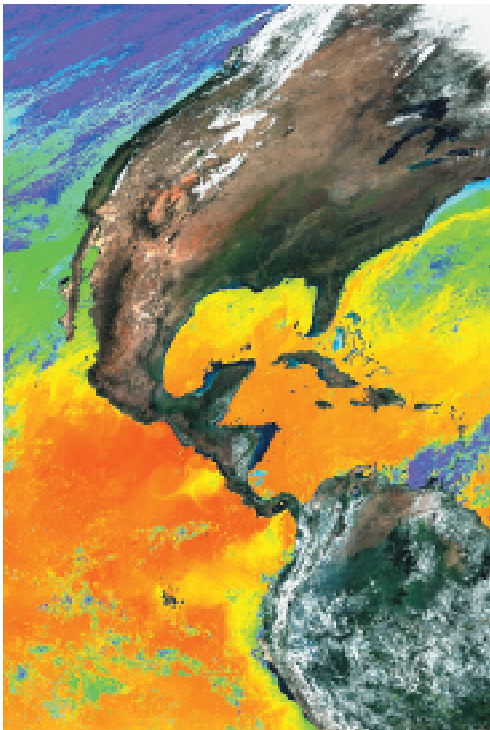
EXHIBIT M

Part 5

Pages 101 to 150

CHAPTER 10

Modeling Strategy



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Goal 2: Provide the infrastructure and capacity necessary to support a scientifically rigorous and responsive U.S. climate modeling activity.

Goal 3: Coordinate and accelerate climate modeling activities and provide relevant decision support information on a timely basis.

This chapter introduces goals and objectives intended to provide accelerated scientific improvements in climate and climate impact models responsive to the needs of the Climate Change Science Program's (CCSP) scientific research and decision support activities.

Models are essential tools for synthesizing observations, theory, and experimental results to investigate how the Earth system works and how it is affected by human activities. 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. Comprehensive climate system models provide the primary quantitative means to integrate scientific understanding of the many components of the climate system and, thus, are the principal tools available for making quantitative projections.

The CCSP modeling strategy consists of three goals: Improve the scientific basis of climate and climate impacts models; provide the infrastructure and capacity necessary to support a scientifically rigorous and responsive U.S. climate modeling activity; and coordinate and accelerate climate modeling activities and provide relevant decision support information on a timely basis. In order to achieve these goals, three modeling arenas will be implemented: (1) diverse and disparate research activities that represent new process understanding in models; (2) assimilation and integration efforts that employ new types of observations and tools and next-generation understanding and model coupling; and (3) "high-end" climate models run for scenarios required in periodic scientific assessments or to achieve higher resolutions.

The CCSP strategy envisions two complementary streams of climate modeling activities. The first is principally a research activity, which will maintain strong ties to the global change and computational science research communities to rapidly incorporate new knowledge into a comprehensive climate and Earth system modeling capability. Closely associated with the research activity, but distinct from it, will be the sustained and timely delivery of predictive model products that are required for assessments and other decision support needs. CCSP will ensure 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.

In his 11 June 2001 speech, the President asked his Administration to work to "develop state-of-the-art climate modeling that will help us better understand the causes and impacts of climate change." In response to this directive, the program is addressing the following overarching question:

> ***How can we most effectively accelerate the development, testing, and application of the best possible scientifically based climate and climate impact models to serve scientific research and decision support needs?***

Based on recommendations in National Research Council (NRC) reports on U.S. climate modeling (NRC, 1999b, 2001d), the CCSP agencies initiated new activities to strengthen the national climate modeling infrastructure. These activities will accelerate the delivery of improved model products that are especially important for making climate simulations, predictions, and projections more usable and applicable to the broader research, assessment, and policy communities (see Annex D for definitions of climate "prediction" and "projection"). The new activities form the basis of a longer term solution that will maintain the pace and progress of the basic research, while simultaneously creating a path for the rapid exploitation of new knowledge in model development, testing, and applications.

Goal 1: Improve the scientific basis of climate and climate impacts models.

Virtually all comprehensive climate models project a warmer Earth, an intensified hydrologic cycle, and rising sea level as consequences of increasing atmospheric concentrations of greenhouse gases. However, projections of the details about the magnitude, timing, and specific regional impacts and consequences are variable (IPCC, 2001a,b). The program is placing the highest priority on research aimed at addressing known modeling deficiencies (see Chapter 4, Question 4.1). The following objectives in pursuit of Goal 1 describe CCSP's long-term approach.

Objective 1.1: Accelerate research on climate forcing, responses, and feedbacks aimed at improving methods for quantifying and reducing uncertainties in the current generation of prediction and projection models

The climate system responds in complex ways to changes in forcing that may be natural (e.g., variations in the magnitude of solar radiation reaching the top of the atmosphere) or human-induced (e.g., changing atmospheric concentrations of greenhouse gases). Several of the program's science elements will provide climate modelers with the best scientific estimates of past and expected future climate forcing factors—for example, the Climate Variability and Change research element for solar variability; the Atmospheric Composition, Carbon Cycle, and Human Contributions and Responses research elements for radiatively active trace gases and aerosols; and the Land-Use/Land-Cover Change and Ecosystems research elements for land surface cover changes and energy exchanges.

The direct response of the climate to a change in forcing may be either diminished or amplified by feedback processes within the climate system itself. For example, warmer upper oceans will result in increased evaporation and, thus, increased concentrations of atmospheric water vapor—itself a strong greenhouse gas—a positive or amplifying feedback. Increased water vapor will alter cloudiness, which may be either a positive or a negative feedback, depending on the cloud height and type. Climate-induced changes at the land surface (e.g., through more intense and higher frequency droughts) may in turn feed back on the climate itself, for example, through changes in soil moisture, vegetation, radiative characteristics, and surface-atmosphere exchanges of water vapor.

Near-Term Priorities

- Because of the highly interdisciplinary and complex nature of climate processes in general, understanding and modeling feedbacks is a challenging research task. The program will give high priority to research conducted under the research elements aimed at understanding and modeling the most important known feedback processes (see Chapter 4, Question 4.1), with the goal of better quantifying and reducing uncertainties in climate predictions and projections.
- CCSP-supported climate modeling centers will work closely with scientists to use observations and research advances to improve modeling capability and provide more useful products for decision support. The knowledge transfer will be enabled and accelerated by **C**limate **P**rocess and Modeling **T**eams (CPTs), a new paradigm for CCSP climate modeling and applications research (CPTs are discussed later in this chapter and in Box 4-1).

Enhanced understanding and improved representation in models of the processes that influence climate will improve confidence in model forecasts and projections. Reductions in uncertainty will be measured by the degree to which differences between the major climate models as well as differences between observations and relevant model fields are reduced.

Objective 1.2: Develop the next generation of global climate models through the addition of more complete representations of coupled interactive atmospheric chemistry, terrestrial and marine ecosystems, biogeochemical cycling, and middle atmospheric processes

Past emphasis has been on the development and testing of physical aspects of coupled atmospheric and ocean general circulation models (GCMs). This occurred primarily because climate models have their roots in numerical weather prediction models (atmospheric GCMs with some ocean coupling that treat primarily physical processes), and the available observations were those derived for the application of weather prediction models. Significant advances have been achieved on the physical aspects of climate modeling, but much more research is required (see Chapter 4).

In the 1990s, motivated by unresolved questions about long-term climate change, modeling efforts expanded to include additional components of the climate system, such as chemistry and biology, that are important to longer term climate processes. Here too, much has been accomplished, but much remains to be done. In parallel with continued research into physical climate processes and modeling, the program will enhance efforts to more fully develop the chemical and biological components of climate models, including their human dimensions, in the context of a coupled interactive system, and also expand the atmospheric domain to include middle-atmosphere processes. This priority is motivated by the need to provide answers to pressing questions about long-term change and variability that may result from human-induced climate forcing involving chemical, biological, and human-induced processes.

Near-Term Priorities

- In the near term, work will concentrate on improved representations of aerosols, elements of the carbon cycle,

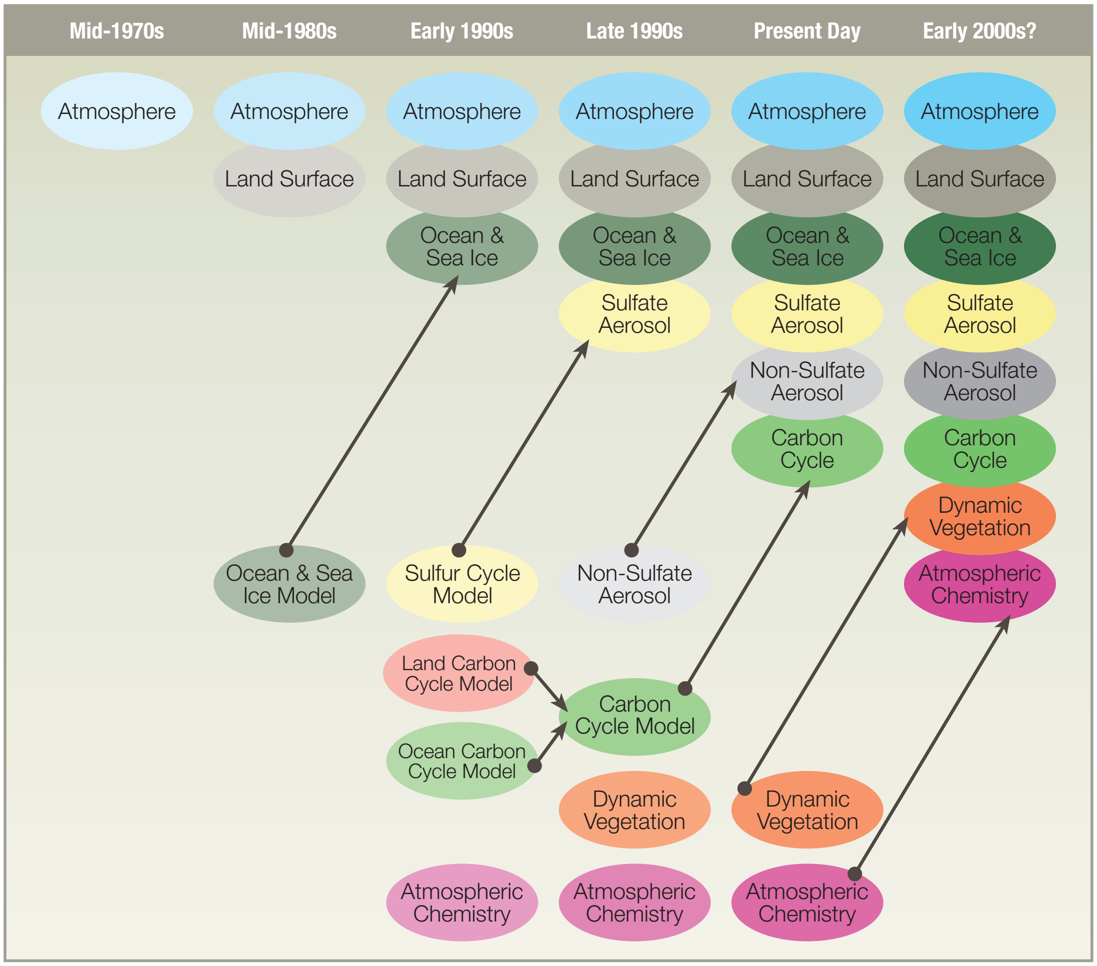

Figure 10-1: The development of climate models over the last 25 years showing how the different components are first developed separately and later coupled into comprehensive climate models. Source: IPCC (2001a).

interactive land surface-atmospheric processes, and middle-atmosphere dynamics and chemistry. This work will integrate research advances by the CCSP research elements (see Chapters 3-9). The products will be next-generation climate system models with enhanced capabilities to more comprehensively model the interactive physical, chemical, and biological components of the climate system. This work will continue over the longer term, leading to fully interactive Earth system models. For a more detailed description of research planned for one key next-generation climate system model, see the Community Climate System Model website, <http://www.ccsm.ucar.edu/management/sciplan2004-2008>.

The Role of the Middle Atmosphere in Climate

- The representation of the stratosphere will be improved in climate models, including feedbacks between stratospheric dynamics and stratospheric ozone, and between stratospheric dynamics and water vapor (see Chapter 4).
- CCSP will examine whether variations in solar irradiance can play a significant role in the natural variability of the climate system. Models will be developed that extend vertically through the mesosphere and include interactions between ultraviolet radiation, ozone chemistry, and atmospheric circulation and transports (see Chapters 3 and 4).

Interaction of Aerosols, Chemistry, Ecosystems, and Hydrology

- CCSP will develop the capability to model a fully interactive aerosol system within climate models, in order to examine the multi-faceted roles of aerosols in the climate system (see Chapters 3, 4 and 5).

Atmospheric Composition

- CCSP climate system models will be developed to include both tropospheric and stratospheric chemistry, chemical processes related to interactions at the Earth's surface, and interactions with hydrologic processes, in order to adequately represent the sources, sinks, and transformation processes of those molecules that are important for climate because of their ability to absorb and/or emit radiation and whose concentration and properties must be adequately simulated in climate models (see Chapter 3.)

Biogeochemistry and Ecosystems

- CCSP will develop the modeling tools and validation data sets for incorporating and assessing historical and future land use; the dynamics of managed forest, rangeland, agricultural, coastal, and ocean systems; and deliberate carbon sequestration activities (see Chapters 6-9).

High-Resolution Climate Model

- At present, there are two complementary approaches to modeling climate change and climate impacts at regional and sector scales. One approach uses a variety of "downscaling" techniques, ranging from nested mesoscale (regional scale) models to adaptable global grids (see Objective 1.6). The second approach is to increase the resolution of the global models themselves, throughout the entire global domain. The former approach is complicated by several unresolved issues, ranging from the effects of lateral boundary processes to conservation principles. The second approach is not practical without very large increases in computing capability. The CCSP strategy is to continue to support research in and applications of regional-scale climate models and other downscaling methods. On a smaller scale, the program will support pilot projects for next-generation very high-resolution global climate model development, in anticipation of continuing advances in computational technologies.

Climate models and observations are intimately connected, as described under Objectives 1.3-1.5 below. Models must be evaluated and constrained by observations, which also serve to initialize models used for prediction. Models provide a dynamically consistent framework into which diverse climate observations can be assimilated to produce "value-added" data sets of gridded, continuous time series of hybrid field observations and modeled data.

Objective 1.3: Foster model analysis and testing through model diagnostics and intercomparison activities, including comparison with observations

Given the complexity of climate models, it is difficult to ascertain why a particular model performs "better" or "worse" than others in any given situation. Generally speaking, a measure of a model's quality is its ability to simulate the current climate [global averages, annual cycle, major modes such as the El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO), etc.] and the climate of the past centuries (19th and 20th) as measured by available observations. Therefore, it is essential to carefully identify and document model deficiencies, such as systematic biases ("bias" refers to the tendency of a model's prediction to drift toward the model's climatology, which may be at variance with the real world). Furthermore, thorough diagnostics of model deficiencies (e.g., intercomparison of various models, comparison of models to observations, analysis of physical mechanisms using simplified or conceptual models, and carrying out model sensitivity experiments) are essential to identify sources of model errors, which then provide the basis for model improvement.

Near-Term Priorities

- Various projects aimed at fostering intercomparison among climate models or their components are underway. The program will continue to support these efforts in model intercomparisons, with an emphasis on the diagnostics for the sources of deficiencies common to many climate models, such as the "double Intertropical Convergence Zone (ITCZ)" problem in the tropical Pacific Ocean, which is closely associated with the modeling of tropical deep convection and cloud feedbacks. A key approach is to bring together the expertise and interests of observation specialists, process modelers, diagnosticians, and climate modeling centers to tackle the problem from various angles in a coordinated manner (e.g., the CPT approach).
- Given the status of observations, it is not obvious which model(s) are "better" (see Chapter 12, Goal 4). In practice, when assessing how models simulate the present climate, most of the comparisons are made using "reanalysis data" provided by one of several groups. A wealth of satellite data is already available, with much more coming available. The linkage between satellite data and the needs of modeling groups that has been made very effectively in some modeling organizations (e.g., NASA's Data Assimilation Office, NOAA's National Centers for Environmental Prediction) should be replicated by other CCSP modeling groups. The program will address the role of both the modeling groups and the remote-sensing teams (see Chapter 12, Goal 6). Those modeling groups that have not made use of satellite data in the past will be encouraged to utilize it as part of their activity. Remote-sensing projects will be better integrated into the modeling community, with the scientific research team associated with each instrument encouraged to provide user-friendly data sets for modeling as part of their data collection responsibility.
- For paleoclimate studies, there is often a large gap between the actual data being obtained and the interpretation of those data in terms of the climate variables output from each model. When there is an apparent mismatch between model output and climate interpretation, it is often unclear whether the interpretation of the paleoclimate proxy data is responsible. To minimize this problem, the program will encourage modelers to include direct representations of the paleoclimate proxy data (e.g., water isotopes), so that comparisons can then be made with the proxy data independent of any climate interpretation. This will also help to improve the value of proxy data.
- At times, model performance can look satisfactory when compared with one reanalysis data set, and less so compared with another. As in the case of GCM differences, the reasons for the reanalysis differences need to be better understood. The program will encourage improved understanding through close cooperation between the reanalysis modeling data centers and observational and empirical scientific research (e.g., via a CPT). This effort will require international cooperation, and possibly some joint funding of such comparisons through international entities, such as the World Meteorological Organization (see also Objective 1.5).

Some key examples of global climate model intercomparison projects include the Atmospheric Model Intercomparison Project (AMIP, <www-pcmdi.llnl.gov/amip/>), the Coupled Model Intercomparison Project (CMIP, <www-pcmdi.llnl.gov/cmip/>), and the Paleoclimate Model Intercomparison Project (PMIP, <www-lsce.cea.fr/pmip/>). AMIP was initiated in 1989, for the purpose of identifying and documenting the differences among the various atmospheric models and observations, to provide a basis for model improvement. Nearly all atmospheric models in use today have been calibrated using the AMIP experimental protocol. AMIP is closely integrated with CMIP, and provides a calibration for understanding how coupled models respond to increasing levels of greenhouse gases. Model-model and model-measurement intercomparisons have been carried out for a number of component models that will ultimately need to be incorporated into global climate models. For instance, multi-dimensional stratospheric composition models have been intercompared with both each other and with observations in a series of "Modeling and Measurement" papers.

CMIP, like AMIP, is an activity of the World Climate Research Programme (WCRP). It was initiated in 1995 with the goal of collecting and intercomparing simulations from global coupled climate models—that is, models that operate over the complete global three-dimensional domain of the climate system, with components typically consisting of atmosphere, ocean, sea ice, and land surface. Virtually every global coupled model group worldwide is participating in CMIP, including groups from Australia, Canada, China, France, Japan, Germany, South Korea, Russia, the United Kingdom, and the United States.

PMIP, launched in 1994 and endorsed by the International Geosphere-Biosphere Programme and WCRP, is an international project involving members of all the major modeling groups worldwide. The aims of the PMIP project are to improve understanding of the mechanisms of climate change by examining such changes in the past, and to evaluate the ability of climate models to reproduce paleoclimate conditions radically different from present-day climate.

Objective 1.4: Improve short-term climate predictions through model initialization with enhanced observational data

Over the past several decades, progress in improving numerical weather forecasting has been achieved primarily through the continuing increase in model resolution and improvement in initializing (specifying the values of the model's variables at the start of the forecast) the prediction models. Initialization has been improved through the increase in available observations, particularly from remote-sensing platforms, and by advances in data assimilation techniques.

Improving climate prediction can follow a similar path. Although seasonal climate forecasting using coupled climate models is still at an early stage of development, the most significant impact on forecasts in the past decade has come through the use of ocean data assimilation to assimilate *in situ* observations for initializing the coupled models for ENSO forecasts.

Near-Term Priorities

- To improve short-term climate forecasts, CCSP modeling will incorporate new and improved technologies in data assimilation, such as coupled ocean-atmosphere data assimilation and land data assimilation, and better utilization/assimilation of *in situ* and remotely sensed global oceanic, atmospheric, and terrestrial observations (e.g., better utilization of altimetric sea-level data and improved methodologies for assimilating soil moisture and sea surface salinity; see also Chapter 12).
- The most significant challenge in data assimilation for climate prediction is the bias in prediction models. To reduce model bias, CCSP will significantly improve physical formulations of climate models, through improved incorporation of existing and new observations as well as through results from new process studies.
- Observations of several new variables have been demonstrated to be critical for improving seasonal forecasts, including sea surface salinity (SSS), particularly in tropical oceans, and soil moisture over the land. Satellite missions for measuring SSS and soil moisture have been planned for the next decade (see Chapter 12). In conjunction with efforts to make these observations available globally, the program will invest in research and development on the use of salinity and soil moisture observations in data assimilation for initialization of climate forecast models.

Objective 1.5: Provide comprehensive observationally based model-assimilated climate data sets for climate process research and testing of climate model simulations and retrospective projections

There is a critical need for an ongoing effort to provide complete descriptions of the present and past state of the atmospheric and oceanic components of the global climate system, together with continually updated data sets compiled in consistent ways to enable comparison of models with observations (see Chapter 12). As new climate observations are obtained, it is essential to place them in a historical context to enable the accurate evaluation of departures from normal, and trends and change in variability. New observations can provide additional information about climate when they are put in the context of past observations at uniformly spaced points in space. This is accomplished through the systematic processing and integration of climate observations using the state-of-art climate models and data assimilation methods.

Near-Term Priority

- The program will support research and development of advanced data assimilation methods and the production of global climate time series to establish reliable climatologies, identify real versus fictitious trends, and develop techniques to minimize the effects of changing observing systems and model biases.

Objective 1.6: Accelerate the development of scientifically based predictive models to provide regional- and fine-scale climate and climate impacts information relevant for scientific research and decision support applications

Regional climate models (RCMs, also called mesoscale models) are used in conjunction with GCMs to provide "downscaling" of climate variables for regional-scale predictions or projections. RCMs operate on scales that could not be accessed directly in GCMs due to computational capability limitations. Thus, while global climate models will be approaching 100-km resolution in the foreseeable future, it is unlikely that in the near future they will reach the 10-km scale that regional models can simulate. RCMs represent the most prevalent current approach to dynamic downscaling. An alternative approach is statistical downscaling, for which the applicability to climate change is uncertain. Other dynamic approaches include stretched-grid GCMs, with uneven horizontal resolution, which can provide regional-scale resolution over certain domains.

RCMs can also be used for "upscaling" of information to test GCMs. To the extent that many small-scale processes, parameterized in general circulation models as "sub-grid scale," can be better simulated in regional models, they can provide feedback on the adequacy and limitations of the coarse-grid parameterization schemes.

While the finer resolution provided by regional-scale models is desirable, the quality of the resulting solutions is limited, except perhaps in better delineating orographic (mountain region) precipitation. There are several broad issues involved in the use of regional models. While such models may allow many physical processes to be incorporated on the scale at which they occur (e.g., rainfall in the vicinity of mountains), the physics on regional scales is often uncertain. The uncertainties have led to the existence of multiple versions of most RCMs. When utilizing them for climate change simulations, the different versions can produce results that differ from each other by as much as the observed climate changes they are attempting to simulate, which questions their use by policymakers and decisionmakers.

A second issue is consistency. Regional-scale models of necessity generally utilize physical parameterizations that differ from those of the GCM, if for no other reason than because parameterizations are often scale-dependent. The GCM supplies boundary conditions generated with one physics package, and the RCM utilizes these boundary conditions in conjunction with different physics. This effect is made worse in "two-way coupling," in which the mesoscale result is fed back to the GCM. Using a mesoscale model over the Rocky Mountains, for example, and not at the same time over the Himalayas, provides inconsistent forcing for the GCM planetary wave structure, which is affected by both mountain chains.

Near-Term Priorities

- Many challenging downscaling and upscaling research issues remain to be addressed in order to provide the most useful information possible for decision support. Although regional modeling is highly relevant to most of CCSP's participating agencies, research and applications are often centered on the missions and interests of individual agencies. This has resulted in a need for more focused leadership and coordination following the guidelines given in Chapter 16. Toward this end, CCSP will establish a process for coordination of regional modeling activities, including the development of methods to transfer regional decision support products into operations. Regional and sectoral climate and climate impacts research and modeling is a high program priority and its support will be accelerated.
- Reducing the uncertainty associated with such issues will require diagnostics and intercomparison of regional-scale models and application techniques. With CCSP support. regional models will be tested systematically when forced by real-world and GCM-produced boundary conditions, and the results quantified against regional observations for different locations. The different physical parameterizations being used on regional scales will be compared with observations when available, and assessments made of their realism. Regional reanalysis and observational data sets will be used for verification purposes when evaluating RCM output.
- To provide greater consistency and to help improve GCMs, CCSP will support upscaling of well-validated physics at the regional level to provide insight into parameterizations for the coarser grid GCM. For example, the mesoscale model resolution will be expanded systematically to learn how the results change, and help determine what is appropriate for GCMs. This approach is promising (e.g., for physically based cloud-resolving models).

Goal 2: Provide the infrastructure and capacity necessary to support a scientifically rigorous and responsive U.S. climate modeling activity.

The principal U.S. agencies that support climate model development and application commissioned NRC to analyze U.S. modeling efforts as well as to suggest ways that the agencies could further develop the U.S. program so that the need for state-of-the-art model products can be satisfied. The NRC reports, *The Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities* (NRC, 1999b) and *Improving the Effectiveness of U.S. Climate Modeling* (NRC, 2001d), provided valuable guidance on how to improve U.S. climate modeling efforts. Also, the U.S. Global Change Research Program issued *High-End Climate Science: Development of Modeling and Related Computing Capabilities* (USGCRP, 2000), a report commissioned by the Office of Science and Technology Policy to make recommendations on climate modeling activities.

These documents emphasized four key points: (1) the acknowledged U.S. leadership in basic climate research that generates the knowledge base, which underpins both domestic and international modeling programs; (2) the limited ability of the United States to rapidly integrate the basic climate research into a comprehensive climate modeling capability; (3) the challenges, including software, hardware, human resource, and management issues, to routinely produce comprehensive climate modeling products; and most important, (4) the need to establish a dedicated capability for comprehensive climate modeling activities, including the global climate observations and data that support modeling.

Objective 2.1: Provide the computing, data storage and retrieval, and software engineering resources required to support a world-class U.S. climate modeling activity

The production of global model predictions of climate variability and change with sufficient resolution and veracity to provide useful regional information to decisionmakers requires a comprehensive computational infrastructure of computing resources, data centers, networks, and people. The success of this enterprise is predicated on a long-term commitment of the program to sustain the institutional support and investment required to maintain a resilient and state-of-the-art computational and information technology infrastructure.

Near-Term Priority

- CCSP will support researchers in developing more comprehensive coupled models that need to be evaluated, then exercised to produce ensemble projections of multi-century climate change scenarios. The results from these runs will be analyzed and employed by hundreds of researchers engaged in climate studies, impacts research, and assessment.

High-end computing needs are often divided into the two broad and overlapping categories of *capability* needs and *capacity* needs. The former refers to applications that require the *capability* to do sophisticated, cutting-edge simulations that were impossible just a few years ago because the computing platforms to execute them did not exist. Typically, these simulations require the dedicated use of the most powerful computer available for several weeks at a time. Ensemble simulations with the current and next generations of coupled models fall into this category. In addition to capability resources, CCSP requires a large amount of *capacity* resources to carry out the bulk (in terms of total computing cycles) of its modeling and analysis needs.

Near-Term Priority

- To meet its mandate, CCSP will provide researchers at the major modeling centers with access to steadily growing computational resources that increase by a factor of four each year. This will result in a 256-fold increase in available computing power over 4 years and a roughly 1,000-fold increase over 5 years. The factor of 1,000 will provide a three-fold increase in resolution which corresponds to a factor of 20 increase in computing requirements, a factor of two for improved process representation, a factor of four for increased comprehensiveness, a factor of three for increased ensemble size, and a factor of two for an increased number of scenarios. This level of enhancement will meet the computational requirements for the next-generation climate system models (described in Objective 1.2). This will be accompanied by appropriately scaling investments in software engineering, input/output systems, and local storage systems together with increasing investments in high-end analysis and visualization software development. A part of the growth will be met as computing equipment is replaced periodically every 3 to 5 years, with better technology at lower prices (Moore's "law").

Currently, capability resources needs are met through a combination of dedicated and shared resources. The dedicated resources—particularly the computers at the NOAA, NASA, DOE, and NCAR laboratories—do not fully meet the needs of the modeling community. The shortfall is made up by additional resources acquired at several shared-access supercomputer centers by the researchers themselves, through individual proposals. These centers are not supported by CCSP and provide computing through a competitive review process among many researchers from many fields of science and engineering. CCSP objectives cannot be met without these additional computing resources.

One example of such computing resources is DOE's National Energy Research Scientific Computing (NERSC) facility at the Lawrence Berkeley National Laboratory. To help meet computing needs for U.S. climate modeling, 10% of the computing cycles at NERSC will be made available to the broader scientific community in an open competition, with a special emphasis on climate modeling. Those cycles that might be allocated for climate modeling in that open competition would supplement the cycles at NERSC already used for climate modeling.

Possible collaborations with the Earth Simulator center in Japan, which has a computer with 20-50 times the capability of any existing U.S. machine for climate model applications, may help meet some of the near future needs. Unfortunately, this resource is now not directly accessible to U.S.-based researchers, because its lack of appropriate communication and mass storage and retrieval capacity requires users to be physically located at the center. Data generated at the center must be transferred to storage media that are then physically transported to data archives in the United States. This problem may be resolved in the near future.

Near-Term Priority

- In April 2003, the Office of Science and Technology Policy initiated a High-End Computing Revitalization Task Force (HECRTF) to assess the current high-end computing capability and capacity within the federal agencies, and to develop a plan to revitalize high-end computing research and enable leading-edge scientific research using high-end computing. CCSP has been coordinating with HECRTF to ensure that the CCSP computing capability and capacity needs are considered.

The divergence in high-end computing architectures over the last decade has made developing models for high-end capability machines more labor-intensive, requiring the addition of a software engineering component to model development.

Near-Term Priority

- Recent CCSP projects, including the NASA Earth System Modeling Framework (ESMF) program (see Objective 3.2) and the DOE Community Climate System Model (CCSM) Software Engineering Consortium program address this requirement. CCSP will support their continuation.

In addition to these primary capability computational resources, CCSP requires a network of available capacity computing engines, data archives, and associated information technology infrastructure to make the model products readily available and accessible, so that further analysis and the development of secondary products, such as downscaled model information, can be used for research and assessment. While the current archive of model results totals several tens of terabytes (trillions of units of information), future model data archives, and associated observational data to evaluate the models, will consume tens of petabytes (thousand terabytes).

Near-Term Priority

- The information technology infrastructure will be tailored to meet the specific needs of the CCSP modeling community, which will require the development and maintenance of both the software and hardware components that form the backbone of the infrastructure. To accommodate the rapid rate of turnover in information technology, the infrastructure will be flexible and dynamic so that it can evolve over time to meet increasing demands and utilize the best available technology. Projects such as the DOE Earth System Grid (ESG) provide a start in this direction by cataloging and making a subset of the existing model archives available over the Internet, but far more is needed. Contingent on continued progress and merit of the ESG project, the DOE Office of Science will continue to directly support ESG through at least 2005.

Objective 2.2: Establish graduate, post-doctoral, and visiting scientist programs to cross-train new environmental scientists for multidisciplinary climate and climate impacts modeling research and applications

The development, testing, and application of climate system models requires environmental and computer technicians and scientists with expertise in a broad range of disciplines. The scientific disciplines include atmospheric physics and chemistry; ocean physics, chemistry, and biology; ice physics; biological ecology; geology; applied mathematics; and the interactions among them. The activity also requires computer software engineering to develop, test, and manage model code (which, for a state-of-the-art climate system model, is currently about 500,000 lines and is projected to grow to about one million lines over the next 5 years).

Near-Term Priority

- As climate modeling becomes ever more complex, a shortage of appropriately trained scientists and technicians has become one of the limiting factors to progress. To meet this need, CCSP will establish a graduate student, post-doctoral, and visiting scientist fellowship program for climate modeling research and applications. The program will offer cross-training opportunities in climate modeling and computer sciences/software engineering. A modest post-doctoral and visiting scientist program has been established in FY2003 and will be expanded in future years.

Goal 3: Coordinate and accelerate climate modeling activities and provide relevant decision support information on a timely basis.

The NRC review of U.S. climate modeling (NRC, 2001d) recommended the following as high priorities for the nation:

- Centralized operations and institutional arrangements for delivery of climate services
- A common modeling infrastructure
- Human resources.

The dispersed and diverse nature of climate research, including climate modeling research, in the United States requires an integrating strategy to rapidly infuse new knowledge into the most complete models used to simulate and predict future climate states. At the same time, the ability to provide decision support requires a robust and ready modeling capability to perform specialized projections and simulations to inform policymaking. A multi-tiered CCSP strategy has evolved over the last several years to address shortcomings identified in NRC reports on U.S. integrated climate modeling efforts (NRC 1999b, 2001d), as well as to meet anticipated future demands. The strategy combines a "bottom-up" approach required to solve difficult basic research problems with a "top-down" approach to focus a component of modeling research on the needs for decision support.

At the most fundamental level of the strategy is the large number of basic research projects at universities, federal laboratories, and in the private sector, which, along with the larger centers, produce new knowledge required to further improve climate models.

The middle level includes modeling centers that conduct essential research and development for climate, weather, and data assimilation applications. These centers are of two types, the first of which are the large modeling centers that develop and maintain state-of-the-science global models but have primary missions other than century-scale global climate projection, although they may have some activities in that area. These centers include the NOAA National Center for Environmental Prediction, which conducts operational weather and climate prediction; the NASA Goddard Institute for Space Studies, which focuses on using satellite data to provide representations of climate forcing fields and uses these to model and study climate sensitivity to natural and human forcings; the NASA Goddard Space Flight Center, which focuses on the use of satellite data to generate research-quality data sets, to improve climate models, and to improve weather and coupled model predictions; the International Research Institute for Climate Prediction, which prepares and internationally distributes seasonal-to-interannual climate prediction and impacts products; and the Center for Ocean-Land-Atmosphere Studies, which focuses on studies of the predictability of climate. The second type is a number of smaller centers that have focused research interests on specific questions in climate research.

The strategy includes, at its third level, two "high-end" climate modeling centers that will continue to develop, evaluate, maintain, and apply models capable of executing the most sophisticated simulations, such as those required for assessments by the Intergovernmental Panel on Climate Change (IPCC). These two centers—one based at the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) and the other based on CCSM and coordinated by the National Center for Atmospheric Research (NCAR)—are complementary, cooperative, and collaborative. Both high-end modeling groups have a long legacy of successful climate change research that predates the IPCC process and have led U.S. participation in international modeling evaluations and assessments.

A healthy balance of resources (financial, human, and computer) among these three levels is essential to maintain a strong U.S. applied modeling program. Researchers collaborate extensively across all three tiers, ensuring the rapid flow of knowledge and understanding, as well as the definition of new problems. One example of such collaboration is support for a common modeling infrastructure (CMI) and the Earth System Modeling Framework to optimize modeling resources and enable meaningful knowledge transfer among modelers. 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 better able to exchange model components.

The multi-tiered strategy provides a structure by which the diverse contributions of the basic research community can be quickly utilized and integrated in state-of-the-art models used for climate simulation and prediction. At the same time, the strategy supports the decision support requirements of CCSP to make model simulations available for policy and impacts studies.

Objective 3.1: Provide routine, on-demand state-of-the-science model-based global projections of future climate

A major CCSP objective is to develop scientifically based global, time-dependent, multi-century projections of future climate change for different scenarios of climate forcing caused by natural variations and human activities. These projections are a primary form of scientific information to support decisionmaking about options to address the potential consequences of climate change. Development of capabilities to produce world-class climate change projections on demand to meet the needs of international and national assessments and other decision support requirements will bring new cohesion and coherence to the efforts of the U.S. climate modeling community. Given current scientific uncertainty and gaps in knowledge, it is essential that the United States maintain more than one high-end modeling center focused on long-term climate change, so that differing approaches to unsolved problems can be explored.

Both CCSM and GFDL support ongoing development of comprehensive climate system models, involving chemistry, biogeochemistry, and ecological processes. The centers are engaged in the development and application of distinct models. Their methods, innovations, and working hypotheses differ regarding many of the outstanding unresolved theoretical and modeling issues. The different approaches are essential at this stage, given the highly complex nature of the climate system with its numerous feedback mechanisms across a broad range of temporal and spatial scales.

Further, a comprehensive U.S. climate modeling strategy benefits from a measure of differentiation between the roles of the two centers. Despite an apparent overlap in responsibilities, the missions and structures of the two centers are more complementary than duplicative. CCSM is an open and accessible modeling system that integrates basic knowledge from the broad, multidisciplinary basic research community for research and applications. The GFDL model development team participates in these community interactions and will focus on model product generation for research, assessments, and policy applications as its principal activity. GFDL models and products are integral to the development of the NOAA Climate Services program, which provides operational climate products and services to policymakers and resource managers. GFDL maintains dedicated computer resources that can be allocated flexibly to meet mission requirements.

Near-Term Priorities

- Results from GFDL and CCSM models will comprise the primary U.S. contributions to IPCC assessments, as well as provide input to other assessments of the science and impacts of climate change. Independent century-long climate projections will be executed by each center on schedules to meet national and international assessment demands.
- CCSM will maintain an open model development system with major changes developed through consensus from the broad scientific community engaged in climate research. Computer resources for CCSM research will continue to be provided mostly at shared-access supercomputer centers through allocations given to the many projects associated with CCSM. This arrangement works well for the IPCC and other major assessments that have long lead-times that allow for sufficient planning.
- GFDL plans to procure additional supercomputing resources to enable the systematic generation of model products needed by the impacts, assessments, and policy communities to document and assess the regional and global impacts of long-term climate variability and change. In addition to products derived from GFDL model simulations, additional products will be generated using results from other modeling centers, including CCSM.
- Although they will maintain separate model development paths, the two centers have developed, and will implement, a plan for extensive scientific interaction and collaboration. The first step is to understand why the two coupled models have significantly different climate sensitivity to increased atmospheric carbon dioxide concentrations. Initial studies indicate that the prediction of changes in cloud amount in response to atmospheric warming is very different in the two models (see Figure 10-2). This suggests that an important factor leading to differences in climate sensitivity is the differences in representation of cloud processes.
- The centers will work with the broader scientific community of university and other laboratory modeling groups to focus research, including climate process studies, to better understand and resolve the differences between the models.
- Further enhancement of the collaborations will be enabled by the following actions, some of which are dependent upon sufficient resources: a program of focused model intercomparisons (see also Objective 1.3); a graduate student, post-doctoral, and visitors program to accelerate interactions (see also Objective 2.2); and development of common model diagnostics.
- The centers will work cooperatively to develop methods for providing global model output for a variety of decision processes (see Chapter 11).

Objective 3.2: Develop mechanisms for effective collaborations and knowledge transfer

Climate Process and Modeling Teams. Climate scientists who conduct observational and empirical research into climate processes are often not well connected with modeling centers and model

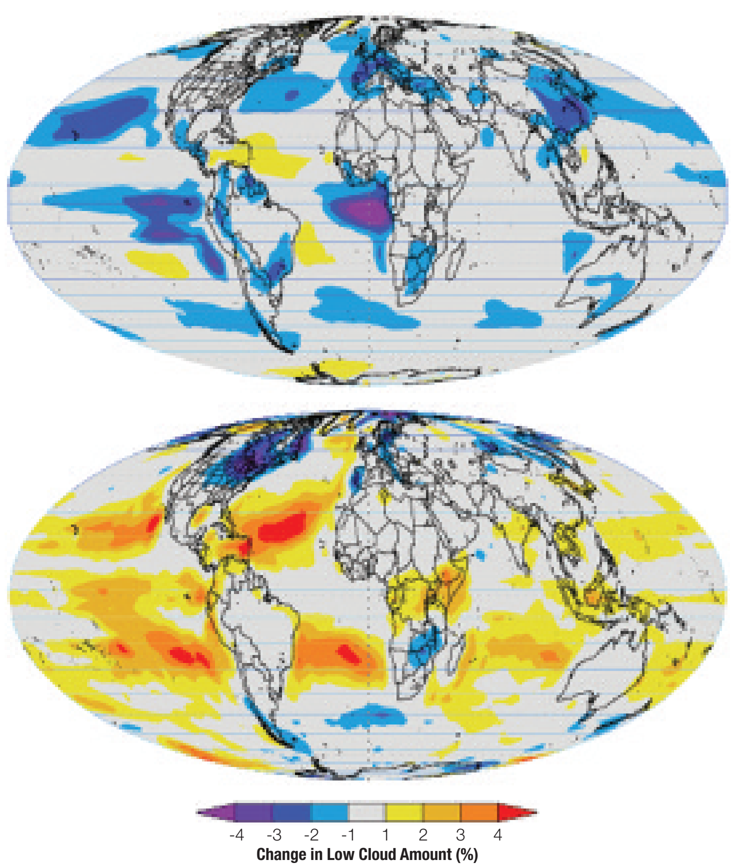

Figure 10-2: Changes in the amount of low clouds simulated by the GFDL model (top) and CCSM (bottom) resulting from a doubling of atmospheric carbon dioxide concentration. In many areas, the amount of low cloud is reduced in the GFDL model, where the amount of clouds increases over most areas in CCSM. This difference in behavior may be a major source of the models' differing climate sensitivities. Source: GFDL and NCAR.

developers. The U.S. Climate Variability and Predictability (CLIVAR) program has developed and promoted a research strategy that involves the formation of **C**limate **P**rocess and Modeling **T**eams in order to improve collaboration between researchers and modelers. CPTs consist of process-oriented observation specialists, researchers, and individual process and parameterization modelers, working collaboratively with climate model developers. The teams are organized around an issue, model deficiency, and/or parameterization(s) that are generic to all climate models. An important distinction between CPTs and other more conventional model development research is the emphasis on directed teamwork, demonstrated progress, and delivery of products that will be tested and possibly implemented in climate models.

Near-Term Priority

- The goal of the CPT approach is to facilitate and accelerate progress in improving the fidelity of climate models and their predictions and projections. Specifically, CPTs will:
  - Speed the transfer of theoretical and practical process-model understanding into improved treatment of processes in climate system models (e.g., coupled models and their component models, assimilation and prediction systems), and demonstrate, via testing and diagnostics, the impact of these improvements
  - Identify process study activities necessary to further refine climate model fidelity
  - Develop observational requirements for climate system models.

  Success of CPTs will be measured not only by advances in knowledge, but more importantly by the development of new modeling capabilities and products. Several pilot-scale CPTs are being funded by CCSP in FY2003 (see Chapter 4).

Common Modeling Infrastructure and Earth System Modeling Framework. One of the great strengths of atmospheric, oceanic, and climate modeling in the United States is the variety, availability, and wide use of models. But this diversity has also led to duplication of effort and a proliferation of models and codes that, due largely to technical reasons, cannot interoperate and have been unable to keep up with and exploit advances in computing technology.

Climate models are increasingly being used to support decisionmaking. The predictive requirements are becoming more stringent. The demand for interoperability of climate model components has intensified as various modeling groups are engaging in collaborative research. Without exchangeable model components, it is often difficult to point to a component as a clearly identifiable cause of divergent results when one model is compared against another or against observations. In order to optimize modeling resources and enable meaningful collaborations among modelers, it is necessary to build common and flexible modeling infrastructure at the major centers.

The common modeling infrastructure that will be implemented by the two centers will enable the exchange of model components between different modeling systems and facilitate analyses and intercomparisons of model results by adopting common coding standards for model components and common output formats, and developing common diagnostics packages. To achieve part of this commonality, the Earth System Modeling Framework project has been established. ESMF is a community-wide engineering effort to develop common software to facilitate interoperability of climate models on various hardware platforms, especially on massively parallel architecture platforms (i.e., many individual computational units operating in parallel, connected by data communication links).

Near-Term Priority

- CCSP will support further development of CMI/ESMF through multi-agency mechanisms that will ensure participation of the major U.S. climate modeling centers and groups. CMI/ESMF will: (1) facilitate the exchange of scientific codes (interoperability) so that researchers may more readily interface with smaller scale, process-modeling efforts and can share experience among diverse large-scale modeling efforts; (2) promote the implementation of standard, low-level software, the development of which now accounts for a substantial fraction of the software development budgets in many institutions; (3) focus community resources to deal with changes in computer architecture; (4) present the computer industry and computer scientists with a unified, well-defined, and well-documented task to address; (5) share the overhead costs of software development, such as platform-specific user libraries and documentation; and (6) provide greater institutional continuity to model development efforts by distributing support for modeling infrastructure throughout the community. Products will include more efficient and rapid transfer of research results into model applications, and human resources and dollar cost savings.

Objective 3.3: Provide for interagency coordination of CCSP modeling activities to improve implementation and external advisory processes to evaluate performance

Near-Term Priorities

- CCSP modeling activities are carried out by a number of agencies. In order to improve the coordination of the implementation of these activities at the program level, CCSP will establish a process for coordination of CCSP modeling activities that lie beyond the boundaries of the missions or programs of single agencies, including coordination of the use of computer resources that can be shared between agencies.
- CCSP will use advisory processes to facilitate its programs (see Chapter 16). In the case of its modeling strategy, CCSP will use a variety of advisory mechanisms to evaluate, guide, and provide feedback. Such mechanisms will include a continuing NRC relationship to examine strategic issues for future development, standing advisory committees, focused ad hoc working groups on technical issues (e.g., ESMF), and specialist workshops.

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CHAPTER 11

Decision Support Resources Development

CHAPTER CONTENTS

The Role of Decision Support

In order to fulfill the scientific assessment requirements of the 1990 Global Change Research Act (P.L. 101-606)[3], and to enhance the utility of the extensive body of observations and research findings developed by the U.S. Global Change Research Program (USGCRP) since 1990, the Climate Change Science Program (CCSP) is adopting a structured approach to match, coordinate, and extend resources developed through the research activities to the support of policy and adaptive management decisionmaking. The USGCRP has made very large investments in research and observing programs since 1990. By comparison, the USGCRP investment in assessment activities and other decision support resources has been much smaller to date. The largest assessment program previously undertaken by the USGCRP was the National Assessment initiated in 1998, which produced overview reports in late 2000 and a series of specialty reports in the period 2001-2003.

The decision support approach for analyses and assessments adopted by the CCSP builds upon the "lessons learned" from earlier USGCRP assessment analyses, as well as other sector, regional, national, and international assessments. The Climate Change Research Initiative (CCRI) will place enhanced emphasis on the extraction of mature scientific knowledge from the core research program for use in assessment and decision support. The principal guidelines for the CCSP decision support approach follow:

- *Analyses structured around specific questions*. This approach enhances consistent communications among all involved scientists and stakeholders addressing designated questions.
- *Early and continuing involvement of stakeholders*. Stakeholder feedback is essential in defining key science and observation questions, and in defining the key issues in each analysis.
- *Explicit treatment of uncertainties*. The CCSP and the general scientific community have the responsibility to define the applicability limits imposed on various projections and other analyses, as related to the uncertainties in the underlying data and analysis methods. The CCSP will consistently address the uncertainties and the limits of applicability (related to underlying uncertainties) associated with the decision support analyses it reports.

[3] "On a periodic basis (not less frequently than every 4 years) the Council, through the Committee, shall prepare and submit to the President and the Congress an assessment which:
1) Integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings
2) Analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity
3) Analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years." (from Section 106).

- *Transparent public review of analysis questions, methods, and draft results*. In the same manner that the CCSP published a *Discussion Draft Strategic Plan* for public review in November 2002, the CCSP will publish drafts of decision support analysis plans for open review. Draft results from the analyses will also be published for review before their completion.
- *Evaluate ongoing CCSP analyses and build on the lessons learned*. The CCSP plans to conduct, through a variety of mechanisms, a limited number of decision support case studies during the next 2 years, and to expand the scope of these analyses only after evaluating scientific and stakeholder community feedback from the initial experiences.

The CCSP activities in Decision Support Resources go beyond what has been accomplished in the past in the breadth of interagency activity and commitment to extend beyond traditional science assessments to new forms of stakeholder interactions that focus development and delivery of information in more effective and credible ways. The CCSP Decision Support Resources activities will build on the science foundation established by the USGCRP, the CCRI, and related international research programs, as well as the lessons learned from other assessments and stakeholder interaction projects conducted during the last decade. The planned decision support resource development will address key recommendations from the National Research Council (NRC), particularly those discussed in *Global Environmental Change: Research Pathways for the Next Decade* (NRC, 1999a), *Climate Change Science: An Analysis of Some Key Questions* (NRC, 2001a), and *The Science of Regional and Global Change: Putting Knowledge to Work* (NRC, 2001e).

Priorities on decision support resources are guided by national and international priorities that have been established with stakeholder partnerships. National priorities include the management of carbon, energy, water, air quality, community growth, disaster, invasive species, and coasts, along with possible negative ancillary impacts associated with health and agricultural efficiency.

The analyses and development of other decision support resources are intended to support the decisionmaking process and to be capacity-building activities. By sponsoring these activities (conducted by government, academic, and other groups), the CCSP will enhance the capabilities of various interdisciplinary research groups to assist in the evaluation of the many different policy and adaptive management questions likely to arise in the coming years. Decision support resources are improved on an iterative basis, requiring a continuous process of incorporating new technologies, processes, and knowledge. The CCSP plan for evaluation is to systematically verify and validate the integration of each new generation of climate change research results into decision support resources and to determine the confidence in using the enhanced tools in a variety of applications.

BOX 11-1

WORKING DEFINITIONS

Decision Support Resources
Decision support resources refers to the set of analyses and assessments, interdisciplinary research, analytical methods (including scenarios and alternative analysis methodologies), model and data product development, communication, and operational services that provide timely and useful information to address questions confronting policymakers, resource managers and other stakeholders.

Policy Decisions
Policy decisions result in laws, regulations, or other public actions. These decisions are typically made in government settings (federal, state, local) by elected or appointed officials. These decisions, which usually involve balancing competing value issues, can be assisted by—but not specified by—scientific analyses.

Adaptive Management Decisions
Adaptive management decisions are operational decisions, principally for managing entities that are influenced by climate variability and change. These decisions can apply to the management of infrastructure (e.g., a waste water treatment plant), the integrated management of a natural resource (e.g., a watershed), or the operation of societal response mechanisms (e.g., health alerts, water restrictions). Adaptive management operates within existing policy frameworks or uses existing infrastructure, and the decisions usually occur on time scales of a year or less.

Planning
Planning is a process inherently important for both policy decisions and adaptive management. It usually occurs in the framework of established or projected policy options.

Stakeholders
Stakeholders are individuals or groups whose interests (financial, cultural, value-based, or other) are affected by climate variability, climate change, or options for adapting to or mitigating these phenomena. Stakeholders are important partners with the research community for development of decision support resources.

Assessments
Assessments are processes that involve analyzing and evaluating the state of scientific knowledge (and the associated degree of scientific certainty) and, in interaction with users, developing information applicable to a particular set of issues or decisions.

Scenario
A scenario is a coherent statement of a potential future situation that serves as input to more detailed analysis or modeling. Scenarios are tools to explore "If …, then…" statements, and are not predictions of or prescriptions for the future.

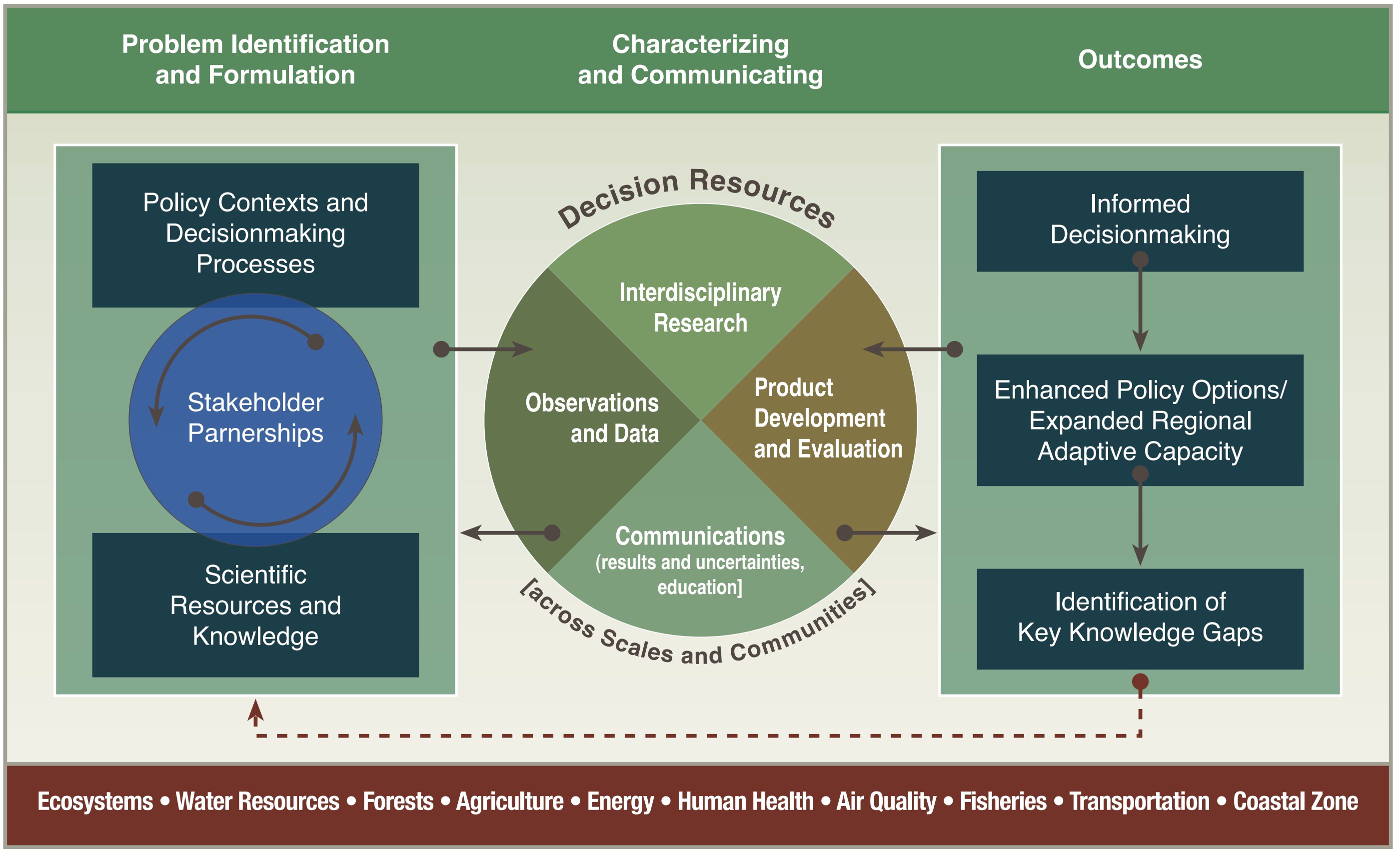

Figure 11-1: Schematic representation of decision support framework illustrating components of problem identification and formulation, development of decision resources, and final outcomes.

The planned CCSP Decision Support Resource activities respond to the following three goals:

1) *Scientific syntheses*. Prepare scientific syntheses and assessments to support informed discussion of climate variability and change issues by decisionmakers, stakeholders, the media, and the general public.
2) *Adaptive management for resources and infrastructure*. Develop information resources to support adaptive management and planning for responding to climate variability and climate change, and transfer these resources from research to operational application.
3) *Support for policymaking*. Develop and evaluate methods (scenario evaluations, integrated analyses, alternative analytical approaches) to support climate change policymaking and demonstrate these methods with case studies.

Management and advisory processes (involving both government and non-government reviewers) will be developed to ensure implementation of a coordinated CCSP decision support effort using review and feedbacks to identify and set priorities.

Three decisionmaking categories will be addressed by the CCSP: (1) public discussion and planning based on state-of-science syntheses and assessments; (2) operational adaptive management decisions undertaken by managers of natural resources and built infrastructure (i.e., "climate services applications"); and (3) support for policy formulation. Each of these decisionmaking categories has a unique set of stakeholders and requires different decision support tools. A common framework of activities will be used where appropriate for all three categories as shown in Figure 11-1. The figure illustrates stakeholder partnerships with scientists to identify and formulate the problems to be addressed, the development of decision support resources, and expected outcomes. Key elements in this framework include:

- Involvement of stakeholders in question identification and formulation
- Science syntheses and assessments focused on the identified question(s)
- Formation of interdisciplinary research teams that interact with the decisionmaking communities, and that integrate the natural and social sciences
- Development, with users, of a decision support "toolbox" (a collection of validated and verified products and processes that can be used by decisionmakers)
- Quantification and communication of the level of confidence in reported findings
- Evaluation and review processes for the decision support analyses that engage the relevant decisionmaking communities.

The "decision support toolbox" refers to the collection of decision support products [including communication methods, integrated maps, geographic information system (GIS)-based analysis products, targeted forecasts for particular sectors, "decision calendars," scenarios, etc.] that have been validated, verified, and evaluated from the perspective of users. In its mature state, decisionmakers will be able to assess the extent to which analytical tools applied in a particular sector or circumstance could be applied or modified in their particular setting. The toolbox depends upon the physical, natural, social science, and, now, assessment foundations of the CCSP, including Earth observation networks and systems, Earth system models, the data and data-handling infrastructure of the CCSP research activities, and an evolving network of socioeconomic data.

The expected outcomes from the CCSP Decision Support Resources activities include:

- Improved science syntheses and assessments for informing public discussion of climate change issues
- Expanded adaptive management capacity to facilitate the responses of resource managers to climate variability and change
- Assessment information for evaluating options for mitigation of and adaptation to climate variability and change
- Identification of information needs to guide the evolution of the CCSP science agenda.

Goal 1: Prepare scientific syntheses and assessments to support informed discussion of climate variability and change issues by decisionmakers, stakeholders, the media, and the general public.

The Global Change Research Act of 1990 (P.L. 101-606, Section 106) directs the USGCRP to support research to "produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change" and to undertake periodic science assessments. Assessments are an effective means for integrating and analyzing CCSP research results with other knowledge, and communicating useful insights in support of a variety of applications for decision support. Assessments also help identify knowledge gaps and thus provide valuable input to the process of focusing research.

During the next decade, CCSP will continue to support assessment analyses. Given the broad set of policy, planning, and operational decisions that would benefit from climate and global change information, there are a wide variety of candidates for CCSP assessment analyses. A focused, systematic approach for selecting and producing a practical number of assessments—and for continuously addressing the "lessons learned" from each assessment analysis—will be developed and published by the CCSP.

Objective 1.1: Produce scientific synthesis reports

The CCSP participating agencies will coordinate their work to produce a number of synthesis reports that integrate research results focused on identified science and decision issues. These reports will provide current evaluations of the science foundation that can be used for informing public debate, policy, and operational decisions, and for defining and setting the future direction and priorities of the program.

The CCSP agencies and scientists funded by these agencies will also continue to participate in the principal international science assessments including the Intergovernmental Panel on Climate Change (IPCC) fourth assessment scheduled for completion in 2007, and the World Meteorological Organization (WMO)/United Nations Environment Programme (UNEP) assessments of stratospheric ozone depletion and associated environmental impacts.

Objective 1.2: Plan and implement designated assessment analyses in collaboration with the stakeholder and research communities

The CCSP will produce a set of assessments that focus on a variety of science and policy issues important for public discussion and decisionmaking. The assessments will be composed of syntheses, reports, and integrated analyses that the CCSP will complete by the third quarter of 2006. CCSP cooperating agencies will sponsor or carry out the analyses with interagency oversight to ensure that resources from the entire program are best utilized. This approach will cover the full range of CCSP goals and will provide a "snapshot" of knowledge concerning the environmental and socioeconomic aspects of climate variability and change. A list of the planned CCSP scientific synthesis and assessment reports is provided in Box 11-2. This list reclassifies the product summary in Table 2-1 (Chapter 2) by primary decision support purpose.

Goal 2: Develop resources to support adaptive management and planning for responding to climate variability and climate change, and transition these resources from research to operational application.

Adapting to climate variability and potential change poses challenges to management of resources, infrastructure, and the economy. The pressures of increased population densities and intensified land use, common throughout much of the United States and other nations, increase the demand for effective management of resources sensitive to climate in many regions. For example, information on short-term climate variability (i.e., weekly, monthly and seasonal projections) is relevant for the development of state and regional drought action plans, agricultural operations management, water resource system management, and fishery management. Much of the information from CCSP research is relevant to these decisions, but often is insufficiently focused on management applications to be directly useful. Thus, the CCSP decision support resource activities will play an important role in the "transition from research to operations" for major elements of the underlying research. In the transition process, particular attention will be placed on the establishment of validation and verification guidelines for the extension of the research, analyses and assessments, model and data products, and other resources into operational decision support.

CCSP research results, data products, forecasts, and model results are already being applied to adaptive management decision support in a limited number of regional and sectoral case studies. Elements of climate and associated ecosystem observations from satellite, ground-based, and *in situ* platforms are also being synthesized into useful data products for decisionmakers. Examples include a variety of maps for crop management, water quality management, and urban planning, and integrated products illustrating snowpack, precipitation, streamflow, and potential for drought conditions. Climate projections, especially those from El Niño-Southern Oscillation (ENSO) analyses (which have demonstrated elements of seasonal- to biennial-scale forecast skill), have provided information for state and local emergency preparedness organizations; water resource management plans for the western regions; agricultural planning for the southeast; and fire management for drought-stricken

BOX 11-2

CCSP TOPICS FOR INTEGRATED SYNTHESIS AND ASSESSMENT PRODUCTS CATEGORIZED BY PRIMARY END USE

Science Reports to Inform Evolution of the Science Research Agenda

- Temperature trends in the lower atmosphere—steps for understanding and reconciling differences
- Past climate variability and change in the Arctic and at high latitudes
- Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with the Climate Change Technology Program (CCTP); review of integrated scenario development and application
- North American carbon budget and implications for the global carbon cycle
- Climate models and their uses and limitations, including sensitivity, feedbacks, and uncertainty analysis
- Climate projections for research and assessment based on emissions scenarios developed through the CCTP
- Climate extremes including documentation of current extremes; prospects for improving projections
- Relationship between observed ecosystem changes and climate change
- State of the science of socioeconomic and environmental impacts of climate variability

Synthesis and Assessment Products to Inform Adaptive Management Decisions

- Risks of abrupt changes in global climate
- Coastal elevation and sensitivity to sea-level rise
- Within the transportation sector, a summary of climate change and variability sensitivities, potential impacts, and response options
- Preliminary review of adaptation options for climate-sensitive ecosystems and resources
- Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions
- Best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decisionmaking
- Decision support experiments and evaluations using seasonal-to-interannual forecasts and observational data

Synthesis and Assessment Products to Inform Policy Decisions

- Re-analyses of historical climate data for key atmospheric features; implications for attribution of causes of observed change
- Aerosol properties and their impacts on climate
- Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure and climate change
- State-of-knowledge of thresholds of change that could lead to discontinuities (sudden changes) in some ecosystems and climate-sensitive resources
- Scenario-based analysis of the climatological, environmental, resource, technological, and economic implications of different atmospheric concentrations of greenhouse gases

regions. Decision support tools are also employed by federal agencies to serve the public in local and regional decisionmaking and include applications in the management of carbon, water, disasters, invasive species, and coastal ecosystems along with information on public health, agriculture efficiency, and energy use. All of these products have been co-developed by scientists and users after extensive dialogue and are potential resources for a "decision support toolkit."

Making use of information on variability and potential future changes in climate requires that decisionmakers be directly involved in shaping their key questions, and not passive consumers of general scientific information. User partnerships that actively engage scientists provide the opportunity for understanding where scientific resources and knowledge can best be used and what new research may be needed. Outputs from such interactions include decision calendars and assessments that frame the context in which the science will be used, determination of what products need to be developed using the science information base and experiential knowledge of stakeholders, and determination of the limits of existing knowledge to be applied to the problem.

Decision support for adaptive management requires advances in basic knowledge and progress in applying scientific information within adaptive management settings. Conducting research within a decision support framework can provide multiple benefits for both practitioners and scientists. Ideally, users of research information are served so that new options exist for minimizing negative impacts or pursuing opportunities, and researchers benefit from refinement and prioritization of research agendas through the identification of the uncertainties most relevant to decisionmaking.

CCSP will play an important role in generating processes and products relevant to adaptive management decision options. Examples of pilot products include historical data analyses and products; forecasts for particular sectors at key time periods; probabilistic climate variability and change information integrated with decision models; "decision calendars;" geo-referenced maps of critical climate and associated environmental parameters; and specific model runs or data sets. The CCSP will also develop mechanisms to sustain interactions between users and researchers in order to better understand how to optimize the delivery of research results, data products, and forecasts.

Objective 2.1: Conduct research to extend the uses and identify the limits of existing decision support resource capabilities for adaptive management

The CCSP's approach for accelerating and enhancing decision support for adaptive management will be based on the following:

- Enhancement of existing case studies of adaptive management decision support using a variety of approaches sponsored by CCSP agencies
- Implementation of evaluation processes to address (1) the role of scientific uncertainties in the analyses and (2) feedback information to help frame future research agendas
- Development and demonstration of elements of a decision support toolkit.

CCSP research will target adaptive management issues and information use, including the potential entry points and barriers to using climate information as well as the types of new information that would provide the greatest benefit to decision processes. This research will integrate natural and social systems within an application context of managed resources or infrastructure, utilizing climate and environmental observations, model outputs, socioeconomic data, and decision models. It will incorporate elements of regional/ sub-regional climate science and associated environmental processes, socioeconomic impacts, technological capabilities, management institutions and policies, and decision processes including evaluation.

CCSP will integrate lessons learned from current adaptive decision support case studies sponsored by CCSP participating agencies. These lessons will provide a mechanism for evaluating how scientific information is currently used by decisionmakers (to help frame problems) and for evaluating the quality of the scientific resources available to be applied to the problems.

Within a case studies framework, CCSP will support development of resources for decision support, and will develop methods to quantify uncertainty and its effect on the adaptive management process in a range of example cases. Illustrative resources to be developed are listed in Box 11-3.

CCSP will periodically organize workshops and forums to gather information on lessons learned from adaptive management decision support activities, and will prepare summary reports that help transition knowledge and resources across regions and sectors. The resources (processes and tools) that emerge from this research in decision support are the foundation for a "tool kit," a term that describes a range of products useful to individuals and institutions responding to the effects of climate variability and change. The CCSP will support the mechanisms to help users identify and use the capabilities in the tool kit, including web-based tutorials, workbooks, and interactive forums.

Objective 2.2: Promote the transition of resources from research to operations for sustained use

Once decisionmakers begin using new products, there is a need to ensure the continuity of that product through services entities. While the CCSP itself does not have a service mission, many of the CCSP collaborating agencies do. The CCSP will work to facilitate the successful transitioning, verification and validation, and maintenance of newly developed decision support products within its collaborating agencies or other non-federal service entities. CCSP will work to support collection of data, information, and other resources utilized by the decision support products and will aid in the transition of this collection to operational entities when appropriate. In the transition process, it is important to benchmark

BOX 11-3

ILLUSTRATIVE RESOURCES TO BE DEVELOPED FOR ADAPTIVE MANAGEMENT DECISION SUPPORT

New experimental long-lead (12-month) streamflow forecasts for major watersheds of the United States, coupled with improved decision-support for water managers and users [2-4 years].

Experimental to operational decision support systems for agriculture and ranching in selected regions (Southwest and Southeast) of the United States [2-4 years].

Prototype regional (Western and Southeastern) integrated "multi-stress" and multi-jurisdiction decision support systems for forest and wildfire management [2-4 years].

Development of a blueprint for the improved regional climate, hydrologic, and ecological observing systems needed for enhanced decision support, particularly in mountainous regions [2-4 years].

Tests of existing regional modeling capabilities, and definition of the improved regional modeling capabilities needed for enhanced decision support [2-4 years and beyond].

Improved public health decision support for major climate-modulated infectious disease threats in the United States, including mosquito-borne viral disease, Hantavirus, and Valley Fever [2-4 years].

Analysis of historical records in target areas to gain a better understanding of past and current climate variability across all time-scales for use in sensitivity analyses of existing and planned physical infrastructure [2-4 years and beyond].

Assessments of potential effects of climate change and land-use change on water and vector-borne diseases [2-4 years].

Assessment of the potential effects of climate change, land-use change, and UV radiation on aquatic ecosystems [2-4 years].

the improvement in performance of solutions that result from integrating research-quality observations with research-quality predictions and outlooks into operational decision support tools.

Two case studies of adaptive management decision support, summarized in Boxes 11-4 and 11-5, illustrate the transition of decision support analyses into the type of operational management resources anticipated by the CCSP Decision Support Resource development goals.

Goal 3: Develop and evaluate methods (scenario evaluations, integrated analyses, alternative analytical approaches) to support climate change policymaking and demonstrate these methods with case studies.

Policy-related questions regarding climate change typically arise from numerous sources, for example from:

- Consideration of climate change policy within federal government

BOX 11-4

HANTAVIRUS PULMONARY SYNDROME IN THE SOUTHWESTERN UNITED STATES

This case study describes research and assessment activities undertaken to better understand the cause of outbreaks of hantavirus pulmonary syndrome (HPS) in the southwestern United States in the 1990s. The research and assessment efforts led to pilot production and evaluation of risk maps, which were then used by public health officials for on-the-ground interventions to prevent disease outbreaks and protect public health. This study illustrates how multidisciplinary, place-based research and assessment, conducted in response to questions raised by a particular user group (public health officials), can lead to the development of products (risk maps) that successfully increase regional adaptive capacity (enhanced public health care).

Problem Formulation

In 1993, a disease characterized by acute respiratory distress with a high death rate (greater than 50%) among previously healthy persons was identified in the southwestern United States. This disease, HPS, was traced to a virus maintained and transmitted primarily within populations of a common native rodent, the deer mouse (*Peromyscus maniculatus*). Public health officials wanted to understand the cause of the outbreak so they could develop effective techniques for intervening and preventing the disease.

Researchers hypothesized that the outbreak was due in part to the unusual weather in 1991-1992 associated with the El Niño-Southern Oscillation. Unseasonable rains in 1991 and 1992 during the usually dry spring and summer, and the mild winter of 1992, were thought to have created favorable conditions for an increase in local rodent populations. It was suggested that a cascading series of events from weather—through changes in vegetation, to virus maintenance and transmission within rodent populations—culminated in changes in human disease risk from HPS.

The Assessment

A study explored this hypothesis by comparing the environmental characteristics of sites where people were infected with those sites where people were not infected. The study used a retrospective epidemiologic approach to risk assessment. Satellite imagery (Landsat Thematic Mapper images), combined with epidemiologic surveillance, retrospectively identified areas at high risk for HPS associated with *Peromyscus* populations over broad geographic regions during the 1993 outbreak. Thematic Mapper data identified environmental conditions approximately 1 year before the outbreak that were measurably different near HPS sites than in rural, populated sites where the disease did not occur.

Pilot Production and Evaluation of Risk Maps as a Decision Support Tool

The assessment revealed that environmental conditions near HPS sites varied with the presence or absence of ENSO. The geographic extent and level of predicted HPS risk were higher during ENSO, supporting the view that El Niño may increase the likelihood of HPS outbreaks.

It was then determined that high-risk areas for HPS can be predicted more than 6 months in advance based on satellite-generated risk maps of climate-dependent land cover. Predicted risk paralleled vegetative growth, supporting the hypothesis that heavy 1992 rainfall due to El Niño was associated with higher rodent populations that triggered the Hantavirus outbreak in 1993. Landsat satellite remote-sensing images from 1995, a non-El Niño "control" year, showed low risk in the region, whereas the images from the 1998 strong El Niño again showed high risk areas as in 1992-1993. Trapping mice in the field validated the satellite-generated risk maps with mouse populations directly related to risk level, with a correlation factor of over 0.90. Risk classification also was consistent with the numbers of HPS cases in 1994, 1996, 1998, and 1999.

Next-Generation Integrated Knowledge

This information was used to develop an early warning system, with intervention strategies designed to avoid exposure. These strategies, developed in partnership with the Centers for Disease Control and Prevention (CDC) and the Indian Health Service, are already being implemented by the U.S. Department of Health and Human Services for disease prevention in the southwest.

BOX 11-5

CLIMATE-ECOSYSTEM-FIRE MANAGEMENT

Wildland fires burn millions of acres each year and major resources are committed to fuel (live and dead vegetation) treatment, fire prevention, and fire suppression. Effective decision support products and tools can improve resource allocation decisions and maintain a high standard of safety for firefighters and the public. The fire-climate assessment tool, which is in essence a structured process, allows fire and fuels specialists and fire weather meteorologists in each of the National Interagency Fire Center's eleven Geographic Area Coordination Centers (GACCs) to work with climatologists to develop GACC-level assessments of fire risk at seasonal to shorter time scales. The tool also allows Predictive Services staff to develop and update a national map and discussion of fire potential for the fire season each year.

Problem Formulation

- La Niña conditions prompted the first climate-fire-society stakeholder workshops in 2000. These annual workshops have established a dialogue between stakeholders (fire managers and decisionmakers) and climatologists.
- The workshops evolved over 3 years, refining the contribution of climate information to seasonal fire outlooks at the regional level and focusing on "fire science," including the nature of the fire regime (frequency, size, intensity); conditions in the natural system (adaptive ecosystems, vegetation, fuels, watershed, soil, wildlife); and characteristics of the human systems (property, economic sectors affected, policy and land-use planning, multi-agency jurisdictions).
- The workshop process is supported by interdisciplinary teams of research scientists interested in focusing climate impacts research on information and insights essential to decision challenges influenced by climate variability and change.

Research Modules

- Design and communication of climate information and forecasts useful for fire management involves collaboration between decisionmakers and scientists in the conduct of research to improve institutional capacity to integrate scientific information and predictions into planning and operations; analysis of individual stakeholder perceptions of fire risk and of their capabilities and willingness to use scientific information in their decision processes; and identification of the factors (environmental, economic, and public health) that are most relevant in the context of overall public good, as viewed across geographic and agency boundaries.
- Climate and ecological processes including improving understanding of the spatial variability of fire. Recent investigations have found strong associations between the Palmer Drought Severity Index (PDSI) several months to 2 years earlier and fire season severity. Correlating anomalous wildfire frequency and extent with the PDSI illustrates the importance of prior and accumulated precipitation anomalies to future wildfire season severity.
- Risk assessment and mitigation including strategic planning for fire use (i.e., prescribed burns and allowing selected fires to burn) and fire suppression; improving predictive capabilities based on improved understanding of relationships between wildland fire and climate before, during, and after events; and determination of how science can inform development of wildland fire objectives important to interagency preparedness planning.
- Development of an integrated model called Fire-Climate-Society (FCS-1) to provide a planning tool, accessible to fire managers and community members, that would integrate the climate, fuels, fire history, and human dimensions of wildfire behavior for strategic management.

Next-Generation Integrated Knowledge

The objective is to develop an understanding of the interactions among climate, ecology (e.g., fuel load), and human factors (e.g., real estate, land use, recreation, conservation, jurisdiction, law) such that decision support insights reflect the true "multiple-stressor" realities of wildland fire risk and management. Particularly important are questions such as:

- What federal/state policies and programs increase fire risks and severity; what policies pose barriers to adoption of innovations such as new decision support tools?
- What are the scales of impacts (temporal and spatial) that influence fire regimes?
- What are the connections between multi-year drought and fire risk?

Pilot Product Development and Evaluation

- A new Predictive Services program has been launched to anticipate where fires are most likely to occur in order to allocate the appropriate firefighting resources to these areas. Geographic area predictive services units, established by the 2000 National Fire Plan, are tasked with integrating information about climate, weather, fire danger, and firefighting resources to provide decision support to fire managers on the location, timing, and severity of fire potential.
- The National Wildland Fire Outlook is the compilation of the 11 geographic area outlooks generated at the National Seasonal Assessment Workshop, and provides the first national-level, interagency, climate-based seasonal fire outlook.

In the spirit of the adaptive learning approach built into many of the regional projects, pilot products are inspiring a new round of research into understanding decision structures and constraints in order to transfer knowledge gained in this particular decision support experience.

- Proposals advanced by private and non-governmental organizations
- Preparation for international negotiations
- Consideration of legislative proposals
- Priority-setting processes for science and technology programs.

The CCSP will work in close collaboration with the Climate Change Technology Program (CCTP) to develop evaluations of relevant policy questions that incorporate up-to-date knowledge of both scientific and technology issues. The CCSP will focus on two objectives in this area: (1) developing scientific syntheses and analytical frameworks ("resources") to support integrated evaluations, including explicit characterization of uncertainties to guide appropriate interpretation, and (2) initially conducting a limited number of case studies with evaluation of the lessons learned, to guide future analyses.

Objective 3.1: Develop scientific syntheses and analytic frameworks to support integrated evaluations, including explicit evaluation and characterization of uncertainties

One of the challenges of developing scientific syntheses is providing a systematic way of integrating knowledge across disciplines, each having their own methodologies, resolutions, and degrees of certainty of scientific information. Meeting this challenge requires defining and meeting information needs across these borders, and developing methods and approaches to put information from different disciplines in compatible formats. Integrated models are an important tool for synthesis and comparative evaluation because they impose stringent standards of cross-disciplinary consistency and intelligibility. The CCSP supports the development of a number of integrated modeling frameworks that are useful for exploring many dimensions of climate and global change. The CCSP will also adopt other approaches for synthesis, including integration of expert knowledge across the relevant fields.

The CCSP will structure its syntheses and integrated analyses of policy questions related to climate variability and change using four types of approaches and drawing on research results produced throughout all areas of the program. These four approaches are:

1) Evaluations of net greenhouse gas flux and uptake using a variety of methods
2) Climate system analyses to study sensitivities and quantify ranges of climate variability and change
3) Analyses of the effects of climate variability and change
4) Integrated analytic frameworks.

Evaluation of net greenhouse gas flux and uptake in the Earth system (including human activities, the land surface, ecosystems, the atmosphere, and the oceans). The CCSP will use several methods to evaluate historical, current, and projected future patterns of greenhouse gas flux uptake, and consequent concentrations. These methods include state-of-science syntheses for emissions and carbon cycle information, evaluation of the effects of future technology adoption in the United States and globally (in collaboration with the CCTP), use of expert working groups (including both government and non-government specialists) to evaluate historical and projected greenhouse gas emission information and uncertainties (including uncertainties arising from different assumptions about human driving forces), and various inverse-calculation methods to verify greenhouse gas flux rates compared to recent and current observations of greenhouse gas levels. Consistent with overall CCSP guidelines, these analyses will be developed in response to specific questions, and will be released for public review prior to publication in final form.

Climate system analyses. The CCSP will examine the range of natural variability (short- and long-term), responsiveness of the climate system to changes in net greenhouse gas fluxes and concentrations, and the potential for abrupt climate changes. CCSP analyses will use analytic approaches to improve the evaluation of uncertainty in important variables. It is well-recognized that there are significant questions about climate model sensitivity, as well as questions about verification of climate model projections when compared to long-term observation records. The CCSP will prepare an updated analysis on the uses and limitations of climate models for various policy support applications, and this CCSP analysis will guide the use of climate models in other CCSP analyses. In addition to computer-based climate models, several other analytical techniques will be used by the CCSP in developing policy-support analyses. These include atmospheric and oceanographic process research, historical and analog evaluations, and various data analysis and projection techniques. The CCSP supports a major program of climate model development and verification (see Chapter 10), and results from this program will be used in support of syntheses as appropriate.

Analyses of the effects of climate variability and change. Evaluation of the potential impacts associated with different atmospheric concentrations of greenhouse gases and aerosols is an important input to weigh the costs and benefits associated with different climate policies. Further research is required to integrate our understanding of the range of effects of different concentration levels and to develop methods for aggregating and comparing those impacts across different sectors and settings. Working with external advisory groups and the broad range of CCSP scientists, the CCSP-supported research will analyze a range of possible climate change impacts determined from climate system modeling and arising from different assumptions about natural and human influences, including (among many others) implications for agriculture, forestry, drought, fire, water resources, fisheries, coastal zones, and built environments such as ports. It will also address (to the extent possible given uncertainties) the potential implications of various response options for both the climate system and the economy.

Integrated analytic frameworks. Integrated analysis of climate change is essential for bringing together research from many contributing disciplines and applying it to gain comparative insight into policy-related questions. Full integration of information including research on human activities, greenhouse gas and aerosol emissions, land-use and land-cover change, cycling of carbon and other nutrients, climatic responses, and impacts on people, the economy, and resources is necessary for analysis of many important questions about the potential implications (both economic and environmental) of different greenhouse gas concentrations and various technology portfolios. Development and use of techniques for scenario and comparative analysis is useful for exploring the implications of different hypothetical policies for curbing emissions growth or encouraging adaptation. Answers from integrated analysis can only reflect the existing state of knowledge in component studies, but it is important to develop frameworks and resources for integration, exercise them, and learn from analysis of the results. CCSP will encourage innovation and development of approaches to integrated analysis, and test these approaches in case study evaluations.

Evaluation of uncertainty. For all four of the analytical approaches described above, the issue of evaluation and communication of uncertainty and levels of confidence is fundamental. Uncertainties can arise from lack of knowledge; from problems with data, models, terminology, or assumptions; and from other sources. Integrated models are strong tools for examining uncertainty through repeated model runs with variation of key parameters. Use of scenarios, sensitivity analysis, and the specification of probability distributions for many inputs coupled with model runs are among the ways in which integrated models can be used to explore uncertainty. CCSP will use these and other techniques to evaluate uncertainty, and couple this analysis with its commitment to reporting levels of confidence and uncertainty clearly and transparently. The approaches to uncertainty evaluation and communication will enable users of CCSP analyses to understand the uses and limits of the information. As indicated elsewhere in this plan, broad guidelines for consideration of scientific uncertainty by the CCSP include the following:

- Uncertainty by itself (i.e., without regard to its magnitude in each specific case) should not prevent the development of analyses that may provide useful information for policy considerations.
- The magnitude (or importance) of uncertainty should be directly reported as a key element of analytical results in all cases where policy-supporting analyses are conducted.

Analytic approaches. Within the four analytical domains described above, a variety of approaches will be used and tailored to the study of a particular set of policy questions. The approaches are a means for examining proposed courses of action that incorporate knowledge of important key factors and uncertainty. In addition to development of decision support-related resources, the CCSP will also support research that furthers development of resources for integrated and comparative analysis, including:

- Use of historical climates (climate analogs)
- Techniques for posing and analyzing "If …, then…" questions, and reporting analytical results in the form of probability distributions of possible outcomes, thereby incorporating uncertainty information directly in the projected outcomes
- Models and qualitative frameworks for integrating scientific and technical information to compare environmental and socioeconomic effects of alternative response options
- Techniques for developing and analyzing scenarios using only a few of the most important variables (parametric analysis techniques)
- Techniques for "inverse analysis" that start from the study of temperature, precipitation, and other climate inputs required to maintain a system or activity, then identify rates or levels of climate change that would lead to discontinuities or thresholds.

An emphasis will be placed on the development of the greenhouse gas net flux scenarios through collaboration with CCTP. The distinctive feature of scenarios is that they integrate knowledge from the full range of relevant sources into a consistent description of potential future events. The specific variables incorporated in scenario development depend on the question being addressed. Scenarios for atmospheric chemistry, climate, impacts, adaptation, and mitigation models all require different techniques and variables. Scenarios will be constructed using 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). CCSP will coordinate its scenario development plans with CCTP plans for analysis of different plausible technology portfolios and with the scenario efforts of the IPCC.

Objective 3.2: Conduct a limited number of case study analyses and evaluate the lessons learned in order to guide subsequent analyses

During the next 2 years, CCSP will conduct a limited number of case study integrated analyses using the approaches described above. For each case study analysis, a project team will be established that is responsible for design and implementation of the decision support methodology and products. Diverse input will be solicited to frame the questions, determine analytic methodologies to be used, identify needed observations to address the problem, and determine what resulting analyses and products are to be prepared. Stakeholder involvement will be sought throughout the case studies to aid in question development, selection of analytical methods, review of products, and guidance for communication of results. CCSP will provide support and coordination of the scientific community, stakeholder, and public interactions. End products of each case studied will include appropriate assessment reports, as well as the related "lessons learned" documents.

The lessons learned during the decision resource case studies conducted in the next 2 years will be used to guide the definition of a wider set of analyses to be completed in a 2- to 4-year time period. Both the initial and subsequent case studies will be specified (e.g., by choice of technical issues addressed, and by parameters selected for analysis) to reflect relevant climate variability and change issues. An illustrative case study demonstrating the application of the policy decision support process to an examination of technology mitigation is summarized in Box 11-6. Note that this illustration does not constitute a specific plan for analysis. As mentioned previously, CCSP will present specific plans for decision support analyses in separate announcements when ready, and will solicit public comment on each proposed plan.

Other case studies being considered for short-term (within 2 years) or longer term (2-4 years) analysis include:

- Possible climate and ecosystem responses to long-term greenhouse gas stabilization at various specified levels
- Projected climate, socioeconomic, and environmental outcomes of various carbon sequestration initiatives adopted both in the United States and globally
- Application of scientific information on the carbon cycle, ecosystems, and other research elements for the development of guidelines for crediting carbon sequestration activities—for example, as related to land use and soil type, cover species type, management practices, and so on
- Possible outcomes (in terms of projected greenhouse gas concentrations and climate system response) projected for various scenarios of new energy technology penetration both in the United States and globally
- Risk analyses related to various examples of abrupt climate change

BOX 11-6

TECHNOLOGY SCENARIO CASE STUDY: AN ILLUSTRATIVE CASE STUDY (IN CONJUNCTION WITH THE CCTP)

Evaluate Two Categories of Scenarios

1) What combinations of technologies can be expected to provide energy consistent with different emission levels between now and 2050?
2) What are the range of plausible consequences (on the climate system and socioeconomic parameters) of different emission scenarios reflecting the technology options responsive to the previous question?

Analysis Planning

A project workshop—with expert stakeholders including climate scientists, energy technology engineers and scientists, energy economists, and industry, government, and non-government organization representatives would be held (late 2003/early 2004) to gain alignment and organize cooperative research on deliverables. Additional project working groups would be formed for continued dialogue throughout the project time frame. A draft study plan, including competitive proposal processes and federal in-house research assignments, and a timeline for completion of tasks would be prepared by early 2004. CCSP would post the draft plan for public comment on its website, <www.climatescience.gov>.

Scenarios for Technology Performance with Alternative Profiles

Each profile would include technologies that are presently part of the global energy system and that are expected to have their performance improved over time, as well as new technology options presently under development (e.g., carbon capture and disposal, hydrogen systems, fusion energy, and biotechnology). Performance improvements with alternative technology options would also be explored. Estimates of potential benefits in terms of greenhouse gas emissions, energy security, and oil dependence would be assessed. The scenarios would also explore the potential for unintended consequences—both positive and negative. For example, if wind energy were extracted over large areas, it could reduce conventional air pollution as well as reduce greenhouse gas emissions, but it could also conceivably affect regional atmospheric circulation. Interaction with CCTP would be essential in developing these baseline scenario profiles. Incorporation of current scientific information about socioeconomic, technological, climatic, and environmental factors would be undertaken, with a characterization of the uncertainty in the scenarios. The scenarios would be completed by the end of 2004.

Modeled Climate Change for Each Greenhouse Gas Scenario, including Dynamic Carbon Cycle and Reasonable Projections of Land Use

This climate modeling task would be the responsibility of the large U.S. modeling groups. The model runs would also estimate the uptake of greenhouse gases by natural systems. This modeling must be informed by the results of carbon cycle research. The veracity of the model simulations for carbon sources and sinks needs to be tested ahead of time by comparisons to historical observations of the carbon cycle and the contribution of land-use changes. The model results would likely be presented in probabilistic form, and would be required to achieve agreed confidence limits to be considered usable for decision support. The large baseline computer modeling would be completed by mid-2005.

Modeled Environmental Impacts on Soil Moisture, Streamflow, and Vegetation

It is likely that one or both of the high-end U.S. climate models used for these studies would include fully interactive hydrologic-carbon-biogeochemical cycles (i.e., the major natural systems being impacted by climate). Workshops would be held to engage the broader community of researchers studying climate impacts in the analysis of these experiments, and provide guidance as to how process-driven impacts models can be interfaced with these simulations. The baseline global impacts modeling would be completed with probability distributions of projected outcomes by the end of 2005. Higher resolution (50-km or greater) simulations may be available for portions of the baseline scenarios starting in FY06, but only if such higher resolution models are shown to have useful confidence limits by that time.

Analyses, Assessments, and Reports

Throughout the process, several interim analyses, assessments, and reports would be generated. Example products for this case could include the following:

- Synthesis report on the scenario development and the characterization and evaluation of the uncertainties in the scenarios (2005).
- Evaluation of the impacts on the climate system for the baseline and alternative technology pathways. Report on the analysis of the scenarios of response of the climate system to various emission scenarios with emphasis on intercomparison of the different pathways (2006).
- Analysis of the scenarios of environmental responses to those response scenarios of the different climate states. Reports on the inter-comparison of those responses to the different climate states. One example may be an evaluation of the potential for carbon sequestration in different ecosystems and agricultural systems, including initial greenhouse gas accounting analyses and guidelines for agriculture and forestry (2006).
- Final synthesis report on the inter-comparison of different technology pathways with the baseline pathways including an analysis of potential environmental benefits and associated costs of each scenario (2007).

- Projected climate and ecosystem outcomes related to significant changes in land use and land cover, both in the United States and globally
- Analysis of adaptation strategies related to specified changes in climate or ecosystem parameters.

Decision Support Management Strategy

CCSP management and advisory processes will ensure implementation of an open and credible process for development of decision support resources.

Management Structure

Leadership and direction will be provided by the CCSP interagency governing body, working with representatives of the Interagency Working Group on Climate Change Science and Technology (IWGCCST) and CCTP to:

- Select syntheses or assessments to be conducted by the program, and provide oversight for these activities
- Review needs for decision support focused on adaptive management and promote development of CCSP research and resources to respond to these needs
- Periodically identify and define topics of importance to national decisionmaking to be addressed by the CCSP case studies of integrated analyses and scenario evaluations
- Establish external advisory mechanisms.

CCSP decision support activities will be implemented through an interagency working group with management and coordination support from the Climate Change Science Program Office (CCSPO). Specific responsibilities of the working group include:

- Carry out approved activities (e.g., identify resource requirements, develop implementation plans) under supervision of the CCSP interagency governing body
- Evaluate program needs and develop initiatives that respond to these needs
- Maintain an inventory of ongoing decision support and assessment activities within the CCSP agencies
- Coordinate agency activities
- Support advisory mechanisms as directed by the CCSP, including workshops, committees, or NRC activities.

CCSPO will support development of decision support activities, under the supervision of the CCSP interagency governing committee. CCSPO will be responsible for helping to coordinate the preparation of assessment and synthesis products; connecting the assessment activities, lessons learned, and decision tools development to broader interests and communities; and evaluating, reporting, and communicating results from the decision support activities.

Stakeholder Input and Evaluation

CCSP decision support activities will be conducted openly with input from external technical experts and other stakeholders. Advisory processes will be structured to meet specific requirements for each activity. Past experience has indicated that open framing of the questions to be addressed and methods to be adopted are crucial to establishing an open process and credible product. Ongoing advisory processes will provide independent review and oversight and ensure that products developed bring in all relevant perspectives. Independent evaluation of both products and processes will be included as a component of decision support efforts to ensure that future activities are improved by consideration and application of experience garnered through initial case study activities.

A first step that will be taken in developing stakeholder input is to hold a focused workshop to provide comments on (1) initial selection of topics/questions for policy decision support activities; (2) possible structures of "If …, then…" scenario analyses and other approaches for providing insight into the identified topics; (3) suggestions regarding the appropriate role of CCSP-supported research in fostering problem-oriented/solution-based adaptive management decision support; and (4) suggestions for ongoing external advisory and review mechanisms.

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CHAPTER 12

Observing and Monitoring the Climate System

CHAPTER CONTENTS

For each of six overarching goals, this chapter introduces objectives that provide products and milestones to be addressed in the coming decade based upon current knowledge.

Goal 1: Design, develop, deploy, integrate, and sustain observation components into a comprehensive system.

Goal 2: Accelerate the development and deployment of observing and monitoring elements needed for decision support.

Goal 3: Provide stewardship of the observing system.

Goal 4: Integrate modeling activities with the observing system.

Goal 5: Foster international cooperation to develop a complete global observing system.

Goal 6: Manage the observing system with an effective interagency structure.

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 for the development and deployment of a global, integrated, and sustained observing system to address science requirements and decision support needs at appropriate accuracies and space and time resolutions.

The Climate Change Science Program (CCSP) strategy for observations and monitoring includes guiding principles, identification of priorities, and effective management of available resources. The purpose of this chapter is to describe how all the disparate observations described by the CCSP plan will be systematically organized and managed to improve our understanding of the climate system. The data management discussion that follows (see Chapter 13) describes the plan for archival and distribution of these data.

The CCSP observations and monitoring component seeks to address the following overarching question:

How can we provide active stewardship for an observation system that will document the evolving state of the climate system, allow for improved understanding of its changes, and contribute to improved predictive capability for society?

The development of space-based and *in situ* global observing capabilities was a primary focus of the program's first decade. Several new Earth-observing satellites, *in situ* networks, reference sites, and process studies are now producing unprecedented high-quality data that have led to major new insights about the climate system. The observing system for the future will build upon this success. For the purposes of this document, surface-based remote-sensing observations, as well as aircraft or suborbital measurements—in addition to direct observations within the atmosphere, ocean, ice, or land—will be considered as *in situ* measurements, and any references to *in situ* measurement networks should be considered as applying to networks using these techniques wherever appropriate.

The challenge for the coming decade is to maintain current capabilities, implement new elements, make operational the elements that need to be sustained, and integrate these observations into a comprehensive

"Knowledge of the climate system and projections about the future climate are derived from fundamental physics and chemistry through models and observations of the atmosphere and the climate system. Climate models are built using the best scientific knowledge of the processes that operate within the climate system, which in turn are based on observations of these systems. A major limitation of these model forecasts for use around the world is the paucity of data available to evaluate the ability of coupled models to simulate important aspects of past climate. In addition, the observing system available today is a composite of observations that neither provide the information nor the continuity in the data needed to support measurements of climate variables. Therefore, above all, it is essential to ensure the existence of a long-term observing system that provides a more definitive observational foundation to evaluate decadal- to century-scale variability and change. This observing system must include observations of key state variables such as temperature, precipitation, humidity, pressure, clouds, sea ice and snow cover, sea level, sea surface temperature, carbon fluxes, and soil moisture. Additionally, more comprehensive regional measurements of greenhouse gases would provide critical information about their local and regional source strengths."

Climate Change Science: An Analysis of Some Key Questions (NRC, 2001a)

global system to address the objectives of the CCSP research elements and decision support activities. Fundamental questions about the climate system and societal benefits that can be addressed are described in Chapters 3 through 11; these provide the basis for the observing system design and implementation. Illustrative examples of CCSP observation needs and milestones that address the research questions are described in Appendix 12.2. In addition, the overall climate observing system must address the five basic integrating goals for CCSP outlined in the introductory chapter:

- Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change
- Improve quantification of the forces bringing about changes in the Earth's climate and related systems
- Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future
- Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes
- Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

A system that integrates atmospheric, oceanographic, terrestrial, cryospheric, and cross-cutting observations does not currently exist *per se*. However, many components are available. For example, the Global Climate Observing System (GCOS) is a fairly well documented but not completely implemented international approach that has components in place to satisfy some climate requirements (see GCOS, 2003). GCOS is intended to provide a focused set of observations from a subset of established measurement sites that are considered to have a sufficient climate history and spatial distribution. The system discussed here, however, goes beyond GCOS. CCSP has expanded the initial inventory of important climate observations (see Appendix 12.1) to encompass the needs of research on and applications to the global cycles of carbon, water, energy, and biogeochemical constituents; atmospheric composition; and changes in land use.

Building on the CCSP mission, the United States has also taken a leading role in fostering the development of a more broadly defined and integrated global observing system for all Earth parameters—for example, including geological as well as climate information. The United States hosted a ministerial-level Earth Observation Summit in July 2003, with participation by many developed and developing nations as well as many intergovernmental and international nongovernmental groups. This summit initiated a 10-year commitment to design, implement, and operate an expanded global observing system that builds on the major observational programs currently operated by the U.S. and many other governments and international organizations. CCSP agencies have provided the leadership, definition, and support for the Earth Observation Summit, and CCSP will closely integrate the U.S. observation and data management programs with the international programs launched at the summit.

The global observation system needed to fully implement CCSP includes the evolution of the observing capability provided through the U.S. Global Change Research Program (USGCRP) and the operationally oriented monitoring systems routinely provided by several federal agencies. The latter were never included as part of USGCRP, and may or may not be included as part of CCSP in budget inventories. In fact, as noted below, a critical issue associated with the implementation of the observing system for CCSP is the transitioning of research observations, typically made through USGCRP, into operations, not currently included as part of USGCRP (see Objective 1.3). Any consideration of budgets associated with global observations should be based on those for all the component programs, and not the historic USGCRP budget.

The basic elements of a global observing system must consist of:

- Routine and continuing measurements of selected variables, collected using established principles
- Shorter term exploratory observations carried out with satellites, process-oriented field campaigns with *in situ* techniques, and other, finite duration, research observations, collected using established principles
- A comprehensive and reliable distribution network and long-term archive
- Analysis and integration activities, including the use of four-dimensional (space, time) data assimilation and scientifically validated models.

These elements must be managed by an effective national entity, and coordinated at the international level. The management must have the capability to establish observing protocols, provide oversight, address deficiencies, and mobilize resources as required to maintain the integrity of the entire end-to-end system. A major challenge for CCSP in this decade will be the transition of many observation elements developed in a research mode to a sustained and operational environment [e.g., NASA research satellites to National Polar-orbiting Operational Environmental Satellite System (NPOESS) and some *in situ* networks]. The resulting global system must obviously engage many countries in a cooperative enterprise. Developing such a system presents a daunting challenge that must be met to provide essential information for decisionmakers.

In order to move toward a global observing system, CCSP will focus on six goals:

1) Design, develop, deploy, integrate, and sustain observation components into a comprehensive system
2) Accelerate the development and deployment of observing and monitoring elements needed for decision support
3) Provide stewardship of the observing system
4) Integrate modeling activities with the observing system
5) Foster international cooperation to develop a complete global observing system
6) Manage the observing system with an effective interagency structure.

Goal 1: Design, develop, deploy, integrate, and sustain observation components into a comprehensive system.

A system is the integration of interrelated, interacting, or interdependent components into a complex whole. The path to an overall observing system must address a number of key issues in addition to the observation components themselves, including the priorities for development, the implementation strategy, assessment, utilization, cooperation with other providers of environmental measurements, data management, international development, and system management. Some of these activities are considered in this goal, but others are of sufficient complexity that they are a goal unto themselves and are discussed later in this chapter.

Prioritization. Observing elements are in place within existing 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 are required because resources are limited. The CCSP research element questions and decision support goals provide the basis for determining priorities. In CCSP implementation plans, the research and decision support elements will provide a link between research question or decision support goal, measurement requirements, and the observation elements that meet the requirements. The prioritization criteria include: benefit to society, scientific return, partnership opportunities, technology readiness, program balance, and implementation of the climate monitoring principles (see Appendix 12.4). The management of the program will recommend priorities in consultation with the scientific community using the management mechanisms outlined in Chapter 16.

Evaluation. A key lesson learned over the past decade is that observing systems and networks must be implemented in a way that allows

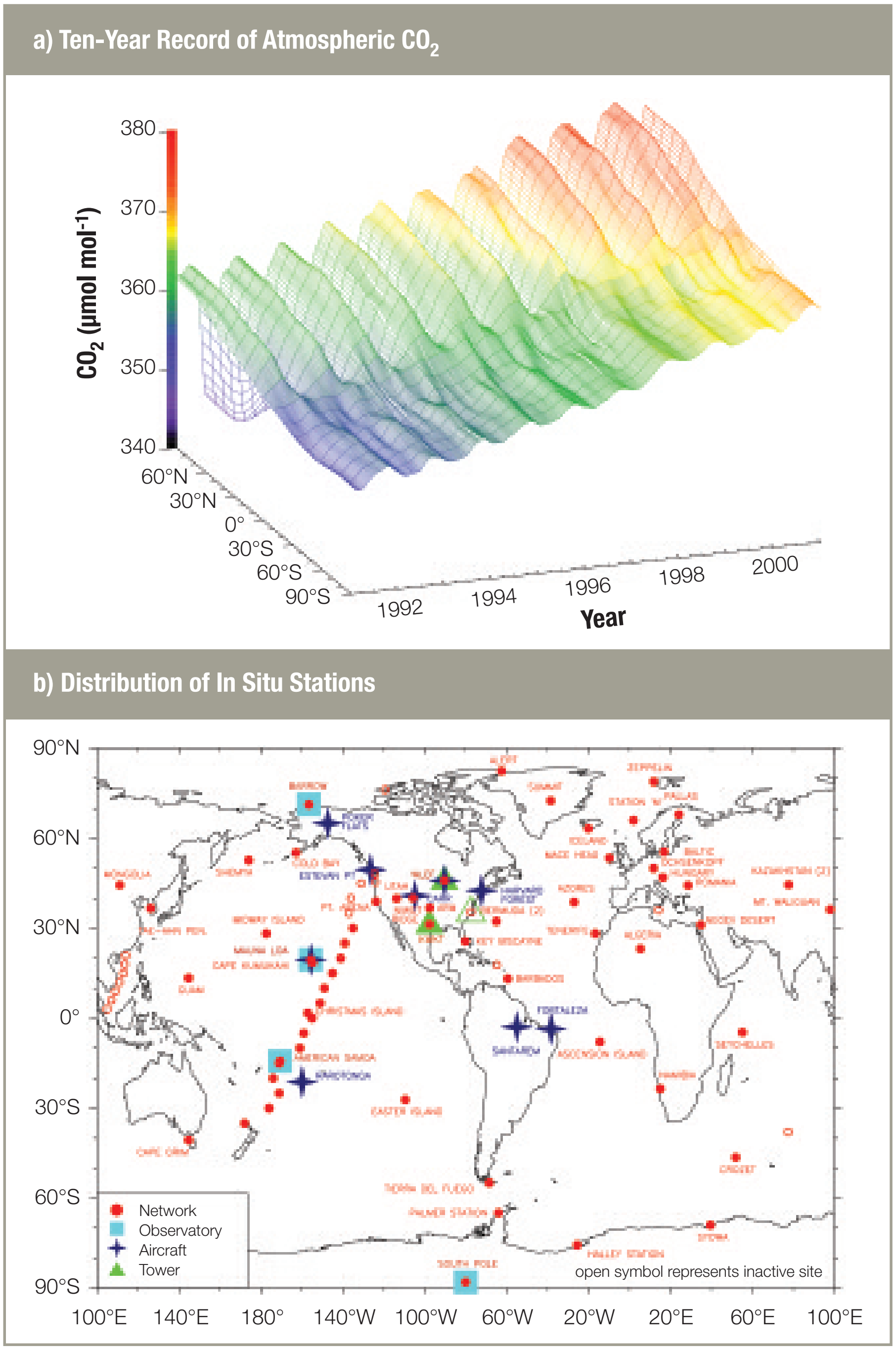

Figure 12-1: (a) Ten-year record of atmospheric carbon dioxide (CO_2) at a variety of stations as a function of latitude, and (b) distribution of *in situ* stations collecting data on CO_2 and other greenhouse gases. Source: Pieter Tans, NOAA CMDL. For more information, see Annex C.

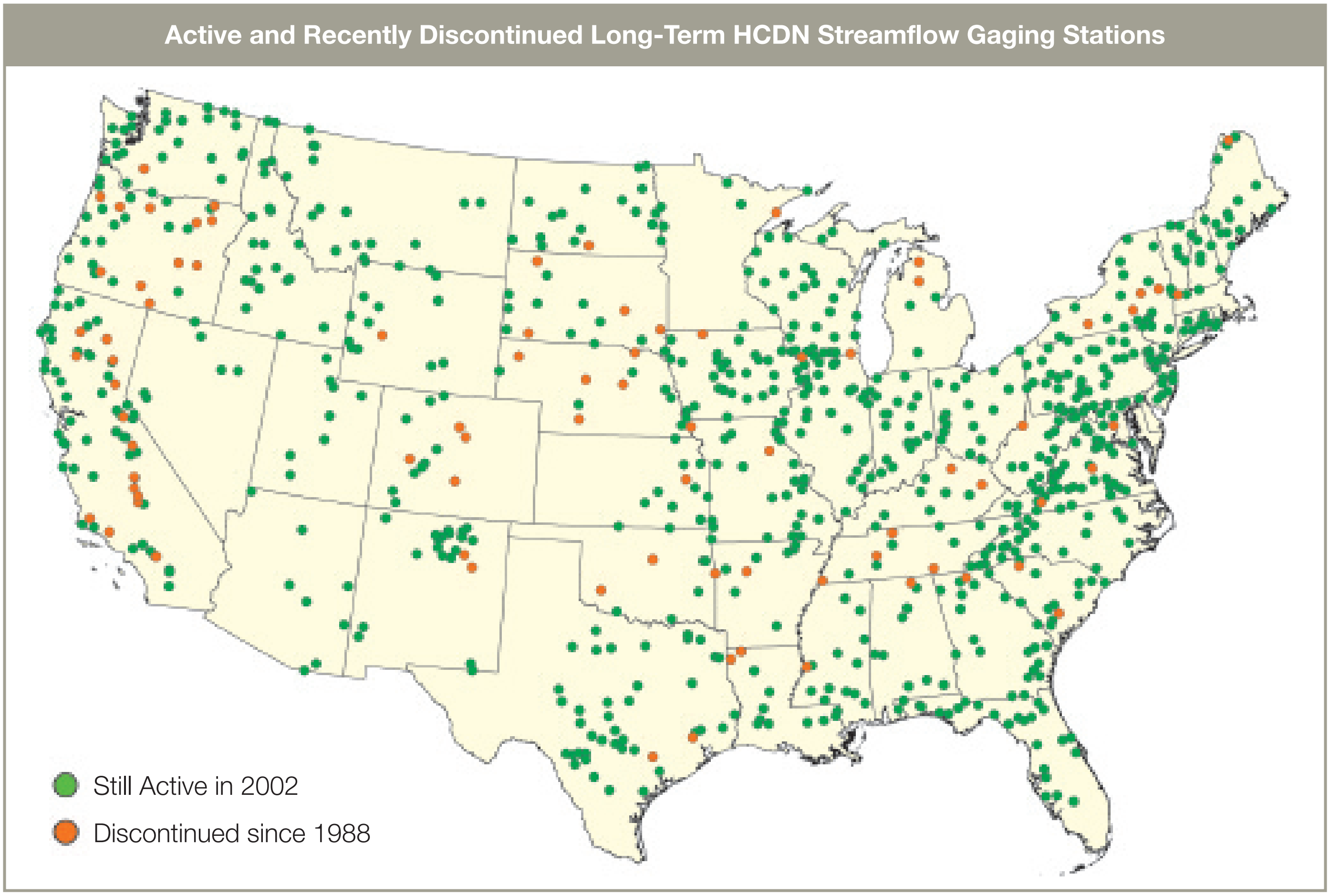

Figure 12-2: The U.S. Geological Survey (USGS) Hydro-Climatic Data Network (HCDN) was compiled in 1988 and included 854 gauges that were active and had at least 36 years of record. Stations that are still active are shown in green. Stations discontinued since 1988 are shown in red. These stations would have had at least 50 years of record as of 2002, if they had been kept in operation. Source: William Kirby, Global Hydroclimatology Program, USGS. For more information, see Annex C.

flexibility as both requirements and technology evolve. Therefore, the program will regularly assess the science and decision support requirements and propose modifications to the observing systems required for CCSP to execute its research plans. This process will 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 (see Goal 6).

Cooperation. Many important observing systems are developed and operated by organizations that are not formal participants in CCSP, making the development of strong cooperative relationships that extend beyond the current CCSP a necessity. CCSP will work with observing system partners and the scientific community to identify climate requirements for these observing systems and to set priorities in light of available resources and competing needs.

Objective 1.1: Develop a requirements-based design for the climate observing system

A requirements-based design will be developed to identify baseline and minimum requirements that will address CCSP research element questions and decision support goals. U.S. needs and contributions will be weighed in the global context of the requirements and contributions of other nations and coordinated with them in a manner that will lead to a global system. The most efficient and effective observation elements and networks will be selected that will meet the requirements.

Objective 1.2: Stabilize and extend existing observational capabilities

CCSP will maintain and improve basic research observing facilities, networks, and systems (both space-based and *in situ*). Climate-quality data requires long-term continuous records (see Chapter 4, Figure 4-1). It is critical to maintain records required to answer research questions before they are lost for other reasons (see Figure 12-2). Long-term observations require a focus on maintenance and replacement to sustain the capability at a sufficient level of accuracy to detect climate change over decades. To meet this objective, CCSP will:

- Continue satellite missions (see Figure 12-3) that are critical to answering the research element questions and upgrade the quality of their data to climate standards
- Extend and stabilize *in situ* networks for global coverage with consistent data quality, including moored, drifting, and ship-based networks in the ocean; surface and upper air networks in the atmosphere; and the major terrestrial networks
- Provide a uniform global set of surface reference sites of key ocean, land, atmosphere, and hydrology variables [see Figure 12-1 as an example of a global system for carbon dioxide (CO_2)]

- Provide careful calibration and overlapping operation of new and old technology during transitions to maintain quality control of data records
- Extend the capacity in terrestrial inventory programs to provide comprehensive information for key ecosystems within the United States.

Objective 1.3: Develop and implement a strategy for the transition of proven capabilities to an operational mode

The transition of proven research observation elements to sustained or operational status will make these components more cost-effective and sustainable for long-term benefit. CCSP will work toward an effective integration for the planning and development of research and operational systems. CCSP will develop a strategy to transition from research to operations that will adhere to the climate monitoring principles (see Appendix 12.4), including continuity, in order to have the most benefit to its objectives. Management structures will be developed to provide for a handoff from research management to operational systems management. The operation management will be responsible for continuing the research mission and producing and delivering day-to-day operational results and products.

Objective 1.4: Incorporate climate and global change observing requirements in operational programs at the appropriate level

Operational observation networks continue to be the backbone of climate system measurements. These networks, with only modest incremental costs, will satisfy significant parts of the climate observing requirements as described in the climate monitoring principles (see Appendix 12.4). Scientific, as well as decision support, oversight of operational systems for climate must be implemented using the concept of Climate Data Science Teams described in Goal 6 below.

Objective 1.5: Identify, develop, and implement measurement improvements

CCSP must maintain a sustained research and technology development program to address major deficiencies in observing systems and the paleoclimate record identified in Chapters 3 to 9 (e.g., closing the budgets for carbon, energy, and water cycles; integrating the coastal ocean monitoring systems; and completing records about decadal- and century-scale climate variability prior to the instrumental record). To the extent possible, new or improved measurements will be integrated into existing networks so as to minimize redundant operations and costs. Future global measurements from satellites and regional *in situ* networks will be developed that dramatically improve quality and vertical, spatial, and/or temporal resolution, especially to enhance regional coverage for decision support applications.

Objective 1.6: Continue intensive field missions

The science chapters have described and justified numerous field studies that 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

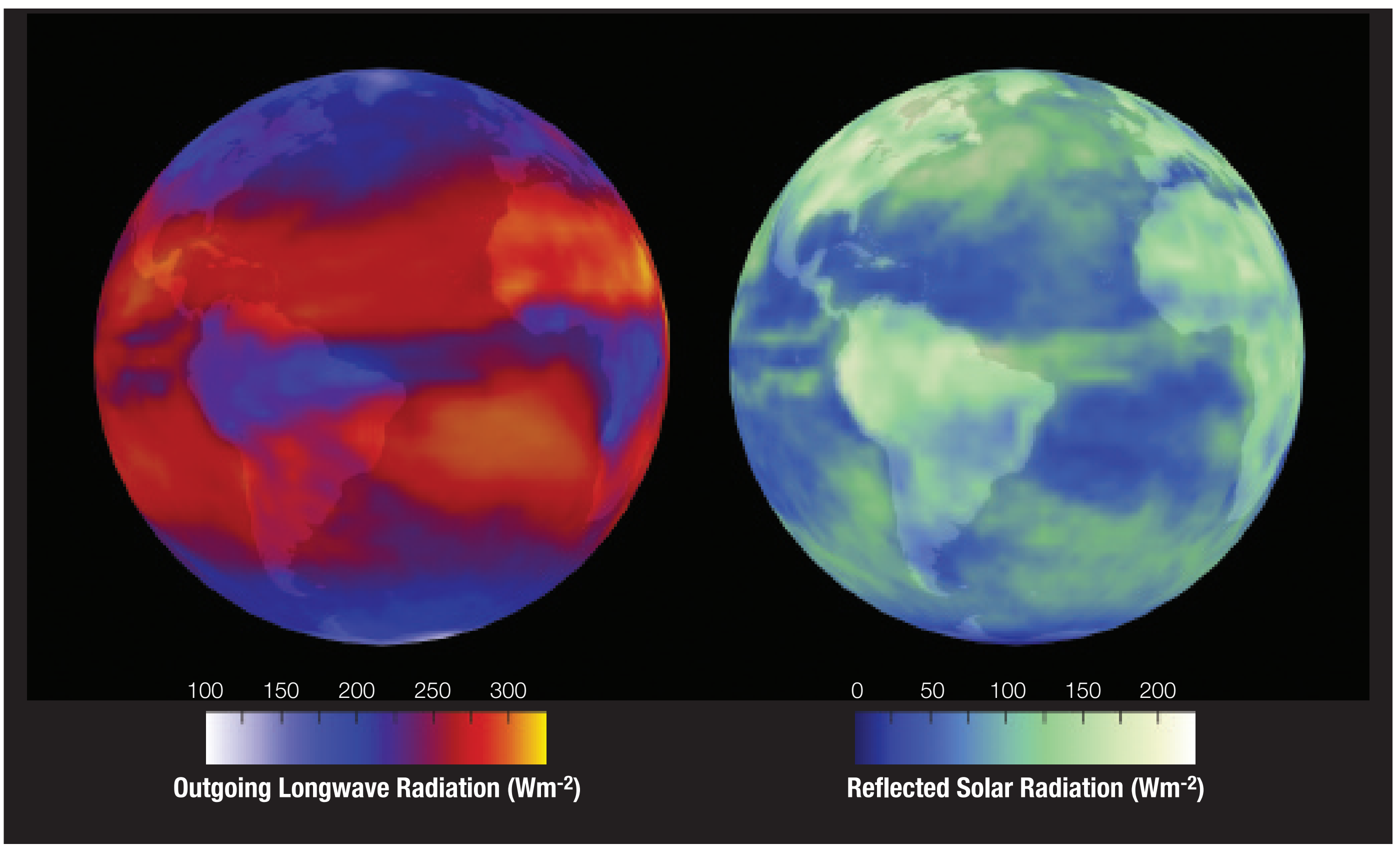

Figure 12-3: For scientists to understand climate, they must also determine what drives the changes within the Earth's radiation balance. From March 2000 to May 2001, the Clouds and Earth's Radiant Energy System (CERES) satellite measured some of these changes and produced new images that dynamically show heat (thermal radiation) emitted to space from Earth's surface and atmosphere (left sphere) and sunlight reflected back to space by the ocean, land, aerosols, and clouds (right sphere). Source: CERES Project, NASA (<http://asd-www.larc.nasa.gov/ceres/ASDceres.html>).

testing and validating satellite retrieval algorithms, and for the fine-scale resolution necessary to test, validate, and constrain physical processes in 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. Aircraft remain a valuable platform for CCSP and mechanisms to make efficient use of these facilities across the CCSP agencies will be investigated.

Objective 1.7: Assess observing system performance with uniform monitoring tools and evaluation standards

A global effort of this magnitude must be managed as a system in order to be effective. For agencies to assess the performance of the observing system, an institutional mechanism must be put in place to monitor the status of the globally distributed components and to evaluate their combined capabilities.

CCSP, working with international partners, will develop a system architecture for monitoring distributed global operations that establishes and maintains links among the *in situ* and satellite elements and the data and modeling activities that are essential components of climate observation. The purpose is to provide a framework so that the nation can manage its observing system more efficiently and effectively, and:

- Provide an integrated view of the observing system linked to the CCSP mission
- Develop a more cost-effective observation system
- Allow all observations to be accessible by all customers when needed
- Provide a framework for examining future requirements and costs
- Allow for evolutionary improvements
- Identify gaps and overlaps
- Identify opportunities to migrate observations from the research elements into a sustained operational status.

The guiding principles for development of this uniform interagency and international monitoring capability include:

- Provide a system that is requirements-based
- Provide elements that are standards-based and interoperable
- Provide for system evolution that is minimally intrusive to other national and international missions
- Provide ample margins to accommodate changing requirements
- Provide a basis for continual evaluation and evolution.

Objective 1.8: Generate climate information through analysis and assimilation

Many countries have gathered climate system data to document climate system variability using many different instrument types during the past 150 years. In order to document and understand change from a historical perspective, we need to develop global, comprehensive, integrated, quality-controlled databases of climate system variables based on historical or modern measurements, and provide the user community with open and easy access to these databases. We must integrate these records as far into the past as is practical to reduce uncertainties in the climate trend estimates of individual parameters.

Our understanding of some of the changes in the physical climate system over the past 50 or more years has improved because of systematic reprocessing and integration of climate observations using state-of-the-art climate models and data assimilation technology. This must be continued through a routine and iterative improvement process that incorporates a rigorous research and validation component.

Objective 1.9: Initiate or participate in end-to-end pilot demonstrations of atmosphere, ocean, and terrestrial hydrologic observing systems

The integration of satellite and *in situ* observing networks for synthesis of the ocean, atmosphere, or terrestrial spheres in a systematic manner will be addressed through focused pilot programs. The Global Ocean Data Assimilation Experiment, while not specifically focused on climate issues, is an example of a pilot approach to the synthesis of ocean observations.

Objective 1.10: Develop a requirements-based program for collecting, integrating, and analyzing social, economic, and health factors with environmental change

Across the range of research on human response and consequences to climate change there is a particularly strong need for the integration of social, economic, and health data with environmental data (see Chapter 9). Observations will be used to address gaps in understanding, modeling, and quantifying the sensitivity and vulnerability of human systems to global change and measuring the capacity of human systems. Using retrospective analyses of consequences of shifts in climate will also help model future ability of hazard and resource management institutions to respond.

Goal 2: Accelerate the development and deployment of observing and monitoring elements needed for decision support.

CCSP provides resources to develop observation systems and processing and support systems that will lead to reliable and useful products. These products will provide critical policy-neutral information for decision support and policymakers in areas such as climate and weather forecasting, human health, energy, environmental monitoring, greenhouse gases, and natural resource management.

CCSP will enhance the existing long-term monitoring elements with accelerated focused initiatives to provide a more definitive observational foundation for determining the current state of the climate. Many shortcomings of the current climate observing system relate to understanding climate forcings. In addition, fundamental observations for characterizing and understanding the state of the climate are needed for the global ocean, atmosphere, land surface, and ice variables. For the atmosphere, only half of the GCOS Upper-Air Network (GUAN), established for climate purposes, has been reporting regularly, and the GCOS Surface Network (GSN) for climate has had similarly disappointing results. The ocean is poorly observed below the surface, which limits our understanding about the ocean's response to a warming planet and its ability to naturally sequester greenhouse gases. Over land, the spatial heterogeneity requires detailed measurements and presents a major challenge.

In the budget requests for the past 2 years (FY2003 and FY2004), progress has been made to address many of these deficiencies, as described in Appendix 12.3. The objectives in this goal outline specific CCSP elements that will expand on this progress and support a directed strategy to focus resources and accelerate observations for climate change and decision support.

Objective 2.1: Complete the required atmosphere and ocean observation elements needed for a physical climate observing system

Within the climate monitoring arena, atmosphere and ocean observation elements to measure the physical aspects of the climate system are the most complete, and are ready to be brought together as a system. For example, the detailed open ocean observing system has been designed at both national and international levels through numerous community workshops, and implementation is about 40% complete (see Figure 12-4). The atmospheric system, which is a mixture of both climate and non-climate elements, has been recently examined (GCOS, 2003) and needs support for fixing degradations, sustaining current capabilities, and adding improvements. An accelerated effort to complete these two subsystems will improve understanding of climate characterization, forcing, and prediction, as well as facilitate the implementation and testing of the interagency management of complete observing systems. Focused new data management practices are being developed and will promote efficient acquisition, validation, delivery, and archival of the measurements and data products. In order to complete these systems the following steps need to be taken in conjunction with international partners:

- GSN measures surface temperature, pressure, and precipitation at about 1,000 sites within the World Weather Watch (WWW) surface climate network. The network is not providing useful data at many sites in underdeveloped countries because of a lack of resources and training. Furthermore, only one-third of the network has provided historical data for examining climate extremes. CCSP will improve GSN data reporting.
- GUAN collects upper atmosphere temperature, wind, and humidity at 150 stations around the world. Performance at about one-third of the stations is poor. CCSP will improve *in situ* atmospheric column observations in GUAN. In addition, CCSP will identify techniques and implementation strategies for *in situ* atmospheric column observations of temperature, wind, and water vapor over the ocean, where GUAN cannot be used.
- CCSP will complete the U.S. Climate Reference Network of 250 stations nationwide to provide long-term homogeneous observations of temperature and precipitation that can be coupled to past long-term observations for the detection and attribution of present and future climate change.

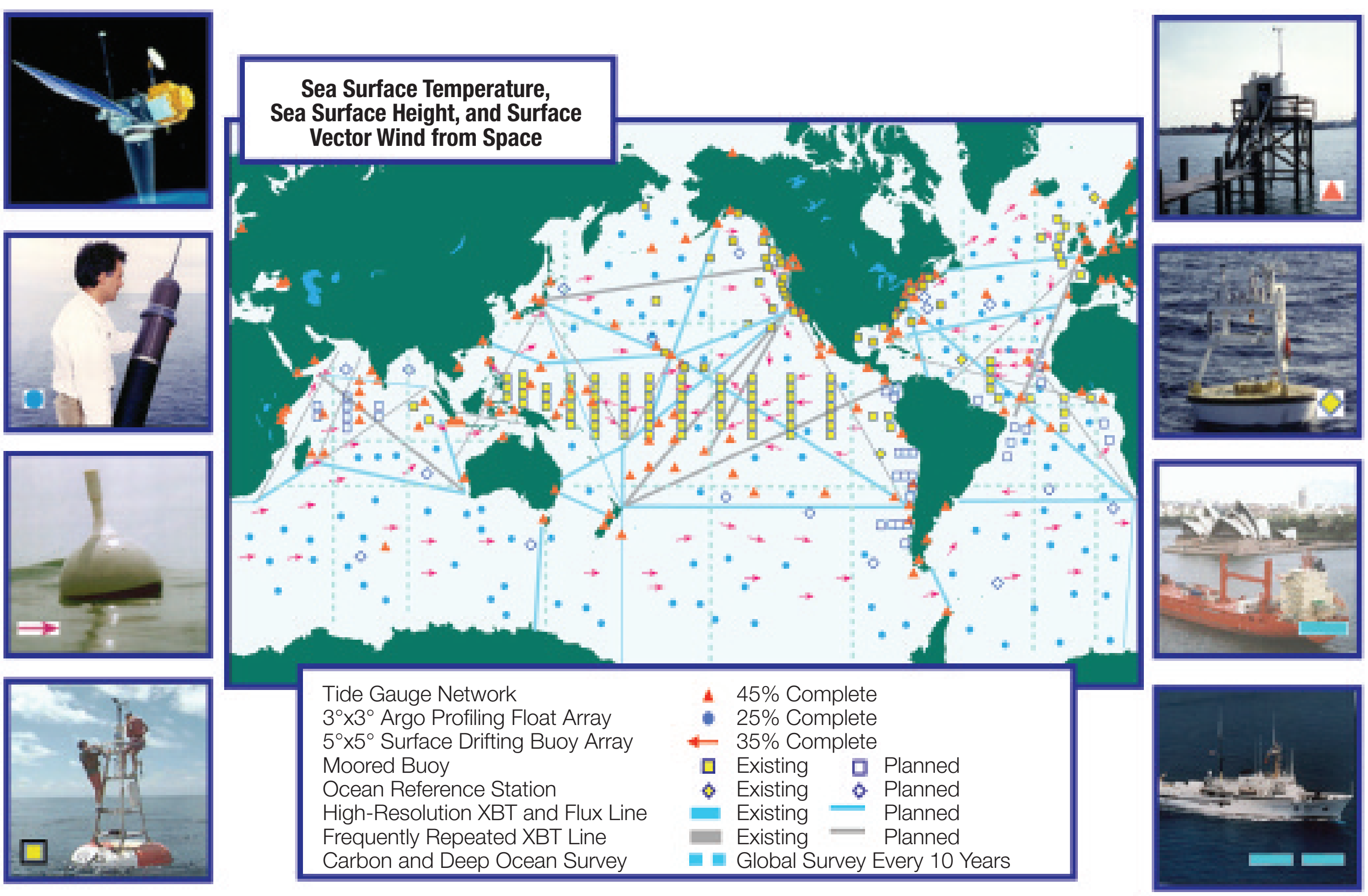

Figure 12-4: In 2003, the international global ocean observing system for measurements of the physical climate system was 40% complete. Source: Michael Johnson, NOAA Office of Global Programs.

- The United States will increase contributions to monitoring upper-ocean temperature and salinity structure that will improve understanding of the ocean's response to a warming planet. CCSP will support 50% of the international ocean profiling float program (Argo) and additional expendable bathythermographs from ships-of-opportunity to observe changes in heat and freshwater content.
- CCSP will improve estimates of global sea surface temperature for climate model initialization for better prediction capability, as well as regional barometric pressure and surface current velocity for improved model validation, by completing the global distribution of 1,250 surface drifting buoys.
- CCSP will reduce uncertainty in sea-level rise estimates by obtaining absolute positions for sea-level stations that are required to improve the calibration of satellite altimeters, used for the detection of long-term sea-level trends.
- The United States will continue to monitor the state of the tropical atmosphere and oceans in the Pacific and Atlantic Oceans with instrumented moored buoys and satellites, and contribute to the development of a similar network in the Indian Ocean for improved climate prediction and research.
- CCSP will improve model-based global air-sea flux estimates with surface flux reference moored buoy sites and Volunteer Observing Ships (also collect routine surface meteorological observations) with upgraded instruments for climate-quality observations.

Objective 2.2: Retrieve important paleoclimate records to provide a global long-term perspective on historical changes in climate

There are three aspects of the paleoclimatic record that need to be addressed by accelerated and focused programs within CCSP in order to improve characterization of long-term climate change and provide a valuable benchmark for testing models that are used to project the future (see Goal 4):

- Increase priority for retrieving rapidly disappearing paleoclimate information (e.g., melting glaciers, loss of corals and trees whose growth patterns are used for dating purposes, etc.) before these records are permanently lost
- Accelerate efforts to obtain interannual climate information in the Southern Hemisphere and tropics to develop a global record of millennium-scale climate variability
- Improve the integration of paleoclimatic observations and measurements with historical and modern climate data to form continuous time series of climatic information.

Objective 2.3: Develop new capabilities for ecosystem observations

Changes in an environmental variable—most often warming, but also changes in precipitation and air quality—have often been related to observed changes in biological and ecological systems. Several examples were mentioned in the Working Group II contribution to the Intergovernmental Panel on Climate Change's Third Assessment Report (IPCC, 2001b), including thawing of permafrost, lengthening of the period of active photosynthesis in mid- and high-latitude ecosystems, poleward shifts of plant and animal species ranges, movement of plant and animal species up elevation gradients, earlier spring flowering of trees, earlier spring emergence of insects, earlier egg-laying in birds, and shifts in a forest-woodland ecotone (the boundary between the forest and the woodland).

These changes in ecosystems and organisms are consistent with warming and changes in precipitation, but the possibility remains that the observed biological and ecological changes were caused (in part) by other factors such as biological invasions or human land and marine resource management. Because of this, the attribution of the causes of biological and ecological changes to climatic change or variability is extremely difficult. Moreover, because many ecosystem-environment interactions play out over long periods—ultimately involving evolutionary changes and adaptations within ecosystems—long periods of study are needed in many cases to draw firm conclusions about relationships between environmental change, effects of that change on biological and ecological systems, and the significance of any observed biological or ecological changes for the functioning of ecosystems (see Chapter 8).

New research is needed to provide a significantly more complete picture of how biological and ecological systems may have responded to recent climatic change and variability, including possible biological or ecological responses to extreme events. New observational systems will also be needed to appropriately monitor potential future changes in the environment and accompanying biological or ecological changes (if any). A key challenge will be to provide organization, guidance, and synthesis for the emerging field of observed effects of climate change on biological and ecological systems.

CCSP will initiate studies of early effects and indicator systems across diverse ecosystems and geographic regions. A substantial amount of existing climate and effects data, a variety of monitoring efforts, and comparisons to scenario-based effects studies can be marshaled in this effort. CCSP will facilitate linked analyses of climatic trends and observed biological and ecological effects by supporting identification of appropriate past and ongoing monitoring efforts, design of needed new monitoring systems, and synthesis of results across ecosystems and regions. Research efforts will target those ecosystems that are subjected to the most rapid or extensive environmental changes and/or are most sensitive to possible environmental changes.

Long-term, spatially explicit, and quantitative observations of ecosystem state variables and concomitant environmental variables are needed. Initial activities and products will include:

- Define ecosystems sensitive to climate change and thresholds for measurable impacts
- Identify ecosystems and the interfaces between ecosystems (ecotones) that are either sensitive or resilient to environmental change
- Identify ecosystems experiencing the most rapid environmental changes (e.g., ecosystems located at high latitudes and high elevations or coastal ecosystems affected by ongoing sea-level rise and intensive human influences)
- Identify concurrent trends in other factors, such as population and land-use change and provide links to data sets that document these trends
- Identify links to biological and ecological data sets from monitoring programs, including those from remote-sensing platforms

- Validate impacts studies done with climate change scenarios over the near term or for small amounts of warming using observed climate and impact data
- Develop observational design criteria related to risk assessment and identification of causes of changes in distribution of pests and pathogens (e.g., climatic change interacting with weather)

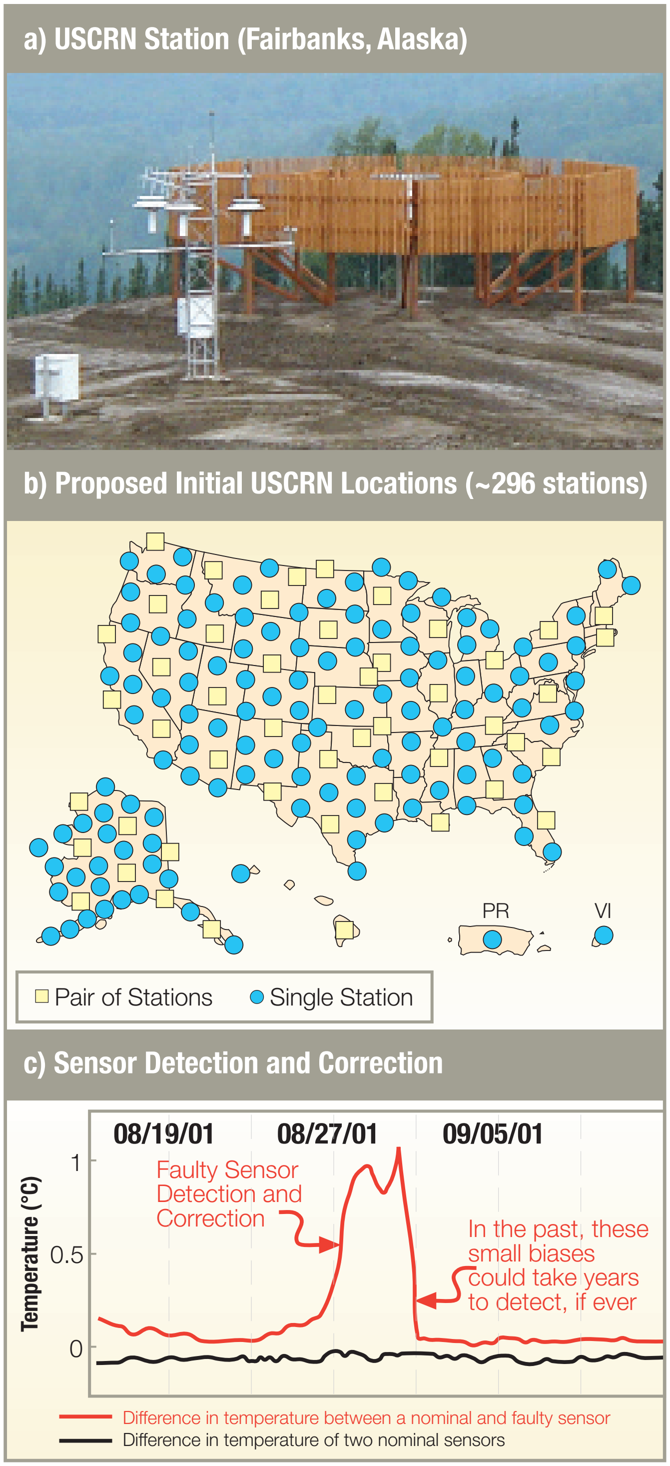

Figure 12-5: The U.S. Climate Reference Network is being established to reduce uncertainty and biases in long-term trends of key atmospheric variables at 296 stations (a&b). The monitoring system is designed such that multiple independent measurements are being made to capture sensor drift or biases (c). Source: NOAA National Climate Data Center.

- Develop design criteria for remote and *in situ* observations of biological and ecological systems that will help determine whether any observed ecological changes are attributable to global change
- Produce global, synoptic observational data products from satellite remote sensing documenting changes in biomass, albedo, leaf area and duration, and terrestrial and marine ecosystem composition for use in geographic information system (GIS)-based decision support systems
- Produce climate data at appropriate temporal and spatial scales for impacts studies.

Objective 2.4: Provide regular reports documenting the present state of the climate system components

CCSP will initiate a regular reporting program on the state of the climate system. Reports on various components of the system will highlight analysis products from the observing system to address the overarching question stated at the beginning of the chapter:

- Provide regular *State of the Climate* reports that include analyses of trends and variability in climate throughout the historical record using instrumental and paleoclimate records
- Evaluate the capabilities of existing and planned observing networks for providing data that will support the analysis of changes and trends in climate extremes and hazards
- Calculate the number of Climate Reference Network observing sites required to reduce the uncertainty in the observed climate signal for surface temperature to less than 0.1°C per century and precipitation to less than 1% per century on national and regional scales (see Figure 12-5)
- Regular reports evaluating the reduction in time-dependent biases in the space-based observing system obtained through implementation of the GCOS satellite monitoring principles and scientific data stewardship including the development of complementary independent observation and analysis techniques for critical climate variables
- For all operational monitoring networks, develop the tools necessary to identify time-dependent biases in the data as close to real-time as possible
- For climate monitoring networks, develop an operational system to identify non-climatic biases in the observing system for those climate system variables identified by the NRC (1999g) report on the adequacy of climate observing systems as relevant to detection, attribution, and direct societal impacts
- Identify and quantify the source of biases in climate system variables in existing climate reference data sets.

Goal 3: Provide stewardship of the observing system.

Observations of the climate require careful scientific oversight because climate signals are usually quite small relative to higher frequency phenomena in the data. Consequently, the climate science community has developed a set of principles that can be uniformly applied to all relevant measurements. In addition, special rigor must be applied to the algorithms, which are used to translate fundamental physical measurements into useful geophysical products,so that consistent results can be obtained and improved. Finally, scientific oversight of the algorithm, instrument calibration, and data processing and validation is critical to understanding the differences between instrument error and climate signal, and reduction of the error bars that define the uncertainty. This approach is captured in the four objectives of this goal.

Objective 3.1: Follow climate monitoring principles

Efforts in the last decade to use current research and operational data sets in global climate change research have provided a critical set of lessons learned. These lessons have been gathered into two sets of climate monitoring principles (see Appendix 12.4). These principles and experience will be used to guide the major improvements needed for the observing system. Instrument calibration, characterization, and stability become paramount considerations. Instruments must be tied to national and international standards such as those provided by the National Institute of Standards and Technology (NIST). When observations cannot achieve sufficient absolute accuracy or changes in spatial or temporal sampling occur, overlapping observations with high stability are required to ensure accurate monitoring of global change. Agreed-upon measurement protocols and procedures (e.g., continuous data validation and intercomparisons) are required to produce climate-quality data.

Objective 3.2: Provide independent measurement and analysis

To be policy-relevant, climate data must have reliable confidence intervals. Narrow intervals are most effective for decision support and policy development. Experience from previous scientific assessments, NIST, and other national standards laboratories have shown that actual accuracy is only known after comparison of independent measurements and analysis from multiple laboratories. Most climate observing systems are pushing the edge of capability in calibration. This suggests a final climate observing principle that climate observations should strive to address: *Each key climate variable will be measured using independent observations and examined with independent data analyses.*

Observation independence verifies instrument accuracy, while analysis independence verifies algorithms and computer code. For sea surface temperatures, examples of independent observations include satellite-derived measurements via infrared [Advanced Very High-Resolution Radiometer (AVHRR)] and passive microwave [Advanced Microwave Scanning Radiometer (AMSR)], and *in situ* instruments on ships, buoys, and floats. But many climate variables do not yet have independent sources. When surprises in climate data sets occur relative to current theory, independent confirmation is essential to ensure policy-relevant confidence in the results. A recent key example of this need is the air temperature record from radiosondes and the Microwave Sounding Unit (MSU) satellite data, as well as the different results from two analyses of the MSU satellite record. Using a single measurement of a key climate variable is a high-risk approach to reducing uncertainty for policymaking decisions.

Objective 3.3: Provide a sound foundation for climate-quality data products that will maintain integrity over time using well-characterized sensors and validated algorithms

An instrument radiometric mathematical model, termed the "measurement equation" by metrology experts, is developed to define, describe, and represent the relationship between the sensor output and desired physical observable (e.g., volts to temperature, counts to radiance, etc.). Additional models are used to reference the results in space and time (geo-location), and, finally, models are used to derive desired physical parameters (ozone profile, chlorophyll concentration, etc.). This process of characterization has been very successful in the past, especially for satellite programs. Its practice will continue to be encouraged, the results promulgated, and the instrument designs critically evaluated so that future measurements will produce the desired results.

It is important to understand that a sensor does not have to be ideal, but it must be well-characterized so that systematic effects can be evaluated and removed, even years after the mission, if new effects are identified. If these data are not available, the utility of the measurements is greatly compromised. The measurement equation approach defines the problem and places the entire procedure on a scientific basis. In the future all climate-quality observations need to be linked to their climate data records through an approved algorithm model that is described, for example, in an algorithm theoretical basis document (ATBD). These documents were pioneered by NASA in its implementation of the Earth Observing System (EOS) and provide a valuable lesson learned for future measurements.

Objective 3.4: Scientific stewardship for production of climate data records

Achieving climate accuracy with global and decadal sampling represents a unique scientific and organizational challenge. Calibration and stability requirements for climate data are often an order of magnitude more stringent than weather data. This accuracy is often achieved in research *in situ* and satellite data sets, with the length of this accuracy being dependent on the lifetime of the platforms and rate of instrument degradation; while in the longest satellite case (Earth Radiation Budget Satellite) this may approach 2 decades, in other cases it is much shorter. Global decadal sampling is often achieved in operational data sets, but without the accuracy and stability. Scientific data stewardship addresses this challenge through the production of Climate Data Records (CDRs).

Ultimately, the production of CDRs includes setting climate accuracy and stability requirements, instrument calibration and characterization, algorithm selection and development, end-to-end data validation and error analysis, quality control, and data production. Long-term archival and effective distribution are also essential and are addressed in Chapter 13. Experience in the last decade has shown that achieving CDR stewardship requires active and continual collaboration with the science community including both data producers and data users. Examples include Atmospheric Radiation Measurement (ARM) and Aeronet surface observations, the global surface temperature record, Tropical Atmosphere-Ocean buoys, and many forms of satellite observations for ocean, land, and atmosphere climate variables. Climate Data Science Teams (CDSTs) will be discussed in Goal 6 as a critical implementation strategy for the climate observing system.

Long-term CDRs will come about through the harmonious integration of highly accurate, research-quality observing systems with longer term operational and paleoclimate data. To reach the desired level of climate quality will also require additional efforts for current operational systems. We anticipate that CDSTs will be required to produce climate-quality data and represent the organizational link that provides operational level continuity with research-quality science direction.

The stewardship of scientific data is required to produce the climate-quality data sets that are a critical resource for policymakers and a legacy for future generations. As the length of CDRs increase, the power of the data to narrow uncertainties will increase and provide a basis for future decisions.

Goal 4: Integrate modeling activities with the observing system.

There are two primary roles for observations in the improvement of climate models: evaluation and initialization. At the same time, climate system models provide important insights for the improvement and interpretation of measurements through the use of simulations. These two-way interactions of observations and models affect not only the design but also the improvement of the observing system.

Objective 4.1: Develop protocols to evaluate models with climate-quality observations

Model testing uses observations to determine the uncertainties in current climate models and to prioritize needed improvements in future models. This is the most critical function of climate data records and depends primarily on two factors: (1) accuracy and stability of the climate data; and (2) the intrinsic background variability or noise in the Earth's climate system. Both factors vary with temporal and spatial scale. Climate system noise is typically largest at short time scales and small spatial scales (e.g., seasonal/regional scales), and smallest at long time scales and large spatial scales (e.g., century/global scales). Useful climate model tests require that both the data accuracy and the climate system noise be carefully assessed. As a result, climate accuracy requirements cannot be specified as a single number per variable, but must also be defined at several relevant temporal and spatial scales. Examples of relevant temporal/spatial scales include monthly/local, seasonal/regional, annual/zonal, and decadal/global. Some climate data records will have sufficient accuracy or stability to resolve regional climate change but inadequate coverage to resolve global changes and *vice versa*.

Consequently, observations and models of the climate system cannot make progress without continuous interaction between and understanding of the uncertainties in each research area (see also Chapter 10, Objective 1.3). Rapid progress requires regular interaction between the modeling and observation communities through CDSTs. One of the most critical collaborations between climate model and measurement scientists in the future will be the definition of prediction accuracy metrics capable of constraining key model uncertainties, such as cloud and water vapor feedback. Currently, such metrics are rather ad hoc because of the difficulty in unraveling the complex nonlinear climate system and in documenting climate data accuracy as a function of time and space. In the simplest sense, how would you recognize a perfect climate model if you had one? What tests would it pass? How will we know when the observing network is sufficient to characterize, attribute, and predict climate changes accurately? The answers are a function of both climate models and the climate observing system design.

The definition of climate model evaluation metrics will affect observing system design. As models and data improve in quality, these metrics will evolve in an iterative fashion over the next decade.

Objective 4.2: Use observations to initialize climate variability models

Climate model initialization is primarily effective only for seasonal-to-interannual time scales, and for initialization of the state of the world's oceans, soil moisture, and vegetation. These latter conditions reflect climate processes with sufficiently long time scales that their initial state can affect seasonal-to-interannual climate states. The prime initialization example is prediction of El Niño events using initial ocean conditions. To improve short-term climate forecasts, it will require new and improved technologies in data assimilation and better utilization of *in situ* and remotely sensed global ocean, atmosphere, and terrestrial observations of key physical variables, such as ongoing observations of temperature and new measurements of salinity and soil moisture (see Chapter 10, Objective 1.4).

Objective 4.3: Utilize climate system models to assist in the design of observation systems

While climate models are not perfect, for some variables they can strongly support the estimation of accuracy requirements for CDRs. Consider the following simple paradigm of climate change: **forcing** => **feedback** => **response** => **climate change**. If the Earth were such a simple linear system, then designing observing systems and testing climate model predictions would be a relatively straightforward process. But the climate system is highly coupled and fundamentally nonlinear. Consequently, intrinsic internal variability is an inherent part of the real climate system. Climate change must be detected and understood. However, this signal is usually smaller than the background climate variability (e.g., year-to-year climate variability). CDRs will require accuracies at a temporal and spatial scale greatly below the level of natural variability.

Unfortunately, most quantitative observations of the climate system only exist for the last century and are a combination of background and climate variability, climate change, and observation error. Using the total variability of the system to define measurement requirements represents only an upper limit on required accuracy and is not likely to be sufficient. Climate model simulations, on the other hand, do not include the full complexity of the Earth's climate system. The models typically represent an underestimate of background variability. As a result, climate model ensemble simulations can be used to estimate the required accuracy for the observation system. The ensembles can also specify intrinsic variability of the system as a function of temporal and spatial scale. These simulations can use varying climate forcing and can separate background variability from the climate signal by running large numbers of simulations with slightly varying initial conditions, but the same boundary conditions.

Objective 4.4: Develop protocols for validating data assimilation and reanalysis products from the observing system

Increasingly, global and regional data sets derived from data assimilation models and retrospective reanalysis models are being used for climate research, monitoring (time series), diagnostics, applications, and impact assessments (see Objective 1.8 and also Chapter 10, Objective 1.5). Evaluation protocols must be developed to assess the accuracy and stability of these reanalysis products for climate applications. Acceptable error standards need to be established that will provide guidance on whether the data sets are usable or not, especially at regional scales and for model-derived/computed parameters.

Goal 5: Foster international cooperation to develop a complete global observing system.

The range of global observations needed to understand and monitor climate processes, and to assess human impacts, exceeds the capability of any one country. Cooperation is therefore necessary to address priorities without duplication or omission (see Chapter 15). Satellite missions and *in situ* networks require many years of planning. Observations of the state of and trends in planetary processes cut across land, water, air, and oceans. National programs need to fit into larger international frameworks. At the international level, participation in both science and operational oversight committees must be continued, and strengthened or developed in disciplines that have not yet developed a global system.

In 1998, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) noted with concern the mounting evidence of a decline in the global observing capability and urged Parties to undertake programs of systematic observations and to strengthen their capability in the collection, exchange, and utilization of environmental data and information. The United States supports the need to improve global observing systems for climate, and will join other Parties in submitting information on national plans and programs that contribute to the global observing capability.

Objective 5.1: Foster and support international partnerships in observations

The United States is an active and leading partner in the development and support of a global observing system that assembles key elements from a number of observing networks under the aegis of appropriate international organizations. With regard to climate, GCOS has fostered the integration of key elements including meteorological observations from the WWW Global Observing System, atmospheric constituents from the Global Atmosphere Watch, hydrological observations from the World Hydrological Observing System, critical oceanographic climate variables from the Global Ocean Observing System (GOOS), and several terrestrial variables from the Global Terrestrial Observing System (GTOS). Coordination of global satellite observations is carried out through the Committee on Earth Observation Satellites (CEOS). This is particularly important as multi-national, multi-spacecraft constellations and increased use of higher altitude orbits (e.g., geostationary) are used to improve the temporal resolution of global observations that may further enhance decision support.

Given the importance of validating satellite observations under a broad range of geophysical and biogeochemical conditions, participation of international partners—in providing coincident and correlative information that can be used to test and improve satellite observations—is especially important. International partners are also important in the implementation of field campaigns that are best carried out with the full scientific involvement and logistical support of the host countries.

The full implementation of a global system for climate will require enhanced international coordination and commitment. Components for atmospheric, oceanic, terrestrial, and satellite observations are supported at varying levels depending on scientific priorities, availability of national contributions, and the sophistication of the relevant observing technologies. A specific focus on climate variables is essential to provide an adequate database to meet climate needs.

Recently, these observing systems, their sponsors, and the satellite community have developed the International Global Observing Strategy (IGOS). IGOS is a strategic planning process, uniting the major satellite and surface-based systems for global environmental observations of the atmosphere, oceans, and land in a framework for decisions and resource allocations by individual partners. The IGOS Partnership (IGOS-P) focuses specifically on the observing dimension in the process of providing environmental information for decisionmaking. This includes all forms of data collection concerning the physical, chemical, and biological environments of our planet, as well as data on the human environment, pressures on the natural environment, and environmental impacts on human well-being. IGOS-P is currently focusing on identifying and gaining commitments for essential requirements for observing oceanic processes, global carbon, atmospheric chemistry, the global water cycle, geo-hazards, and coral reefs as part of a future coastal initiative.

Bilateral agreements provide another strategy for achieving partnerships in observations and monitoring. Additionally, activities such as the U.S.-led Earth Observations Summit, the Subsidiary Body for Scientific and Technical Advice (SBSTA) meetings, and UNFCCC Conferences of the Parties provide opportunities to build international consensus—both scientific and political—for the implementation of a more integrated global climate observing system.

Objective 5.2: Provide support for key observations in developing countries

Developing countries provide key opportunities and challenges for observing systems. While many developing countries have the potential to make routine weather observations, and do so on a regular basis, many do not have the capability to collect and disseminate reliable observations of other variables that are critical for climate characterization and understanding. Further, many developing countries do not have adequate human resources to take full advantage of climate projections that would yield many benefits to their citizens.

It has been established that many developing countries lack either the capital or human resources to support high-quality observations or to sustain data and information systems. Countries often lack adequate capital for investment in equipment and supplies, trained technical staff, or maintenance capability.

The U.S. research community can point to numerous examples where it has contributed to measurements of key variables in developing countries. Many of these have provided valuable long-term data. The networks to measure atmospheric constituents through flask sampling and through vertical soundings have contributed a global database of important information on greenhouse gases. The oceanographic community has successfully engaged many coastal nations to participate in one or more of its observing systems (e.g., sea level, drifting floats and buoys, volunteer ships, etc.). International programs addressing terrestrial processes have demonstrated similar successes in observing ecosystems, obtaining hydrologic information, and initiating cryospheric measurement.

CCSP has specifically noted the key role that the United States can play in improving observational networks. In the President's June 2001 Rose Garden speech, he stated that "We'll also provide resources to build climate observation systems in developing countries and encourage other developed nations to match our American commitment."

The United States can contribute further by:

- Evaluating existing networks' capability to meet established climate requirements
- Improving existing networks through direct contributions to international programs [e.g., the World Meteorological Organization's (WMO) Voluntary Cooperation Programme]
- Forming partnerships with other developed countries to make directed investments to meet developing country inadequacies
- Providing direct assistance through U.S. programs of aid to specific developing country activities, such as the U.S. Agency for International Development (USAID)
- Continuing and expanding the collaborative international scientific programs that address critical climate variables.

Objective 5.3: International coordination through membership in key international groups

It is essential for the United States to maintain a leadership role in those international programs, both research and operational, that support climate observations of importance to U.S. programs. The principal international research programs (e.g., the World Climate Research Programme, the International Geosphere-Biosphere Programme, and the International Human Dimensions Programme) invite members from the U.S. scientific community and often from federal agencies to serve on relevant steering committees and working groups. These committees and working groups provide a forum for planning future research campaigns and for developing observational components that often lead to continuing measurement strategies. Individuals participating in these groups provide key links between U.S. and international research programs.

With regard to observations, U.S. scientists serve on the steering committees and working groups of the global observing systems and provide continuing advice to them. The principal programs for atmosphere, ocean, and terrestrial observations of climate include GCOS, GOOS, and GTOS, as well as their working groups.

U.S. scientists also serve on more operationally oriented international committees that support ongoing observational activities. Examples include the Commissions of the WMO (e.g., Basic Systems, Climatology, Hydrology, etc.) and the Joint Commission for Oceanography and Marine Meteorology sponsored by WMO and the Intergovernmental Oceanographic Commission. Individuals named to such groups serve as national representatives. These groups establish observing requirements, develop protocols for data and information exchange, and obtain international commitments.

CCSP encourages U.S. scientists to continue their important roles in support of these diverse international programs.

Goal 6: Manage the observing system with an effective interagency structure.

The development of a national observing and monitoring system will require a coordinated management plan, which involves all federal agencies that conduct research and operational observations of the climate system. The management approach described in this goal follows the general guidelines outlined in Chapter 16. However, based upon the "best practices" learned over the history of USGCRP, a more detailed management structure is described for the observation system within this goal. Experience has shown that scientific oversight is key for the maintenance of climate-quality data from observing systems; consequently, the management plan will engage the science and user communities in key oversight and evaluation capacities. Finally, the observing system will be global and carried out with the nations of the world; therefore, cooperation at the international level for both operational and scientific oversight will need further development (see Goal 5).

At present, some of these management elements are in place, but a well-coordinated national management plan for observing the climate system is not, and will be addressed in the coming decade. At the federal level, coordination at the program level will be strengthened to address implementation, and oversight by agency principals will be established. Scientific oversight will occur through a layered pyramid of working groups starting at the most basic level of instrument teams and building up to an observing system science advisory council. This structure has been demonstrated to be an effective strategy over the lifetime of USGCRP and this goal expands the "best practices" learned to the observing system as a whole.

Objective 6.1: Provide coordinated management groups for the observing system elements

The management of the observing system elements will vary depending on size and complexity. Space systems, both operational and research, require focused project management groups that are dedicated to monitoring health and safety, providing command and control, receipt and quality control of downlinked data, fault recovery, and ground tracking, if necessary.

In situ systems can vary from control and maintenance of a single convenient site on land to maintenance of a large international network at sea. While the former can rely on a simple management program, the latter requires a much larger national management group and international coordination. CCSP will coordinate management groups of similar measurement techniques and logistics; coordinate with international management where applicable; work with international implementation coordination groups, such as the Joint Commission on Oceanography and Marine Meterology; and finally provide overall management and guidance for the national system as a whole through an interagency working group. The selection and oversight of management groups will depend on whether they are research or operational, and federal, commercial, or university.

Objective 6.2: Provide Climate Data Science Teams for climate data stewardship

The foundation of the management strategy is to obtain key CDRs through the use of CDSTs. Definition of the CDSTs is based on the last 2 decades of experience and lessons gained from previous Earth observation systems focused on climate measurements. A clear message from this experience is the need for CDSTs. These teams are composed of a group of scientists and engineers whose purpose is to convert raw instrument data into CDRs, including calibration, algorithm development, validation, error analysis, quality control, and data product design. If the data volume is small, the CDST may also produce and distribute the data products. If the data volume is large, the CDST may interface to a separate data center for production, archiving, and distribution.

Examples of effective CDSTs include the production of climate versions of the surface air temperature records; most NASA EOS satellite data products, as well as those of precursor activities such as the Total Ozone Mapping Spectrometer, Stratospheric Aerosol and Gas Experiment, and Active Cavity Radiometer Irradiance Monitor; the international Argo ocean profiling float program; the NOAA-led Baseline Surface Radiation Network; and DOE's ARM Program. The reason that CDSTs are required for most, if not all, climate data records is the extreme accuracy needed for rigorous climate records (see Objective 3.1). Because the methods of measurement vary so greatly, effective CDSTs focus on just a few of the climate data records, and some only on a single CDR. A minimal list of variables needed as CDRs is given in Appendix 12.1.

Most CDSTs are chosen by scientific peer review. They consist of a principal investigator and a set of co-investigators. The co-investigators lead key instrument, algorithm, sampling, validation, and data management functions. CDSTs include members of the climate modeling or climate analysis community (i.e., data users). This is key to keeping the CDST focused on the most effective approach to meeting users' needs. Most CDSTs are currently funded by a single U.S. agency. CDSTs have their work and products peer-reviewed. CDSTs are often used in national and international assessments of the state of climate science and climate impacts. They document the

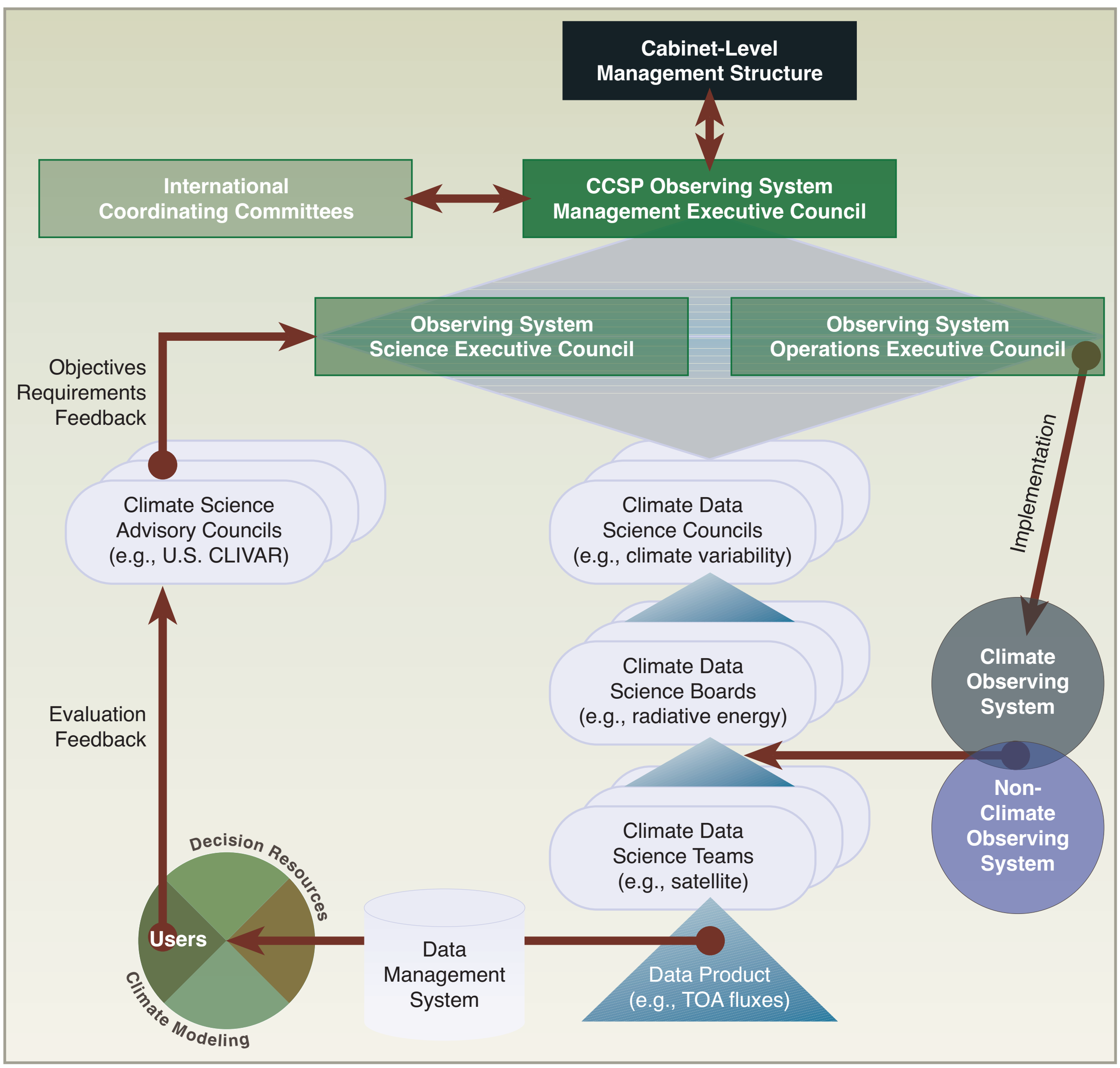

Figure 12-6: Schematic of the overall management structure for the observing system.

climate data products and their quality through web documents, conference papers, and journal papers.

Objective 6.3: Develop science and management advisory boards and councils to prioritize across climate system components and to guide system evolution

Observing system science direction will be provided by boards and councils. It is too long a step between a single CDST focusing on one or two climate variables and CCSP. A logical structure will be needed between these two extremes. The structure chosen must be able to handle the following set of changes and prioritizations:

- Evolving scientific understanding and changes in accuracy requirements
- Changing financial/human resources and delivery schedules
- Evolving technology for developing and implementing improvements
- Changing instrument, surface site, and spacecraft operations
- Changing data management interfaces and technology (e.g., production, distribution, and archival)
- User-driven changes in data product format requirements.

Addressing these trade-offs between resources, requirements, and climate variables will require a hierarchical science management committee structure. While there are many ways to provide such a structure, climate data and climate modelers will be best served by a structure that gives highest priority to tight integration of major climate system components (see Figure 12-6). Portions of such a system have evolved over the last decade, primarily at the international level as discussed under Goal 5. It is most fully evolved and effective for ocean observations, while the process for terrestrial observations is at a much earlier stage of development. More of this structure will be developed by CCSP for the United States.

The CCSP cabinet-level management structure is at the top level, responsible for resource commitments to the climate observing system.

The second level consists of a sub-group of CCSP—the Observing System Management Executive Council (OSMEC), composed of agency executives capable of committing agency funding. This group will provide a formal interface with international coordination groups, such as CEOS and IGOS-P.

Two groups comprise the third level. The first is an interagency program management group responsible for providing resources to implement the observations and to support science investigations—the Observing System Operations Executive Council (OSOEC). The second is the highest level science advisory group—the U.S. Observing System Science Executive Council (OSSEC). This science council makes recommendations to both OSMEC and OSOEC by prioritizing across the entire climate observing system. In addition, OSSEC will develop the objectives and requirements for the observing system, based on input from the Climate Science Advisory Councils of the research elements and decision support groups, and will evaluate the ability of the observing system to meet these objectives. These Climate Science Advisory Councils will also provide OSSEC with evaluation reports on the performance of the system in meeting the needs of its users.

At the fourth level, Climate Data Science Councils are responsible for climate observations to support each of the seven major CCSP research elements: Atmospheric Composition, Climate Variability and Change, Water Cycle, Land-Use/Land-Cover Change, Carbon Cycle, Ecosystems, and Human Contributions and Responses, as well as Decision Support activities. The Climate Data Science Councils could be a sub-group of the Climate Science Advisory Councils shown in Figure 12-6. Some of the Climate Science Advisory Councils already exist, such as the U.S. Climate Variability and Predictability (CLIVAR) team for the Climate Variability and Change theme. The Climate Data Science Councils address the complete range of climate variables within their theme.

A minimum set of climate variables is given in Appendix 12.1. Some variables will be relevant to several of the Climate Data Science Councils. Such overlaps are inevitable in any management structure given the tight coupling of processes in the climate system. It is the responsibility of OSSEC to assign primary responsibility for each variable to one of the Climate Data Science Councils. The Climate Data Science Councils are responsible for setting CDR requirements for absolute accuracy, stability, and space/time sampling.

At the fifth level, Climate Data Science Boards will address data parameters grouped into the most natural subsets for climate processes and/or for the type of instrumentation. For example, one of the Climate Variability and Change science boards would cover radiative energy from the top of atmosphere to the surface of the Earth. Some of these groups have already been formed by individual agencies (e.g., sea surface topography, ocean winds, sea surface temperature, and ocean color within NASA). Within each Science Board there are *in situ*, satellite, and field experiment observations. The advantage of this approach is that the linkages of surface, satellite, and *in situ* data types for key climate parameters are actively considered in any observing system trade-offs and will be valuable to the implementation decisions of OSOEC. Each CDST will report to the relevant Climate Data Science Board.

The Climate Data Science Boards and Executive Councils will meet as required to assess progress in the data system, nominally once per year. These meetings are expected to be indepth workshops sufficient to deal with the complex trade-offs and linkages between the observing system components. Every 5 years, a major assessment of the entire climate observing system would be produced, reviewed by the National Research Council, and coordinated with international assessments (e.g., the International Conference on Ocean Observing Systems for Climate, GCOS Adequacy Reports, IPCC assessments).

These boards and councils must include members of the climate data user community (e.g., climate modelers, climate analysts), as well as CDST representatives and data management representatives. In addition, members of the community who participate in international science or operations groups will be *ex officio* members of their appropriate counterpart board or council. The most efficient organization will be to maximize the extent that the data management and climate modeling management structures parallel that of climate observing and monitoring.

Objective 6.4: Provide a management structure that allows clear interagency responsibility, prioritization, peer review, and evolution of the observing system

Observations and monitoring of the climate system are carried out by a number of federal agencies. Success will require a series of steps to be initiated jointly by OSMEC, OSOEC, and OSSEC. These steps include:

- Assign agency responsibility for measurement contributions to each variable and measurement type. These contributions would typically be defined in terms of measurement system (satellite, *in situ*, field experiment) and sampling (e.g., satellite orbits, number/location of ground sites). OSSEC will be necessary in this step in order to ensure that the climate monitoring principles (see Appendix 12.4) are adhered to in assigning these responsibilities and evaluating the ability of the observations to meet the science objectives and requirements. If more than one agency is involved in measuring a single parameter, OSSEC must clearly define the responsibilities of each. Given the need for independent observations, it is recommended that the United States and the international community each provide at least one measurement of each variable. This would ensure the absolute minimum of two observations for each key climate variable.
- Assess the state of the climate observing system, including current agency plans. This assessment must include climate observing system requirements for each component as well as current and planned capabilities.
- Once shortcomings are identified, the Executive Councils (Science, Operations, and Management) and international groups must coordinate a plan for eliminating these shortcomings over time.
- Select the CDSTs for each climate variable, preferably through peer review. Typically, for any given variable, there will be separate CDSTs for surface and satellite observations. This is dictated by the large differences in instrumentation, calibration, operations, and sampling for these systems.

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APPENDIX 12.1

EARTH CLIMATE SYSTEM OBSERVATIONS

This table provides a summary of "State" and "Forcing/Feedback" variables for the major components of the Earth system for which observations are required. In parentheses, "I" and "S" denote measurements made by *in situ* and space-based instruments, respectively. See Annex C for source information.

STATE VARIABLES	EXTERNAL FORCING OR FEEDBACK VARIABLES
(1) Atmosphere	
• wind (I/S) • upper air temperature (I/S) • surface air temperature (I/S) • sea-level pressure (I) • upper air water vapor (I/S) • surface air humidity/water vapor (I/S) • precipitation (I/S) • clouds (I/S) • liquid water content (I/S)	• sea surface temperature (I/S) • land surface soil moisture/temperature (I/S) • land surface structure and topography (I/S) • land surface vegetation (I/S) • CO_2 and other greenhouse gases, ozone and chemistry, aerosols (I/S) • evaporation and evapotranspiration (I/S) • snow/ice cover (I/S) • shortwave and longwave surface radiation budget (I/S) • solar irradiance and shortwave/longwave radiation budget (S)
(2) Ocean	
• upper ocean currents (I/S) • sea surface temperature (I/S) • sea-level/surface topography (I/S) • sea surface salinity (I/S) • sea ice (I/S) • wave characteristics (I/S) • mid- and deep-ocean currents (I) • subsurface thermal structure (I) • subsurface salinity structure (I) • ocean biomass/phytoplankton (I/S) • subsurface carbon (I), nutrients (I) • subsurface chemical tracers (I)	• ocean surface wind and wind stress (I/S) • incoming surface shortwave radiation (I/S) • downwelling longwave radiation (I/S) • surface air temperature/humidity (I/S) • precipitation (freshwater/salinity flux) (I/S) • evaporation (I/S) • freshwater flux from rivers and ice melt (I/S) • CO_2 flux across the air-sea interface (I) • geothermal heat flux—ocean bottom (I) • organic and inorganic effluents (into ocean) (I/S) • biomass and standing stock (I/S) • biodiversity (I) • human impacts—fishing (I) • coastal zones/margins (I/S)
(3) Terrestrial	
• topography/elevation (I/S) • land cover (I/S) • leaf area index (I) • soil moisture/wetness (I/S) • soil structure/type (I/S) • permafrost (I) • vegetation/biomass vigor (I/S) • water runoff (I/S) • surface ground temperature (I/S) • snow/ice cover (I/S) • subsurface temperature and moisture (I/S) • soil carbon, nitrogen, phosphorus, nutrients (I) • necromass (plant litter) (I) • subsurface biome/vigor (I) • land use (I/S) • groundwater and subterranean flow (I) • lakes and reservoirs (I/S) • rivers and river flow (I/S) • glaciers and ice sheets (I/S) • water turbidity, nitrogen, phosphorus, dissolved oxygen (I/S)	• incoming shortwave radiation (I/S) • net downwelling longwave radiation (I/S) • fraction of absorbed photosynthetically active radiation (I/S) • surface winds (I) • surface air temperature and humidity (I/S) • albedo (I/S) • evaporation and evapotranspiration (I/S) • precipitation (I/S) • land use and land-use practices (I/S) • deforestation (I/S) • human impacts—land degradation (I/S) • erosion, sediment transport (I/S) • fire occurrence (I/S) • volcanic effects (on surface) (I/S) • biodiversity (I/S) • chemical (fertilizer/pesticide and gas exchange) (I) • waste disposal and other contaminants (I) • earthquakes, tectonic motions (I/S) • nutrients and soil microbial activity (I) • coastal zones/margins (I/S)

APPENDIX 12.2

ILLUSTRATIVE RESEARCH MILESTONES FOR OBSERVATIONS AND MONITORING

This table provides examples of observing priorities highlighted in the research element chapters (Chapters 3-9) of this plan.

Atmospheric Composition

- Continue baseline observations of atmospheric composition over North America and globally.
- Improve description of the global distributions of aerosols and their properties.
- Develop and improve inventories of global emissions of methane, carbon monoxide, nitrous oxide, and nitrogen oxides (NO_x) from anthropogenic and natural sources.
- Monitor global distributions of tropospheric ozone and some of its precursors (e.g., NO_x).
- Continue monitoring trends in ultraviolet radiation.

Climate Variability and Change

- Improve effectiveness of observing systems, including deployment of new systems and re-deployment of existing systems, as well as the collection of targeted paleoclimatic data.
- Improve estimates of global air-sea-land fluxes of heat, moisture, and momentum.
- Regularly update and extend global climate reanalyses.
- Conduct process studies for needed observations of critical ocean mixing processes.
- Develop a paleoclimatic database to evaluate climate models.

Water Cycle

- Develop an integrated global observing strategy for water cycle variables.
- Characterize water vapor in the climate-critical area of the tropical tropopause.
- Monitor drought based on improved measurements of precipitation, soil moisture, and runoff.
- Test parameterizations for clouds and precipitation processes.
- Initialize and test boundary layers and other components in models.

Land-Use/Land-Cover Change

- Continue to acquire global calibrated coarse-, moderate-, and high-resolution remotely sensed data.
- Provide global maps of areas of rapid land-use and land-cover change, and location and extent of fires.
- Quantify rates of regional, national, and global land-use and land-cover change.
- Develop global high-resolution satellite land-cover databases.
- Provide operational global monitoring of land use and land-cover conditions.

Carbon Cycle

- Provide U.S. contributions to an international carbon observing system, including measurements of carbon storage, fluxes, and complementary environmental data.
- Assessment of the quality of measurements that support global carbon cycle science.
- Measure atmospheric carbon dioxide and methane concentrations and related tracers in under-sampled locations.
- Observe global air-sea fluxes of carbon dioxide, lateral ocean carbon transport, and delivery of carbon from the land to the ocean.
- Develop database of agricultural management effects on carbon emissions and sequestration in the United States.

Ecosystems

- Define requirements for ecosystem observations to quantify feedbacks to climate and atmospheric composition, to enhance existing observation systems, and to guide development of new capabilities.
- Quantify biomass, species composition, and community structure of terrestrial and aquatic ecosystems in relation to disturbance patterns.
- Maintain and enhance satellite terrestrial, atmospheric, and oceanic observing systems and networks, to monitor trends in ecosystem variables to parameterize models and verify model projections.
- Continue and enhance long-term observations to track changes in seasonal cycles of productivity, species distributions and abundance, and ecosystem structure.
- Provide data quantifying aboveground and belowground effects of elevated carbon dioxide concentration in combination with elevated ozone concentration on the structure and functioning of agricultural, forest, and aquatic ecosystems.

Human Contributions and Responses to Environmental Change

- Gridded world population database, including time series as far as possible into the past.
- Human footprint data set that depicts the geographic extent of human impacts on the environment.
- Produce elevation maps depicting areas vulnerable to sea-level rise and planning maps depicting how state and local governments plan to respond to sea-level rise.

APPENDIX 12.3

CLIMATE CHANGE RESEARCH INITIATIVE (CCRI) ACTIVITIES IN OBSERVATIONS AND MONITORING

CCRI Milestones

Ocean Observations

CCRI funds will be used to work toward the establishment of an ocean observing system that can accurately document climate-scale changes in ocean heat content, carbon uptake, and sea-level changes. Global tropical measurements will be augmented to improve seasonal forecasts. Ocean reference stations will be added to improve routine analyses of ocean-atmosphere fluxes at these stations to improve energy balance studies and coupled modeling parameterizations. In addition, key locations will be instrumented to improve understanding of abrupt climate change detection. The requirements for ocean observations for climate have been well documented, the relevant technology is available, and the international community is mobilized through GCOS and GOOS to implement key elements of the system.

Atmosphere Observations

CCRI funds will be used to work with other developed countries to reestablish the benchmark upper air network, emphasizing data-sparse regions; to upgrade the GCOS surface network for baseline variables; to deploy mobile Atmospheric Radiation Measurement program facilities; to begin planning for an early copy of an NPOESS aerosol instrument; and to place new Global Atmospheric Watch stations in priority sites to measure pollutant emissions, aerosols, and ozone, in specific regions.

Aerosol Observations

Aerosols and tropospheric ozone play unique, but poorly quantified, roles in the atmospheric radiation budget. CCRI investments will be used to begin implementation of plans developed by the interagency National Aerosol-Climate Interactions Program to define and evaluate the role of aerosols that absorb solar radiation, such as black carbon and mineral dust. Proposed activities include field campaigns, *in situ* monitoring stations to measure black carbon and aerosol precursors, global climatologies of tropospheric aerosols, and satellite algorithm development.

Carbon Cycle Observations

Research objectives for carbon cycle science include improved observations to address some of the field's greatest areas of uncertainty. CCRI funds will be targeted for the integrated North American Carbon Program (NACP), a priority of the *U.S. Carbon Cycle Science Plan*. NACP calls for implementing a North American Carbon Cycle Observing System consisting of a network of small aircraft stations and tall towers to obtain profiles of carbon gases for determining sources and sinks of carbon dioxide in the United States, expansion of the AmeriFlux sites, the development of automated carbon dioxide and methane sensors, improvements in ground-based measurements, and inventories of forest and agricultural lands. In addition, funds are provided for improved estimates of carbon dioxide over and into the ocean derived from ship-based instruments.

In addition, CCRI will select and award development assistance projects for climate monitoring in developing nations.

APPENDIX 12.4

GCOS CLIMATE MONITORING PRINCIPLES[4]

Effective monitoring systems for climate should adhere to the following principles:

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms, and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional, and global observing priorities.
6. Operation of historically uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators, and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully planned manner should be promoted.
10. Data management systems that facilitate access, use, and interpretation of data and products should be included as essential elements of climate monitoring systems.

Furthermore, satellite systems for monitoring climate need to:

a. Take steps to make radiance calibration, calibration monitoring, and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system.

b. Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

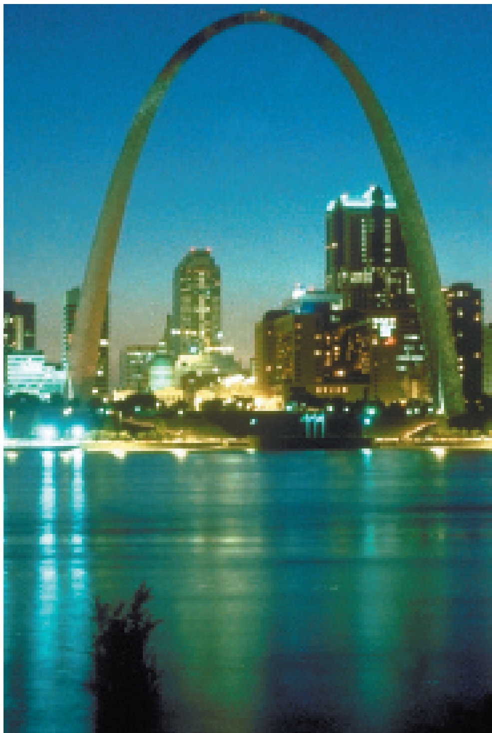
Thus, satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
13. Continuity of satellite measurements (i.e., elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
17. Data systems needed to facilitate user access to climate products, metadata, and raw data, including key data for delayed-mode analysis, should be established and maintained.
18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.
19. Complementary *in situ* baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

[4]The ten basic principles were adopted (in paraphrased form) by the Conference of the Parties (COP) to the U.N. Framework Convention on Climate Change through Decision 5/CP.5 of COP-5 at Bonn in November 1999.

13 CHAPTER

Data Management and Information



CHAPTER CONTENTS

For each goal, this chapter introduces the objectives for data management to be addressed in the coming decade based upon current knowledge and infrastructure.

Goal 1: Collect and manage data in multiple locations.

Goal 2: Enable users to discover and access data and information via the Internet.

Goal 3: Develop integrated information data products for scientists and decisionmakers.

Goal 4: Preserve data.

Management Structure

National and International Partnerships

One of the goals of the U.S. Climate Change Research Initiative (CCRI) is to enhance and integrate observation, monitoring, and data management systems to support climate process and trend analyses. This chapter lays the strategy for managing integrated data and information for the next decade.

The nature of the concerted effort of the Climate Change Science Program (CCSP) calls for an overarching data policy that provides full and open access to Earth science-related data in a timely fashion. The terms and conditions of exchange and use for this purpose should be agreed to both nationally and internationally. In the early 1990s, the U.S. Global Change Research Program (USGCRP) agreed to data exchange principles that are still adhered to today (see Box 13-1). The governing law for U.S. Government agencies, OMB Circular A130, specifically states that the "open and efficient exchange of scientific and technical government information, subject to applicable national security controls and the proprietary rights of others, fosters excellence in scientific research and effective use of federal research and development funds." Office of Management and Budget (OMB) Circular A130 establishes agency user charges at the marginal cost of dissemination, including a provision that agencies can plan to "establish user charges at less than cost of dissemination because of a determination that higher charges would constitute a significant barrier to properly performing the agency's functions, including reaching members of the public whom the agency has a responsibility to inform". This lofty standard should be emulated by all participants in the larger endeavor described by this plan.

The need to manage data as a shared national resource in a manner that focuses on the needs of end users has not previously been recognized, nor has the challenge been undertaken in a serious and systematic manner. Climate data are complex and variable as the data are obtained by diverse means, across a broad range of disciplines, for a variety of purposes, and by wide-ranging organizations—individual researchers; institutions; private industry; and federal, state, and local government organizations. These data come in different forms, from a single variable measured at a single point (e.g., a species name) to multi-variate, four-dimensional data sets that may be petabytes (10^{15} bytes) in size.

Although new data sets that integrate information from multiple sources are being developed, current efforts are limited in scope and a significant expansion is required to meet the needs of policymakers and scientists. The challenge is that data are often inconsistently calibrated in space or time—making scientifically sound integration of multiple data sets difficult. No simple data standard can be designed that all data providers will utilize. Moreover, the U.S. government has limited resources to support long-term electronic data management beyond the life of individual investigators' projects or programs. Currently, no interagency management structure

BOX 13-1

DATA MANAGEMENT FOR GLOBAL CHANGE RESEARCH POLICY STATEMENTS

- The USGCRP requires an early and continuing commitment to the establishment, maintenance, validation, description, accessibility, and distribution of high-quality, long-term data sets.
- Full and open sharing of the full suite of global data sets for all global change researchers is a fundamental objective.
- Preservation of all data needed for long-term global change research is required. For each and every global change data parameter, there should be at least one explicitly designated archive. Procedures and criteria for setting priorities for data acquisition, retention, and purging should be developed by participating agencies, both nationally and internationally. A clearinghouse process should be established to prevent the purging and loss of important data sets.
- Data archives must include easily accessible information about the data holdings, including quality assessments, supporting ancillary information, and guidance and aids for locating and obtaining the data.
- National and international standards should be used to the greatest extent possible for media and for processing and communication of global data sets.
- Data should be provided at the lowest possible cost to global change researchers in the interest of full and open access to data. This cost should, as a first principle, be no more than the marginal cost of filling a specific user request. Agencies should act to streamline administrative arrangements for exchanging data among researchers.
- For those programs in which selected principal investigators have initial periods of exclusive data use, data should be made openly available as soon as they become widely useful. In each case, the funding agency should explicitly define the duration of any exclusive use period.

exists to develop and enforce adoption of a complex data management solution. Scientific data that are not institutionally managed are at serious risk of vanishing when the scientist or data collector turns to other projects or retires.

Traditional core activities within data management have been regarded to be data curation—quality control, context-setting (i.e., metadata), preservation, etc.—and distribution of data sets. In order to focus on the needs of the scientists who use the data, we must significantly expand this core to include data discovery (the ability to locate data that are distributed across multiple institutions and disciplines) and data interoperability (changes to how we conduct data management in ways that free users from the productivity losses associated with incompatible formats, unwieldy file sizes, and large non-aggregated collections).

In addition, many of the scientific and decision support needs of the CCSP require analysis and processing of data into specialized products. Even with a large number of measurement systems, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Thus, physical models using instrument data as inputs are implemented and can help fill some of the unmet measurement needs of the program. Additionally, products are developed not to fill unmet measurement needs, but instead to improve the quality of existing measurements.

Fulfilling the need for climate and climate-related data that are useful for scientists, planners, and other end users will be a complex task. The overall challenge, then, is:

> *To provide seamless, platform-independent, timely, and open access to integrated data, products, information, and tools with sufficient accuracy and precision to address climate and associated global changes.*

This challenge can be met through development of a system that efficiently links observations to data management and analysis, and ensures timely delivery of climate data and related information and their preservation for future generations (see Figure 13-1). This integration can be implemented using proven and emerging technologies such as the Internet and digital libraries. Specific goals in this effort are:

1) Collect and manage data in multiple locations
2) Enable users to discover and access data and information via the Internet
3) Develop integrated information data products for scientists and decisionmakers
4) Identify data to be preserved.

These goals will be achieved through implementation of an effective management structure that will ensure interagency coordination of these efforts, scientific and technological guidance, and user input and requirements.

Researchers, planners, and decisionmakers need seamless access not only to information produced by CCSP efforts, but also to 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 attention on the information content of the data, rather than how to discover, access, and use it. The challenge for data management is a system 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 with standard tools, such as web browsers, geographic information system (GIS) programs, and scientific visualization/analysis systems, without concern for data format, data location, or data volume.

The strategy for building this framework must be an evolutionary process with a development model based on ongoing interactions with users. In addition, modifications to existing systems and the development of new systems will require use of existing technologies

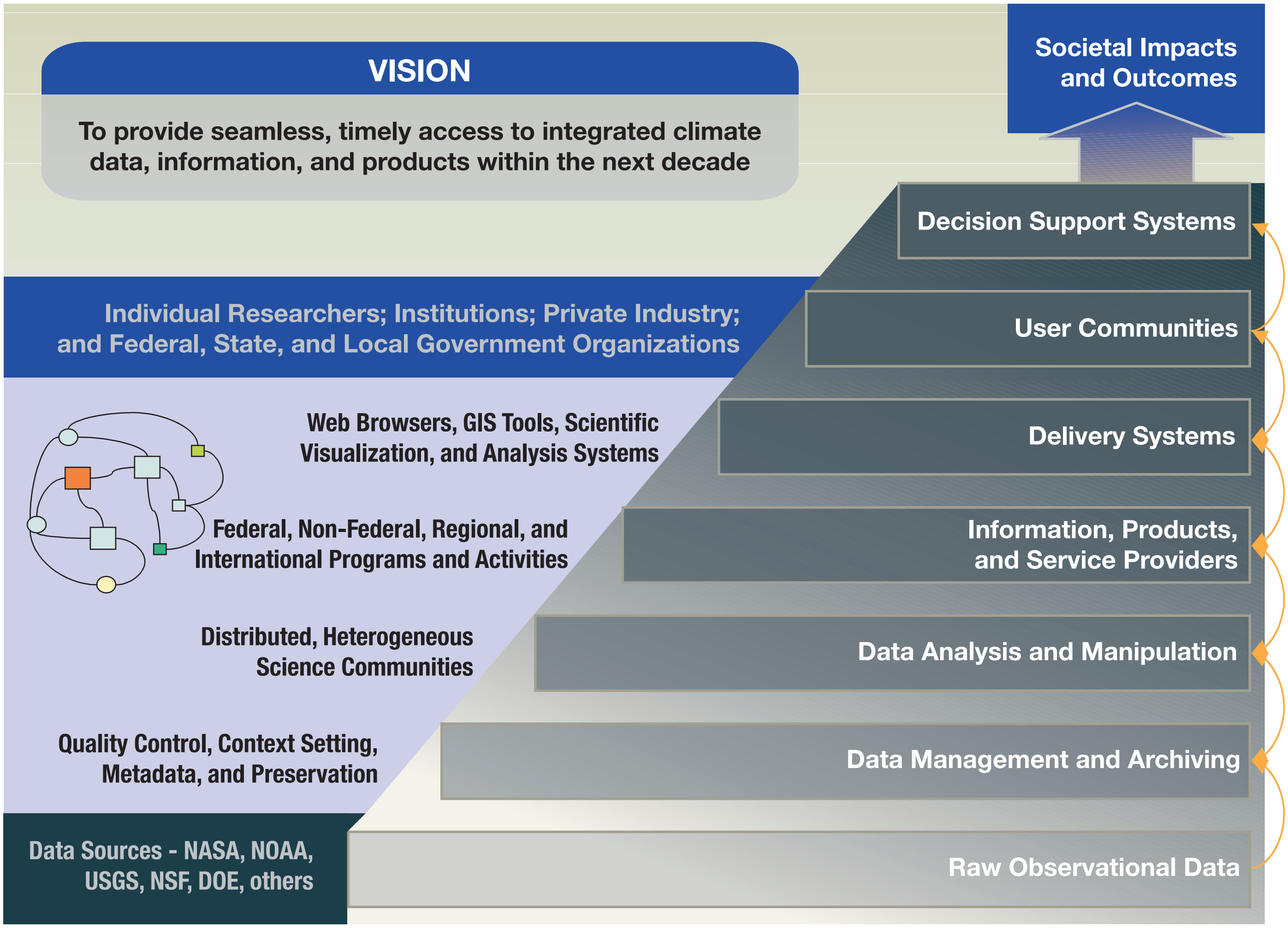


Figure 13-1: Roadmap from data collection to decision support. Source: NASA.

with the vision that the systems would be regularly updated with new technologies to respond to user requirements. Such a framework, with established metadata and quality control/quality assurance standards, mechanisms of transport, protocols, and requirements, will permit data and product providers to contribute their information as well as allow users to query and access the system for relevant information. The challenges to CCSP will be pursuing unprecedented levels of cooperation across current data management institutions and programs and a commitment to mapping the future development and execution of a suitable strategic plan.

The guiding principles for this CCSP data management plan are:

- The measure of success will be the ability of scientists and decisionmakers to access "stand-alone" or "integrated" data and information in a consistent and easily accessed format.
- The value added will be integration—many types of climate data from different suppliers will be available in a manner consistent with user requirements.
- The methods used by data suppliers to deliver data to their "customers" need will evolve with new technology.
- It will be easy for users to discover and access data (local, regional, national, and international).
- The system will be responsive to user feedback.
- The system will preserve irreplaceable data, making use of effective compression technologies where appropriate.
- There will be an open design and open standards process.
- Operations will be reliable, sustained, and efficient.

Goal 1: Collect and manage data in multiple locations.

A distributed system requires CCSP to exploit advances in information technology that enable the 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; and non-governmental organizations. Our ability to provide Climate Data Records (CDRs; see Chapter 12, Objective 3.4) and climate information to the community will depend on the interoperability of the system and metadata standards. Long-term archiving and stewardship of the data will be the responsibility of accredited (typically federal) data centers.

Objective 1.1: Develop standard metadata guidelines

Under this objective, CCSP will provide additional specific community-based guidelines for scientific metadata content where and as appropriate. One approach will be to adopt the ISO 19115/TC211 Geographic Information/Geomatics standard (<http://www.isotc211.org>), which is built on the Federal Geospatial Data Clearinghouse (FGDC) core standards.

Objective 1.2: Expand collaboration among data providers

CCSP will expand the collaboration between the federal data centers and external (university, commercial, and non-profit) data service providers. This collaboration will build on the strong foundation provided by existing distributed systems, encompassing the data centers established by federal science agencies, such as the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Department of Energy, U.S. Department of Agriculture, U.S. Geological Survey (USGS), and the National Science Foundation. The data management plan also calls for expanding 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. These collaborations should improve access to regional, state, and local data.

Goal 2: Enable users to discover and access data and information via the Internet.

This goal requires a greater emphasis on the development of 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 need to be targeted to develop standards and processes for sound data management. System upgrades need to include the implementation of tools to enable communication among multiple data locations. The process of identifying the data requirements of the program on a regular basis, including visualization, analysis, and modeling requirements, needs to be strengthened. Human resources will be required to perform these tasks, particularly individuals with the technical expertise to support user requirements. These needs will be addressed by CCSP (see Figure 13-2).

Objective 2.1: Improve access to data

Several activities are planned under this objective which will enable improved access to data:

- Expand the Global Change Master Directory (GCMD) to facilitate access to data. Agencies will provide descriptions in the format needed for this action.
- Ensure the provision of socioeconomic data collected by federal statistical agencies (e.g., the Census Bureau and the Bureau of Economic Affairs), by resource management agencies (e.g., the U.S. Department of Agriculture, U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, the U.S. Bureau of Land Management, and the U.S. Fish and Wildlife Service), by energy-related agencies (e.g., the Department of Energy and the Environmental Protection Agency), and by state and local agencies.

Objective 2.2: Management of biological data

Management of biological data will receive priority. Objective 2.3 of the Observing and Monitoring research element focuses on developing new capabilities for ecosystem observations. This is a CCRI priority and is a critical need for evaluating the effects of

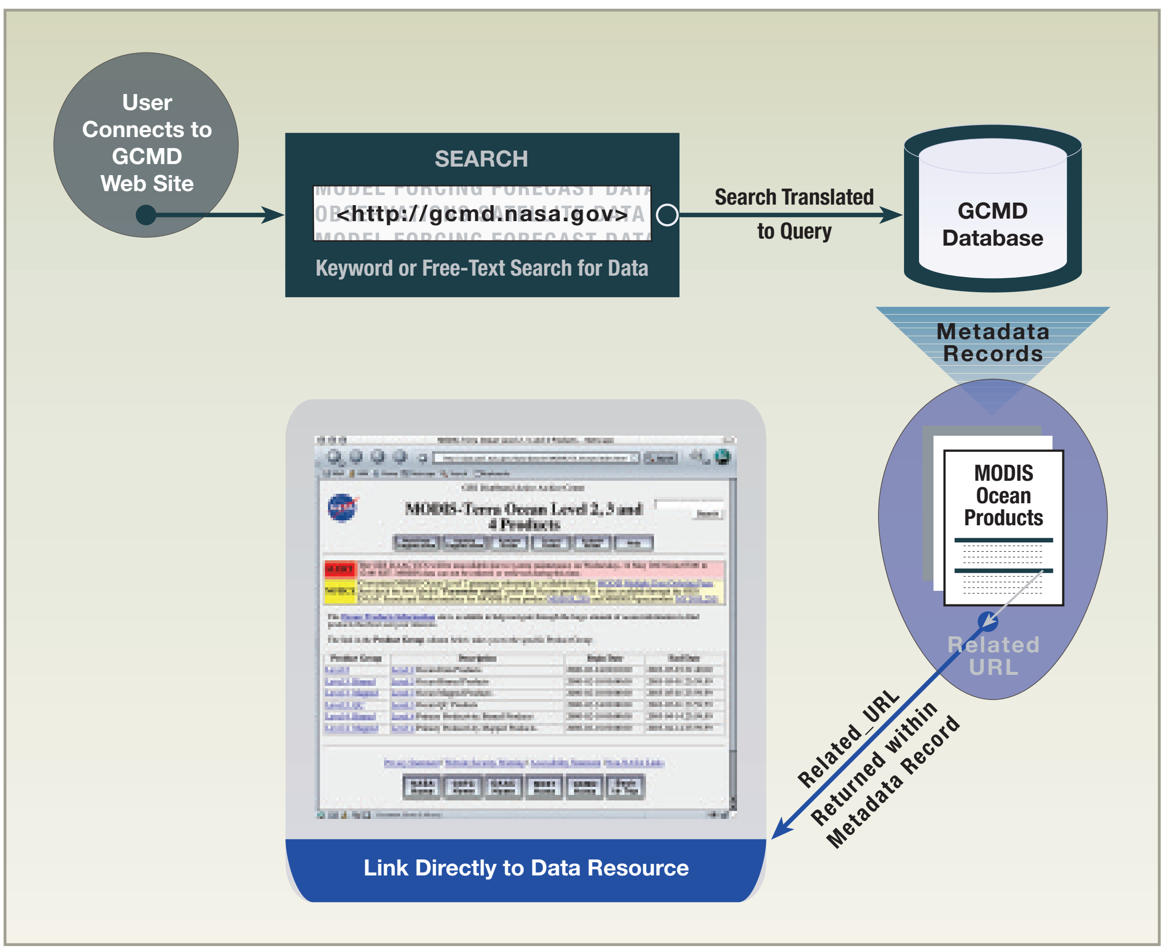


Figure 13-2: Search and direct retrieval of data set information from NASA's Global Change Master Directory. Source: NASA.

climate change on ecosystems. Biological data management is hampered by its requirement for extensive metadata, changes in named taxonomic species, and availability (at present mostly in non-electronic form and in the hands of individual investigators).

Objective 2.3: Data and information portals

Under this objective, CCSP will consolidate agency data information into one portal; that is, an agency home page would provide a mechanism for identifying all available data and information. CCSP will create special, tailored portals for data products of interest to 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. This will require implementation of climate-quality 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. Additionally, CCSP will work toward supporting the national climate observing system monitoring architecture described in Chapter 12 (Objective 1.7)

Goal 3: Develop integrated information data products for scientists and decisionmakers.

The goal of information analysis and interpretation is to incorporate the multidisciplinary science elements of the CCSP in order to integrate information and provide integrated products. This requires that links between scientists and data managers on one hand and data quality and data products on the other need to be enhanced to provide a more effective translation of user requirements into data products (see Chapter 12, Objective 3.4). Data managers must be able to understand, communicate, and work closely with scientists and others to ensure proper stewardship for the data archive and its distribution. Data managers must be included in scientific working groups and steering committees to guide the integration of data management and science and decision support. CCSP will ensure data quality and preservation by making data management an integral part of any observing or data collection program. Decision support needs will set the priorities for integrated products and help to define and address data management issues associated with the integrated products.

Objective 3.1: Establish links between data providers and decisionmakers

A dialogue needs to be established between data providers and decisionmakers to understand how scientific resources and knowledge are currently used by decisionmakers. Scientific discussion, planning, and implementation are needed for key data issues (e.g., gridding algorithms, gap-filling periods of missing observations) to permit assimilation of many CCSP data products. CCSP data analysis will draw on and promote further advances in data-processing automation, data visualization techniques, and web-based data delivery mechanisms. Activities under this objective include:

- Create a link on the CCSP website where decisionmakers can search for, locate, and link to data and information products identified by CCSP working groups as potentially of significant utility.
- Develop a prototype of the provision of support services for decision support systems. Provide an initial operational capability that interfaces one or more CCSP data systems to one or more decision support systems.
- Implement procedures to solicit climate information requirements from regions, sectors, and users who are using climate projections for management and policy decisions.

Objective 3.2: Application of data products and information

The emphasis on regional data, modeling, and decision support activities is increasing. Researchers and stakeholders are collaborating to develop applications based on research findings. An example of this effort is an experiment to integrate scientists and stakeholders to frame and apply El Niño-Southern Oscillation forecasts and other research products in a variety of regions and economic sectors. Regional environmental data products that can provide up-to-date information on environmental conditions to decisionmakers—and, if appropriate, allow an interactive "If…, then…" environment—must be anchored in considerations of input and process uncertainties and outcome accuracies. Decision support services must provide information about uncertainty to be of maximum utility to decisionmakers. This objective includes:

- Improve access to climate data and information for addressing regional concerns and issues
- Provide geo-referenced and spatially and temporally averaged socioeconomic data products for integrated studies
- Continually improve and clearly articulate the accuracy of regional data.

Objective 3.3: Harness emerging technologies

CCSP needs to take advantage of emerging information systems such as Digital Libraries (DLs). DL is a paradigm for investment by several agencies that has the potential of becoming the world's most vital environment for discourse and resources promoting excellence in science and education. Data management could be greatly informed and enabled by the DL technology. The guiding principles for the development of DL are to provide a spectrum of interoperability, to provide one library with many portals, and to leverage the energy and achievements of others. DL's effort will focus on building a comprehensive library of digital resources and this effort will enhance CCSP's successful implementation.

Goal 4: Preserve data.

One daunting challenge of the 21st century is the management of the large volume of highly diverse data describing the Earth's climate. These data are a result of comprehensive observing and monitoring systems and models producing new data sets from the climate observations. The size of the data archives is growing faster than we can derive information from them. For example, NASA's Earth science data holdings increased by a factor of six between 1994 and 1999; the total amount of data doubled between 1999 and 2000. It is estimated that by 2010, the size of a major U.S. archive for data from NOAA, NASA, and USGS will be 18,000 terabytes (10^{18} bytes). Lessons learned from NASA's pioneering efforts in handling their current holdings (more than 2,500 terabytes) must be used by

BOX 13-2

EXAMPLES OF DATA PRODUCTS

Chapter 3 – Atmospheric Composition
- Improved description of the global distributions of aerosols and their properties.
- A 21st century chemical baseline for the Pacific region against which future changes can be assessed.

Chapter 4 – Climate Variability and Change
- New and improved climate data products, including assimilated data from satellite retrievals and other remotely sensed and *in situ* data for model development and testing; consistent and regularly updated reanalysis data sets suitable for climate studies; centuries-long retrospective and projected climate system model data sets; high-resolution data sets for regional studies; and assimilated aerosol, radiation, and cloud microphysical data for areas with high air pollution.
- A paleoclimatic database designed to evaluate the ability of state-of-the-art climate models to simulate observed decadal to century-scale climate change, responses to large changes in climate forcing, and abrupt climate change.

Chapter 5 – Water Cycle
- Integrated long-term global and regional data sets of critical water cycle variables such as evapotranspiration, soil moisture, groundwater, clouds, etc., from satellite and *in situ* observations for monitoring climate trends and early detection of climate change.
- Enhanced data sets for feedback studies, including water cycle variables, aerosols, vegetation, and other related feedback variables, generated from a combination of satellite and ground-based data.

Chapter 6 – Land-Use/Land-Cover Change
- Global high-resolution satellite remotely sensed data and land-cover databases.
- Operational global monitoring of land use and land-cover conditions.

Chapter 7 – Carbon Cycle
- Global, synoptic data products from satellite remote sensing documenting changes in terrestrial and marine primary productivity, biomass, vegetation structure, land cover, and atmospheric column CO_2.
- Landscape-scale estimates of carbon stocks in agricultural, forest, and range systems and unmanaged ecosystems from spatially resolved carbon inventory and remote-sensing data.

Chapter 8 – Ecosystems
- Data sets for examining effects of management and policy decisions on a wide range of ecosystems to predict the efficacy and tradeoffs of management strategies at varying scales.
- Synthesis of known effects of increasing CO_2, warming, and other factors (e.g., increasing tropospheric ozone) on terrestrial ecosystems based on multi-factor experiments.

Chapter 9 – Human Contributions and Responses to Environmental Change
- Assessments of the potential economic impacts of climate change on the producers and consumers of food and fiber products.
- Elevation maps depicting areas vulnerable to sea-level rise.

the community. In addition, new technologies need to be developed that will enable us to keep all data needed for long-term global change research, reducing the need to prioritize which data will be archived. This endeavor would also consider lessons learned from communities that already handle this volume of data (e.g., defense intelligence, commercial video streaming).

Objective 4.1: Enhance the data management infrastructure

Telecommunications bandwidth capacity must be adequate to accommodate the movement of these larger data volumes as they progress through an information cycle including measurements, distributed scientific analyses, science models, predictions, decision support tools, assessments, and policy and management decisions. Increased levels of bandwidth will become available through government research, development, and funding; commercial availability and acquisition; and non-profit sector partnering. It is important to keep in mind that the evolutionary realization of this vitally needed infrastructure must be continually planned. Another critical area requiring enhancement is the development of new technologies for storage of large volumes of data and information.

Objective 4.2: Preserve historical records

At the same time, many important heritage data sets face a growing risk of loss due to deterioration of paper records, obsolescence of electronic media and associated hardware and software, and the gradual loss of experienced personnel (see, e.g., Figure 13-3). We look to these historical records, from which we can derive long-term trends, to help provide the missing pieces of the overall climate puzzle. The primary focus under this objective will be to identify and rescue data that are at risk of being lost due to media deterioration, poor accessibility, or limited distribution.

Objective 4.3: Support an open data policy

Another data management challenge is data policy—described as the set of rules, regulations, laws, or agreements governing the access and use of data. Database protection legislation, enacted in Europe and proposed in the United States, has raised concerns that the flow of scientific information may become much more constrained.

Many of these policies are in conflict with each other and the challenge will be to understand these conflicts and chart a course that benefits all. This will necessitate the close interaction of and negotiation between the database rights holders and users, in order to strike a balance between protection and fair use (NRC, 1999f). Compiling long-term climate-quality data sets from which long-term climate trends can be derived will be greatly affected by the future data policies of national and international bodies. CCSP will develop and implement guidelines for when and under what conditions data will be made available to users other than those who collected them.

Management Structure

Working in partnership with members and representatives of the research community in federal agencies and academia, and with appropriate committees of the National Research Council, CCSP will seek to identify the data requirements of the program on a regular basis, including visualization, analysis, and modeling requirements. Priority attention will be given to those observations and data that are central to a specific research element but for which requirements are not currently being met, or that exist but are not part of a publicly available data system. Accomplishment of these goals will require an integrated management structure that involves the CCSP agencies with oversight by members of the external community. A Data Management Steering Committee composed of federal, state, academic, and industry managers and decisionmakers will provide oversight, priorities, coordination, and recommendations to the CCSP Data Management Working Group (DMWG). DMWG will be responsible for the preparation, implementation, and periodic review of data management activities, and publication of annual reports describing milestones achieved and future activities. Close links via shared membership will be maintained with the Observing and Monitoring boards and councils as described in Chapter 12.

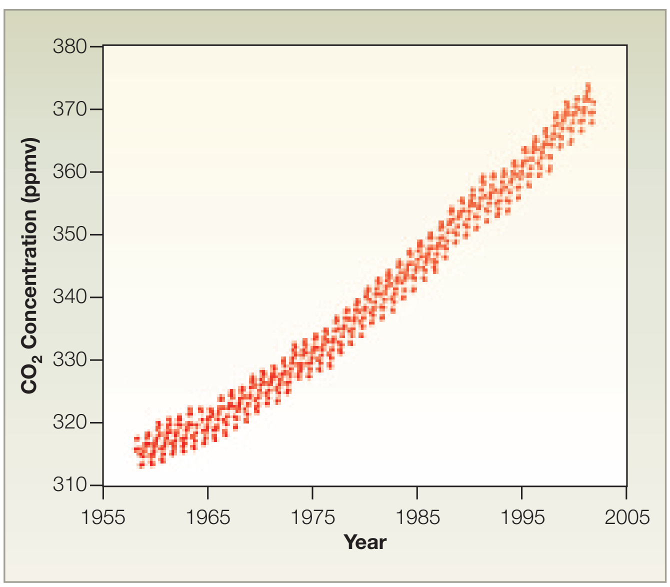


Figure 13-3: Changes in atmospheric carbon dioxide (CO_2) concentration at Mauna Loa, Hawaii, over time. This figure illustrates the critical need to preserve historical data. Source: Dave Keeling and Tim Whorf, Scripps Institution of Oceanography.

National and International Partnerships

CCSP will facilitate access to the data and information required and generated as part of this program. A critical need for observations and data are identified throughout this plan. Box 13-2 provides examples from each research chapter that illustrates the type of data products to be generated; Box 13-3 provides examples of the type of information products. Note that this latter box does not reflect output from the various modeling activities described in each chapter.

BOX 13-3

EXAMPLES OF INFORMATION PRODUCTS

Chapter 3 – Atmospheric Composition

- A *State of the Atmosphere 2006* report that describes and interprets the annual status of the characteristics and trends associated with atmospheric composition, ozone layer depletion, temperature, rainfall, and ecosystem exposure.

Chapter 4 – Climate Variability and Change

- Documented impacts of climate extremes on regions and sectors, and evaluations (both positive and negative) of the implications should climate change in the future.

Chapter 5 – Water Cycle

- Assessment reports on the status and trends of water flows, water uses, and storage changes for use in analyses of water availability.

Chapter 6 – Land-Use/Land-Cover Change

- Report on the regional and national impacts of different scenarios of land use and land cover on water quality and quantity.

Chapter 7 – Carbon Cycle

- *State of the Carbon Cycle* report focused on North America.

Chapter 8 – Ecosystems

- Reports describing the potential consequences of global and climatic changes on selected arctic, alpine, wetland, riverine, and estuarine ecosystems; selected forest and rangeland ecosystems; selected desert ecosystems; and the Great Lakes.

Chapter 9 – Human Contributions and Responses to Environmental Change

- Assessments of the potential health effects of combined exposures to climatic and other environmental factors (e.g., air pollution).

The generation of U.S. and global data products will require cooperation with national and international data centers and institutions. The CCSP will utilize and participate in the development of the data discovery and data interoperability framework being advanced by other programs such as the U.S. Integrated Ocean Observing System effort. CCSP will coordinate its activities with international programs to take advantage of emerging data management and information tools and technologies and sharing of climate change data and information. Examples of international programs that actively engage in data management include the World Data Center system, which functions under the guidance of the International Council of Scientific Unions (ICSU) and facilitates international exchange of scientific data; the World Climate Research Programme, which sponsors multiple major projects involving international cooperation and data collection with guidance by a Joint Scientific Committee; the International Human Dimensions Programme on Global Environmental Change Data and Information System (IHDP/DIS), which links social science data centers and scientists; and the Data Management Coordination Group of the Joint World Meteorological Organization/Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology, which is currently developing an Oceans Information Technology Pilot Project.

CHAPTER 13 AUTHORS

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