Climate Change: A Growing Scientific Impetus for Policy

Ronald G. Prinn
Massachusetts Institute of Technology

Wednesday, February 28, 2007

Testimony to the Committee on Ways and Means
U.S. House of Representatives

The Honorable Charles B. Rangel, Chairman

Honorable Chairman and Members of the House Committee on Ways and Means, I respectfully submit the following testimony in response to your invitation of February 14, 2007.

I have been a member of the faculty of the Massachusetts Institute of Technology since 1971. I specialize in atmospheric science, and 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 appreciation of the various other disciplines in the natural and social sciences involved in the climate debate.

I will address here some key issues that in sum provide a significant scientific impetus for lowering greenhouse gas emissions. First, I will briefly say something about the current evidence for climate change. Second, I will discuss detection of the human influence on climate that is so important to policy. Third, I will address the uncertainty in current forecasts. Fourth, I will review the risks to humans and natural ecosystems that arise from allowing very significant future global warming to occur. Finally, I will comment on the unresolved issues in climate science that need future resolution.

IS CLIMATE CHANGING?

Climate is usefully defined as the average of the weather we experience over a ten- or twenty-year time period. Long-term temperature, rainfall and sea level 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.

Global warming or cooling 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 colorless aerosols) which efficiently reflect sunlight back into space and are thus a cooling influence. Easily the most important greenhouse gas is water vapor but this gas typically remains for only a week or so in the atmosphere. Water vapor and clouds are handled internally in climate models. Concerns about global warming revolve around less important but much longer-lived greenhouse gases, especially carbon dioxide. The concentrations of carbon dioxide and many other long-lived greenhouse gases (methane, nitrous oxide, chlorofluorocarbons, lower atmospheric ozone) have increased substantially over the past two centuries due totally or in large 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 which raises 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 that then causes sea level to rise. This delaying action of the oceans means we are already committed to future warming due simply to the greenhouse gases already in the atmosphere.

The Intergovernmental Panel on Climate Chance (IPCC) Fourth Assessment, whose summary for policy makers was released earlier this month, summarizes the direct observations of recent climate.[1] They conclude that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." They also conclude that "at continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones." There is no doubt in my mind that climate is already changing in very significant ways. This begs the obvious question; how much of this is due to human activity?

CAN WE DETECT HUMAN INFLUENCE?

Human influence on climate is indicated if the observed global patterns of climate change over say the past 50-100 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. The imperfections of current climate models make them less than ideal 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.

Ten years ago, I gave testimony during the House "Countdown to Kyoto" hearings in which I stated that I was not convinced at that time that the human signal had arisen from the noise of natural variability. I am now convinced that the human influence is proven with significant probability. The observations of continued rapid warming over the last 12 years, which include the 2 warmest years, and 11 of the 12 warmest years since 1850[1], and the recent improvements in climate theory and number and quality of models, are among the reasons for the change in my conclusion.

The IPCC Fourth Assessment has concluded that there is greater than 90% chance that most of the observed increase in globally averaged temperatures since the mid-20th century is due to the observed increase in anthropogenic greenhouse gas levels.[1] Some of the arguments for this strong conclusion are visibly captured in Figure 1 reproduced here from the IPCC report.

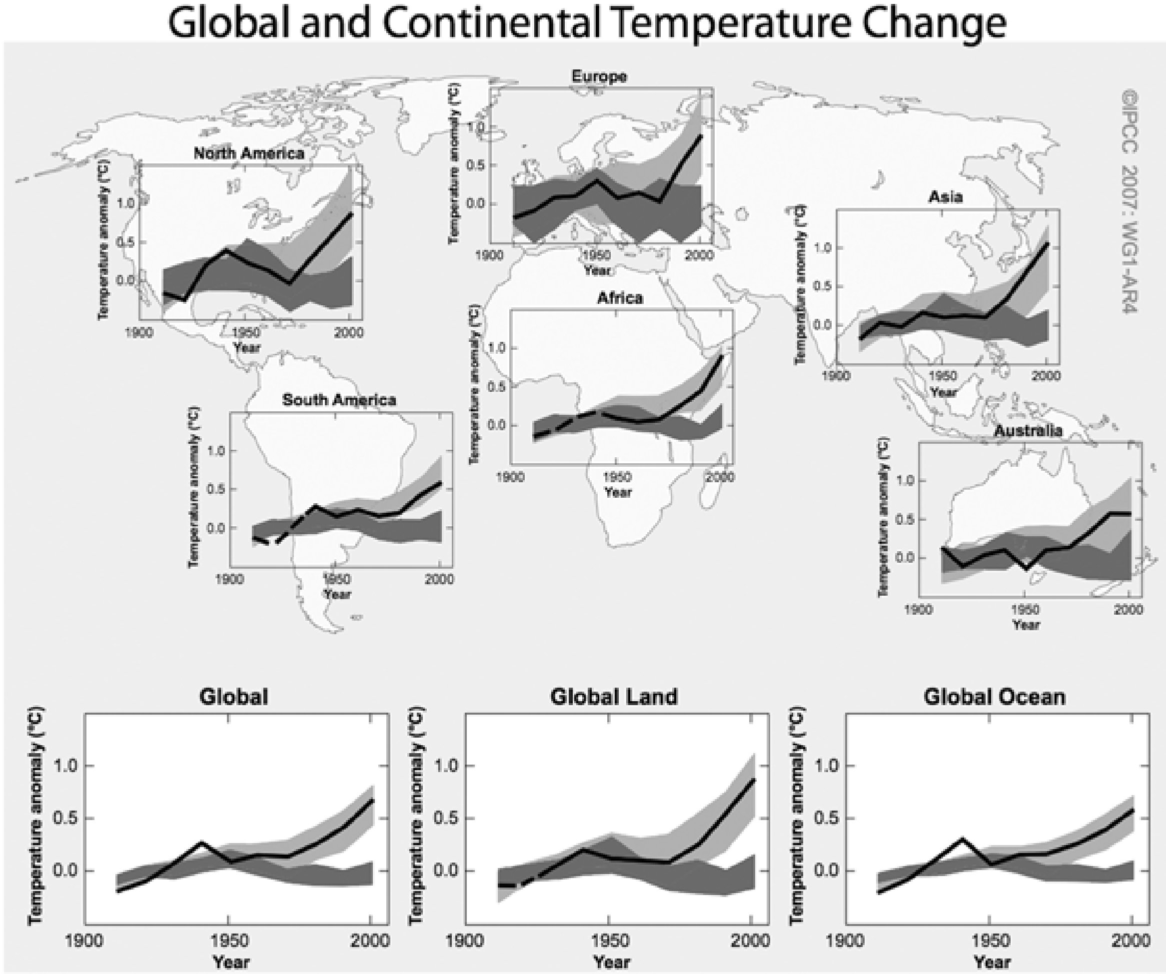

Figure 1. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings from the IPCC Fourth Assessment[1]. Decadal averages of observations are shown for the period 1906–2005 (black line) plotted against the center of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage of observations is less than 50%. Dark gray shaded bands show the 5–95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Light gray shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings.

The observed 1906-2005 temperatures are shown at the global and continental scales and are compared to two bands; one band shows the range of multi-model simulations without anthropogenic forcings (i.e. the "noise") while the other shows the range with these forcings (i.e. the "signal"). The separation of these two bands during recent decades, and the fact that the observations follow the "forced" band much more closely, argue that the "signal" of human influence has arisen from the "noise". Even if the probability is not quite 90%, the conclusions about human influence by the IPCC Fourth Assessment provide a substantial impetus for lowering future greenhouse gas emissions.

HOW GOOD ARE THE FORECASTS?

Concern about climate change is driven especially by forecasts of significant warming over the next century. The computer models used to make these forecasts attempt to simulate with some, but not complete success, the behavior of clouds, water vapor, long-lived greenhouse gases, atmospheric and oceanic circulation, and many other essential climate processes on the regional and global scale. These models are remarkable in their complexity and, despite their limitations, are invaluable tools for scientific research.

Integrating and understanding the diverse human and natural components of the problem is a must when informing policy development and implementation. As a result, climate research should focus on predictions of key variables such as rainfall, ecosystem productivity, and sea level that can be linked to estimates of economic, social, and environmental effects of possible climate change. Projections of emissions of greenhouse gases and atmospheric aerosol precursors should be related to the economic, technological, and political forces at play. In addition, such assessments of possible societal and ecosystem impacts, and analyses of mitigation strategies, should be based on realistic representations of the uncertainties of climate science. At MIT, we have developed an Integrated Global System Model (IGSM) to address some of these issues and to help inform the policy process. The IGSM consists of a set of coupled sub-models of economic development and associated emissions, natural biogeochemical cycles, climate, air pollution, and natural ecosystems. It is specifically designed to address key questions in the natural and social sciences that are amenable to quantitative analysis and are relevant to climate change policy.[2] The IGSM is arguably unique in its combination of scientific and economic detail, climate-atmospheric chemistry-ecosystem feedbacks, and computational efficiency. It does make some important simplifications to enable computational efficiency, but the effects of these are likely to become important, at least for global average climate forecasts, only after 2100.

To help decision-makers evaluate how policies might reduce the risk of climate impacts, quantitative assessments of uncertainty in climate projections are very useful. We have used several hundreds of runs of the IGSM together with quantitative uncertainty techniques to achieve this assessment.[3] The IGSM physical climate model is flexible, which enables it to reproduce quite well the global behavior of more complex climate models. This flexibility allows for analysis of the effect of some of the structural uncertainties present in existing models. The MIT study includes uncertainties in anthropogenic emissions of all climatically important gases and aerosols, and in critical climate processes involving clouds, aerosols and deep ocean overturning. The MIT estimates of key climate model uncertainties are constrained by observations of the climate system. Also, uncertainty in emissions includes expert judgment about variables that influence key economic projections.

The probability of changes in the mean global surface temperature and sea level between 1990 and 2100 were calculated for two hypothetical cases: no explicit climate policy, and a stringent policy. The stringent policy keeps atmospheric CO_2 levels in the year 2100 in the median case to be just below 550 parts per million (which is about twice the preindustrial CO_2 level). Absent mitigation policies, the median projection in this study shows a global average surface temperature rise from 1990 to 2100 of 2.4℃, with a 95% confidence interval of 1.0℃ to 4.9℃. For comparison, the recent Fourth Assessment Report of the IPCC reports a range for the global mean surface temperature rise by 2100 of 1.1 to 6.4℃ for 6 assumed emission scenarios.

Communicating the results of an uncertainty study like this to the public and policy makers needs to be achieved with clarity. The average person on the street is in fact very familiar with the problems of dealing with uncertainty-- they just do not describe it with probabilities. Anyone who plays cards, bets on horses, or plays roulette is gambling with significant knowledge about the odds of various outcomes. Similarly, people have become comfortable with these issues when it refers to their health-- you have high bad cholesterol levels and your doctor informs you that your chances of a heart attack are significantly greater than average unless you take steps to lower these levels. With this in mind, I share with you one way that I (and my MIT colleagues) have found quite effective in communicating the value of climate policy despite the uncertainties.[4] We call it the "greenhouse gamble" which is a variant on the "wheel of fortune." The probabilities of various amounts of warming from the above MIT study are projected onto two wheels, as shown in Figure 2.

Figure 2. The probabilities for various amounts of global average warming between 1990 and 2100 calculated from two multi-hundred sets of model forecasts are projected onto two wheels.[3] The left-hand wheel is for "no policy" and the right-hand wheel is for "policy" (see text).

The "no policy" wheel shows about 1 chance in 4 of greater than 3 degrees centigrade warming between now and 2100 if there are no significant efforts to curb greenhouse gas emissions. Such a warming is regarded by most climate scientists as very dangerous. The "policy" wheel, that keeps greenhouse gas levels below twice their preindustrial levels, indicates that the odds of exceeding 3 degrees centigrade warming drop dramatically. Imagine that you are playing "the greenhouse gamble" and have $100,000 in winnings. To end the game and collect your money you must finally spin one of these two wheels. If you land on any of the sectors of the wheel corresponding to warming exceeding 3 degrees centigrade you lose say $10,000 of your winnings. You can spin the "no policy" wheel for free but must pay to spin the "policy" wheel with its much lower odds of losing your money. In this game the $10,000 represents an (arbitrary) penalty for the damages caused by dangerous climate change and the money you are willing to give up represents the cost of mitigating policy. How much of your $100,000 would you be willing to give up in order to spin the "policy" wheel?

I emphasize that the uncertainty represented by the "no policy" wheel is not a sound argument for inaction. The fact that there is some probability for small amounts of warming is countered by comparable probabilities for dangerous amounts of warming. I emphasize that the exact odds of various amounts of warming depicted in the two wheels are not as important as the qualitative differences between them. Indeed, more recent research at MIT[5], and other work reported in the IPCC Fourth Assessment[1], implies that the probabilities of large amounts of warming may be underestimated in these wheels.

WHAT ARE THE RISKS?

The projected warming of the Arctic and Antarctic regions in the MIT "no-policy" case are about 2.5 and 1.8 times greater respectively than the quoted global average warming (this uneven warming is evident from past observations and is seen in essentially all other climate model simulations). Also, the warming in the "no-policy" case is accompanied by projected sea-level rises of 0.2 to 0.84 meters due to warming (and hence expanding) oceans and melting of mountain glaciers. The IPCC Fourth Assessment reviews forecasts from a large number of other more comprehensive climate models revealing qualitatively similar asymmetry in warming, and sea level rises of 0.18 to 0.59 meters (1990 to 2095) depending on the emission scenario used. These sea level estimates are conservative since they do not include the possibility of significant melting of the Greenland and Antarctic ice sheets.

These conclusions and many others in the literature point to the great vulnerability of coastal and polar regions to global warming. The Greenland and West Antarctic ice sheets together contain the equivalent of 12 meters of sea level rise. It is therefore significant that the IPCC Fourth Assessment[1] concludes that "the last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 meters of sea level rise." Also vulnerable are Arctic tundra and frozen soils which contain the equivalent of about 80 years of current fossil fuel carbon emissions[6], and Arctic summer sea ice cover (a cooling influence) that is already decreasing.[1]

Other expected consequences of global warming include increases in heat waves and high latitude precipitation. There are also expected to be some benefits of warming, for example increases in the length of the growing season in cold regions, that also need to be considered. Recent research has suggested a significant connection between increasing sea surface temperatures and the duration and wind speeds in typhoons and hurricanes.[7] If further research confirms this, the increased storm damages, which typically rise as the cube of the windspeed, could be very costly. There are other thresholds and vulnerabilities in the climate system that, added to those discussed above, make it prudent to attempt to limit the amount of future global warming by lowering greenhouse gas emissions.[8]

CONCLUDING REMARKS

Regarding the needed emission reductions, it is important to note that it matters very little where the long-lived greenhouse gases are emitted and that, according to our emissions projections[3], very substantial reductions will require ultimate participation by all nations, not just the currently rich countries. Another important point 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 offset by lower emissions later on.

To better calibrate the policy response, we need to improve the accuracy of estimates of the impacts of climate change on natural and human systems. Here the research is less mature, but we 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. Natural terrestrial, coastal, and oceanic ecosystems may not be able to adapt. We also need to address the environmental impacts of future potential renewable energy sources operating at the multi-trillion watt scales needed for them to make a significant contribution to future total energy demand (e.g. billions of acres of land for biofuels, many millions of wind turbines). It goes without saying that quantitative studies of all of these issues 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.

Finally, I emphasize that we should not wait for perfection in either climate forecasts or impact assessments before taking action. The long-lived greenhouse gases emitted today will last for decades to centuries in the atmosphere and the severity of the risk is obvious from the fact that scientists cannot presently rule out the rapid warming forecasts. Added to this is the multi-decade period needed to change the global infrastructure for energy and agricultural production and utilization without serious economic impacts.

REFERENCES

(1) Intergovernmental Panel on Climate Change, Climate Change 2007: The physical science basis, Summary for Policy makers (2007), http://www.ipcc.ch/

(2) Prinn, R.G., Complexities in the Climate System and Uncertainties in Forecasts, *in The State of the Planet: Frontiers and Challenges in Geophysics,* eds. S. Sparks and C. Hawksworth, Geophysical Monographs, **150**, American Geophysical Union, pgs. 297-305, 2004.

(3) Webster, M., C. Forest, J. Reilly, M. Babiker, D. Kicklighter, M. Mayer, R.G. Prinn, M. Sarofim, A. Sokolov, P. Stone and C. Wang, Uncertainty Analysis of Climate Change and Policy Response, *Climatic Change*, **61**, 295-320, 2003.

(4) MIT Joint Program on the Science and Policy of Global Change, http://web.mit.edu/globalchange/

(5) Forest, C.E., P. Stone and A.P. Sokolov, Estimated PDFs of climate system properties including natural and anthropogenic forcings, *Geophysical Research Letters*, 33, L01705, doi:10.1029/2005GL023977, 2006.

(6) Sabine, S. L., M. Heiman, P. Artaxo, D. Bakker, C. A. Chen, C. Field, N. Gruber, C. LeQuere, R.G. Prinn, J. E. Richey, P. Lankao, J. Sathaye and R. Valentini, Current Status and Past Trends of the Global Carbon Cycle, in *The Global Carbon Cycle*, ed. C. Field and M. Raupach, Island Press, Washington D.C., pgs. 17-44, 2004.

(7) Emanuel, K. A., Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, **436**, 686-688, 2005.

(8) Rial, J., R. Pielke, M. Beniston, M. Claussen, J. Canadell, P. Cox, H. Held, N. de Noblet-Ducoudre, R.G. Prinn, J. Reynolds and J. Salas, Nonlinearities, Feedbacks and Critical Thresholds within the Earths' Climate System, *Climatic Change*, **65**, 11-38, 2004.