TESTIMONY

TESTIMONY OF THOMAS R. KARL, DIRECTOR NATIONAL CLIMATIC DATA CENTER NATIONAL ENVIRONMENTAL SATELLITE DATA AND INFORMATION SERVICES NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION BEFORE THE COMMITTEE ON GOVERNMENTAL AFFAIRS UNITED STATES SENATE

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Good morning, Mr. Chairman and members of the Committee. I am Tom Karl, Director of the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC). The NCDC is the largest archive of weather and climate data in the world and it is one of three data centers operated by NOAA's National Environmental Satellite Data and Information Services line office, within the Department of Commerce. I have been invited to discuss the science of climate change.

The information I present to you today is based on the findings from two assessments, one carried out internationally and one carried out nationally. Specifically, I refer to the 2001 report of the Intergovernmental Panel on Climate Change (IPCC) and the National Academy of Sciences (NAS) June 6, 2001, report, "Climate Change Science: Analysis of Some Key Questions." Over the past three years, I have had the privilege of working with my scientific peers as a Coordinating Lead Author and panel member, respectively, on each of these two recent assessments.

The IPCC assessment took almost three years to prepare and represents the work of hundreds of scientific authors worldwide. It is based on the scientific literature, and was carefully scrutinized by hundreds of scientific peers through an extensive peer review process. The independent NAS report was requested by the current administration, and was a consensus report compiled by an 11-member panel of leading U.S. climate scientists, including a mix of scientists who have been skeptical about some findings of the IPCC and other assessments on climate change. The NAS panel addressed a series of questions posed by the present administration.

First, I want to emphasize two fundamental issues of importance. These have been long-known, are very well understood, and have been deeply underscored in all previous reports and other such scientific summaries.

* *The natural "greenhouse" effect is real, and is an essential component of the planet's climate process.* A small percentage (roughly 2%) of the atmosphere is, and long has been, composed of greenhouse gases (water vapor, carbon dioxide, ozone and methane). These effectively prevent part of the heat radiated by the Earth's surface from otherwise escaping to space. The global system responds to this trapped heat with a climate that is warmer, on the average, than it would be otherwise without the presence of these gases. In the absence of these greenhouse gases the temperature would be too cold to support life as we know it today. Of all the greenhouse gases, water vapor is by far the most dominant, but other gases are more effective at trapping heat energy from certain portions of the electromagnetic spectrum where water vapor is semi-transparent to heat escaping from the Earth's surface.

In addition to the natural greenhouse effect above, there is a change underway in the greenhouse radiation balance, namely:

* *Some greenhouse gases are increasing in the atmosphere because of human activities and increasingly trapping more heat.* Direct atmospheric measurements made over the past 40-plus years have documented the steady growth in the atmospheric abundance of carbon dioxide. In addition to these direct real-time measurements, ice cores have revealed the atmospheric carbon dioxide concentrations of the distant past. Measurements using air bubbles trapped within layers of accumulating snow show that atmospheric carbon dioxide has increased by more than 30% over the Industrial Era (since 1750), compared to the relatively constant abundance that it had over the preceding 750 years of the past millennium. The predominant cause of this increase in carbon dioxide is the combustion of fossil fuels and the burning of forests. Further, methane abundance has doubled over the Industrial Era, but its

increase has slowed over the recent decade for reasons not clearly understood. Other heat-trapping gases are also increasing as a result of human activities. We are unable to state with certainty the exact rate at which these gases will continue to increase because of uncertainties in future emissions as well as how these emissions will be taken up by the atmosphere, land, and oceans. We are certain, however, that once in the atmosphere these greenhouse gases have a relatively long life-time, in the order of decades to centuries. This means they become well mixed throughout the globe.

**The increase in heat-trapping greenhouse gases due to human activities are projected to be amplified by feedback effects, such as changes in water vapor, snow cover, and sea ice.* As atmospheric concentrations of carbon dioxide and other greenhouse gases increase, the resulting increase in surface temperature leads to less sea ice and snow cover helping to raise temperatures even further. As snow and sea ice decrease, more of the Sun’s energy is absorbed by the planet instead of being reflected back to space by the underlying snow and sea ice cover. Present evidence also suggests that as greenhouse gases increase, evaporation increases leading to more atmospheric water vapor. Additional water vapor acts as a very important feedback to further increase temperature. Our present understanding suggests that these feedback effects account for about 60% of the warming. The magnitude of these feedback effects and others, such as changes in clouds, remain a significant source of uncertainty related to our understanding of the impact of increasing greenhouse gases. Increases in evaporation and water vapor affect global climate in other ways besides increasing temperature such as increasing rainfall and snowfall rates.

The increase in greenhouse gas concentrations in the atmosphere implies a positive radiative forcing, i.e., a tendency to warm the climate system.

**Particles (or aerosols) in the atmosphere resulting from human activities can also affect climate.* Aerosols vary considerably by region. Some aerosol types act in a sense opposite to the greenhouse gases and cause a negative forcing or cooling of the climate system (e.g., sulfate aerosol), while others act in the same sense and warm the climate (e.g., soot). In contrast to the long-lived nature of carbon dioxide (centuries), aerosols are short-lived and removed from the lower atmosphere relatively quickly (within a few days). Therefore, human generated aerosols exert a long-term forcing on climate only because their emissions continue each day of the year. Aerosol effects on climate can be manifested directly by their ability to reflect and trap heat, but they can also have an indirect effect by changing the lifetime of clouds and changing their reflectivity to sunshine. The magnitude of the negative forcing of the indirect effect of aerosols is highly uncertain, but may be larger than the direct effect of aerosols.

Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate. There are also natural factors which exert a forcing on climate, e.g., changes in the Sun's energy output and short-lived (about 1 to 2 years) aerosols in the stratosphere following episodic and explosive volcanic eruptions. The forcing estimates in the case of the greenhouse gases are greater than for these two other forcing agents.

What do these changes in the forcing agents mean for changes in the climate system? What climate changes have been observed? How well are the causes of those changes understood? Namely, what are changes due to natural factors, and what are changes due to the greenhouse-gas increases? Is there a safe level of greenhouse gas concentrations? And, what does this potentially imply about the climate of the future? These questions bear directly on our understanding of the science of climate change.

* *There is a growing set of observations that yields a collective picture of a warming world over the past century.* The global-average surface temperature has increased over the 20th Century by 0.4 to 0.8° C (0.7 to 1.4°F). This occurred both over land and the oceans. The average temperature increase in the Northern Hemisphere over the 20th Century is likely to have been the largest of any century during the past 1,000 years, based on "proxy" data (and their uncertainties) from tree rings, corals, ice cores, and historical records. The 1990s are likely to have been the warmest decade and 1998 the warmest year of the past 1000 years. Other observed changes are consistent with this warming. There has been a widespread retreat of mountain glaciers in non-polar regions. Snow cover, sea ice extent and sea ice thickness, and the duration of ice on lakes and rivers have all decreased. Ocean heat content has increased significantly since the late 1940s, the earliest time when we

have adequate computer compatible records. The global-average sea level has risen between 10 to 20 centimeters (4 to 8 inches), which is consistent with a warmer ocean occupying more space because of the thermal expansion of sea water and loss of land ice.

**It is likely that the frequency of heavy and extreme precipitation events has increased as global temperatures have risen.* This is particularly evident in areas where precipitation has increased, primarily in the mid and high latitudes of the Northern Hemisphere. Other extremes have decreased such as the frequency of extremely cold weather and the frequency of frost during the period of the instrumental record , e.g., 50 to 200 years depending on location.

* *There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.* The 1995 IPCC climate-science assessment report concluded: "The balance of evidence suggests a discernible human influence on global climate." There is now a longer and more closely scrutinized observed temperature record. Climate models have evolved and improved significantly since the previous assessment. Although many of the sources of uncertainty identified in 1995 still remain to some degree, new evidence, longer and more precise data sets, and improved understanding support the updated conclusion. Namely, recent analyses have compared the surface temperatures measured over the last 1000, 140, and 50 years to those simulated by mathematical models of the climate system, thereby evaluating the degree to which human influences can be detected. Both natural climate-change agents (solar variation and episodic, explosive volcanic eruptions) and human-related agents (greenhouse gases and aerosols) were included. The natural climate-change agents alone do not explain the warming.

* *Scenarios of future human activities indicate continued changes in atmospheric composition throughout the 21st century.* The atmospheric abundances of greenhouse gases and aerosols over the next 100 years cannot be predicted with high confidence, since the future emissions of these species will depend on many diverse factors, e.g., world population, economies, technologies, and human choices, which are not uniquely specifiable. Rather, the IPCC assessment aimed at establishing a set of scenarios of greenhouse gas and aerosol abundances, with each based on a picture of what the world

plausibly could be over the 21st Century. Based on these scenarios and the estimated uncertainties in climate models, e.g., feedback effects, the resulting projection for the global average temperature increase by the year 2100 ranges from 1.3 to 5.6° C (2.3°to10.1°F). Approximately half of the uncertainty in this range is due to model uncertainties related to feedback effects and half is due to different scenarios of future emissions. Regardless of these uncertainties, such a projected rate of warming would be much larger than the observed 20th Century changes and would very likely be without precedent during at least the last 10,000 years. The corresponding projected increase in global sea level by the end of this century ranges from 9 to 88 centimeters (4 to 35 inches). Uncertainties in the understanding of some climate processes make it more difficult to project meaningfully the corresponding changes in regional climate. Future climate change will, of course, depend on the technological developments that enable reductions of greenhouse gas emissions.

There is a basic scientific aspect that has been underscored with very high confidence in all of the IPCC climate-science assessment reports (1990, 1995, and 2001). It is repeated here because it is a key (perhaps "the" key) aspect of a greenhouse-gas-induced climate change:

* *A greenhouse-gas warming could be reversed only very slowly.* This quasi-irreversibility arises because of the slow rate of removal (centuries) from the atmosphere of many of the greenhouse gases and because of the slow response of the oceans to thermal changes. For example, several centuries after carbon dioxide emissions occur, about a quarter of the increase in the atmospheric concentrations caused by these emissions is projected to still be in the atmosphere. Additionally, global average temperature increases and rising sea levels are projected to continue for hundreds of years after a stabilization of greenhouse gas concentrations (including a stabilization at today's abundances), owing to the long time scales (decades to centuries) on which the deep ocean adjusts to climate change. Because of its large specific heat capacity and mass, the world ocean can store large amounts of heat and remove this heat from direct contact with the atmosphere for long periods of time.

**It is presently not possible to generally define a safe level of greenhouse gases.* This issue was specifically addressed in the recent NAS study. There are several difficulties related to answering this question. First, as I have indicated, there are still large uncertainties related to the projected rate and magnitude of climate change. The determination of an acceptable concentration of greenhouse gases depends on knowing this as well as knowledge of the risks and vulnerabilities to climate change. A range of climate sensitivities and emission scenarios could be used to explore sensitivities to climate change. A first attempt was reported in the National Climate Assessment and the recent IPCC report. Analyses reveal that sectors and regions vary in their sensitivity to climate change, but generally those societies and systems least able to adapt and those regions with the largest changes are at greatest risk. This includes the poorer nations and sectors of our society, natural ecosystems, and those regions likely to see the largest changes. For example, on average, the largest increases of temperature and relative changes in precipitation projected by all models are in the mid to high latitudes of the Northern Hemisphere. Clearly, as the rate and magnitude of climate change increases, the risk of exceeding a safe level of greenhouse gases also increases. This includes the possibility of surprises. As greenhouse gases continue to increase there is an ever increasing, but still very small chance, that the climate system could respond in an unpredictable fashion. Examples include a shut-down of the transport of heat in the North Atlantic Ocean thermohaline circulation which could lead to large regional climate anomalies, melting of the Greenland Ice Sheet or the Antarctic Ice Shelf, substantial increases in hurricane intensity, and other possibilities. None of these changes are foreseen at present, but we cannot absolutely dismiss the possibility of a surprisingly large and rapid change in climate.

**Because there is considerable uncertainty in current understanding of how the natural variability of the climate system reacts to emissions of greenhouse gases and aerosols, current estimates of the magnitude and impacts of future warming are subject to future adjustments (either upward or downward)*. Nonetheless, it is noteworthy that our best estimates of climate sensitivity to greenhouse gases have essentially remained unchanged over the past three decades, since the first National Academy of Sciences report on this topic back in the 1960s. In addition to the uncertainty related to the rate and magnitude of climate change, there is considerable uncertainty related to quantifying the impact of climate change on natural and human systems.

**To address these uncertainties, several areas of study have been identified in the assessments*. Because understanding the climate system and its impacts is so complex, progress will be hindered by the weakest link in the chain. At the present time, there are several weak links that need to be addressed. First and foremost a climate observing system is needed to monitor long-term change for basic variables needed to describe the climate system. Current observing systems yield uncertainties in several key parameters, especially on regional and local space scales. Although we have been able to link observed changes to human activities, it is not possible to quantitatively identify the specific contribution of each forcing factor, which is required for the most effective strategy to prevent large or rapid climate change.

To address these uncertainties, the President has directed the Cabinet-level review of U.S. climate change policy. Based on the Cabinet's initial findings, the President in his June 11 remarks committed his Administration to invest in climate science. He announced the establishment of the U.S. Climate Change Research Initiative to study areas of uncertainty and to identify areas where investments are critical. He directed the "Secretary of Commerce, working with other agencies, to set priorities for additional investments in climate change research, review such investments, and to provide coordination amongst federal agencies. We will fully fund high-priority areas for climate change science over the next five years. We'll also provide resources to build climate observation systems in developing countries and encourage other developed nations to match our American commitment."

I would like to underscore that we will use the descriptions of the uncertainties identified in the NAS report as the basis for development of U.S. research in climate. Cited areas of uncertainty include:

- Feedbacks in the climate system that determine the magnitude and rate of temperature increases and related precipitation changes
- Future usage of fossil fuels
- Carbon sequestration on land and in the ocean

- Details of regional climate change
- Natural climate variability and the interaction of these modes with other climate forcings including greenhouse gases and the direct and indirect effects of aerosols

Finally, we have found that no matter how good our understanding of future climate change might be, we ultimately must understand how this will impact natural and human systems. To achieve this understanding will require (a) interdisciplinary research that couples physical, chemical, biological, and human systems, (b) improved capability to integrate scientific knowledge, including its uncertainty, into effective decision support systems, and (c) a better understanding of the impact of multiple stresses on both human and natural systems at the regional and sectoral level.

I look forward to continuing to work with you on these issues. Thank you again for the invitation to appear today. I hope that this summary has been useful. I would be happy to address any questions.

Assessments Cited:

Committee on the Science of Climate Change. Climate Change Science: An Analysis of Some Key Questions. National Academy Press: Washington, D.C. 2001. 28 pp.

Summary for Policy Makers, Climate Change 2001: The Scientific Basis. Summary for Policymakers and Technical Summary of the Working Group I Report. Cambridge University Press, 98pp. Also available at http://www.ipcc.ch.

The full report will be available later this summer.

Parallel IPCC reports:

Climate Change 2001: Impacts, Adaptation and Vulnerability - Contribution of Working Group II to the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report.

Climate Change 2001: Mitigation -

Contribution of Working Group III to the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report.

IPCC, 2000: IPCC Special Report on Emissions Scenarios. Cambridge University Press.