CHAPTER THREE

CLIMATE QUALITY OBSERVATIONS, MONITORING, AND DATA MANAGEMENT

from the

Strategic Plan for the Climate Change Science Program

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

Review draft dated 11 November 2002

Contents

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11 November 2002

Dear Colleague,

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

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

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

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

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

Sincerely,

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

Instructions For Submission of Strategic Plan Review Comments

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

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

Format Guidance for Comments

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

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

Format Example for Comments

I. Background Information

Name(s): John Doe
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II. Overview Comments on Chapter 5: Atmospheric Composition

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

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

III. Specific Comments on Chapter 5: Atmospheric Composition

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

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

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

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

Foreword

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

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

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

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

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

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

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of the
Strategic Plan for the Climate Change Science Program

CHAPTER 3

CLIMATE QUALITY OBSERVATIONS, MONITORING, AND DATA MANAGEMENT

This chapter's contents…

1. How did the global climate change over the past fifty years and beyond, and what level of confidence do these data provide in attributing change to natural and human causes?

2. What is the current state of the climate, how does it compare with the past, and how can observations be improved to better initialize models for prediction?

3. How real are the differences in surface and tropospheric temperature trends?

4. How do we improve observations of biological and ecological systems to understand their response to climate variability and change?

5. How accessible is the climate record?

The US Climate Change Research Initiative (CCRI) provides resources to develop climate observation systems. It encourages partnerships with developed countries and support for developing countries in order to build a global observing system. A climate observing system must go beyond climate observations themselves to include the processing and support system that leads to reliable and useful products. To be most effective it must also provide critical data for decision support and policymakers in areas such as climate and weather forecasting, human health, energy, environmental monitoring, and natural resource management. The specific emphasis on climate observing and information systems within CCRI will be to document the past, observe the current state, and archive a high quality and consistent record that is accessible to everyone. These objectives are considered through representative research questions.

1. How did the global climate change over the past fifty years and beyond, and what level of confidence do these data provide in attributing change to natural and human causes?

Observations of current and past climates play an important role in improving the characterization of processes in the ocean, atmosphere, land surface, and polar regions, and in validation of climate models. The climate record is a time series of key variables, such as temperature, precipitation, and pressure, at monitoring sites or aggregated at regional and/or local levels. These data are essential input to climate models and therefore key to meeting the complex challenge of predicting future climate. The climate record itself provides valuable information for industrial planning in sectors such as electric utilities, transportation, construction, insurance, and many others. The need for refining, extending (both backwards and forwards), and analyzing the long-term climate record to better discriminate natural variability from human-induced global change is self-evident. Space-based and *in situ* observations, often associated with weather networks, have provided the most important data so far for the detection and attribution of causes of global change. Documentation of decadal to centennial climate changes requires records of much longer duration than available based on modern instrumentation. Therefore, we need a systematic search for, and recovery of, naturally existing proxies (substitutes) for such instrumentation—proxies that reveal the past history over hundreds and thousands of years with adequate quality and temporal resolution.

Many individuals in many countries have gathered climate system variables using many different instrument types during the past 150 years to document climate system variability. 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 to provide the user community with open and easy access to these databases. We need to integrate these records as far into the past as is practical to reduce uncertainties in the climate trend estimates of individual parameters. In addition, we can now reanalyze the past states of the climate system using the modern tools of data assimilation within the context of a numerical global circulation model. These model-based reanalyses have proven successful for the atmosphere and are now being explored for the oceans. A strategy for routine reanalysis must be established to exploit the iterative nature of improvements in this process.

Understanding the magnitude and impact of past climate variations and change is key to developing confidence about how climate may change in the future. This requires comprehensive documentation about the full spectrum of climate forcings, feedbacks, and responses, especially over the past century when human influences have been most pronounced. Although the recent Intergovernmental Panel on Climate Change (IPCC) assessment (IPCC, 2001) provides information about climate changes and variations for a variety of variables, more can be done in an organized and timely way to support climate-related policy. Much of this information is not routinely updated and integrated into a clear comprehensive assessment, nor is it combined into a convenient format for policymakers.

RESEARCH NEEDS

- Perform data archaeology and mining for specific climate related events and trends using rehabilitated historical records.
- Begin to reanalyze historical records to improve data fidelity so they are more useful for improved long-term climate records.

PRODUCTS AND PAYOFFS

- Regular ocean and atmosphere reanalyses to assess the state of the climate over the last 50 years and beyond, including a related assessment of data and observations.
- State of the climate reports describing decadal-, centennial-, and millennial-scale changes.
- A statistical characterization of climate system extremes from historical data.

2. What is the current state of the climate, how does it compare with the past, and how can observations be improved to better initialize models for prediction?

The state of the climate is determined from the global climate observing network. This network is also used to examine the current state relative to the past, often in the form of anomalies (differences) relative to a mean state, and to examine long-term trends of climate-sensitive variables, such as sea level rise, air and sea temperatures, sea ice concentration and extent, and upper ocean heat content. The future state of the climate is predicted by starting from the present state of the climate. The importance of observations for producing an accurate assessment of the present state of the climate is recognized through a core objective of the CCRI.

Climate research and monitoring require an integrated strategy of land, ocean, and atmospheric observations, including both *in situ* and remote sensing platforms, modeling, and analysis. An adequate global climate observing system should be made up of instruments on various platforms, including aircraft and satellites, ground stations, ships, buoys, floats, ocean profilers, balloons, flux towers, and samplers. The existing network is in need of repair and maintenance, and many elements must be brought up to modern standards.

One of the more pressing needs from a climate monitoring perspective is the identification and correction of time-dependent data biases in observation systems as early as possible. This is a fundamental aspect of scientific data stewardship. Too often, time-dependent biases have been discovered ten or more years after the fact, often through data archaeology or reprocessing efforts. This degrades the climate record, even if adjustments can be developed to correct the deficiencies, and often requires considerable extra effort. Achieving early detection of time-dependent biases will require new research on the most effective means of finding biases early on. In addition, a system must be put in place so that when biases are found, network operators can be notified and corrective action taken. These biases are sometimes due to sensor degradation, but just as frequently result from changes in algorithms or spatial and temporal sampling methods that at first appear innocuous. All these issues will need to be addressed.

The CCRI will enhance the existing long-term monitoring system 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 surface and upper air atmospheric measurements and observations of atmospheric composition, global ocean, land surface, and ice variables. For example, only half of the Global Climate Observing System (GCOS) Upper-Air Network (GUAN), established for climate purposes, has been reporting regularly in its first few years of operation, and the GCOS Surface Network (GSN) for climate has had similarly disappointing results. The ocean is poorly observed below the surface and large parts of the ocean have never been measured in some seasons (such as the Southern Hemisphere oceans in winter). Over land, the great spatial heterogeneity requires extremely detailed measurements and presents a major challenge.

A truly global observing system is only possible through international cooperation and coordination. 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, in particular the Global Observing Systems (G3OS), which include GCOS, the Global Ocean Observing System (GOOS), and the Global Terrestrial Observing System (GTOS). The full implementation of G3OS will require 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.

Climate prediction systems depend on robust and broad global observations to project the present state of the climate into the future. In addition, observations are used to validate and evaluate model predictions, which leads to model improvement. Key variables, such as sea surface temperature, must be available with sufficient accuracy and resolution for prediction systems to provide maximum benefit.

RESEARCH NEEDS

- For all operational monitoring networks, develop the tools necessary to identify time-dependent biases in the data as close to real-time as possible.
- Evaluate the capacities of existing and planned networks (e.g., G3OS) to recognize changes in extremes and hazards.
- Repair the GCOS Surface Network to improve data reports.
- Improve atmospheric column observations of temperature, humidity, and winds by repairing the GCOS Upper Air Network that collects data, but fails to provide adequate and timely reports.
- Measure emissions, aerosols, and ozone in the Asia Pacific area by adding new Global Atmosphere Watch (GAW) stations. Improve global estimates of atmospheric ozone and carbon by upgrading GAW stations.
- Monitor upper-ocean temperature and salinity structure with additional ocean profiling floats and expendable bathythermographs to observe changes in heat and freshwater content.

- Improve estimates of global sea surface temperature for climate model initialization, as well as regional barometric pressure and surface current velocity for model validation, by completing the global distribution of surface drifting buoys.
- Reduce uncertainty in sea level rise estimates by obtaining absolute positions for sea level stations required for altimeter calibration and detection of long-term trends, and fixing "core network" sea level stations that do not provide data on ocean circulation.
- Monitor the state of the global tropical atmosphere and oceans with instrumented moored buoys for climate prediction and research.
- Improve model-based global air-sea flux estimates with surface flux reference moored buoy sites and Volunteer Observing Ships (which collect routine surface meteorological observations) with instrument upgrades for climate-quality observations.
- Accelerate validation of satellite-based sea ice thickness measurements by enhancing validation-oriented field measurements.

PRODUCTS AND PAYOFFS

- Reduced uncertainty related to time-dependent biases in the climate record.
- Estimates of the number of years a climate record is required at each new US Climate Reference Network station to recognize a climate trend and/or variation.
- Regular reports documenting the present state of the climate system components (i.e., atmospheric composition, climate variability and change, water cycle, carbon cycle, land cover and land use change, and ecosystems) in context with historical data to provide an essential perspective on current trends and variations.
- Integrated estimates for the general user community of the current state of important climate parameters, such as:
  - Atmospheric temperature and water vapor;
  - Sea level rise;
  - The variability of ocean heat content;
  - Surface temperatures; and
  - Sea ice thickness.

3. How real are the differences in surface and tropospheric temperature trends?

A key role for the CCRI's accelerated focus on observing systems is to reduce the significant uncertainties in our understanding of climate change. A crucial issue that remains unresolved relates to the rate of warming in the troposphere compared to the surface during the latter part of the 20th century. Climate model simulations, forced by anthropogenic changes in atmospheric composition, project significant increases in tropospheric temperature that are somewhat larger than the increases near the surface in the tropics. Several analyses of the observational data suggest that the rate of warming at the surface has been at least twice that of the troposphere, especially in the tropics and sub-tropics, since about 1980, and about the same since around 1960. The failure of the troposphere to warm at the same rate as the surface during the last few decades has called into question both our understanding of the causes of any change, in particular the impacts of enhanced greenhouse gas concentrations, and the data used to calculate temperature trends. For these reasons, the IPCC's *Third Assessment Report* (IPCC, 2001) devoted considerable discussion to assessments of both climate model simulations and observational data in order to resolve the apparent differences in the rate of warming projected inaccurately in climate models with those observed in the troposphere and at the surface. Climate models were used to help understand how the surface and tropospheric temperatures may have responded differently to a variety of natural and anthropogenic forcings. Prior to the IPCC report, a panel of the National Research Council (NRC) attempted to reconcile the differences in the observations from satellites, weather balloons, and the near-surface temperature record derived from surface weather stations and ocean ships and buoys (*Reconciling Observations of Global Temperature Change*, NRC, 2000). The IPCC (2001) concluded that it was very likely that there are significantly different trends of temperature at the surface, in the troposphere, and in the stratosphere.

Several new analyses have been completed since the IPCC and NRC reports were published. The differential surface and tropospheric warming remains a complex issue from an observational standpoint. Several independent estimates of tropospheric temperature trends since 1958, based on radiosondes, have yielded quite different results ranging from little or no warming to 0.2ºC per decade. New and updated analyses of the satellite record indicate warming in the troposphere of more than 0.1ºC per decade in one data set, but only a statistically insignificant trend in another, both over the period 1979 to 2001.

Model simulations have been run to interpret the observational data. Coupled climate models with combined anthropogenic and natural forcings have been unable to simulate the large differences in trends reported by several of the observational analyses. The inability to reliably simulate the observed differential warming is due to a combination of model error and missing or inaccurately specified external forcings, e.g., the effects of increased greenhouse gases and stratospheric ozone depletion in the upper troposphere. An alternate explanation assumes that observational errors are not trivially small. The truth could lie somewhere in the middle.

RESEARCH NEEDS

To help resolve this issue that is central to detecting and attributing climate change, and ensure that future monitoring systems deliver data free of time-dependent biases, a focused effort will be made to ensure improved retrospective and prospective atmospheric temperature measurements. This includes:

- Improvements for data and observations
  - More comprehensive information regarding the type of radiosondes used by various countries and how they have changed over the decades.
  - More effort to obtain observations and data from overlapping measurements for the various observing systems (e.g., radiosondes, surface observations, and satellites) when instruments change or there are changes in spatial and temporal sampling.

- Algorithm adjustments are required for the operational microwave satellite record to ensure continuity between records from adjacent satellites. Attention to calibration issues (including overlap of satellite records) needs to be increased.
- A closer analysis of the height of the tropopause, which has been measured on radiosondes and more recently on Global Positioning System occultation data, will be useful for understanding both troposphere and stratospheric changes.
- Updates, adjustments, and the newer versions of data sets for both the satellite-derived and the *in situ* temperature measurements are required to narrow unexplained differences in the data sets.
- A cost effective means to implement the GCOS climate monitoring principles for satellites and *in situ* systems.

- New modeling simulations
  - Simulation of the spatial and temporal sampling of the National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites used to calculate tropospheric and stratospheric temperatures in the historical record.
  - Additional ensemble simulations of the climate of the last 40-50 years from several of the key climate models with the inclusion of both natural and anthropogenic forcings are crucial to trying to explain the observed changes.
  - Analysis of data from model new reanalysis projects will be emphasized to better understand significant time-dependent biases that may have affected the observing system.

PRODUCTS AND PAYOFFS

- An improved international radiosonde network to produce better data sets of upper air temperature and humidity, with special emphasis on the tropics and subtropics where data are most difficult to harmonize with the surface.
- An improved international surface monitoring network using the principles set forth by the NRC (see Chapter 12) for improved data sets for surface temperature, precipitation, and barometric pressure.
- Data to support reduction of climate model uncertainties regarding surface and tropospheric temperature response to a variety of natural and anthropogenic forcings.
- Satellite missions adhering to the GCOS climate monitoring principles for reduced discontinuities in the satellite record.
- Evaluation of biases in the observational records to produce a more consistent climate record.

4. How do we improve observations of biological and ecological systems to understand their response to climate variability and change?

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 section of the IPCC's *Third Assessment Report* (IPCC, 2001), including thawing of permafrost, lengthening of the period of leaf display in mid- and high-latitude ecosystems, poleward shifts of plant and animal species ranges, movement of plant and animal species up elevational 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 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.

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.

The CCRI 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. The CCRI 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 new needed monitoring systems, and synthesis of results across ecosystems and regions. Research efforts will target those ecosystems that are subjected to (or may be subject to in the future) the most rapid or extensive environmental changes and/or are most sensitive to possible environmental changes.

RESEARCH NEEDS

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

- Identifying ecosystems that are either sensitive or resilient to environmental change;
- Interfaces between ecosystems (ecotones), which are governed by and presumably most sensitive to environmental factors;
- Ecosystems experiencing the most rapid environmental changes today, or that may experience the most rapid changes in the near future, such as ecosystems located at high latitudes and high elevations. Coastal ecosystems should also be a priority because of ongoing sea level rise and intensive human uses;
- Concurrent trends in other factors, such as population and land use change; and
- Validation of the results of impacts studies done with the climate change scenarios over the near term or for small amounts of warming using observed climate and impact data.

PRODUCTS AND PAYOFFS

- A comprehensive report describing ecosystems that will potentially be affected by environmental change, especially climatic changes, as well as those that are resilient to change, and a detailed map of the geographic extent of those ecosystems.
- 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).
- 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.
- 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.
- Links to biological and ecological datasets from monitoring programs, including those from remote sensing platforms.
- Annual reports on observed ecosystem changes attributable (or attributed) to global change.
- Requirements for a system for observing interactions of climate and ecosystems.
- Climate data at appropriate temporal and spatial scales for impact studies.
- Links to datasets documenting trends in other variables, such as population and land use change, relevant to observed climate impacts.

The payoff from the initial products will be information needed to establish effective networks of observing systems directed at identifying, quantifying, and explaining resilience as well as changes in ecosystems resulting from global changes. The information will be used to design appropriate observing systems, which will in turn be needed to implement effective observational systems that may be able to provide key information to decisionmakers and scientists about effects of global change on ecosystems. It will begin to lay the foundation for future analyses of how ecosystem responses in turn cause feedbacks to the climate system.

5. How accessible is the climate record?

The key priority for scientists and decisionmakers is access to the climate record. Scientists studying Earth system variability and change must have an accurate, uninterrupted series of key geophysical climate data records. These data records stretch from paleoclimatic proxy data to measurements from today's observation systems. To provide maximum accessibility, scientific quality assurance, and ease of utility of these key products spanning multiple decades, multiple projects, and multiple government agencies now and in the future is key to the success of understanding and providing the science-based information that is the mandate of the Climate Change Science Program (CCSP).

The provision of data and information in forms needed for cross-disciplinary analysis and projection remains a challenge. Some science questions by their very nature pose needs for the concerted gathering of "bundles" of data, information, and services. Throughout this document, which discusses key and emerging science questions, are specific needs for data sets related to large regional problems, large-impact processes, field campaigns, and analyses that combine *in situ* data, remotely sensed data, process studies, and model output. Integrated data set needs are most effectively answered by community-aggregated data, information, tools, and services dedicated to removing usage barriers, such as temporal and spatial differences.

It is now well known that for climate change research, life-cycle data management—including long-term stewardship—must be considered and planned throughout the entire design, implementation, and life cycle of any observing system. Long-term stewardship includes the long-term preservation of the scientific integrity of the data, monitoring and improving data quality, significantly enhancing access to the data, and extracting further knowledge from the data.

A continuous and complete data record for the observational instrument series or network of stations, including history and metadata (information about the data set), provides the details necessary to support a high degree of confidence in the data employed by the scientific research community in forecast and prediction modeling. In turn, this provides decisionmakers with a high degree of confidence when making environmental and economic policy decisions. In addition, data collected as part of process studies is of great value for improving the fidelity of climate models. Consequently, data providers must assemble, document, and subject these data to high quality standards. Such data should be assembled, processed, integrated, and made openly accessible to the research community. Adequate support for safeguarding by federal depository centers will ensure long-term access.

As we move to implement the CCRI, achieving integrated (land, atmosphere, and ocean) data access will require multidisciplinary analysis of data and information to an extent never before attempted. This includes the analysis of interlinked environmental changes that occur on multiple temporal and spatial scales, which is very challenging both technically and intellectually. For example, many types of satellite and *in situ* observations at multiple scales need to be integrated with models, and the results presented in understandable ways to all levels of the research community, decisionmakers, and the public. In addition, very large volumes of data from a wide variety of sources, and results from many different investigations, need to be readily accessible to scientists and other stakeholders in usable forms.

The success of every element in this plan requires accessible, high-quality, interoperable, and thus easily usable, data in order to reduce the uncertainties in our models, and to be able to understand and characterize the processes and feedbacks when addressing the key questions about atmospheric composition, the carbon and water cycles, land use and land cover, ecosystems, and climate variability and change. The data and information must be presented in a way that facilitates its use in scenario development, studies of human contributions and responses to environmental change, and decision support tools. The accessibility of quality data will be a focus of CCRI, and its success will rely on partnerships with existing national and international efforts currently focusing on these issues (i.e., G3OS, Ocean.US, the International Geosphere-Biosphere Programme (IGBP), and the World Climate Research Programme (WCRP)).

RESEARCH NEEDS

- Establish a framework for providers' data, quality control, metadata documentation standards, and formatting policies that will make possible the combined use of targeted data products important to high-priority areas of research. This will also encourage provision of common tools and services in the public and private sectors.
- Provide defined key elements for data management planning. A data management plan should be required as part of any new observational or monitoring activity. This plan needs to address the data life cycle, with special focus on data access and archiving.
- Develop a cross-agency mechanism to coordinate implementation of the climate observing system, identify where efficiencies could be gained, and support leveraged activities.
- Access and document the information architectures, systems, and data products produced and managed to provide an overall architecture diagram or catalog of information systems and services. This will enable effective management of, and facilitate access to, the distributed climate-related data and information gathered by federal and non-federal activities. This will lead to a harmonized evolution of existing distributed systems and services for utilization of data and information in analyses and models.

PRODUCTS AND PAYOFFS

- Coordinated climate observing instrument series and monitoring networks, administered by different agencies, maximizing the use and utility of the data.
- Mechanisms to encourage and permit regional, project, and commercial observational networks to make their data available for analysis and model validation and to receive feedback on data quality and utility of their data.
- Data from future monitoring and observing networks will be more readily added to the climate record, and digested into the information available for decisionmakers.
- Coordinated implementation of the climate observing system both at the national and international level.
- Provision of information portals where decisionmakers can locate the data, information, models, analysis tools, and other services that are identified as potentially important to their needs by the CCSP research community.

References:

IPCC, 2001. Intergovernmental Panel on Climate Change, *Climate Change 2001*. Third Assessment Report of the IPCC. (Cambridge, United Kingdom, and New York: Cambridge University Press). Includes:

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