Climate Change: State of the Science and Implications for Policy

Ronald G. Prinn
Massachusetts Institute of Technology

Tuesday, October 7, 1997

Testimony to the Subcommittee on Energy and Environment of the Committee on Science
U.S. House of Representatives
The Honorable Ken Calvert, Chairman

Honorable Chairman and Members of the House Subcommittee on Energy and Environment, I respectfully submit the following testimony in response to your invitation of September 25, 1997.

I have been on the faculty of the Massachusetts Institute of Technology since 1971. While I specialize in atmospheric science, in my capacity as Director of the MIT Center for Global Change Science and Co-Director of the MIT Joint Program on the Science and Policy of Global Change, I have also gained some appreciation of the various disciplines in the natural and social sciences involved in the climate debate, and carried out research aimed toward better understanding of interactions between the natural and human systems which affect climate.

I want to address here a few specific points. First, I will briefly say something about the definition of climate, the reality of the greenhouse effect, and how reliable the forecasts of future climate are. Second, I will look at why the detection of the human influence on climate is so difficult, but also so important to both the science and policy of the issue. Third, I will address certain areas of the scientific research which I think are especially important for informing policymaking. Finally, I will argue that because the science is both uncertain and evolving, scientists should be in much closer contact with the policy development process than they are at present.

I want to say right up front that current predictions of future climate are very uncertain: forecasts of quite slow or quite rapid warming can both be defended as plausible. But this uncertainty is not a sound argument for waiting for more knowledge before taking some action. The long-lived greenhouse gases emitted today will last for decades to centuries in the atmosphere and scientists cannot presently rule out the rapid warming forecasts. Our policy response needs to be carefully measured, however. To quote a metaphor from a recent report by my colleagues and me[1], "It would be irresponsible to ignore such a risk, just as it would be irresponsible to do nothing when you smell smoke at home until and unless you see flames. It would also be irresponsible, of course, to call the fire department and hose down all your belongings at the slightest whiff of what might be smoke".

Climate and the Greenhouse Effect

What do we mean by the word climate? Climate is usefully defined as the average of the weather we experience over a ten- or twenty-year time period. Long-term temperature and rainfall changes are typical measures of climate change, and these changes can be expressed at the local, regional, country, or global scale. When the global average temperature changes we call that global warming or cooling.

What produces global warming or cooling? Fundamentally, it can be driven by any imbalance between the energy the Earth receives, largely as visible light, from the sun, and the energy it radiates back to space as invisible infrared radiation. The greenhouse effect is a warming influence caused by the presence in the air of gases and clouds which are very efficient absorbers and radiators of this infrared radiation. The greenhouse effect is opposed by substances at the surface (such as snow and desert sand) and in the atmosphere (such as clouds and aerosols[2]) which efficiently reflect sunlight back into space and are thus a cooling influence.

Easily the most important greenhouse gas is water vapor which typically remains for a week or so in the atmosphere. Water vapor and clouds are handled internally, although with significant uncertainty, in climate models. Concerns about global warming, however, revolve around less important but much longer-lived greenhouse gases, especially carbon dioxide. The concentrations of carbon dioxide and some other long-lived gases (methane, nitrous oxide, chlorofluorocarbons, lower atmospheric ozone) have increased substantially over the past two centuries due at least in part to human activity. When the concentration of a greenhouse gas increases (with no other changes occurring) it temporarily lowers the flow of infrared energy to space and increases the flow of infrared energy down toward the surface. The Earth is then temporarily receiving more energy, for example 1% more, than it radiates to space. This small imbalance, which is often called “radiative forcing”, tends to raise temperatures at the surface and in the lower atmosphere. The rate of surface temperature rise is slowed significantly by the uptake of heat by the world’s oceans. The greenhouse effect as quantified by this radiative forcing is real and the physics relatively well understood. What is much more uncertain, and the cause of much of the scientific debate, is the complex system that determines the response of our climate to this radiative forcing. Feedbacks in this system can either amplify or dampen the response in ways which are only partially understood at present.

How Good Are The Climate Forecasts?

Much of the climate change debate is driven by forecasts of significant warming over the next century. The computer models used to make these forecasts attempt to simulate the behavior of clouds, water vapor, ocean circulation, and many other essential climate processes on the regional and global scale. These models are remarkable in their complexity and are invaluable tools for scientific research. However, many critical small-scale features like clouds are not resolved individually in these models because the computational demands involved in these simulations already tax the capabilities of the world’s largest computers. But even more fundamental is our incomplete knowledge about the physical, chemical, or biological processes that control these clouds, the ocean circulation, the natural cycles of greenhouse gases, and natural and manmade aerosols.2 Current climate models cannot simulate realistically the remarkable natural climate changes exemplified by the succession of ice ages and warm periods over the last 250,000 years. There may even be fundamental limitations to our ability to predict climate due to chaotic processes such as we already see in weather predictions. As a result, forecasts of future climate changes due to future emissions of greenhouse gases are very uncertain. The uncertainty in these forecasts is increased even further because the predictions of future emissions of greenhouse gases are dependent on equally uncertain global forecasts of populations, economies, and energy technologies.

There is surely no doubt that our present understanding of climate and ability to predict climate are inadequate to provide a sharp focus for policymaking. We need to find out what key processes determine natural variability, and if there are limits to climate prediction like those that exist for weather prediction. I feel strongly that ongoing efforts need to be accelerated. But we have become too dependent on just a few of the needed complex climate models, located mainly at National Laboratories and Centers. I argue that the full intellectual strength of the nation's universities needs to be brought into the area of such climate modeling. With the recent rapid advances in computers it is now possible for individual universities to make major contributions to reducing current uncertainties. However, they lack the relatively modest resources to do so.

To shed more light on the current substantial uncertainty in forecasts, we have recently developed at MIT a coupled model of global economic development, climate processes, and ecosystems.[3] This model is unique in its combination of coverage of critical areas and level of scientific and economic detail. Within this model we have made some plausible but differing assumptions about future human activity, and about fundamental climate processes, to produce a family of seven forecasts of various climate indicators. Each forecast in the family can be defended as reasonable given current knowledge, and each forecast assumes no explicit regulations are enacted to restrict future greenhouse gas emissions.

The accompanying graph shows the predictions for the change in global average surface temperature from its 1990 value.3 Evidently, by the year 2100, forecasted temperature changes as small as two degrees or as large as nine degrees Fahrenheit (one to five degrees Centigrade) can be defended. About two thirds of the overall range in the seven forecasts are due to differing assumptions affecting climate and the other one third to assumptions affecting emissions. What is very important to realize from the graph is that we do not know which of these paths (or indeed other plausible paths) we are heading along in the absence of regulation. If we are on the lowest warming path, the impacts are likely to be relatively small. If we are on the highest warming path, the impacts and resultant concern are likely to be very large, and there are compelling reasons therefore to take very significant action to avoid this path. I emphasize also that there may be significant changes in climate over the next hundred years driven by purely natural processes not well handled by this or any other current climate model. In this case the whole family of forecasts in the figure may be invalidated.

What Path Are We On?

How can we determine which path, absent regulations, that we are really on? Obviously, further research focusing on testing and improving the climate and emissions forecast models should help to narrow the range in these forecasts. The difficulties here for climate models include the need for more observations and better understanding of the roles of oceans, aerosols, and clouds, and of chaos and other processes limiting predictability. But another, not unrelated, approach is to determine definitively whether human activity has already begun to substantially change climate. To this end, in 1996, the Intergovernmental Panel on Climate Change (IPCC) declared in its Summary for Policymakers that “the balance of evidence suggests a discernible human influence on climate”.[4] There were qualifications and hedging in the Summary and much more so in the Working Group Report upon which it was based. Nevertheless this statement, largely in isolation, became widely reported and began to influence policy discussions around the world. But was this isolated, unqualified summary statement a scientifically defensible conclusion?

Human influence is indicated if the observed global patterns of climate change over the past 100 years are shown to be consistent with those predicted by climate models which include the human influences, but not consistent with the patterns predicted when the human influences are neglected. The predictions which neglect human influence are taken as a measure of the natural variability of climate and are thus used to represent the “noise” out of which the human-caused “signal” must arise for a definitive detection. Herein lies a major problem. The imperfections of current climate models make them both inadequate tools for defining natural variability and uncertain predictors of the climate response to human forcing. There are other difficulties associated with the inadequacies in climate observations and poor knowledge of past levels of aerosols and their quantitative effects on sunlight reflection.

For these and other reasons, there were a few scientists who were skeptical about the IPCC’s “balance of evidence” statement from the beginning. But now there are a growing number of scientists, including some who were involved significantly in the original IPCC conclusions, who are expressing doubts. A recent important editorial on this subject describes the growing unease about the original IPCC Summary conclusion, and the growing realization that it may be a decade or more before the human effects can be discerned above the noise of natural variability.[5] I would describe the current view of experienced climate scientists on this issue as “equivocal”.

How Can Scientists Help Policy Development?

The needed policy response is uncertain because the science is uncertain. How can scientists help better in the evolving policy process? First, the search for a definitive signal of human influence should be one important goal for scientists in the upcoming years and decades, in order to inform policy. To illustrate this in a simplified way, I refer again to the graph of predicted temperature changes. The shaded region at the bottom of the graph is intended to represent the albeit uncertain range of natural variability or noise.1 Evidently, the greater the predicted warming, the sooner the signal of the human effects emerges from this noise. This conclusion holds irrespective of the uncertainty in defining the noise level itself. Achievement of a detection therefore helps to calibrate both the climate response to changes in human-induced radiative forcing, and the needed level of policy response.

Another calibration for policy response is provided by estimation of the climate changes avoided by enacting specific regulations. To do this very well, requires significant improvements in the climate forecasts as noted earlier. To illustrate this point, the MIT model has been used to examine one sample proposal in which the 20 rich OECD countries return their carbon dioxide emissions to 1990 levels by the year 2000, then bring their emissions down to 20% below 1990 by 2010, and finally hold them at this level thereafter.[6] There are no restrictions on any of the countries outside the OECD. The predicted temperature increases are reduced by only about 15% relative to the no-policy forecasts shown in the earlier graph. This analysis makes it clear that if we are heading along one of the rapid warming roads, the needed emissions reductions to avoid this path will need to be substantially greater even than those proposed in the above policy. Indeed, very substantial reductions will require ultimate participation by all nations, not just the currently rich countries.1 Another important point that arises from analyses like these is that the predicted warming in 2100 is sensitive to the total emissions up to that time but relatively insensitive to the temporal pattern of the emissions. Hence higher emissions in the near term can potentially be off set by lower emissions later on (and vice versa).7 This provides potential breathing time, but we need to use it very wisely.

The policy response can be further calibrated by quantifying the expected impacts of climate change on natural and human systems. Here the research is much less mature but there is clearly a serious need to better understand and quantify these effects. Some of these effects, specifically impacts on human health, agriculture, forestry, water supply and quality, and flood-prone coastal and riverine settlements, can be potentially mitigated or avoided by adaptation. Other potentially impacted regions, specifically natural terrestrial, coastal, and oceanic ecosystems, may not be able to adapt. Hence we certainly need many more observations and much better fundamental understanding of the processes controlling these natural ecosystems. It goes without saying that quantitative estimates of all of these effects will require significant improvement in the accuracy of climate predictions at the country and regional level. The challenges here are great, but accurate quantification of impacts is essential to define the appropriate balance between the costs of policies to lower greenhouse gas emissions and the impacts avoided by these policies.

Is the Science-Policy Interrelation Adequate?

To summarize, science has potentially a significant role to play in helping both to define the needed level and assess the effectiveness of proposed policies. But, how can the needed intimate and continuous interaction between natural scientists, economists, and policymakers best be achieved? The IPCC process, while it has its merits, is simply not structured to provide the required continuous up-to-date integrated assessment mechanism for policy. There will, for example, be very significant policy development under the Framework Convention on Climate Change prior to the IPCC Third Assessment which is not due until the year 2001. We cannot afford to let scientists be just spectators to this policy development. This task of linking science and policy can, however, be undertaken by suitably cohesive and interdisciplinary research groups; this is a major goal of the program we have developed at MIT.

In closing, I emphasize that if improved scientific understanding shows that we are definitely on one of the rapid warming pathways shown in the graph then very significant action to lower total long-term greenhouse gas emissions will become necessary. This is why my colleagues and I have recently made the case that we need to take the steps now to make the political agreements, and develop the technological capabilities, to substantially lower emissions if and when the science shows that to be necessary.[7] In the technology area, we are all well aware that the U.S.

annual investment in Energy R&D decreased from about $5.1 billion in 1985 to $3.3 billion in 1994.[8]

Honorable Chairman and Members, let me end with an extension of the “smoke and flame” metaphor quoted at the beginning of my testimony. I believe we need to increase the accuracy of our smoke detectors, design the fire extinguishers with the needed power, and agree on the worldwide mechanisms for using these extinguishers, should the smoke detectors show that to be necessary.

Thank you.

Notes

1. Henry Jacoby, Ronald Prinn & Richard Schmalensee, 1997, “Needed: A Realistic Strategy for Global Warming”, MIT Joint Program on the Science and Policy of Global Change Report 21, 8 pages. (http://web.mit.edu/globalchange/www/report21.html)

2. Aerosols are submicroscopic particles, ten or more times smaller than cloud particles, that are suspended in air. Volcanoes are important natural sources, and coal combustion important human sources of aerosols.

3. Ronald Prinn, Henry Jacoby, Andrei Sokolov, Chien Wang, Xiangming Xiao, Zili Yang, Richard Eckaus, Peter Stone, A. Denny Ellerman, Jerry Melillo, Jean Fitzmaurice, David Kicklighter, Gary Holian & Yuexin Liu, 1999, “Integrated Global System Model for Climate Policy Assessment: Feedback and Sensitivity Studies”, *Climate Change*, Vol. 41, No. 3/4, pp. 469-546.

4. Intergovernmental Panel on Climate Change Working Group I, *Climate Change 1995: The Science of Climate Change* (Cambridge, United Kingdom: Cambridge University Press, 1996), John Houghton *et al*. (eds.), 572 pages.

5. Richard Kerr, 1997, Greenhouse Forecasting Still Cloudy, *Science*, Vol. 276, pp. 1040-1042.

6. Henry Jacoby, Richard Eckaus, A. Denny Ellerman, Ronald Prinn, David Reiner & Zili Yang, 1997, CO_2 Emissions Limits: Economic Adjustments and the Distribution of Burdens, *The Energy Journal*, Vol. 18, pp. 31-58.

7. Thomas Wigley, Richard Richels & Jae Edmonds, 1996, Economic and Environmental Choices in the Stabilization of Atmospheric CO_2 Concentrations, *Nature*, Vol. 379, pp. 240-243.

8. Jae Edmonds, James Dooley & Marshall Wise, 1997, Atmospheric stabilization and the role of energy technology, Climate Change Policy, Risk Prioritization and U.S. Economic Growth (ACCF: Washington DC), pp. 73-94.