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GLOBAL WARMING

Limitations of General Circulation Models

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Mr. Chairman and Members of the Subcommittee:

We appreciate the opportunity to appear before the Subcommittee as you focus on issues concerning the use of climate change models. Over the past century, human activity has increasingly emitted heat-trapping greenhouse gases, such as carbon dioxide, into our earth's atmosphere. As these emissions have grown, so too has concern over how they will affect our climate in years to come. Temperature increases could begin to melt the polar ice caps, raise the sea level, and alter patterns of precipitation. These effects could lead to serious consequences such as severe flooding. On the other hand, actions to reduce greenhouse gas emissions in order to avoid potential catastrophic effects of global warming could have significant economic consequences, and must be based on a sound understanding of the issues.

One such major issue that should be considered when discussing the implications of global warming and the appropriate actions to control greenhouse gas emissions, is the range of projected temperature increases and the degree of uncertainty in these estimates. In July of this year, we reported on the limitations of general circulation computer models used to make such predictions.[1] These sophisticated computer models consist of complex mathematical equations that represent various climatic processes and interrelationships among variables, such as seasonal changes in sunlight and global air currents. Our testimony today is based on our July 1995 report.

In general, we found that general circulation models are better now than they were a decade ago at predicting future climate changes. Nevertheless, the accuracy of the models' estimates is still limited. Specifically, we reported that:

-- For general circulation models, as for other computer models, the quality of the output depends upon the quality of the input--the models are only as good as the data and scientists' understanding of how the climate system works. One limiting factor is that the models currently provide only incomplete or inaccurate representation of some of the processes, such as cloud formation, affecting climate because scientists do not fully understand how the climate system responds to these processes. As a result, models can produce different projections of future climatic conditions, such as global temperature.

-- A second major limiting factor is insufficient computing power to process the vast quantities of data required to more accurately simulate changes in the global climate.

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[1]Global Warming: Limitations of General Circulation Models and Costs of Modeling Efforts (GAO/RCED-95-164, Jul. 13, 1995).

Modelers try to overcome this limitation by introducing assumptions that deliberately simplify some operations in order to free computer time for other, more critical operations. These simplifications can affect the accuracy of the models' estimates.

-- To improve the accuracy of general circulation models' estimates, scientists are developing models that better incorporate the processes affecting the climate system and that better reflect the interactions between or among the ocean and the atmosphere. They are also developing larger and faster computers that could process data for smaller areas. Given the complexity of the climate processes that need to be incorporated in the models, scientists believe that significant reductions of the uncertainties in projecting changes and trends in the climate will require sustained efforts that are very likely to require a decade or more.

BACKGROUND

General circulation models are the most highly developed tools available to help understand the global climate system's response to greenhouse gas emissions. Scientists use three types of general circulation models to predict climatic change: atmospheric, oceanic, and coupled. In general, atmospheric models predict the physical behavior of the atmosphere. Oceanic models represent the physics of the ocean. Coupled models, which scientists regard as the most advanced type of model, physically join the atmospheric and oceanic models. In the United States, the development of general circulation models is supported through the coordinated efforts of the U.S. Global Change Research Program and five federal agencies.[2]

During the Forum on Global Climate Change Modeling, held in October 1994, scientists agreed that the buildup of greenhouse gases is creating an enhanced greenhouse effect that will lead to global warming.[3] They estimated that the surface temperature of the earth will rise by 1 to 3.5 degrees Fahrenheit from 1990 to 2050 if emissions continue to grow without restriction. More

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[2]These five agencies are the Department of Energy, the National Aeronautics and Space Administration, the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Environmental Protection Agency.

[3]The purpose of the Forum, convened to respond to GAO and White House Office of Science and Technology Policy questions, was to produce a consensus document on issues concerning the use of climate models and to provide policymakers with information on future climatic changes.

recently, the International Panel on Climate Change reported that human activities are increasing the atmospheric concentration of greenhouse gases and that this increase will raise the global mean temperature between 1.8 and 6.3 degrees Fahrenheit by 2100.[4]

FACTORS LIMITING THE ACCURACY OF MODELS' ESTIMATES

General circulation models' estimates of future climatic changes are considerably better than they were a decade ago. The models have demonstrated skill in simulating many aspects of the observed climate, providing useful indications of future climatic conditions. For example, atmospheric models have demonstrated some skill in portraying aspects of atmospheric variability, such as the surface temperature of the sea. Oceanic models have simulated the general circulation of the ocean, including the patterns of principal currents. Coupled models, though still prone to small-scale errors, have simulated the current climate on a large scale as well as portrayed atmospheric and oceanic behavior over large regions.

Though much progress has been made, the models remain limited in their ability to estimate, with desired accuracy, the magnitude, timing, and regional distribution of future climatic changes. These limitations stem from scientists' imperfect understanding of the climate system and computers' insufficient capacity to perform the detailed calculations needed to make more precise estimates.

Incomplete or Inadequate Representation of Processes Affecting Climate

According to the U.S. Global Change Research Program, general circulation models include the most important processes--such as radiation, convection, and water vapor--that affect the climate. However, the extent to which they incorporate and accurately represent these processes and their interactions varies and can affect the accuracy of the models' estimates. For example, some climate processes are not included or fully incorporated, even in the more advanced coupled models. And for some of the more important climate processes and interactions that are included in models, their representation is less than adequate primarily because scientists do not fully understand the climate system.

Atmospheric and oceanic models include fewer processes than coupled models where the oceans and the atmosphere meet, such as oceanic pressures, climatic fluctuations, and the effects of winds

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[4]The International Panel on Climate Change was established in 1988 by the United Nations Environment Programme and the World Meteorological Organization to assess scientific and technical information about climatic change.

at the surface of the oceans. Consequently, these models' simulations are more limited and, in some cases, less accurate. For example, a 1991 test of atmospheric models produced systematic errors in the projections of sea level pressure, temperature, wind, and precipitation.

Coupled models more accurately simulate current climatic conditions than either atmospheric or oceanic models, but their estimates of temperatures and precipitation still deviate from actual conditions. For example, in an experiment conducted by the National Center for Atmospheric Research, the models' estimated wintertime ocean temperatures were 7 degrees warmer than observed temperatures for the icebound region of Antarctica and 9 degrees colder than observed temperatures for the tropics. Scientists believe that the deviations stem from gaps in their understanding of the interactions between atmospheric and oceanic variables.

Although today's general circulation models include many of the most important feedback mechanisms (e.g., water vapor and clouds) they do not yet adequately represent the interactions of these mechanisms with greenhouse gases. Such interactions can amplify, dampen, or stabilize the warming produced by increased concentrations of greenhouse gases. Modelers do not fully understand the effects of feedback mechanisms and have not learned how to represent them with sufficient accuracy. Modelers have clarified the role of water vapor and improved their ability to model its effects. However, they are still seeking to understand and accurately model the effects of clouds, which have the greatest potential of all feedback mechanisms to amplify or moderate global warming.

Insufficient Computing Power

The accuracy of general circulation model estimates are further limited by computers' insufficient capacity to store and analyze the vast quantity of data required to accurately simulate global climate changes on a regional scale. In an effort to overcome these limitations, modelers introduce assumptions into their models that deliberately simplify some operations in order to free the models' capacity and time for other, more critical operations.

One such simplification used in certain models, referred to as the cold start error, assumes that the oceans did not absorb greenhouse gas emissions before 1985. As a result, these models do not adequately account for the oceans' reduced capacity to absorb these emissions in the future. In fact, the oceans will reach their capacity possibly decades sooner than the models have predicted. They will then deflect more of the heat-trapping emissions to the atmosphere, thereby enhancing global warming more rapidly than the models predict. Scientists estimate that cold start error causes models to underestimate temperature changes,

resulting in projections of average annual temperatures that differ by as much as 0.7 degrees after 50 years. Months of additional computer time would be required to address just this one existing limitation.

Another simplification that modelers use to deal with insufficient computer capacity is to divide the earth into large segments, or grids, for analytical purposes. Although the grids, which cover an area about the size of South Carolina, enable the models to depict large-scale regional effects in relatively large, homogeneous regions, they do not allow modelers to incorporate detailed regional features to forecast climatic changes for smaller, less homogeneous regions.

Improving Models' Estimates

A number of efforts are under way to improve the accuracy of general circulation models' estimates. Scientists are working to develop models that incorporate more of the processes affecting the climate system--particularly cloud formation processes--and to better reflect interactions among various components of the climate system, including interactions between or among the ocean and the atmosphere. Scientists are also developing larger and faster computers to manipulate data for longer periods of time and to better understand regional effects resulting from using smaller grids. In addition, they are collecting more data and conducting more research on the processes affecting climate and improving the international exchange of such data. Various international programs, such as the World Climate Research Programme[5] and the Global Climate Observing System[6], also currently have research programs under way to improve the accuracy of the models' estimates.

CONCLUSIONS

Although the accuracy of general circulation models has improved over the past decade, these models are still limited by incomplete and inaccurate representations of the processes affecting climate and by insufficient computing power. While these limitations do not change the likelihood that the climate will change in response to increased greenhouse gas emissions, they do

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[5]This program was established as a joint undertaking of the International Council of Scientific Unions and the World Meteorological Organization, to foster an improved understanding of the climate's variability and predictability.

[6]This international organization was established in 1992 to monitor climatic changes and obtain data for application to national economic development.

limit the ability to predict with certainty how the climate will respond--how much warming will occur, how soon it will happen, and what regional impacts will occur. Efforts are under way to collect and analyze data, improve representations of various climatic processes, and develop and use more powerful computers. These efforts, which are anticipated to take a decade or more, should improve the accuracy of the models.

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Mr. Chairman, this concludes my prepared statement. We will be pleased to respond to any questions you or other Members of the Subcommittee may have.

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