CHAPTER 12

GRAND CHALLENGES IN MODELING, OBSERVATIONS, AND INFORMATION SYSTEMS

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

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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 <u>identify the page and line number</u>s 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
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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

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of the
Strategic Plan for the Climate Change Science Program

CHAPTER 12

GRAND CHALLENGES IN MODELING, OBSERVATIONS, AND INFORMATION SYSTEMS

This chapter's contents…

1. Observations
2. Modeling capabilities
3. Data and Information Management

Research into the basic processes of global environmental change provides the foundation of knowledge required to improve projections and understand the consequences of interacting stresses on natural resources and human activities. However, the seven research elements described in Part II cannot meet the Climate Change Science Program (CCSP) objective for the coming decade. Even the first part of the objective—extending knowledge of the Earth system and improving projections of global change at scales relevant to decisionmaking—cannot be met without more extensive integration, regional synthesis, advances in modeling capabilities, and sustained commitment to observations and data information systems.

Observations, modeling, and data and information dissemination have been thought of as crosscutting, "enabling" activities since the US Global Change Research Program's (USGCRP) inception—hence these are already tightly coupled to the seven research elements. These are needs that are particular to a given research area and must be planned and implemented in close association with the research that they support or draw on. However, they also need to be managed in a focused manner because they provide essential infrastructure that must serve multiple purposes within the CCSP—enabling fundamental research, as well as supporting assessment and decisionmaking—and because they depend on the distributed assets of CCSP agencies, some of which were originally developed to serve other needs.

These activities are of the highest priority for the CCSP. Because of their crosscutting nature, these capabilities are also particularly challenging to foster. The sections that follow outline new objectives and approaches that will improve CCSP implementation of these areas and contribute to the evolution of the program into one that successfully integrates research and responds to the needs of the next decade.

1. Observations

The study of global change requires a strong base of observations. The Global Change Research Act of 1990 specifically calls for "global measurements, establishing worldwide observations necessary to understand the physical, chemical, and biological processes responsible for changes in the Earth system on all relevant spatial and time scales," as well as "documentation of global change, including the development of mechanisms for recording changes that will actually occur in the Earth system over the coming decades." The program continues to respond to this call by following a strategy to address observations on appropriate space and time scales. The strategy includes guiding principles, identification of priorities, and effective management of available resources.

The development of new space-based global observing capabilities was a primary focus of the program's first decade. Several new Earth-observing satellites—including TOPEX/POSEIDON, Jason-1, TRMM, QuikSCAT, SeaWiFS, EOS-Terra, EOS-Aqua, and Landsat-7—are now producing unprecedented amounts of high-quality global data for the research community and other users, and new data from satellites soon to be launched are not far behind. There have also been advances in programs that provide additional important data for global change research such as the Global Climate Observing System (GCOS) Surface Network (GSN), the Tropical Atmosphere-Ocean moored array (TAO), Argo, the Joint Global Ocean Flux Study, the Global Terrestrial Network for Permafrost (GTN-P), and the Ameriflux network. Many new ground-based and ocean observing technologies have also been developed and demonstrated.

Yet despite these major achievements, many serious observing-system challenges remain for the CCSP. Several fundamental challenges for the next decade include:

- Completing the development and deployment of systematic space-based and *in situ* global climate and ocean observing components that are needed for long-term climate change research and the accurate characterization of global change and its causes and consequences.
- Implementation of observing systems, such as a terrestrial observing system to obtain crucial climate measurements related to carbon cycles, surface hydrology (including precipitation, evaporation, runoff, stream-flow, and soil moisture), ecosystems, and the cryosphere (including snow cover, glaciers, and permafrost).
- Regular assessment of and response to the observational priorities of the program's research elements and the scientific community.
- Establishment of a linkage between observation and assimilation technology and between surface and space-borne sensors with regular whole-atmosphere column measurements made from the ground and especially suborbital platforms.
- Development of a comprehensive system integrating remote sensing and *in situ* measurements designed to observe the Earth's climate change and climate variability.

- Development of explorer class satellite observations to measure missing variables in order to enhance discovery and improve understanding of climate processes.
- Continuous improvement of state-of-the-art measurements within the atmosphere (on aircraft and/or balloons) to validate the new space-borne measurement capabilities, to supply essential information not obtainable from space or surface networks.
- Long-term investment in the maintenance of our terrestrial, ocean, and atmosphere observing systems.
- Developing more effective cooperation with operational observing programs that are not part of the CCSP, including high-level agreements and a process for effective transition of research measurements to operational status.
- International cooperation.

OBSERVATIONAL PRIORITIES

A range of observational requirements are identified in the CCSP research elements described in Part II of this plan, including both existing measurement programs that must be maintained and enhanced, and new measurements that must be initiated (see box). A key lesson learned over the past decade is that observing systems and networks must be implemented in a way that allows flexibility as both requirements and technology evolve. Therefore, the program will regularly assess the evolving science requirements and priorities and propose modifications to the observing systems that are required for the CCSP to execute its research plans. This process must involve the scientific community and program managers working on each research element, as well as those involved in modeling, scientific assessment, and other integrative activities.

Observational Priorities in CCSP Program Elements

Atmospheric Composition (Chapter 5)

- Continue global observation of ozone distribution and trends, and a representative sample of source, reservoir, and tracer molecules that govern stratospheric chemistry.
- Develop and implement global observations of aerosol distribution and properties.
- Improve surface-, aircraft-, and space-based measurements of global and regional troposphere pollutants, and atmospheric chemistry.

Climate Variability and Change (Chapter 6)

- Maintain and improve long-term space-based and *in situ* observations of temperature, humidity, wind strength and direction, clouds, precipitation, pressure, sea ice, snow cover, glaciers, and ice sheets.
- Develop and maintain an Integrated Ocean Observing System, combining *in situ* and satellite observations, to monitor ocean topography and circulation, heat content, salinity, sea level, and ocean-atmosphere exchange of momentum, heat, and freshwater.
- Maintain and improve space-based and *in situ* measurements of key climate forcings (greenhouse gases, aerosols, solar radiation, and land cover change)

Water Cycle (Chapter 7)

- Develop and maintain the continuity and consistency of climate-quality observations of atmospheric temperature, water vapor, and clouds by operational environmental satellites.
- Develop and implement space-based global measurements of precipitation, continental soil moisture, soil freezing/thawing, and snow accumulation.
- Maintain and expand surface-based operational measurements of precipitation, soil moisture, snow accumulation, river discharge, groundwater levels, water chemistry, and other hydrologic variables.
- Develop and implement systematic regional hydrologic, climate, and radiation measurement test beds, and advanced technologies involving ground based remote sensing and water isotope analysis.

Land Use and Land Cover Change (Chapter 8)

- Maintain high-resolution observations of rapid changes in global land cover and land use.
- Maintain the research quality of long-term, global observations of land cover and land use at low and moderate resolution through the transition to operational observing systems.
- Develop *in situ* ecosystem observations and the collection of relevant local and regional socioeconomic data.
- Improve links between ground-based and remote-sensing land use and land

management data systems.
- Maintain and expand a research program to evaluate the utility of existing and planned sensing systems to assess their utility for land use/land cover change applications.

Carbon Cycle (Chapter 9)
- Strengthen and ensure the continuity of continental inventories of forests, other ecosystems, and major land uses, and derived estimates of soil carbon storage.
- Continue and enhance a national carbon dioxide (CO_2) flux measurement network that covers all major ecosystem types, and promote the development of a worldwide network of cooperating sites.
- Strengthen and ensure the continuity of global oceanic chlorophyll observations, and derived estimates of oceanic primary productivity and carbon budget.
- Strengthen and ensure the continuity of surface-based measurement of ocean carbon and air-sea carbon flux.

Ecosystems (Chapter 10)
- Expand age, size, and vertical structure measurements of forests with known management histories.
- Develop satellite remote sensing capabilities to determine terrestrial ecosystem productivity.
- Increase collection of ground truth data at Long Term Ecological Research and similar sites in all major natural and managed ecosystem types.

The National Research Council (NRC) has specified six attributes of the Earth's climate system that are especially important to society: (1) precipitation and water availability, (2) temperature, (3) storms, (4) solar radiation, (5) sea level, and (6) ecosystem structure and functioning. Developing a better understanding of natural and human-induced climate changes is dependent on accurate long-term measurements of the mean state or condition, variability over time scales, geographic variability, and the frequency and persistence of extreme values of each of these variables. The CCSP has expanded this initial inventory to encompass the needs of research on and applications to the global cycles of carbon, water and biogeochemical constituents, atmospheric composition, and changes in land use. The need to characterize the vulnerability and resilience of society and of natural and managed ecosystems to change, and thus to develop a more complete understanding of the potential impacts of global change, adds yet another dimension to observational requirements.

Observing systems are currently in place within both research and operational programs that partially fulfill the requirements for meeting these objectives. Other key sensors and observing networks still need to be developed and implemented. Priorities for these augmentations will be determined by the scientific needs of the research elements and a set of agreed criteria (see box). The management of the program will recommend these augmentations in consultation with the scientific community. The continued development and deployment of new technology that can improve the accuracy and lower the costs of space-based observing systems and suborbital measurements (i.e., those within the atmosphere, at Earth's surface, and below it) is also critical. Careful calibration and overlapping operation of new and old technology during transitions is a necessity for maintaining the quality control of data records.

Observing System Prioritization Criteria

The following prioritization criteria should be considered in selecting CCSP observing program initiatives:

- **Scientific Return:** significance of the expected increase in fundamental knowledge.
- **Benefit to Society:** extent to which the outcome may be utilized for great societal benefit.
- **Mandated Programs:** support of programs mandated by law.
- **Partnership Opportunities:** the extent to which needed work can be carried out with partners in the United States and abroad.
- **Technology Readiness:** the extent to which current technology enables a question to be productively addressed.
- **Program Balance:** distribution of resources to ensure scientific progress is not impeded by the lack of key information.

Integration and transition of experimental and operational systems

There is an immediate need to work with US Government agencies to prevent the further deterioration of operational observing systems that provide essential data for global change research. In some cases, it may be cost effective to invest in stabilizing and upgrading existing operational systems rather than in the creation of new systems. In other cases, the transition of proven research systems to operational status may help fill both operational and research requirements in a more cost effective way. More effective integration of the planning and development of research and operational systems will benefit both communities.

A Global Observing System

The need for dedicated observing systems for climate change research is well established, and the CCSP is poised to assist agencies to build on the successful deployment of many elements of such systems over the last five years. Thus a near-term priority for the program is augmentation of existing observations to initiate the Global Climate Observing System (GCOS), as described in Chapter 3. There is a clear consensus on a core set of long-term measurement requirements for GCOS, many of which are parts of existing operational observing systems and many of which need to become parts of operational systems. A system to meet requirements for long-term continuous data must be coupled with ongoing opportunities, such as explorer satellites, to initiate shorter-term measurements of key processes and forcing factors. The major near-term challenge is to seek every opportunity to improve and maintain the coverage, quality, and consistency of land, ocean, and atmosphere measurements to complement the research observation capabilities that have been initiated by the USGCRP in the past and new capabilities developed over the next decade. Additionally, provisions must be made for observations that do not necessarily require continuity, e.g. monitoring changes of ice sheets and glaciers over time. Such observations, which must be particularly well calibrated, differ from many others in that they do not directly feed into routine climate-related models and do not fit the "transition to operational" paradigm. They are necessary, however, for addressing critical elements of the CCSP plan.

Opportunities for international collaboration

The creation of US networks is a valuable step in creating an observing system; however the overarching need is for *global* networks and systems. The CCSP will continue to support the international development of the Integrated Global Observing Strategy, and the Global Climate, Ocean, and Terrestrial Observing Systems. As the largest supporter of global change research and observations, the United States has a special responsibility to lead the development of an integrated global Earth observing system, but this task cannot be accomplished without active international support and participation. The CCSP will continue or expand efforts to assist and support developing nations in improving their observing networks.

The Road Forward

It is the responsibility of the CCSP to ensure that decisions on the implementation and maintenance of important space-based and in situ observing system components are based primarily on scientific needs. However, many important observing systems are developed and operated by organizations that are not formal participants in the CCSP, making the development of strong cooperative relationships that extend beyond the current CCSP a necessity. The CCSP will work with observing system partners and the scientific community to identify requirements and set priorities in light of available resources and competing needs, in order to develop the observing system priorities identified in the table “Observational Priorities in CCSP Program Elements.” Near-term CCSP observing system objectives include:

- **Stabilize existing observational capabilities.** Maintain and improve basic data center archives and research observing facilities, networks, and systems (both space-based and *in situ*), including extension of the moored, drifting, and ship-based networks to all oceans.
- **Identify and implement critical measurement improvements.** Maintain a sustained research and development program to address major deficiencies in observing systems (e.g., missing carbon sinks, closing the budgets of the regional and global water cycles, and integrating the coastal ocean monitoring systems). To the extent possible, new observational capabilities should be integrated into existing networks so as to minimize redundant operations and costs.
- **Incorporate climate and global change observing requirements in operational programs at the appropriate level.** Operational observation networks continue to be the backbone of climate measurements. These networks, with only modest incremental costs,

could satisfy significant parts of the climate observing requirements. Providing essential additional research capability to operational observing systems, and continuing to improve mechanisms for transition of research and experimental observing systems to operational platforms, are both important.

- **Continue intensive field missions.** Integrate airborne (*in situ*), surface, and satellite observations over regional scales and durations from days to several weeks. These intensive observation periods provide valuable data for testing and validating satellite retrieval algorithms, and for the fine scale resolution necessary to test, validate, and constrain climate models. These coordinated observation efforts will need to become even more sophisticated as satellites evolve towards formation flying, onboard processing, and smart sensor technology.
- **Continue a vigorous program in data reanalysis to ensure the time consistency and spatial homogeneity of global change data sets.** Fully exploit the information value of historical data series using the latest technologies, quality control and assurance, and processing methodologies. This involves continuing mining of historical records.

2. Modeling capabilities

Modeling is one of the most important components of the CCSP. 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. Models provide the only quantitative means to integrate scientific understanding of the many components of the climate system and, thus, are the only tools available for making quantitative projections. Comprehensive climate models represent the major components of the climate system (atmosphere, oceans, land surface, cryosphere, and biosphere) and the transfer of water, energy, organic chemicals, and mass among them, but are still in their formative stages. Comprehensive climate models are complex and require "high-end" computer resources to run.

The current organizational structure of the US modeling effort has not fully supported the product-driven modeling that is especially important for making climate model information more usable and applicable to the broader global change research community. The NRC (1999b and 2001b) reports provide valuable guidance on how to improve US climate modeling efforts. They emphasize:

- The recognized US leadership in basic climate science research;
- The shortcomings of US efforts to integrate the basic climate research into a comprehensive climate modeling capability;
- The challenges, including software, hardware, human resources, and management issues, of routinely producing comprehensive climate modeling products; and most importantly,

- The need to establish a dedicated capability for comprehensive climate modeling activities, including the global climate observations and data that underpin them.

In the next decade, the CCSP modeling component must expand beyond the simulation and prediction of the physical climate system to include the complex and interrelated nature of the many processes that make up the Earth system, including dynamic ecosystems and biogeochemistry. Previously, the focus in model development has been primarily on the largest spatial scales (especially global). It is clear that many emerging modeling needs, especially for predictive applications, are at the regional scales at which most societal and environmental resource decisions are made. It is thus increasingly important that models have the capacity to integrate across the multiple components and processes needed to describe the Earth system in sufficient complexity, while simultaneously providing reliable information on increasingly refined spatial scales. In addition, the computational capability, software, and model physics must be developed to allow for model resolutions at the smaller scales that support regional decisions. These are two immense challenges. Over the long term, the CCSP must define a path that leads from comprehensive climate modeling as a research activity alone to the point where it can routinely produce high quality, but standard products, on demand. Further, the CCSP must guarantee that a productive partnership is maintained between product-driven modeling activities and the discovery-driven modeling research program that will underpin its credibility and future success.

The CCSP strategy envisions two complementary climate-modeling activities. The first will be principally a research activity. It will maintain strong ties to the research communities in both global change and computational science to incorporate new knowledge rapidly into a comprehensive climate and Earth-system modeling capability. Although the mission of this activity is research, it will be "product driven" in the sense that it must make models and model products available to the broader community. Tightly connected research institutions with complementary areas of expertise can form the core of a distributed modeling program that maintains collaborations with perhaps hundreds of external contributors. Areas of research emphasis would include model development, computational science, and data assimilation.

Closely associated with the research activity, but distinct from it, will be a prediction capability responsible for sustained and timely delivery of model products that are required for assessment and other needs. This "quasi-operational" capability should maintain a research component that is an integral part of the research modeling activity described above. Additionally, the "quasi-operational" entity would be charged with producing, on demand, the required modeling products for policy analysis and assessment. This activity might include both operational forecasts of seasonal-to-interannual variability (e.g., El Niño-Southern Oscillation (ENSO)), because we can model these shorter-term variations at a level of skill appropriate to operations, as well as quasi-operational decadal- to centennial-scale modeling, because there are operational needs, such as scenario preparation for sensitivity studies of impacts, that we can meet with existing skill levels. The addition of product-driven model research to a strong base of discovery-driven research, together with strong links between them will result in a suite of

CCSP modeling activities that will better support and drive the interdisciplinary research objectives of the CCSP.

These two activities are complementary and both are required for a successful modeling program. They should both employ a common modeling framework and maintain constant interaction. Full implementation of such a strategy will take several years. Key to the success of the strategy are substantial and continuing investments in high-end computing, archival storage, collaboration technology, and associated information technology infrastructure.

The approach toward a having a comprehensive climate and Earth-system modeling capability will be to incorporate the modeling needs of the seven CCSP elements (see box).

1

Modeling Priorities and Linkages in CCSP Program Elements

Atmospheric Composition (Chapter 5)

- Carry out chemical transport modeling activities, with emphasis on cross-tropopause processes, the role of particles in accelerating ozone-loss chemistry, and stratospheric transport.
- Use models to describe the interactions of various types of aerosols and to estimate the net sign, magnitude, and uncertainty in the cooling–warming role of aerosols.
- Build and evaluate diagnostic/prognostic models of the coupled climate, chemistry/transport, and ecological systems (in collaboration with other elements of the program).

Climate Variability and Change (Chapter 6)

- Refined estimates of the role of climate feedback processes in affecting climate sensitivity and improvements in their representation in climate models.
- Predictions of regional patterns of different modes of climate variability.
- Improved predictions of ENSO, particularly the onset and decay phases, and assessment of potential predictability beyond ENSO, e.g., the Pacific Decadal Oscillation, the Arctic Oscillation, monsoons.
- An improved ability to separate the contributions of natural versus human-induced climate forcing to climate variations and change, resulting in more credible answers to "what if" policy-related questions.
- More advanced knowledge about the changes in natural variability that may result from anthropogenic forcing.
- Improved understanding of the primary natural and forced mechanisms for abrupt climate changes.
- Models of the full three-dimensional circulation of the global ocean.
- Time dependent models of ice sheet changes to assess underlying mechanisms and their contributions to future sea level rise.
- Climate monitoring and forecast capabilities for regional applications and risk reduction.

Water Cycle (Chapter 7)

- New parameterizations for water vapor, clouds, and precipitation processes for use in climate models, using new cloud-resolving models created in part as a result of field process studies.
- New models capable of simulating the feedbacks between the water cycle and the climate system (including biogeochemical cycles).
- Models that partition precipitation among surface and subsurface pathways, route flows, and quantify physical and chemical interactions for evaluating climate and pollution impacts.

- Integrated models of total water consumption for incorporation into decision support tools that identify water-scarce regions and efficient water use strategies.

Land Use and Land Cover Change (Chapter 8)

- Urban growth models.
- Identification of the regional components of a US land use and land cover change model.
- National- and global-scale land use and land cover change projection models.
- Climate models incorporating land use and land cover data.
- National- and global-scale models with a coupled climate-land use system.

Carbon Cycle (Chapter 9)

- Carbon cycle models including data assimilation customized for North America (developed under part I).
- Models of ocean carbon cycling based on linkages between carbon and nitrogen in coastal environments, and of ocean carbon sequestration that incorporate biogeochemistry, ocean circulation, and the potential impact on ecosystems.
- Global maps of carbon storage derived from model-based analysis of actual land cover (cooperative effort with the Land Cover element).
- Advanced carbon models that include the long-term effects of actual land use history and are able to simulate interannual variability at ecosystem and landscape scales.
- Improved projections of climate change forcings and quantification of dynamic feedbacks among the carbon cycle, human actions, and the climate system, with better estimates of uncertainty and errors, from prognostic carbon cycle models.

Ecosystems (Chapter 10)

- Spatially explicit ecosystem models at regional to global scales, based on data from experimental manipulations focused on the effect of interactions among global change variables, to improve our capacity to observe contemporary, historical, and long-term changes in ecosystem structure and functioning.
- Data and spatially explicit models for examining the impact of management and policy decisions on a wide range of ecosystems, to predict the efficacy and tradeoffs of management strategies at varying scales relevant to the decisions at hand.

Human Contributions and Responses to Environmental Change (Chapter 11)

- Development of integrated assessment models with the ability to analyze the effects of measures directed at the reduction of urban air pollution and greenhouse gas emissions.
- Development of integrated assessment models that introduce new energy and carbon sequestration technologies.
- Model-based simulation studies of the influence of social and economic factors on vulnerability and adaptive capacity in households, organizations, and communities.
- Analyses of the consequences of rapid climate changes in the past and the ability of

hazard and resource management institutions to respond to surprising shifts in climate and to seasonal forecasts.
- Model-based simulation studies of the influence of demographic, social, economic and climate change factors on the incidence and distribution of infectious diseases.

LINKAGES

The grand challenge modeling components will ultimately result in a multidisciplinary approach toward the Earth system climate model, which couples the chemical and ecological systems to atmospheric processes and incorporates:

- Reduced uncertainties such as ozone-layer responses to climate change and the role of aerosols in cooling and warming.
- Better prediction of modes of variability based on results from Chapters 4 and 6.
- Sensitivity analysis.
- Natural versus human-induced climate forcing.
- Land use and land cover parameterizations.
- Knowledge gained under Chapter 4 about important climate feedback processes and their improved representation in climate models will be applied, leading to significantly reduced uncertainties in climate projections.

Outcomes will span a wide range of options, such as sets of ensemble global simulations projecting possible climate change at continental and regional scales from various emissions scenarios; and comprehensive studies of greenhouse-relevant emissions and potential climate change that include carbon aerosols in an integrated assessment model and the appropriate specification of emissions, costs of control, and chemical and radiative characteristics of those aerosols.

3. Data and Information Management

Providing access to distributed and varied forms of data, products, and information is a central objective of CCSP data systems. Researchers, planners, and decisionmakers need seamless access to information produced not only by CCSP efforts, but also the larger scope of information produced by other federal, non-federal, regional, and international programs and activities. These users should be able to focus their attentions on the information content of the data, rather than how to find and access the data. The vision of the future CCSP system is one where the user experience will change fundamentally from the current process of locating, downloading, reformatting, and displaying to one of accessing information, browsing, and comparing data in the form of basic scientific graphics through a standard Web browser, GIS tools, and scientific visualization/analysis systems, without concern for data format, data location, and data volume.

This vision can only be achieved by harnessing advanced technologies and developing frameworks for interoperability between heterogeneous systems, which are part of a common collective. Such a framework, with established metadata and quality control/quality assurance standards, mechanisms of transport, protocols, and requirements, would permit federal and non-federal data and product providers to contribute their information to the common collective as well as allow users to query and access the system for relevant information. The system will call for each cooperating system to conform to such protocols enough to ensure that it will interface seamlessly with the overall climate information system thereby maintaining a distributed architecture.

Such a data management strategy is being pursued for the ocean observing system (i.e., Ocean.US) and holds great promise. Much of the technology required to make this vision a reality exists already; however, significant challenges remain that require short-term as well as strategic investments. The challenge to CCSP will be pursuing unprecedented levels of cooperation across current data management systems and programs and a commitment to mapping the future development and execution of a suitable strategic plan.

Opportunities lie ahead for the evolving data and information systems of the CCSP. Evolving new technologies for data collection and management, new science and applications, and new institutional and organizational possibilities indicate that a robust and open data and information system spanning the environmental and socioeconomic realms is achievable in the coming decade. This vision needs to incorporate careful attention to the need for continuity in global change data, for long-term data stewardship, and for equitable access across social or "digital" divides. The CCSP will need to provide leadership both within the US Government and across a diversity of partners to ensure that the Nation's global change data and information capabilities support the achievement of its 10-year objectives and the realization of their full potential benefits to the Nation and the world.

CHALLENGES

At present, data are not integrated, making them difficult for policymakers—and even scientists—to use. They are often not consistently calibrated in space or time to permit simple identification by site or scientifically sound integration of the multiple data sets needed for multidisciplinary research. Moreover, the US Government has limited resources to support long-term electronic data management beyond the life of individual investigators' projects or programs. Scientific data that are not institutionally managed are likely to vanish when the scientist-data collector turns to other projects or retires.

Ongoing advances in information technology will for the first time enable development of a distributed data and information system in which

- Data will be collected and managed in multiple locations, including federal, state, and local agencies, academic institutions, non-governmental organizations, and private companies. Long-term archiving of the data will be the responsibility of federal data centers;

- Users will be able to find and access these data via the Internet, utilizing sophisticated systems for data search and retrieval;
- New techniques for enabling interoperability between databases and data systems will not only support the needs of global change research but also practical applications related to environmental and resource management, disaster mitigation and emergency response, and other data-dependent activities; and
- Historical data are preserved through aggressive data rescue activities enabling a transfer of data from manuscripts and individual scientists to digital databases.

RESEARCH NEEDS

To advance these goals, the CCSP priorities will be to:

- Expand the current data management infrastructure, based on the strong foundation provided by existing distributed systems to:
  - Encompass the data centers established by federal science agencies, such as the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, Department of Energy, and US Geological Survey data centers.
  - Provide a means of identifying and using socioeconomic data collected by federal statistical agencies, such as the Census Bureau and the Bureau of Economic Affairs, by resource management agencies such as the US Army Corps of Engineers, the US Bureau of Reclamation, the US Bureau of Land Management, and the US Fish and Wildlife Service, and by state and local agencies. This socioeconomic data may need to be georeferenced and collected in ways to ensure that it is compatible on temporal and spatial scales with data collected in the physical and natural sciences so that integrated studies may be undertaken.
  - Include partnerships with foreign governments, intergovernmental agencies, and international scientific bodies and data networks to provide data that are needed to address the international character of research and decisionmaking.
- Continue to develop a framework to respond to the need for integration and communication of information across disciplines and among scientists and policymakers. Multi-agency and multidisciplinary institutional and data resources will be a part of the efforts to develop standards and processes for sound data management.
- Identify the data requirements of the program on a regular basis, including visualization, analysis, and modeling requirements.
- Identify and rescue data that are at risk of being lost due to either media deterioration or in the hands of data collectors who may retire or move to other projects.

PRODUCTS AND PAYOFFS

Requirements from the seven CCSP elements will be incorporated as part of the data and information management plan to provide products such as:

- Improved access to climate information and products for addressing regional concerns and issues. This includes both observations and model results.

- Beginning to identify the regions, sectors, and users who are using climate projections for management and policy decisions.
- Beginning to solicit the climate information requirements from the users.
- Reliable, commensurate data sets at the watershed scale that scientists from the several disciplines will use to examine critical water-Earth interactions for improved integrated watershed management.
- Determining what information is required by individuals, organizations, and governments to make better decisions regarding global environmental variability and change; including what individuals, organizations, and governments know (and do not know), including uncertainties, about the state of scientific knowledge regarding global environmental change

In the next five years the data management program will focus on improving the interoperability and usability of agency data sets by the various working groups and researchers. This includes:

- Establishing data and metadata documentation, standards, and formatting policies that will make possible the combined use of targeted data products taken at different times, by different means, and for different purposes.
- As funding is available, creating special, tailored portals for data products of interest and use by the various CCSP working groups. These portals will use the emerging web metadata clearinghouse technology to allow researchers to locate and access coincident data of interest from various observation systems.
- Implementing the national climate observing system architecture developed in Chapter 4.

LINKAGES

The focus of the CCSP plan is to advance our capability for understanding and predicting past, present, and future impacts of our changing climate. Every step in this process, from understanding the variability in climate change through the use of models and observations, to ensuring the continuance of quality long-term records, interpretation of the model and observation results, and communication of and access to these results for resource managers and decisionmakers will rely on the existence of a flexible, accessible, and user-friendly data and information system. The transfer of research information to policymakers and resource managers will require interactions between customers and data system managers including research and operational efforts, and close links to international programs such as the World Climate Research Programme and the International Geosphere-Biosphere Programme.

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