percolating surface melt water) which provides a useful index of summer temperature conditions, and accumulation rate changes, which indicate past snowfall amounts.

Corals provide uniquely detailed records of sea-surface temperatures, from changes in the (temperature-dependent) oxygen isotopes in the carbonate skeletons of the corals. In some cases, salinity variation is the most important factor influencing isotope content, in which case the changes reflect precipitation and runoff from adjacent continental regions.

Varved sediments, from both lake and marine environments, are annual layers that record past environmental conditions in the lake or oceanic region. There are few ocean areas where varved sediments are known to occur (generally upwelling coastal regions where there is little oxygen in the deep waters) but varved lake sediments are found on all continents. Providing the records are clearly annual and a strong climatic signal can be demonstrated, these records can provide useful data from many regions of the world.

Historical records can, potentially, provide seasonal estimates of past climate over wide geographic regions, though at present only European and East Asian sources have been adequately studied.

Details of how these and other paleoclimate proxies are used to reconstruct past climates can be found in the book "*Paleoclimatology*" by R.S. Bradley (1999, Academic Press).