The 2001 Assessment of Climate Change

Testimony of

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before

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Introduction

My name is Kevin Trenberth. I am the Head of the Climate Analysis Section at NCAR, the National Center for Atmospheric Research. I am especially interested in global-scale climate dynamics; the observations, processes and modeling of climate changes from interannual to centennial time scales. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards. I served on the National Research Council Panel on *Reconciling observations of global temperature change*, whose report was published in January 2000. I co-chaired the international CLIVAR Scientific Steering Group of the World Climate Research Programme (WCRP) from 1996 to 1999 and I remain a member of that group as well as the Joint Scientific Committee that oversees the WCRP as a whole. CLIVAR is short for Climate Variability and Predictability and it deals with variability from El Niño to global warming. I have been involved in the global warming debate and I have been extensively involved in the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activity as a lead author of individual chapters, the Technical Summary, and Summary for Policy Makers (SPM) of Working Group (WG) I.

The IPCC is a body of scientists from around the world convened by the United Nations jointly under the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) and initiated in 1988. Its mandate is to provide policy makers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate change and the effects of human activities on climate in particular. Major assessments were made in 1990, 1995 and now 2001. Each new IPCC report reviews all the published literature over the previous 5 years or so, and assesses the state of knowledge, while trying to reconcile disparate claims and resolve discrepancies, and document uncertainties.

WG I deals with how the climate has changed and the possible causes. It considers how the climate system responds to various agents of change and our ability to model the processes involved as well as the performance of the whole system. It further seeks to attribute recent changes to the possible various causes, including the human influences, and thus it goes on to make projections for the future. WG II deals with impacts of climate change and options for adaptation to such changes, and WG III deals with options for mitigating and slowing the climate change, including possible policy options. Each WG is made up of participants from the United Nations countries, and for the 2001 assessment, WG I consisted of 123 lead authors, 516 contributors, 21 review editors, and over 700 reviewers. The IPCC process is very open. Two major reviews were carried out in producing the report, and skeptics can and do participate, some as authors. The strength is that the result is a consensus report. The SPM was approved line by line by governments in a major meeting. The rationale is that the scientists determine what can be said, but the governments determine how it can best be said. Negotiations occur over wording to ensure accuracy, balance, clarity of message, and relevance to understanding and policy. The latest report (IPCC 2001) reaffirms in much stronger language that the climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is happening. A summary and commentary is given in Trenberth (2001).

Observed Climate Change

Analyses of observations of surface temperature show that there has been a global mean temperature increase of about 1.2° F over the past one hundred years. The calendar year 1998 is the warmest on record, exceeding the previous record held by 1997. Preliminary annual global mean temperatures in the latest year, 2000, were about the same as for 1999. The 1990s are the warmest decade on record. Synthesis of information from tree rings, corals, ice cores and historical data further indicates that these years are the warmest in at least the past 1000 years for the Northern Hemisphere, which is as far back as annual-resolution hemispheric estimates of temperatures can be made. The melting of glaciers over most of the world and rising sea levels confirm the reality of the global temperature increases. The warming is observed over land and ocean, and over both hemispheres. It is not an urban heat island effect. Further supporting evidence comes from the substantial retreat and thinning of Arctic sea ice, increased temperatures throughout the upper layers of the global oceans, decreases in Northern Hemisphere snow cover and in the freezing season of lakes and rivers.

There is good evidence for decadal changes in the atmospheric circulation and for ocean changes. These mean that increases in temperature are not uniform or monotonic; some places warm more than the average and some places cool. A good example is the past winter, where it was cold and temperatures were well below average in most of the lower 48 states, but Alaska had its warmest winter on record, averaging 9° F above normal. Similarly it was very warm throughout Europe.

Changes in precipitation and other components of the hydrological cycle vary considerably geographically. It is likely that precipitation has increased by perhaps 1%/decade in the 20th Century over most mid and high latitude continents of the Northern Hemisphere. Over the United States, surface temperatures have not risen as much as over Eurasia and instead it has become wetter, with more very heavy events, and this pattern has been shown to be a response to the general warming of the tropical oceans (Hoerling et al. 2001). Changes in climate variability and extremes are beginning to emerge.

One persistent issue has been the discrepancy in trends from the so-called satellite temperature record and that at the surface. The satellite record begins in 1979 and measures microwave radiation from the Earth coming from about the lowest 5 miles of the atmosphere. Consequently it does not measure the same thing as the surface temperature. Climate models run with increasing greenhouse gases suggest that warming in the lower atmosphere should be larger than at the surface whereas the observed record shows much less warming from 1979–1999 and this has been highlighted by skeptics. However, when observed stratospheric ozone depletion is included, the models suggest that the surface and tropospheric temperatures should increase at about the same rate. In fact this is what has happened from about 1960 to the present based on balloon observations that replicate the satellite record after 1979. The shorter satellite record is influenced by El Niño and effects of volcanic eruptions, and thus the Mt. Pinatubo eruption in 1991 leads to a relative downward trend in the lower atmosphere. Other effects, such as from cloudiness changes, have not been quantified but also influence the two records differently. Accordingly, the small trend in the satellite record is not inconsistent with the observed larger trend in surface temperatures (NRC 2000).

Human Influences

The amount of carbon dioxide in the atmosphere has increased by about 31% since the beginning of the industrial revolution, from 280 parts per million by volume (ppm) to 367 ppm, owing mainly to combustion of fossil fuels and the removal of forests. In the absence of controls, future projections are that the rate of increase in carbon dioxide amount may accelerate and concentrations could double from pre-industrial values within the next 50 to 100 years. Several other greenhouse gases are also increasing in concentration in the atmosphere from human activities (especially biomass burning, agriculture, animal husbandry, fossil fuel use and industry, and through creation of landfills and rice paddies). These include methane, nitrous oxide, the chlorofluorocarbons (CFCs) and tropospheric ozone, and they tend to reinforce the changes from increased carbon dioxide. However, the observed decreases in lower stratospheric ozone since the 1970s, caused principally by human-introduced CFCs, contribute to a small cooling.

Human activities also affect the tiny airborne particulates in the atmosphere, called aerosols, which influence climate in other ways. Aerosols occur in the atmosphere from natural causes; for instance, they are blown off the surface of deserts or dry regions. The eruption of Mt. Pinatubo in the Philippines in June 1991 added considerable amounts of aerosol to the stratosphere which, for about two years, led to a loss of radiation at the surface and a cooling. Human activities contribute to aerosol particle formation mainly through injection of sulfur dioxide into the atmosphere (which contributes to acid rain) particularly from power stations, and through biomass burning. A direct effect of resulting sulfate aerosols, which are seen as the milky whitish haze from airplane windows, is the reflection of a fraction of solar radiation back to space, which tends to cool the Earth's surface. Other aerosols (like soot) directly absorb solar radiation leading to local heating of the atmosphere, and some absorb and emit infrared radiation. A further influence of aerosols is that many act as nuclei on which cloud droplets condense, affecting the number and size of droplets in a cloud and hence altering the reflection and the absorption of solar radiation by the cloud. Because man-made aerosols are mostly introduced near the Earth's surface where they can be washed out of the atmosphere by rain, they typically remain in the atmosphere for only a few days and they tend to be concentrated near their sources such as industrial regions. They therefore affect climate with a very strong regional pattern and usually produce cooling. In contrast, the greenhouse gases are not washed out. Their long lifetimes ensure a build up in amounts over time, as is observed to be happening.

The determination of the climatic response to the changes in heating and cooling is complicated by feedbacks. Some of these can amplify the original warming (positive feedback) while others serve to reduce it (negative feedback). If, for instance, the amount of carbon dioxide in the atmosphere were suddenly doubled, but with other things remaining the same, the outgoing long-wave radiation would be reduced and instead trapped in the atmosphere. To restore the radiative balance, the atmosphere must warm up and, in the absence of other changes, the warming at the surface and throughout the troposphere would be about 1.2° C. In reality, many other factors will change, and various feedbacks come into play, so that the best IPCC estimate of the average global warming for doubled carbon dioxide is 2.5° C. In other words, the net effect of the feedbacks is positive and roughly doubles the response otherwise expected. The main positive feedback comes from increases in water vapor with warming.

In 2001, the IPCC gave special attention to this topic. The many issues with water vapor and clouds were addressed at some length in Chapter 7 (of which I was a lead author, along with Professor Richard Lindzen (M.I.T.), and others). Recent possibilities that might nullify global warming (Lindzen 2001) were considered but not accepted because they run counter to the prevailing evidence, and the IPCC (Stocker et al. 2001) concluded that "the balance of evidence favours a positive clear sky water vapour feedback of the magnitude comparable to that found in the simulations."

Increases in greenhouse gases in the atmosphere produce global heating ("global warming") which leads to expectations for increases in global mean temperatures (often mistakenly thought of as global warming), but other changes in weather are also important. In particular, surface heating enhances the evaporation of moisture and thus enhances the hydrological cycle (see Trenberth 1999). Global temperature increases signify that the water-holding capacity of the atmosphere increases and, together with enhanced evaporation, this means that the actual atmospheric moisture should increase, as is observed to be happening in many places. Because water vapor is a powerful greenhouse gas, this provides a positive feedback. It also follows that naturally-occurring droughts are likely to be exacerbated by enhanced drying. Thus droughts, such as those set up by El Niño, are likely to set in quicker, plants wilt sooner, and the droughts may become more extensive and last longer with global warming. Once the land is dry then all the solar radiation goes into raising temperature, bringing on sweltering heat waves. Further, globally there must be an increase in precipitation to balance the enhanced evaporation. The presence of increased moisture in the atmosphere implies stronger moisture flow converging into precipitating weather systems. This leads to the expectation of enhanced rainfall and snowfall events, which are also being observed in many areas. In general, it is observed that where an increase in precipitation occurs, more falls as heavy events, increasing risk of flooding.

Modeling and Attribution of Climate Change

The best climate models encapsulate the current understanding of the physical processes involved in the climate system, the interactions, and the performance of the system as a whole. They have been extensively tested and evaluated using observations. They are exceedingly useful tools for carrying out numerical climate experiments, but they are not perfect, and so have to be used carefully (Trenberth 1997). Key issues in global climate change remain those of firstly detecting whether the recent climate is different than should be expected from natural variability, and secondly attributing the climate changes to various causes, including the human influences. The latest models have increasingly been able to reproduce the climate of the past century or so. Also their estimates of natural variability are compatible with those from the paleoclimate reconstructions. As a result, they can break down the contributions to the warming into components. Increases in solar luminosity probably were responsible for some of the warming from about 1910 to 1950 (perhaps as much as 0.3° F), but the warming of about 0.7° F in the past 30 years can only be accounted for by the increases in greenhouse gases in the atmosphere. Consequently, after much debate in the final plenary, the IPCC (2001) carefully crafted the following: "In the light of new evidence, and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations."

In 1995 the IPCC assessment concluded that "the balance of evidence suggests a discernible human influence on global climate" (IPCC 1996). Since then the evidence has become much stronger — from the recent record warmth, the improved paleo-record that provides context, better understanding of the role of stratospheric ozone depletion, improved modeling and simulation of the past climate, and improved statistical analysis. Thus the headline in IPCC (2001) is "*There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.*" The best assessment of global warming is that the human climate signal emerged from the noise of background variability in the late 1970s.

Biggest impact is likely to be felt by making the extremes more extreme. For any change in mean climate, there is likely to be an amplified change in extremes. The wide range of natural variability associated with day-to-day weather means that we are unlikely to notice most small climate changes except for the extremes. Extremes are exceedingly important to both natural systems and human systems and infrastructure, as we are adapted to a range of natural weather variations, and it is these extremes that exceed tolerances and cause nonlinear effects: the so-called "straw that breaks the camel's back." For instance, floods that used to have an expected return period of 100 years may now recur in 50 or 30 years. In practice, this effect may be experienced in floods through dams or levees that break, inundating the surrounding countryside and urban areas, resulting in loss of life, water damage, and more subtle effects such as polluted drinking waters.

The attribution of the recent climate change to the increases in greenhouse gases in spite of uncertainties related to aerosols has direct implications for the future. Because of the long lifetime of carbon dioxide and the slow penetration and equilibration of the oceans, there is a substantial future commitment to further global climate change even in the absence of further emissions of greenhouse gases into the atmosphere. Future projections of climate change depend on future emissions. They are given by the IPCC and not detailed here. In spite of differences among models and the many uncertainties that exist, the models produce some consistent results. All show considerable warming. All show larger changes over high northern latitudes and the northern continents, including North America, because land warms up faster than the oceans. Further research is needed to understand why the models respond as they do, and to reduce the uncertainties. While some changes arising from global warming are benign or even beneficial, the rate of changes as projected exceed anything seen in nature in the past 10,000 years and are apt to be disruptive in many ways. The economic effects of the weather extremes are substantial and clearly warrant attention in policy debates.

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