CHAPTER FOUR

DECISION SUPPORT RESOURCES

from the

Strategic Plan for the Climate Change Science Program

By the agencies and staff of the
US Climate Change Science Program

Review draft dated 11 November 2002

Contents

US Climate Change Science Program
1717 Pennsylvania Ave., NW
Suite 250
Washington, DC 20006
Tel: +1 202 223 6262
Fax: +1 202 223 3065

11 November 2002

Dear Colleague,

The Climate Change Science Program will hold the U.S. Climate Change Science Program Planning Workshop for Scientists and Stakeholders at the Marriott Wardman Park Hotel in Washington, D.C., from 3-5 December 2002. The purpose of the Workshop is to provide a comprehensive review of the discussion draft of the Strategic Plan for U.S. climate change and global change research. This Workshop will offer extensive opportunities for the scientific and stakeholder communities to provide comment and input to the Climate Change Science Program Strategic Plan. When finalized by April 2003, the Strategic Plan will provide the principal guidance for U.S. climate change and global change research during the next several years, subject to revisions as appropriate to respond to newly developed information and decision support tools.

We are writing to request your comments on the discussion draft of the Climate Change Science Program Strategic Plan. Comments on all elements of the plan from all communities are essential in order to improve the plan and identify gaps. In your review, we ask you to provide a perspective on the content, implications, and challenges outlined in the plan as well as suggestions for any alternate approaches you wish to have considered, and the types of climate and global change information required by policy makers and resource managers. We also ask that you comment on any inconsistencies within or across chapters, and omissions of important topics. For any shortcomings that you note in the draft, please propose specific remedies. To participate in the review it is not necessary that you review the entire plan.

We ask that comments be submitted by E-mail to <comments@climatescience.gov>. All comments submitted by 13 January 2003 will be posted on the <http://www.climatescience.gov> website for public review. While we are unable to promised detailed responses to individual comments, we confirm that all submitted comments will be given consideration during the development of the final version of the Strategic Plan.

Attached to this letter are instructions and format guidelines for submitting review comments. Following the instructions will ensure that your comments are properly processed and given appropriate consideration. If you wish to distribute copies of the plan to colleagues to participate in the review, please provide them with a copy of this letter as well as the attached instructions and format guidelines. We have posted the plan on the workshop website at <http://www.climatescience.gov>. PDF files for individual chapters of the plan can be downloaded from this site. If you have any questions, please contact: Sandy MacCracken at 1-202-419-3483 (voice), 1-202-223-3065 (fax), or via the address in the footer below.

We appreciate your contribution of time and expertise to this review, and look forward to your response.

Sincerely,

James R. Mahoney, Ph.D.
Assistant Secretary of Commerce for Oceans and Atmosphere, and
Director, U.S. Climate Change Science Program

Instructions For Submission of Strategic Plan Review Comments

Thank you for participating in the review process. Please follow the instructions for preparing and submitting your review. Using the format guidance described below will facilitate our processing of reviewer comments and assure that your comments are given appropriate consideration. An example of the format is also provided. Comments are due by **13 January, 2003**.

- Select the chapter(s) or sections of chapters which you wish to review. It is not necessary that you review the entire plan. In your comments, please consider the following issues:
  - **Overview**: overview on the content, implications, and challenges outlined in the plan;
  - **Agreement/Disagreement**: areas of agreement and disagreement, as appropriate;
  - **Suggestions**: suggestions for alternative approaches, if appropriate;
  - **Inconsistencies**: inconsistencies within or across chapters;
  - **Omissions**: omissions of important topics;
  - **Remedies**: specific remedies for identified shortcomings of the draft plan;
  - **Stakeholder climate information**: type of climate and global change information required by representative groups;
  - **Other:** other comments not covered above.
- Please do not comment on grammar, spelling, or punctuation. Professional copy editing will correct deficiencies in these areas for the final draft.
- Use the format guidance that follows for organizing your comments.
- Submit your comments by email to <comments@climatescience.gov> by 13 January, 2003.

Format Guidance for Comments

Please provide background information about yourself on the first page of your comments: your name(s), organization(s), area of expertise(s), mailing address(es), telephone and fax numbers, and email address(es).

- Overview comments on the chapter should follow your background information and should be numbered.
- Comments that are specific to particular pages, paragraphs or lines of the chapter should follow your overview comments and should identify the page and line numbers to which they apply.
- Comments that refer to a table or figure should identify the table or figure number. In the case of tables, please also identify the row and column to which the comment refers.
- Order your comments sequentially by page and line number.
- At the end of each comment, please insert your name and affiliation.

Format Example for Comments

I. Background Information

Name(s): John Doe
Organization(s): University College
Mailing Address(es): 101 1st Street, New York, New York, 10001
Phone (s): 800-555-5555
Fax(es): 800-555-6666
E-mail(s): John.Doe@univ.edu
Area of Expertise: Atmospheric Composition

II. Overview Comments on Chapter 5: Atmospheric Composition

First Overview Comment: (Comment)
Reviewer's name, affiliation: John Doe, University College

Second Overview Comment: (Comment)
Reviewer's name, affiliation: John Doe, University College

III. Specific Comments on Chapter 5: Atmospheric Composition

Page 57, Line 5: (Comment)
John Doe, University College

Page 58, Line 32 - Page 59, Line 5: (Comment)
John Doe, University College

Table 1-4, Row 3, Column 6: (Comment)
John Doe, University College

Please send comments by email to <comments@climatescience.gov>

Foreword

In February 2002 President George W. Bush announced the formation of a new management structure, the Climate Change Science Program (CCSP), to coordinate and direct the US research efforts in the areas of climate and global change. These research efforts include the US Global Change Research Program (USGCRP) authorized by the Global Change Research Act of 1990, and the Climate Change Research Initiative (CCRI) launched by the President in June 2001 to reduce significant uncertainties in climate science, improve global climate observing systems, and develop resources to support policymaking and resource management.

The President's Climate Change Research Initiative was launched to provide a distinct focus to the 13-year old Global Change Research Program. The CCRI focus is defined by a group of uncertainties about the global climate system that have been identified by policymakers and analyzed by the National Research Council in a 2001 report requested by the Administration.

The Climate Change Science Program aims to balance the near-term (2- to 4-year) focus of the CCRI with the breadth of the USGCRP, pursuing accelerated development of answers to the scientific aspects of key climate policy issues while continuing to seek advances in the knowledge of the physical, biological and chemical processes that influence the Earth system.

This *discussion draft* strategic plan has been prepared by the thirteen federal agencies participating in the CCSP, with input from a large number of scientific steering groups and coordination by the CCSP staff under the leadership of Dr. Richard H. Moss, to provide a vehicle to facilitate comments and suggestions by the scientific and stakeholder communities interested in climate and global change issues.

We welcome comments on this draft plan by all interested persons. Comments may be provided during the US Climate Change Science Program Planning Workshop for Scientists and Stakeholders being held in Washington, DC on December 3 – 5, 2002, and during a subsequent public comment period extending to January 13, 2003. Information about the Workshop and the written comment opportunities is available on the web site www.climatescience.gov. A specially formed committee of the National Research Council is also reviewing this draft plan, and will provide its analysis of the plan, the workshop and the written comments received after the workshop. A final version of the strategic plan, setting a path for the next few years of research under the CCSP, will be published by April 2003. We appreciate your assistance with this important process.

James R. Mahoney, Ph.D.
Assistant Secretary of Commerce for Oceans and Atmosphere, and
Director, Climate Change Science Program

Table of Contents
of the
Strategic Plan for the Climate Change Science Program

CHAPTER 4

DECISION SUPPORT RESOURCES

This chapter's contents…

1. Evaluations and syntheses for policy analysis and operational resource management
2. Analytical techniques for serving decision need
3. Applied climate modeling
4. Resources for risk analysis and decisionmaking under uncertainty

The Climate Change Research Initiative (CCRI) will synthesize the results of the research conducted by the Climate Change Science Program (CCSP) to present critical information to decisionmakers and resource managers both within and outside of the US Government. Decisionmakers, as defined here, engage in the development of national policy such as setting national goals for greenhouse gas emissions and negotiating with other countries over international agreements. Along with resource managers in different regions and sectors, decisionmakers also are engaged in policy, planning, and operational decisionmaking issues related to the management and allocation of natural resources and the associated physical infrastructure. The science and decision support activities sponsored by the CCSP are designed to provide critical information about a number of the decisions and natural resource issues affected by climate variability and change. One major key element of the CCRI is the ongoing engagement of scientists, decisionmakers, resource managers, and other stakeholders in identifying issues and questions, and providing data and products that include characterizations of uncertainties and the level of confidence associated with this information.

One of the principal motivations behind the CCRI is enhancing the CCSP commitment to synthesizing scientific results and producing decision support resources responsive to national and regional needs. Decision support resources include a wide variety of mechanisms for creating and supporting a dialogue between scientists and decisionmakers to identify issues and questions of concern, and for framing the research agenda needed to answer the questions. They also include a variety of analytical techniques, including historical data analysis, scenarios, and applied climate modeling, that serve decisionmakers, and product development that arises from the strong interaction between the science and decisionmaking needs.

One component of the CCRI will focus on national-level challenges associated closely with the mitigation issues (improving understanding of the costs and benefits of particular strategies for reducing emissions) associated with long-term global climate change. In a parallel effort, the CCRI will accelerate the development of a structure and process for integrating science with decision processes to assist the development of regional and sectoral adaptation responses (actions to reduce vulnerability, seize opportunities, and enhance resilience) to variability and long-term changes in climate. These two efforts complement and reinforce each other with lessons learned about how the process of synthesizing and analyzing scientific information can inform policy and operational decisions. Although the actual process of making policy and resource management decisions should remain entirely separate from the research function, the establishment of a new class of working relationships will ensure that the sponsored research is well informed by an understanding of what information is timely and useful for decisionmakers, resource managers, and other stakeholders. Research will provide a continually stronger foundation to help decisionmakers evaluate the suite of alternative policy options and operational strategies.

This section of the Strategic Plan describes activities intended to initiate innovation in decision support resources that are particularly relevant to the driving forces and effects of climate change at a national and regional level, recognizing the need for continued progress in basic climate science questions. Because climate is not the only variable component in the decisionmaking process, and societal challenges rarely reveal themselves as neat, single-issue topics, this initial focus is nested within a commitment to integrate across temporal scales, spatial scales, and multiple effects (both positive and negative).

The following sections lay the groundwork for building decision support into the CCSP: the incorporation of science-based decision support research including scenario development; applied climate modeling; and the development and application of improved methods for dealing with scientific uncertainty in the decision process.

1. Evaluations and syntheses for policy analysis and operational resource management

For the last decade, the primary focus of the development of climate change science information at the national level has been in response to the debate on energy policy. At issue was whether human-induced climate change could be so significant as to require immediate and steep reductions in fossil fuel emissions. The main constraint on any such reductions has been the desire to maintain modern living standards by preserving the ability to serve the energy needs of a growing economy with diverse economic sectors in the context of evolving societal values. Issues central to the debate have included distinguishing between natural climate variability and human-induced climate change; the adequacy of observations to determine climate variability and change; the reliability of climate modeling; and the prediction of the immediate costs and possible benefits of mitigation options.

The CCRI will initiate a process to identify policy decisions that should influence the focus of climate change research programs. It will be important to consider likely future policy decisions, because there can be lag time in the delivery of research results. This process will include meetings with current and past decisionmakers. The resulting articulation of potential policy questions will serve as a foundation for the subsequent decision support activities. One goal is to expand the range of decisions from an emphasis primarily on energy policy to a broader agenda that includes greenhouse gases and pollution other than carbon dioxide (CO_2), emissions that result from land use (particularly deforestation and the cultivation of certain crops), and the management of other resources and decisions at a regional level. Examples of other broad policy arenas that require science-based climate information are agriculture, water resources, air quality, forestry, wildfire management, public health, and foreign aid.

The importance of climate change and variability lies in its impacts on natural resources, the economy, human health, and ecosystem sustainability. Some regions, sectors, and assets will be more vulnerable and some more resilient to climate variability and change, and taking steps to seize opportunities or identify particularly vulnerable assets and enhance their resilience will help ensure economic productivity and the well being of citizens and the environment. Decisionmakers who operate in the resource management arena are confronted with an array of influences that impact their decisions, and these must be considered in work done under the CCRI. Climate variability and change, demographic change, land use, laws, and public values are only a few of the inputs into their decision processes. In addition, they are required to make decisions on a range of time scales from a day-to-day operational perspective to a longer-term planning perspective.

The climate science issues that have emerged over the last decade that have been raised by these decisionmakers include concerns about contradictions in, and the coarse spatial scale of, information on climate change from global climate models, and the lack of availability of useful and effective climate observations and products for use in their decision processes. Regional- and local-scale analyses of potential climate impacts are limited by the fact that currently available model projections are not reliable at the smaller scales that are required for these analyses. However, regional- and sectoral- scale climate diagnostics and analyses, in cases where they prove to be accurate, can be and have been used effectively in regional decisionmaking contexts, creating an important demand for the provision of useful observational products and data.

One goal of the decision-support efforts of the CCRI is to identify national-level decisions and to use that list to develop decision support activities as well as to help prioritize climate change research. A second goal is to articulate and expand upon our understanding of the role of climate in human affairs such that science-based information can be synthesized, analyzed, and incorporated meaningfully into policy analysis and operational resource management.

Research projects that contribute to decision support will be supported under CCSP. These research projects benefit from the results of the US Global Change Research Program (USGCRP) research efforts discussed in Chapters 5-11. Links will also be made to the reporting and outreach activities

(Chapter 13) and to international research cooperation (Chapter 14). The CCRI will provide a means for synthesizing, analyzing, and evaluating scientific results that will provide supporting information for policymaking and operational resource management processes.

IDENTIFICATION OF DECISION ISSUES AT THE NATIONAL LEVEL

The type of issues requiring decisions at the national level for which information about long-term global climate change is relevant has evolved considerably in recent years. The CCRI will attempt to establish mechanisms to foster a new class of working relationships to ensure that relevant issues are identified, articulated, and communicated to the research community. This task is understood to be a particularly challenging one, where decisions for which science-based information will be useful will be a subset of a broader range of decisions. Accomplishing a productive and effective relationship among researchers, federal research managers, and policy specialists will require new working arrangements. The CCRI will devote attention to the type of institutional changes necessary to forge effective interaction between research processes and policy development.

For policy development related to mitigation, it will be difficult to generate a true representation of salient decisions. Over the last several years there has been an interest in issues as diverse as estimating the costs and impacts of concentration paths over time; costs and benefits of various stabilized atmospheric concentrations; priorities for technology R&D; evaluating regulatory instruments; analyzing uncertainties; analyzing the role of the United States with respect to the rest of the world; analyzing which gases to control and how to trade off certain greenhouse gases versus others; the connection of greenhouse gas emissions to other pollutants, such as aerosols; assessing impacts from possible climate change at a local level; high-consequence but low-probability events; and others.

Stakeholder interaction will be essential to the task of identifying decision issues at the national level, but managing this interaction will be a different type of experience than it has been at the regional level, where researchers have spent the last several years learning how to interact with resource managers and local planners. Certain sectors, such as energy, technology development, or international disaster management, are obvious candidates for exploring how to build improved stakeholder relationships. Many of the decision alternatives in these particular areas will be amenable to the "If…, then…" paradigm that uses the scenarios described in the next section.

DECISION SUPPORT RESOURCES FOR REGIONAL RESOURCE MANAGEMENT

The general approach for accelerating and enhancing decision support for regional resource management will be based on the following framework:

- Identification of regions, sectors, and decisionmakers that would most benefit from improved global change information.
- Development of indicators for assessing vulnerability and/or opportunities.
- Research to improve knowledge of global and regional changes.

- Development of data, information, analytic resources, and models to facilitate risk assessment given remaining uncertainties.
- Investigation of how to disseminate information and assist users in evaluating options.
- Promotion of sustained interactions between the scientific community and stakeholders to judiciously apply such knowledge to inform decisionmaking.

Resource managers are challenged every day by the need to make decisions despite the existence of scientific uncertainties and the inability of scientists to begin to make absolute predictions about future outcomes. Through the USGCRP, a sustained relationship between investigators and decisionmakers has been nurtured to create the basis for developing a shared understanding of the general potential for and nature of risk and benefit, and extracting from scientific findings the information to begin to support decisionmaking within a context of managing risk. Through regional and sector-specific research, investigators will continue to work closely with decisionmakers and resource managers to identify the level of certainty required for different decision contexts, and mechanisms for best communicating the uncertainties, which may include acknowledging that it may not be possible to provide meaningful information at the required level of certainty.

A major value of the regional resource management component is in deriving insights from "lessons learned" about how science can be integrated effectively into the operational decisionmaking process and, to the extent possible, into policy analysis and development. This activity involves the analysis of information from multiple disciplines—including the social and economic areas—to address the specific questions being asked by resource managers and other stakeholders. It also includes an analysis of adaptation options to improve society's ability to respond effectively to risks and opportunities as they emerge. Based on the regional and sector-specific research that has been conducted over the last decade, preliminary target areas for accelerated research that will be considered include air quality; water availability and quality; forest and wildfire management; drought; and public health.

PRODUCTS AND PAYOFFS

- Further development of formal mechanisms to establish and perpetuate working relationships between the research and decisionmaker communities to ensure that research and assessments will address the specific issues of concern to the decisionmakers. The decisionmaker/researcher interaction will be evaluated and documented and used to identify needed improvements in decision support resources.
- Selection of a set of potential policy questions that require information support from the climate change community through a stakeholder/scientist interactive dialogue. These issues and the resulting policy-relevant science questions will influence the development of scenarios (6 months).
- Establishment of a consultative process between agency managers, investigators, and key partners in one or more of the target areas to identify the key resource management problems, resulting research questions, needed observational data, and appropriate methods of communicating and using scientific uncertainty in the decisionmaking context.

- Analysis of historical records in the target areas to gain a better understanding of past and current climate, as well as future climate, in order to provide services and design infrastructure to more effectively adapt to future changes.

2. Analytical techniques for serving decision need

LINKING RESEARCH TO DECISIONMAKING

"Decision support" refers to the provision of timely and useful information that addresses specific questions being asked by a decisionmaker. It could be a question that is pertinent to any of a full range of issues related to climate change, including adaptation, the management of resources in the face of scientific uncertainty, mitigation, or technology development. For example, a national-scale question addressing emissions might be framed as, "What are the economic consequences—costs and benefits—associated with the adoption of an emissions goal framed in terms of percentage reductions against a specified base year emissions level?" Alternatively, it might be framed on the regional or local scale to address adaptation questions, such as: "How could water resources be managed if winter snow melt shifts to an earlier time of year?"

Techniques that serve to articulate research findings in ways that resonate with decisionmakers and that incorporate parameters important from their perspective are a key part of the CCRI commitment to build and sustain productive, appropriate interaction between research and action. A variety of resources and approaches are being used to explore the possible range of consequences of climate change, including historical records; integrated assessment models; synthesis, analysis, and presentation of scientific conclusions for incorporation into existing decisionmaking frameworks; communication and outreach processes to policymakers; and sensitivity and "If…, then…" analyses. Although all of these contain sometimes profound uncertainties, their use can provide existing information for decisionmakers, resource managers, and other stakeholders.

METHODS FOR ANALYZING CLIMATE IMPACTS

A variety of methods are available for illustrating and analyzing how fluctuations in climate influence social, economic, and ecological systems, including:

- **Historic records.** Data and records from the past provide an essential perspective on how changes in climate affect human and natural systems. Analyzing variations such as warming; increases in precipitation; decade-long droughts; and reductions in the extent of snow cover, and their effects on human and natural systems, provides important insights into how vulnerable or resilient these systems may be in the future. The need for improved information on such variations, particularly at regional and local scales, is one of the highest priorities for users of climate information.
- **Sensitivity analyses.** "If…, then…" and sensitivity analyses will also be used to determine under what conditions and to what degree a system is sensitive to change. Sensitivity analyses help to identify the degree of climate change that would cause

significant impacts to natural and human systems, i.e., how vulnerable and adaptable these systems are. Such analyses are not predictions that such changes will, in fact, occur. Rather, they examine what the implications would be if the specified changes did occur. For example, an analyst might ask, "How much would temperature have to rise to cause a specified impact?"

- **Climate projections.** Climate model projections are another tool for understanding what future climate might be like, to the extent of their scientific credibility and our ability to develop quantitative statements about levels of confidence. Once again, these projections will not be viewed as specific predictions or forecasts of future outcomes, but rather as probabilistic alternative futures that "paint a picture" of what might happen under particular assumptions. They provide a starting point for investigating questions about an uncertain future and for visualizing alternative futures in concrete and human terms. Using scenarios helps to identify vulnerabilities and opportunities, and to explore potential response strategies. However, it is important to recognize that in some cases the state of knowledge about potential consequences of climate change may not be sufficient to support any climate impacts modeling. Regional- and local-scale analyses of potential climate impacts are limited by the fact that currently available model projections of shorter-term trends over the smaller scales that are required for these analyses are much less reliable than the model projections of continental-scale and century-long trends that are currently available. In fact, different model projections are at times contradictory, a symptom of the unreliability of regional-scale projections at this time.
- **Consultative processes and conceptual models.** Briefings, forums, workshops, and other forms of engagement between researchers and stakeholders, when managed and sustained, have the effect of eliciting information over time and through iteration that enrich the research and increase the likelihood that research will contribute to improved decisionmaking. Methods and products that are "co-produced" have the highest likelihood of application. Products such as "decision calendars" that integrate the worldview of resource managers in a given sector with the natural cycle of the climate system have served to enlighten both researchers and resource managers. At the same time, research must be independent of particular policy agendas in order to remain free of bias.
- **Integrated quantitative and qualitative information for refined decision products.** Climate information can be incorporated into existing sector-based (e.g., agriculture, reservoir management, wildfire management, etc.) and policy analysis/management models such that the potential effects on productivity or particular outcomes can be analyzed. Use of existing models sensitive to institutional realities offers the advantage of identifying moments where climate information is most relevant to planning, budget cycles, early warning systems, or profit maximization and efficient use of resources. Results that offer outcomes expressed in terms of probabilistic distributions of expected events can contribute to decision analysis and assessment of risk in particular settings.

One of the most productive areas for combined research and assessment activities is in building frameworks that integrate component models in response to a well-articulated decision need or "problem" focus. Knowing in advance the concerns of relevant decisionmakers, researchers and other professionals are beginning to refine the techniques necessary to customize model-based and statistical climate information; tailor outputs for consistency with hydrologic, ecological, or other information; and analyze outcomes within the parameters of decision need. Advances made in these types of aggregations of systems would afford new insights into understanding thresholds relevant to climate that are unique to various sectors. These activities also hold important potential for advancing analysis of multi-factor stresses, and can be applied to questions surrounding water resources, wildfire and agricultural management, and carbon sequestration strategies.

SCENARIO DEVELOPMENT

For many decision alternatives, an "If…, then…" analysis enabled by scenarios can be performed that provides information to a decisionmaker. Assuming a particular action is taken, the analysis predicts the consequences of that action. Scenarios play a key role in the decisionmaking process by providing the opportunity to explore options against a variety of alternative possible backgrounds. The term "scenario," as used here, refers to any description of the world as it might evolve or be made to evolve in response to decisions. The goal of the CCRI scenarios activity is to develop, maintain, and enhance the capability to answer "If…, then…" questions relevant to the full range of climate change decisionmaking, from the management of resources to the formation of national and international policy. The activity will seek to ensure that a balanced approach is taken that maintains objectivity and avoids focusing on "worst-case analysis" alone.

Scenarios provide a vehicle for *posing and analyzing* questions, for example, "What if the United States adopts an emissions goal?" The question as framed above, however, is insufficiently specified. It lacks detail. For example, no mechanism by which the goal might be attained is specified. Further, there is no description of areas of concern, such as the effectiveness of the limitations in environmental terms; the impact on jobs, Gross Domestic Product, the economic health of important economic sectors and regions of the country, and international trade; the implications for energy and national security; and the effects on ecosystem goods and services. Decisionmakers and stakeholders, through interactions with researchers, can provide the necessary level of specificity and may together create a better list than either could separately generate. All scenarios start with information originating outside the system in question, contain some description of the system of interest, and provide a mechanism for evaluating a variety of approaches that may be employed.

Scenario development techniques abound, and range from qualitative approaches to formal computer models. Models link statements about key external factors, such as population growth and migration; the abundance and availability of resources; market structure; energy cost and use; international trade; and technology deployment, through algorithms that attempt to capture their relationships. Some scenario development techniques may combine both qualitative and modeling approaches, similar to gaming exercises that provide computer models for role-playing. The Intergovernmental Panel on Climate Change (IPCC) has made extensive use of scenarios to drive climate models, although the model outputs have seen limited use in studying the impacts of climate change. Other qualitative and quantitative scenarios have been used extensively in controversial assessments of the potential consequences of climate change for particular sectors and regions in the United States. The development of scenarios also makes possible potentially fruitful communications with other important policy realms such as the National Climate Change Technology Initiative (NCCTI).

RESEARCH APPROACHES

Research is essential to every part of the scenario process. Scenarios will require the acquisition and synthesis of knowledge about factors that lie both within and outside of the processes in question, including economic growth; energy supply and demand; land use; agricultural practices; ecosystem characterization; and the characterization of the cryosphere, hydrosphere, ocean, and atmosphere. Models of such processes can be extremely detailed, with some requiring extensive time (weeks) on the fastest available computers. It is important to realize that the nature of the question being asked by the decisionmaker, as well as the level of scientific certainty required, influence the construction of the scenario and the type of modeling undertaken.

CCRI scenario development will go beyond past scenario activities such as those of the IPCC. Decisionmakers, resource managers, and other stakeholders will be engaged to help identify the types of scenarios that could be used to provide them with timely and useful information. The CCRI will develop logical and internally consistent scenarios with input from the full range of relevant stakeholders, which potentially include environmental non-governmental organizations (NGOs), industry representatives, natural resource managers, government agencies, and research scientists. It will undertake independent analysis to extract up-to-date information on projections for key variables (e.g., demography; technology characteristics and costs; and economic growth and characteristics) and the relationship of key driving forces to environmental change (e.g., land use and land cover) and adaptive capacity. The CCRI will coordinate its scenario development plans with the new IPCC scenario efforts. The IPCC may be interested in adopting some of the CCRI scenarios or combining CCRI and IPCC efforts.

PRODUCTS AND PAYOFFS

- A new stakeholder-oriented process for ongoing identification of questions relevant to decisionmakers, and scenarios that could be used to address these questions, will be in place. This component of the program will incorporate the most up-to-date scientific information about socio-economic, climatic, and environmental factors. Modeling, integrated analysis, and reporting of results will also be supported.
- A specific set of scenarios that can be used to address relevant policy and resource management questions—at the national, regional, and sectoral levels—will be developed in collaboration with stakeholders (2 years). The scenarios will be used as

input to integrated assessment and other region- and sector-specific impacts models, which will evaluate the consequences of the different scenarios. Reports summarizing insights relevant to the questions posed by the decisionmakers and regional/sectoral resource managers, along with an analysis of the uncertainty, will be written (2 years). Additional reports will summarize the results of more extensive efforts using integrated assessment models linked with natural resource decisionmaking models and the implications for development of risk-management options for resource management and national climate change policy (4 years). A final report on the state of the art of scenarios will be written.

- Integrated assessment models will be improved both in skill and breadth of coverage in order to realistically represent an increased number of actions and consequences important to the decision process.

3. Applied climate modeling

INTRODUCTION

Climate models have been a central part of the US climate program since the 1970's. Models are an essential tool for synthesizing observations, theory, and experimental results to investigate how the Earth system works and how it is affected by human activities. Such models can be used in both a retrospective sense, to test the accuracy of modeled changes in Earth system forcing and response by comparing model results with observations of past change, and in a prognostic sense, for calculating the response of the Earth system to projected future forcing. For the CCSP, we need to consider a subset of the broad domain of climate modeling, in particular those specific tasks that can provide near-term information products to inform management and policy decisions involving climate. This is the area of Applied Climate Modeling. It provides the means for translating the scenarios described in the preceding section into the decision support resources.

There are a number of obstacles facing the application of the best of US capability in climate science to these critical applied modeling issues. The NRC (2001b) found that when comparing US and European high-end modeling, the United States is still lagging in its ability to rapidly produce accurate high-resolution model runs. In addition, there is a need to increase confidence in model results and expand their immediate utility for decision support. These considerations prompt several priority directions for Applied Climate Modeling.

IDENTIFY, QUANTIFY AND SYSTEMATICALLY REDUCE UNCERTAINTY IN CLIMATE MODEL PROJECTIONS

Sensitivity Comparisons

Climate sensitivity is a measure of the climate's response to a unit change in radiative forcing due, for example, to changing atmospheric concentrations of greenhouse gases. It accounts for a major part of the uncertainties in climate projections. The current crop of world-class climate models exhibits an unacceptably large range in climate sensitivity. The major US models that have been used for IPCC scenario assessments—the Community Climate System Model (CCSM), operated at the National Center for Atmospheric Research, and the model developed at the Geophysical Fluid Dynamics Laboratory (GFDL)—lie close to the opposite ends of this range, making them ideal resources for investigating the processes and assumptions responsible for uncertainty in sensitivity.

All current climate models fail to adequately simulate several climate system processes and their feedbacks. One example of such a process is ocean mixing, which to a large degree controls the rate of projected global warming. Atmospheric convection, hydrologic processes, and representation of clouds, all of which strongly influence the magnitude and geographical distributions of global warming, are also poorly simulated. These deficiencies are thought to be related to the large range of climate sensitivity and contribute significantly to model uncertainties. High-priority research will focus on representations in models of the relevant physical feedback processes, using available observational data and, where required, new field observations. This work will enable focused model comparisons to understand the reasons for differences in climate sensitivities. Products will include new knowledge about important climate feedback processes and their improved representation in climate models, potentially leading to a significant reduction in known uncertainties in climate projections. Particular attention will be devoted to cloud/water vapor processes, as described in Chapter 2 (see also Chapter 6).

Characterize and Reduce Key Uncertainties

It will be important to identify the one or two largest sources of uncertainty in feedback processes currently represented in climate models, determine the causes of the uncertainty, and improve the physical representation of those processes in the models. Comparing model simulations and observations indicates that the major problems are generic, affecting all climate models. Climate Process Teams (CPT), a new approach to focused research designed to more rapidly reduce known uncertainties in climate model projections, will conduct the research. The teams of climate process researchers, observing system specialists, and modelers will work in partnership with multiple modeling centers (see also Chapter 6).

Enhance Model Credibility through a Formal Program of Model Testing

In moving towards the development of a more operational applied climate modeling capability, it is necessary that models be put through a more rigorous program of testing than has been the case to date. For weather prediction, such testing is straightforward: information on the accuracy of the forecast is immediately available, and statistics can be generated. For applied climate modeling, such immediate feedback is impossible. It is necessary, as climate modeling moves beyond the research domain, that models be formally tested against specific observational data sets. This needs to be done with sufficient care and fidelity to detect small differences in future climate trajectories. The observations must have tight tolerances for accuracy, sampling protocols, data availability, and cost, and must meet the criteria for long-term stable climate records, as described in Chapter 3. Lastly, there must be a formally reviewed assessment of models' performance, both against these specialized data sets and against each other. The testing program would have four particular components:

- **Testing against the climate record.**
  Model outputs have long been compared to the global average temperature record, with notable successes. But given the number of parameterizations in high-end climate models, it is not clear that that this comparison is sensitive enough (i.e., models might be getting the right answers for the wrong reasons). This implies a need for consistent, climate-quality analyzed fields for the climate record of the 20th century with a particular focus on the last 25 years (for which satellite observations are available) so that models can be tested against such parameters as precipitation and ocean heat content. A periodically repeated reanalysis of the climate record is required, in order to incorporate new and recovered observational data and recent modeling advances. A particular need is for a full exploitation of the satellite data record. The operational satellite archives must be reprocessed to fully exploit their potential and properly test model forecasts. But the operational archives by themselves are insufficient and must be supplemented by current and planned research instruments (EOS, TRMM, CloudSat) that target key climate feedback processes. Lastly, particular attention must be given to the climate forcing data sets used to drive climate models. These data sets are themselves the source of considerable uncertainty, and their ranges of uncertainty must be identified.

  It is also critical that models be tested against the paleoclimatic record. It is not clear that the 20th century will be representative of the future state of the Earth's climate. Models must be able to represent past states of the climate system as seen in the paleoclimatic record in order to project future states. Paleoclimate proxy data must be used in the routine model evaluation process.

  With regard to the climate record, one of the central areas of controversy has been the difference between the surface and tropospheric temperature records. To provide insight into the nature of this difference, a series of model runs will be carried out focusing on surface and tropospheric temperatures and the processes that may lead to their differences. This effort must be coupled with improved analysis of the observational record and improved observing systems and techniques to remove potential future biases.

- **Testing against specialized data sets.**
  In addition to testing models against the climate record in general, there are specialized data sets that may be of particular use in isolating climate feedbacks and their representation in models. There is a need for an innovative and disciplined comparison strategy to connect details of the specialized, consistent observations to the structure of the forecast model. For example, because radiative feedbacks from clouds and water vapor are the primary contributors to the uncertainty in climate model forecasts, any

strategy to improve climate forecasts must test both the integrated global response of the model as well as the individual feedback processes that ultimately determine the response. Specialized data sets are required to first test simulations of feedback processes using simple and/or individual component models (e.g., cloud processes using atmospheric single column models). Data assimilation methods can also be used to examine process representation in models, as has been done successfully in global aerosol modeling. The more demanding and definitive tests must be conducted using the fully coupled climate system model.

Both branches of this strategy—individual component processes and integrated response—require either new data sets or an improved interface with existing data sets.

More generally, there is a need for specific climate benchmark records to provide absolute values of key measurements for testing climate models. Such benchmark records would consist of a limited number of carefully selected measurements focusing specifically on climate forcing and response. A focus on accuracy, with measurements tied to laboratory standards, is a key characteristic. Current examples of benchmark measures include sea level altimetry, solar irradiance, and atmospheric CO_2 measurements. Prospective benchmark observations would include ground and space-based GPS radio wave refraction, which is a direct function of atmospheric density variations, and spectrally-resolved absolute radiances to space.

- **Sensitivity to unresolved ocean processes.**
  Of particular note among the key uncertainties in climate change modeling is the role of the ocean. Because of computer resolution, none of the current coupled climate models resolve the small ocean eddies (with horizontal scales of tens of kilometers) that constitute the dominant scale of oceanic variability. These eddies are thought to play a substantial role in regulating oceanic heat transport (via boundary currents) and heat and carbon storage by regulating transport to deep water. A series of eddy-resolving global ocean sensitivity studies are required to assess how well the parameterizations in current climate models portray the ocean's sensitivity to forcing. In addition, such studies will be used to assess whether the role of marginal sea processes in determining the properties of the dominant ocean water masses and in driving the thermohaline circulation are captured well by the primary coupled climate models.

- **Ability to simulate major modes of climate variability.**
  Another major area of climate model testing concerns the ability of models to simulate known modes of climate variability such as the El Niño-Southern Oscillation (ENSO), the Arctic Oscillation (AO), the Pacific Decadal Oscillation (PDO), and monsoon systems. The research base examining these is detailed in Chapter 6. While these modes of variability by their nature may not be predictable, it is nonetheless necessary that models simulate their amplitudes and frequency structure. If a model does not have a realistic ENSO cycle present, for example, it calls into question the fundamental

dynamics of the predictive system. For this reason, verification against data sets produced by the climate variability research community is a fundamental aspect of climate model testing.

PRODUCTS AND PAYOFFS

As a near-term product, a critical comparison of the model sensitivity of major US models will be undertaken by the major modeling centers (1-1.5 years), followed by publication of a reviewed interim report (3 years). Considerable progress has been made already, as the modeling and diagnostics communities are developing scientific and protocol plans for examining differences between models, as well as differences between models and observations.

CLIMATE CHANGE IN RESPONSE TO SPECIFIED EMISSIONS SCENARIOS AND NATURAL FORCINGS

One of the highest priority applications of climate modeling is the development of new, state of the art projections of the impact on global climate resulting from different scenarios of greenhouse gas emissions. As described in the previous section, well-developed scenarios are essential vehicles for asking the central "If…, then…" questions. These scenarios must consider potential economic changes, possible changes in energy sources, and suites of potential new technologies, along with possible environmental changes which may themselves act as agents of climate change. Analysis of uncertainties will be included as part of the scenario exercise.

PRODUCTS AND PAYOFFS

- **Sets of ensemble global simulations projecting possible climate change at continental and regional scales from various emissions scenarios.** Using these scenarios as input conditions, climate model runs will be generated for research, assessment, and policy applications for the United States (3 years). These ensemble model runs then form the basis for regional analyses, potentially using downscaling techniques (see Chapter 6). The CCRI will coordinate with the IPCC in determining what scenarios to run. It is important that the CCRI modeling plans take into consideration, and work in the context of, international efforts (see Chapter 14).

- **North American scenarios for short-lived species: tropospheric ozone, sulfur-based and black carbon aerosols, and methane.** As described in Chapter 5, the CCSP will furnish a set of scenarios, with uncertainties, that will link potential changes in North American pollutant precursor emissions to resulting changes in the radiative forcing of climate change (4 years). With these radiative-forcing scenarios as part of the input, simulations of potential future climate changes can include a meaningfully broader set of possibilities and hence options.

STRENGTHENING US APPLIED MODELING CAPABILITY

Several recent NRC reports have documented the need to strengthen US modeling capability. In response, a number of steps will be taken to enhance the US climate modeling capability:

- **Two Center Strategy.**
  The US contributions to the IPCC's century-long scenario runs and assessments will be primarily accomplished by the high-end models developed at two complementary high-end modeling centers. The first, the Community Climate System Model (CCSM), operated at the National Center for Atmospheric Research, is an open and accessible modeling system that integrates basic knowledge from the broad, multi-disciplinary basic research community for research and applications. The second model, developed at the Geophysical Fluid Dynamics Laboratory (GFDL), benefits from these community interactions and will focus on model product generation for research, assessments, and policy applications as its principal activity. The success of these two endeavors depends on modeling of specific aspects or sub-components of the climate system conducted by multiple US laboratories and universities.

- **Common Modeling Infrastructure**.
  To optimize modeling resources and enable meaningful collaborations among modelers, it is necessary to build common and flexible infrastructure at our major modeling centers. By adopting common coding standards and system software, researchers will be able to test ideas at any of the several major modeling centers and the centers themselves will be able to easily exchange parameterizations as well as entire modules so that each benefits from the other's work. Products will include more efficient and rapid transfer of research results into model applications.

- **Access to Computational Capability.**
  To improve the effectiveness of the US climate modeling effort, enhanced and stable computational resources should be focused on modeling activities, including climate variability and predictability on seasonal to centennial time scales; national and international climate projections and assessments of anthropogenic climate change; regional impacts of climate change; assimilation of carbon data; and national and international ozone assessments. These activities will require a substantial increase in US computational capability in the form of dedicated machine time for climate model runs.

4. Resources for risk analysis and decisionmaking under uncertainty

Decisionmaking associated with climate change and variability can be viewed as a subset of a larger class of problems that involve decisionmaking under uncertainty. Decisions are made and public policy is developed in many areas other than climate change that involve uncertainties, such as terrorism and genetic engineering. Although each of these issues is associated with its own unique set of factors, they all involve the need to understand longer-term risks for systems where there are many variables, each of which interacts with the others in complex, often nonlinear ways. Fruitful lines of inquiry include many different approaches, such as game theory, preference elicitation, and decision sequencing.

Advancement of theory, approaches, and resources to improve decisionmaking associated with climate change and variability will take a variety of forms. New paradigms will be needed to better integrate the variable spatial, temporal, and organizational scales at which interconnected natural and human systems function. New approaches are needed to conceptualize problems and to obtain and analyze relevant data from a diverse set of sources. New resources need to be created that combine improved operational capabilities with more effective user interfaces, thereby making them more readily useful to decisionmakers and other stakeholders. These resources will require integration of the latest advances in information systems technology with statistical advances, such as visualization and stochastic modeling. Also needed are the development and deployment of more effective forms of communication to facilitate broader dissemination and implementation of scientific insights and information to a broad range of end users.

PRODUCTS AND PAYOFFS

An accelerated fundamental research program will be put in place to develop applications of existing capabilities to the issues of uncertainty in the climate change decisionmaking context as well as to the robust analysis of risk and vulnerability of natural resource systems. Additional research programs will focus on the development of new resources for addressing scientific uncertainty in decisionmaking.

References:

NRC, 2001b. Panel on Improving the Effectiveness of U.S. Climate Modeling, Board on Atmospheric Sciences and Climate, National Research Council, *Improving the Effectiveness of U.S. Climate Modeling* (Washington, DC: National Academy Press).

Authors and Contributors

PART I. THE CLIMATE CHANGE RESEARCH INITIATIVE (CCRI)

Chapter 4. Decision Support Resources

Lead Authors

Susan Avery, CIRES and CCSP
Tom Baerwald, NSF
Jae Edmonds, PNL
Jay Fein, NSF
David Goodrich, NOAA
John Houghton, DOE
David Legler, CLIVAR
Richard Moss, CCSP
Claudia Nierenberg, NOAA
Joel Scheraga, EPA

Contributors

Kris Ebi, EPRI
Harvey Hill, NOAA
Ants Leetmaa, NOAA
Linda Mearns, NCAR
Granger Morgan, Carnegie Mellon University
John Weyant, Stanford
Tom Wigley, NCAR