Modeling Human-Climate Interaction

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If policymakers and the public are to be adequately informed about the climate change threat, climate modeling needs to include components far outside its conventional boundaries. An integration of climate chemistry and meteorology, oceanography, and terrestrial biology has been achieved over the past few decades. More recently the scope of these studies has been expanded to include the human systems that influence the planet, the social and ecological consequences of potential change, and the political processes that lead to attempts at mitigation and adaptation. For example, key issues—like the relative seriousness of climate change risk, the choice of long-term goals for policy, and the analysis of today's decisions when uncertainty may be reduced tomorrow—cannot be correctly understood without joint application of the natural science of the climate system and social and behavioral science aspects of human response. Though integration efforts have made significant contributions to understanding of the climate issue, daunting intellectual and institutional barriers stand in the way of needed progress. Deciding appropriate policies will be a continuing task over the long term, however, so efforts to extend the boundaries of climate modeling and assessment merit long-term attention as well. Components of the effort include development of a variety of approaches to analysis, the maintenance of a clear a division between close-in decision support and science/policy research, and the development of funding institutions that can sustain integrated research over the long haul.

1. ANALYZING HUMAN-CLIMATE INTERACTION

At one level or another almost all of the questions motivating this volume on *The State of the Planet* arise from the interaction between earth's natural systems and the activities of human society. None of these issues, however, presents such a rich combination of complexity and policy immediacy as does anthropogenic climate change. Motivated by this threat, billions of dollars are being spent each year on climate science research. Moreover, the formulation of policy responses occupies political authorities at all levels—from individual cities, to national and regional governments, to the United Nations and summit meetings of the great powers.

Unfortunately, connections remain weak between the efforts of natural scientists to understand potential climate change, and the work of social and behavioral scientists on its human contributors, its economic and environmental consequences, and the formulation of a societal response. As a result, many important efforts on earth observation systems and other data gathering, scientific research, and policy analysis—all needed as guides to action—are diminished in their usefulness for informing policy choice. Here we explore social and behavioral science aspects of global climate change and the ways they are intertwined with the natural science of climate at the frontier of efforts to inform policymakers and the public. As will be argued below, more effective integration of the various components of the issue is both an intellectual and an institutional challenge.

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Figure 1 provides a simplified picture of the dynamics of natural/social science and policy aspects of the issue, and can serve as guide to the discussion. Population growth, technology change and economic development are matters of human choice, producing emissions of greenhouse gases (GHGs) that are building-up over time in the atmosphere. In combination with emissions of aerosols and their precursors, and ozone-producing chemical processes in the troposphere—and the resulting effects on land use and land cover—these human activities are changing the radiative balance of the earth. Mediated by complex interactions and feedbacks among the atmosphere, oceans and terrestrial biosphere, the expected result is some level of global climate change over decades to centuries. Because of the slowness of the process and the noisiness of the climate system, this change cannot yet be dependably sensed by casual observation. However, scientific research involving complex and expensive satellite and other observation systems, intensive mining of data from ice cores, corals, tree rings and other records of past change—combined with sophisticated statistical analysis, and complex theoretical and empirical modeling—is producing an ever more convincing picture of a substantial anthropogenic contribution to the warming seen over the past century or so [*Houghton et al.*, 2001].

Through its regional and global manifestations, climate change is expected to have substantial ecosystem effects [e.g., see *Root et al.*, 2003], so another area of complex scientific analysis, shown in Figure 1, concerns the economic and social consequences of such change. It is the public understanding of these, in turn, that motivates action to reduce emissions (or to counter their global effects by geo-engineering) and to devise measures to ease adaptation to levels of climate change that may be unavoidable. In combination with studies of the costs of measures to mitigate human influence, these relations constitute the main inputs to the ongoing debate about the appropriate policy response to the climate change threat.

Other science-based problems of managing the global commons have a similar structure. The buildup of lead and other toxics in the environment and the destruction of stratospheric ozone by chlorofluorocarbons come to mind. However, characteristics peculiar to the climate issue combine to make it the seemingly intractable policy issue it has become. First are the long lags in the system. Any change in global radiative balance results from the buildup of greenhouse gases only over several decades, which means the emissions in the next few years have only a small influence on the long-term risk. Second is our limited understanding of key climate processes—e.g., the behavior of clouds, the response of ocean circulations, and the influence of aerosols—and the fact that the high natural variability of the system greatly complicates efforts to quantify the human influence. Further complicating the decision of what to do now is the fact that some of these uncertainties may be reduced (or perhaps some even increased) over the next decade or two.

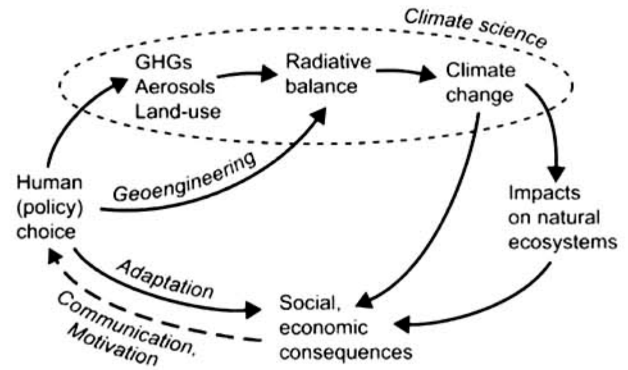

Figure 1. The Expanding Scope of Climate Models. To meet the needs of policymakers and the lay public, conventional boundaries of climate analysis must be expanded to include social and behavioral science aspects.

These complexities might not be so troublesome if greenhouse gases were a minor byproduct of the modern economy, but they are not. Unlike lead or chlorofluorocarbons, whose control was relatively easy, reducing greenhouse gas emissions will require substantial changes in social organization, impacting all nations and all economic sectors, threatening substantial economic cost, and stirring rancorous controversy over the distribution of the burden.

To gain understanding of the combined human-climate system, with its many and complicated interactions and feedbacks, mathematical models at ever increasing levels of complexity have become essential. Indeed, the history of climate analysis can be charted by the progressive extension of the boundaries of these efforts over the last two or three decades—from atmospheric models drawn from earlier work in meteorology, to a coupling of atmosphere and oceans, to integration with the terrestrial biosphere, hydrosphere and cryosphere. Each increase in model scope has been motivated by the recognition of phenomena that could not be understood through analysis of the disconnected components. It is a process familiar in the natural sciences. Moreover, given the scale and cost of research in these areas, the change in scope naturally is reflected not just in the research and analysis, and model structure, but also in the institutions that fund the work and the disciplinary associations that grow along with them.

Now, in the past dozen years or so, a new challenge has emerged in this process of expanding scope. As nations have begun the difficult task of formulating a response to the climate change threat, a need arises to provide better information about how the climate responds to specific aspects of human activity and the likely effectiveness of proposed control schemes, and about the human and ecological consequences of change that we are unwilling or unable to avoid. These policy choices involve the allocation of human and political effort and economic resources, and the essential question is: what should the nations do *now* given current understanding of the risks and costs? The political task is to find the appropriate mix of effort among three areas of effort: (1) mitigation to be undertaken now and in the next few years, (2) adaptation measures to be taken now in anticipation of possible future change, and (3) research to inform these choices. The research and analysis need, and thus the modeling challenge, is to understand the human-climate system as an integrated whole, with a focus on these choices.

Expansion of the scope of analysis, to include the social and behavioral aspects of these choices as illustrated in Figure 1, involves a reach across disciplinary boundaries that is greater than those needed to achieve collaboration among sub-fields of the earth sciences. Moreover, besides the differences in the nature of the systems studied, and the research methods appropriate to each, the institutional and political barriers are more daunting. Unavoidable tension arises between scientific research for the sake of science, and science constrained to focus on some particular decision problem. Furthermore, because climate change is such a contentious political issue, there is a risk that pressures to meet the objectives of some particular economic or ideological interest may corrupt the scientific enterprise.

From the time the climate issue first gained widespread attention, efforts have been under way to carry out this kind of integrated work, and a substantial capacity and body of literature has been developed. (An impression of these efforts can be gained from the survey by the IPCC [*Bruce et al.*, 1995, Chapter 10]). Nonetheless, the intellectual and institutional challenges to integrated analysis of the human-climate system remain considerable. Some of the more troublesome challenges to conventional policy assessment methods are well summarized by *Morgan et al.* [1999]. If we are to understand this system, and make intelligent decisions about anthropogenic influence over coming decades, an ever-stronger strategic collaboration of the natural, social and behavioral sciences is essential. Otherwise nations will continue to face a pair of dangers: key economic studies and policy analysis could proceed on the basis of a flawed understanding of what is known about the science of climate, and opportunities could be missed to direct scientific efforts to questions of greatest importance to policy analysis and political decision.

2. RESEARCH FRONTIERS: THE INTELLECTUAL CHALLENGE

There are many areas of climate analysis that require close coordination between natural and social/behavioral scientists when pursuing an informed policy decision, but the three that follow will illustrate the need. All are at the forefront of current knowledge, all involve the modeling of human-climate interaction, and all are challenging areas of research. With these examples in hand, a few words can be added on the related task of lay communication.

2.1 Climate Change Projections

Implementing a response to the climate change threat involves potentially costly decisions that must be made with a troubling sense of uncertainty as to their consequences. National economies, and the natural ecosystems on which they depend, will be substantially affected by changes in climate, whether with negative or (for some sectors with a few degrees of warming) positive outcomes. But the main risk is of large negative consequences. Year to year, nations will decide how to manage that risk, taking into account the ability to reconsider decisions in the future, perhaps with better information. Certainly, the foundation of any discussion about emissions control and/or anticipatory adaptation is an analysis of the range of possible climate system outcomes if no action is taken. Development of such projections is a complex task because the analysis must consider uncertainties not only in climate system response, but also in population growth, economic development and technological change, and it must take into account potential feedbacks among these systems over time should climate change occur.

A key difficulty, then, is to combine the natural science and social science analyses of these uncertain systems in order to prepare a useful picture of the nature of the risk. For example, in summaries of the state of the science by the Intergovernmental Panel on Climate Change (IPCC), it has been the practice to present possible outcomes in terms of high and low values of temperature change over the 21st Century—between 1.4°C and 5.8°C as stated in the IPCC Third Assessment Report or TAR [*Houghton et al.*, 2001]. This range is supposed to include uncertainty in both anthropogenic emissions and the response of the climate system to them. Unfortunately, this way of expressing results tends to facilitate the rhetoric of advocates and public misunderstanding. Environmental activists (and much news coverage) emphasize the 5.8°C threat while climate "nay-sayers" argue that the science showing this result is flawed, giving credence to the impression that the lower number is correct. In this debate between polar results, lay observers may misperceive the very nature of the risk, which is not a binary choice (it is a problem or it is not), but some more complex distribution of possible outcomes.

The shortcomings of this way of expressing climate change projections have led researchers to attempt a combined analysis of emissions and climate uncertainty. One example from this family of work is the analysis by *Webster et al.* [2003], which is the basis of Figure 2. The analysis is applied using the MIT Integrated Global System Model [*Prinn et al.*, 1999] and summarized in this volume [*Prinn*, 2003]. An analysis of uncertain greenhouse emissions, as projected by its multi-region, multi-sector model of the world economy [*Webster et al.*, 2002], is combined with an analysis of uncertainty in key parameters of its model of the climate system [*Forest et al.*, 2002]. The result is a representation of the uncertain future behavior of this human-climate system over the 21st Century on the assumption that no greenhouse controls are imposed.

Although a strong effort has been made within the IPCC to incorporate uncertainty analysis in its assessments [*Moss and Schneider*, 2000] controversy surrounds this way of applying social science and natural science models to analysis of uncertainty in the combined human-climate system. Disagreement usually arises in some combination of concerns about conclusions drawn from incomplete science models and/or objection to the methods applied to long-term economic and social processes [*Schneider*, 2001; *Reilly et al.*, 2001; *Allen, Raper and Mitchell*, 2001; *Webster*, 2003]. Also, results must be interpreted with special caution when the coupled systems include models subject to mixes of (perhaps interacting) structural and parameter uncertainties, and/or where the components move out of their ranges of well-understood behavior at different rates with time or scale [*Casman, Morgan and Dowlatabadi*, 1999]. At the very least, therefore, care should be taken to be clear that any such result is conditioned on the model structures applied and the climate processes included and omitted. Further, those assumptions to which results are most sensitive should be transparent. With these qualifications, however, representation of the threat in the form of Figure 2, or related outputs of formal uncertainty analysis, is an improvement over ranges of outcomes with no confidence bounds. The more complete analysis can serve both as an aid to public understanding of the nature of the threat and as a first step toward analysis of year-to-year decisions about emissions mitigation. Importantly for this discussion, the credibility of the result depends on careful coordination between the natural science and social science contributors to any joint analysis, which in turn requires that each have some minimal understanding of the methods and assumptions applied by the other.

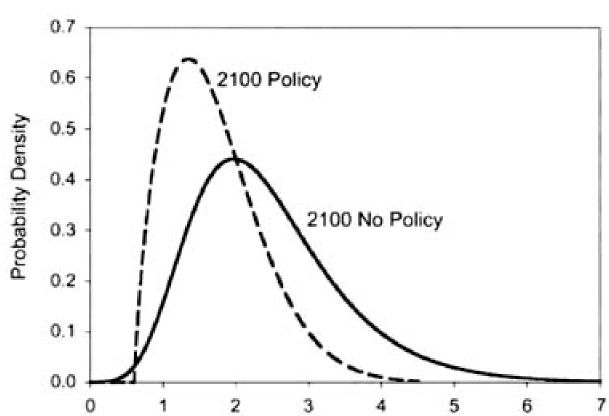

Figure 2. Probability density function (PDF) of global mean temperature change in 2100 under a no-policy case (solid line) and under controls that stabilize atmospheric concentrations at 550 ppmv under a reference projection (dashed line).

2.2 The "Danger" Level of Atmospheric Concentrations

Given the environmental threat suggested by Figure 2, a natural component of the process of international negotiation and national decision is the formulation of some long-term goal to guide society's response. This goal might be defined at several points in the human-climate system, e.g., at the level of economic and environmental consequences, or some set of climate variables. However, perhaps in an effort to avoid the complicating influence of uncertainties in effects estimates and models of climate system behavior, the drafters of the Framework Convention on Climate Change (FCCC) set the goal of international action on climate as,

> . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system . . . [and] allow ecosystems to adapt naturally

Since the Convention has been ratified by 188 nations, this notion of stabilized atmospheric concentrations will be an important component of ongoing negotiations.

In gaining a definition with such useful simplicity, however, the diplomats created other puzzles yet to be resolved. When, in the early 1990s, the Convention was negotiated, focus was heavily placed on CO_2 with little consideration given to other substances, and the role they play in the greenhouse effect. Negotiators also seem to have been little concerned about the complicating role of uncertainty in the climate system as it influences the carbon cycle. Thus continuing problems remain in the definition and use of the stabilization goal—problems that require joint analysis of the climate science and the economics of emissions.

For example, Article 2 of the Climate Convention connects to a provision of Article 4 that requires nations to report periodically on the adequacy of efforts, and to continue doing so "until the objective of the Convention is met". Thus the concept of a concentration target provides a basis for debate about whether current and anticipated emissions control efforts are

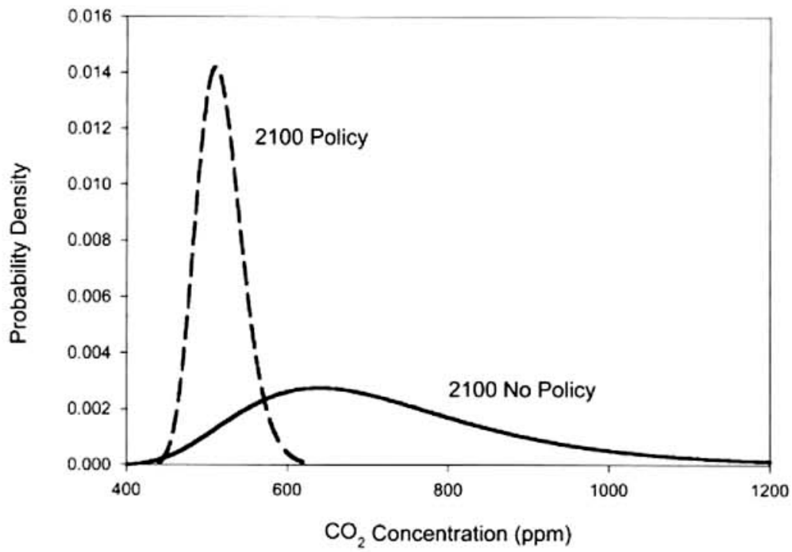

Figure 3. Probability density function (PDF) of atmospheric CO_2 concentration in 2100 under a no-policy case (solid line) and under controls that stabilize atmospheric concentrations at 550 ppmv under a reference projection (dashed line).

consistent with the Convention. Unfortunately, any such judgment must take account of the uncertainties in the carbon cycle, which result from complex processes in the oceans and terrestrial biosphere. There is no deterministic link between emissions paths and atmospheric CO_2 concentrations. At best, any such judgment about the ability of a policy path to attain a particular atmospheric target can only be made in probabilistic terms. This fact is illustrated in Figure 3. It shows PDFs of 2100 CO_2 concentrations for the same two cases that were presented in Figure 2. The solid line shows the no-policy case; the dashed line shows an estimate of the distribution of atmospheric CO_2 concentrations under a profile of global emissions control that would lead to (roughly) a stabilization of greenhouse gases at 550 ppmv under a reference forecast. The insight to be drawn from the figure is that it is not possible to make a one-to-one link between policy action over time and the condition of the atmosphere. Naturally, any projection of the resulting reduction in global temperature change also is uncertain, as shown by the dashed line PDF in Figure 2. At best the policy outcome can be stated in terms of confidence intervals, or the odds that a particular atmospheric concentration or climate result will be achieved.

The non-CO_2 gases introduce other difficulties. The FCCC also covers CH_4, N_2O and a set of industrial gases. Each has a different lifetime and radiative strength, and the lifetime of CH_4 depends on the details of tropospheric chemistry, which changes over time. In this situation even the definition of "stabilization" is not clear. One approach to this puzzle is to seek stabilization in carbon-equivalent terms, with the non-CO_2 gases weighted according to a set of exchange rates (so-called global warming potentials or GWPs) defined by the IPCC, but the result is inconsistent with the intent of the FCCC, which is to stabilize the instantaneous human influence. The target could be defined as stabilization of the concentration of each gas individually, but any strategy to achieve this result would be highly inefficient economically. Finally, some climatically important substances are left out of consideration entirely. Tropospheric ozone is ignored and the influence (both warming and cooling) of aerosols and aerosol precursors remain outside the the FCCC's system of greenhouse accounting [*Reilly, Jacoby and Prinn*, 2003]. Resolution of these issues, to clarify the economic analysis of control schemes and the language of international negotiations, will require joint effort by atmospheric chemists and radiative transfer experts, and those carrying out the economic analysis and policy assessment.

Finally, there is the issue of defining the benefits of restraining atmospheric concentrations, or some other measure of climate change. Such measures are needed for comparison with the expected control costs and to inform discussions of the appropriate long-term atmospheric target. Here again, attaining clarity will require a complex inter-weaving of economic and ecological analysis of the advantages of avoiding change, and the underlying natural science of the change itself. A number of difficult challenges stand in the way of widely accepted estimates of such benefits—including accounting for uncertainty and risk preferences, the difficulties of valuation of non-market impacts, and the puzzles presented by attempts to aggregate effects over very different national circumstances. As a result, it is likely that a portfolio of benefit measures will be used to inform the choice of target, including physical measures, at global and regional scales, computed by global climate models [*Jacoby*, 2003]. Again, if climate model results are to be appropriately applied, natural scientists must inform the related social and political analysis.

2.3. Uncertainty, Learning, and Sequential Decision

The projections of climate change in Figure 2, under a no policy assumption or some imagined path to a stabilization goal, are useful in illustrating the nature of climate change risk. But because of their assumption of a fixed policy path over time they are not realistic representations of the temperature outcomes under possible paths of resolution of climate system uncertainties. The limit to their descriptive capability can be illustrated using Figure 4, which shows a pair of decision trees. The squares represent points where decisions are made; the circles indicate times where uncertainty is resolved. In this example, future climate policy choice is simplified to a set of decisions by a single global authority at a couple of points in time. "No mitigation" or "fixed target" policy scenarios essentially assume that the decision context is the one shown in the upper part of the figure. Choices about a mitigation path are made now, and maintained over time; key uncertainties will not be resolved until the end of the period (for this illustration, the end of the 21st Century). This is the assumption implicit in the results shown in Figures 2 and 3. That is, choices are made today either to take no action over the century, or to follow a trajectory of emissions control that is presumed to lead to 550 ppmv.

Useful as calculations based on this assumption may be for illustrating the nature of the risk, they do not provide an accurate picture of the choice problem. In the jargon of environmental economics, greenhouse gases are a "stock pollutant". As noted earlier, their influence on the environment comes not from emissions today but from their buildup over time—over many decades in the climate case. Furthermore, society does not today decide what response it will take over the long-term future. Even were it wise to commit to such long-term paths, nations are limited in their ability to make far future commitments. Moreover they need not do so: they can decide what to do today knowing that any decision, such as the stringency of mitigation efforts, can be reconsidered in the future (perhaps with some options foreclosed by events along the way). And, since key uncertainties about climate system response to human influence, and the possible economic and ecosystem effects, may be reduced over time by research and observation, there is always a choice between acting now or waiting for more information. Thus the more correct representation appears in the lower part of Figure 4. In a simplified two-stage version, it shows that we will decide and act, then learn over time, then decide again—in a sequence extending far into the future.

Here lies the core of the debate over climate policy and climate research—an issue well illustrated by an early exchange in EOS [*Risbey, Handel and Stone*, 1991a,b; *Schlesinger and Jiang*, 1991a,b]. How much mitigation should be undertaken now given what we may learn over time, what resources should be devoted to ensuring that this learning occurs, and where should resources be directed? The issue of sequential choice under uncertainty, with learning, is an extensive and complex topic in the literature of economics and policy analysis [e.g., *Webster*, 2002], with special complications depending on whether actions are taken by some individual decision maker or as the result of a negotiation involving several parties. In either case, the structure of the human-climate interaction matters, as does the question of which uncertainties are expected to be narrowed, and how soon. Of course, relevance to policy is not the only criterion in deciding climate science research strategy. To the extent it is important, however, those carrying out the social science research and policy analysis need the active involvement of those at the forefront of the natural science work.

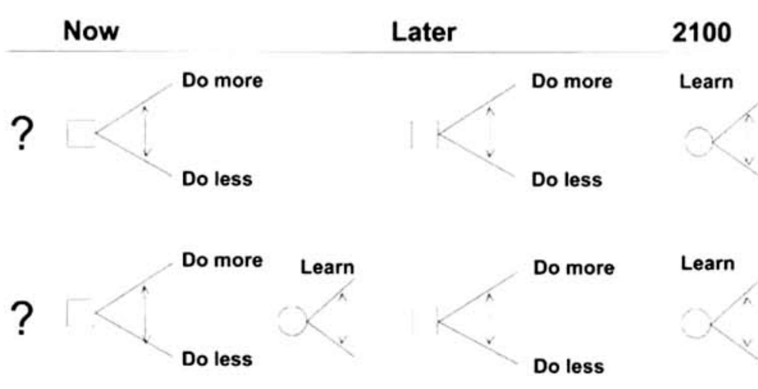

Figure 4. Decision trees for alternative versions of the climate decision problem. The top tree shows the scenario form; the bottom tree represents sequential decision with learning.

2.4 Communicating Results

Up to this point the discussion has proceeded as if the main task was communication and collaboration among natural scientists, social and behavioral scientists, and policy analysts. But there is another key connection that crosses the borders of discipline, and that is communication with policy-makers and the lay public. It is difficult enough for the non-specialist to gain a clear impression of the climate change issue when information is so charged with the agendas of one or another side of disputes over specific policy initiatives. Even more problematic is the fact that natural and social scientists have so little understanding of how their research results—regarding the climate system and its uncertainties, the potential effects of change, and the costs of control efforts—are appropriated and interpreted by non-specialists. Without greater interaction with behavioral scientists, who do try to understand this process, important information may be misperceived or ignored, and policy effort misdirected.

Just two examples will make the point about the need for greater interaction on this disciplinary boundary. Above it is argued that greater care needs to be taken to accurately present uncertainties in projections of emissions and climate outcomes, as if such information (perhaps expressed in PDF's) would be commonly understood, producing a coherent interpretation and reaction. Not so. Studies of attitudes to risk show that they differ among cultures, and across individuals within a culture or nation [*Renn and Rohrmann*, 2000; *Slovic* 2002]. People have different views of the nature of a particular risk, or of what it would be worth to reduce it, even if they agree on the magnitude of the effect under various outcomes. There may be many ways to summarize information about climate change, each with meaning to a particular party, but there may be no way to achieve a uniformly shared impression, and perhaps even a difficulty in achieving a common measuring rod. Moreover, research on cognitive processes shows that people do not absorb new information passively, as if the mind were a blank slate so far as the issue at hand is concerned [e.g., *Kempton, Boster and Hartley*, 1995]. They approach any new phenomenon (like climate change) with a set of existing cultural models and concepts, through which they view the new information. This pattern may help explain why so many lay people think the solution to the climate problem is to control spray cans!

Those of us who work on natural and social science aspects of climate have something important and useful to offer to non-specialists and policymakers, but good work as defined within our own disciplinary standards is not sufficient.

3. INTEGRATED ANALYSIS: THE INSTITUTIONAL CHALLENGE

3.1 Interdisciplinary Modeling and Analysis

For purposes of the work outlined above it is fortunate that strong similarities exist between the analytical methods applied by natural scientists, in models of the climate system and its response to greenhouse gases, and the models used by social scientists (economists mainly) in studies of the origins of these gases and the costs of controlling them. It is thus possible for researchers from these diverse disciplines to come to understand one another's methods, and even to develop mutual respect for the difficulties each faces. Both build models that attempt to capture the structure of a complex system of many components. The natural scientists confront interactions of the atmosphere, oceans and land surface. Economic analysis must integrate multiple nations and economic sectors, each with particular technological characteristics. But both have models that specify these components, their individual behavior, and the interactions among them. Each has some set of natural forcings: existing greenhouse gas concentrations, solar variability, etc. on the climate side, and population change, technological advance, resource depletion and other such phenomena for the economic analysis. Then each discipline forces its model with outside influences: growing greenhouse gas emissions introduced into the climate model, policies such as emissions mitigation imposed on economies.

In both cases the larger models—the atmosphere-ocean general circulation models and multi-region, multi-sector general equilibrium economic models—solve for equilibria period by period, for a range of time steps from minutes to months in climate models and usually a five or ten year period in economic models. Each creates transient projections by introducing vectors of greenhouse forcings or economic processes like technical change. Each is calibrated to match some historical period, and each has parameters—some estimated statistically, some set by expert judgment—that can serve as a basis for exploring within-model uncertainty.

Despite these similarities, of course, substantial differences complicate the integration of social science and natural science modeling efforts. The modeling of human systems must deal with uncertainties that are not faced in the analysis of natural systems. The chemistry and physics of the atmosphere may be uncertain, but modelers need not consider the possibility that future molecules might invent new ways of reacting, or that a forest may anticipate a coming change in soil moisture and start moving a decade ahead of time. In economic models, on the other hand, invention and anticipation are important processes. Furthermore, except in some long-term Darwinian sense processes modeled in the natural sciences don't reflect preferences for ultimate outcomes, or attitudes to risk. These are relevant, however, in modeling the social processes that underlie any response to the climate threat.

These differences in the characteristics of the components of the human-climate system can lead to disagreement over methods, and even to conflict over philosophy of approach to analysis. Thus, the frequentist-subjectivist controversy emerges in the climate debate, and elicitation of expert judgment and application of Bayesian methods are likely to be more familiar and comfortable in some applications than in others [*Webster*, 2003].

The gap is even greater between the natural sciences and social sciences like economics on the one hand, and the behavioral sciences on the other—a phenomenon that can be seen in the paucity of inputs from these fields in existing integrated assessment [*Bruce et al.*, 1995]. The common pool of terminology and techniques, and opportunities for linkage of analytical models, which facilitate collaboration between earth science and economics, are missing in the interaction with behavioral science. The study of human behavior naturally focuses more on survey methods, individual and group experiments and studies of brain function—areas of work unfamiliar to most researchers working on the climate issue. Yet if effective communication is to be achieved, greater understanding is going to be needed about how different groups of people perceive climate information, form judgments, and act.

3.2 Institutional Barriers

Institutional barriers to the strengthening of existing interdisciplinary work are well known. Conventional academic departments, organized along disciplinary lines, are both a blessing and a curse. In their disciplinary orientation they encourage depth of analysis, pushing back the frontiers of the individual field whether it be ocean dynamics, plant biology or economic modeling. But by their laser-like focus on problems in the field they dampen incentives to devote work to topics on the boundaries. The disciplinary journals, at once the arbiters of scientific advance and the key to academic advancement, are major players in this process.

This fact about research, particularly as conducted in academic institutions, leads to other observations about conditions that are helpful if not essential to bringing the best minds to interdisciplinary work. One key requirement is a problem definition that provides a mutual intellectual challenge—one that cannot be successfully attacked by any one discipline alone. Even if such a common challenge is defined, however, top researchers often will resist being diverted completely from their home disciplines. Thus the interdisciplinary work also needs to offer opportunities for contribution to the individual's home field and journals. At least in the academic context, then, the institutional problem of effective interdisciplinary work is to a large degree an intellectual one as well. Problems need to be formulated in ways that attract the needed talent, and standards need to be maintained as to what constitutes quality work in the interdisciplinary domain.

Of course, university departments are not the only sources of work on climate issues. In most countries, government agencies, laboratories and their contractors are the channels for most of the human and financial resources devoted to climate research. Indeed, these agencies often are the funding sources for most of the university-based work. No doubt the disciplinary imperatives apply also here to some degree. In these agencies, moreover, the wide scope of the climate change issue comes again into play as a barrier to integrated work. In normal government organization (using the US as an example) the regulatory and price-incentive policies that might be part of any climate response are spread across one set of agencies (Environmental Protection Agency, Treasury); the major sources of emissions are covered by another set (Agriculture, Transport, Energy, Federal Energy Regulatory Commission); and the major sources of climate research include these agencies, plus several others (National Science Foundation, National Atmospheric and Space Administration, National Oceanographic and Atmospheric Administration). In a recent effort to prepare a strategic plan for US climate science research, over a dozen federal agencies were involved [*US CCSP*, 2003]. Naturally, each has its turf to protect.

As suggested earlier, progress has been made in developing institutions that can integrate the natural science of the atmosphere, oceans and terrestrial biosphere. Unfortunately, despite the efforts cited earlier it has proved more difficult to link this work with analysis critical to public decision about emissions control, adaptation, and research direction. In part the difficulty originates in features already noted: the gulf in terminology and modeling methods is greater than among the natural sciences alone, and the funding agencies are yet more fragmented. But there is yet another source of difficulty. Climate change has become highly charged politically, and existing governments—who are the source of the bulk of the funding—often have policies not only regarding the appropriate policy response but also about the acceptable description of the threat and topics for investigation. The problems that this environment creates for work on human-climate interaction are subtle but important. Some scientists resist bringing their work too close to the human-climate frontier, with its political entanglements, because they fear their efforts will be diverted to what they view as unfruitful areas of work. Even more pernicious is the worry that areas of investigation will be closed off, or at least not encouraged, because they raise issues that have already been decided as a matter of government policy. The concern of individual scientists and research institutions for their reputations, and a long tradition of free inquiry in many countries, are a bulwark against these pressures, but they are nonetheless inevitable in connection with such a contentious social issue.

In an attempt to achieve greater integration, analysis centers have been created in several European countries (with both national and EU funding), in Japan and elsewhere, and they often involve participation by the major climate modeling centers. Although such efforts have a long history in some countries (e.g., the Netherlands), much of this development is relatively new and results are yet to be seen, particularly regarding the integration of policy economics and other social and behavioral science inputs. The same holds for the US where a number of integrated analysis groups are active, some with ties to the federally sponsored climate modeling centers. However, for an issue where the co-evolution of climate learning and policy development is so crucial the level integrated work is inadequate. The Strategic Plan for the US Climate Science Research Program, completed in July 2003, devotes some attention to integration of the type discussed here, under its focus on "decision support" [*US CCSP*, 2003]. Institutional means adequate to achieve this objective remain to be formulated, however. Given the fragmented nature of the disciplines, the large number of agency interests involved, and the high level of political disagreement about the policy response that is warranted at this time, it should be no surprise that the task is so difficult.

4. CLOSING THOUGHTS

As this volume is being prepared the nations are focused on short-term issues including the implementation of Annex B commitments under the Kyoto Protocol, the continuing debate over US policy, and the search for ways to encourage deeper involvement by developing countries. In this discussion, and in the inputs to the process by the IPCC and other assessment efforts, it is discouraging how little effective integration has been attained between the natural sciences and social and behavioral science and policy analysis. However, it should always be kept in mind that climate is a century scale problem, and society is just at the start of an effort to mount a sustained, well-calibrated response. Over and over in the decades to come, nations and sub-national decision makers will revisit their decisions about emissions mitigation (including aid to less developed countries), anticipatory adaptation, and research priorities—at each point seeking guidance from integrated assessments of the then current state of knowledge. An important task today is to create the institutional structure that can facilitate these needed inputs to public and private choice.

Considering the complexity of the human-climate issues illustrated above, and the difficulties in achieving the needed integration of talents and approaches, three suggestions come to mind regarding the organization of this work. First, there is need for a flexible capability to integrate the needed climate science with social and behavioral inputs to studies of different aspects of the climate change issue. Building interdisciplinary teams and carrying out such research and analysis requires years of work, and yet at any one time we do not know what issues will prove most important five or ten years hence. This situation calls for the support of a diverse set of efforts, at least in the research phase, applying a variety of methods. By the same token, it argues against the construction of single, dominant national centers, that attempt to encompass all the needed integrated work in one place or under one organization.

Second, it is important to keep as clear a distinction as possible between the needed research and integrated assessment of policy issues on the one hand, and close-in decision support on the other. All nations use some form of short-term "policy shop" activity to help inform leaders at the point of political decision. It is an essential function, although the institutional form differs substantially from country to country; depending on the circumstance it may be sought from consultants, government laboratories, agency staff, etc. Because of their proximity to political choice, one should always expect that assessments carried out under these conditions will be subject to guidance on the problem definition and the options that can be considered. Moreover, such assessments usually will be on a very short time schedule, as they usually are called into being only when decisions are at hand. From the discussion above of the intellectual and institutional barriers, it can be seen that political direction and a short time scale practically insure that serious integration of natural and social/behavioral science components will not take place.

To achieve the needed joint work, then, research groups need to be created and sustained that are insulated from the short-term political pressures that likely will characterize this issue for the foreseeable future. In some countries it is possible to maintain this type of independence within government agencies and laboratories, and in others not. In keeping with the argument above for diversity, large countries like the US, Japan or major European nations, or the EU itself, can reduce the pressures on any one group by sustaining several. The inputs to short-term decision can then be drawn from them as appropriate by a separate activity for this purpose.

Finally, there is the issue of the funding and organization of the more research-oriented of these two functions. As introduced in the discussion surrounding Figure 1, the extension of modeling and assessment activity outside the conventional boundaries of climate science, to include ecological and societal components, is a much more difficult task than the earlier integration of air chemistry and meteorology, oceanography, and terrestrial biology. Even worse, in some governments (including the US) there is no institutional champion for the integration. To some degree this may be because of a lack of separation between the close-in decision support and policy relevant research; to some degree it may simply reflect the fact that too many governmental agencies have a stake in the problem and in research directed to their particular focus. Solution of these problems thus requires leadership and sustained attention at the highest national level. Given the long-term nature of the issue, it is a goal worth pursuing.

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