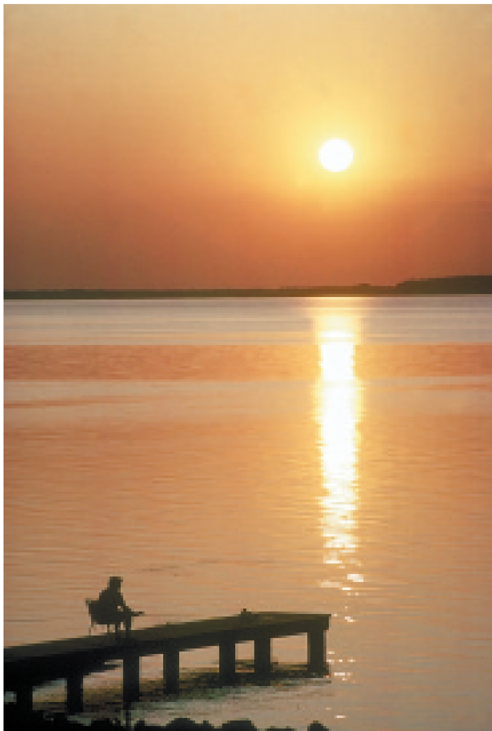
CHAPTER 2 Integrating Climate and Global Change Research



CHAPTER CONTENTS

CCSP Goals and Products

"Critical Dependencies" and Approaches to Integration

Synthesis and Assessment Products

Chapter 2 describes the Climate Change Science Program's (CCSP) overall approach to climate research on different components of the Earth system and the integration of this research to achieve program objectives. This chapter expands on CCSP's five goals (see Chapter 1 and Box 2-1), including a brief overview of current scientific understanding, and illustrates the relationship between these goals and the program's interdisciplinary research elements and cross-cutting activities. Tables listing topics to be covered by CCSP synthesis and assessment products are included and indicate the target time frame for completion of each product. These products will fulfill the requirements for updated synthesis and assessment contained in Section 106 ("Scientific Assessment") of the 1990 Global Change Research Act.

This chapter of the plan also includes research products, milestones, and activities, which are grouped under research focus areas for each goal. These are given here as examples and are not meant to constitute exhaustive lists; completion dates are not provided in this chapter, but are in related discussions in Chapters 3-9, and range from 2004 to beyond 2007 (greater than 4 years). Other sections of this chapter discuss integration of research to give a comprehensive picture of the cumulative effects of natural processes and human activities on the future evolution of climate and related systems.

CCSP Goals and Products

CCSP's goals span the chain of climate-related issues including natural climate conditions and variability; forces that influence climate; cycles and processes that affect atmospheric concentrations of greenhouse gases and aerosols; climate responses; consequences for ecosystems, society, and our nation's economy; and application of knowledge to decisionmaking. This comprehensive characterization provides a useful organizing scheme for examining key climate change issues. CCSP research must focus on the full range of these complex issues if it is to lay the basis for informed discussion and decisionmaking.

The following text explains the five CCSP goals. The discussion of each goal includes a set of topics to be addressed by synthesis and assessment products related to the goal during the next 4 years, and examples of key research activities to be carried out in moving toward the goal, with links to the discussion of research activities in subsequent chapters. Near-term synthesis and assessment products will draw on a large body of research either already completed or currently underway throughout the program, in addition to new research results as they become available. Over time, CCSP research activities and the development of new synthesis and assessment products will evolve in partnership, as scientific research progresses and as new questions related to policymaking, planning, and adaptive management arise.

BOX 2-1

LIST OF CCSP GOALS INCLUDING EXAMPLES OF KEY EXPECTED OUTCOMES

CCSP Goal 1: 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

- Better understand the natural long-term cycles in climate (e.g., Pacific Decadal Variability, North Atlantic Oscillation).
- Improve and harness the capability to forecast El Niño-La Niña events and other seasonal-to-interannual cycles of variability.
- Sharpen understanding of climate extremes through improved observations, analyses, and modeling, and determine whether any changes in their frequency or intensity lie outside the range of natural variability.
- Increase confidence in understanding of how and why climate has changed.
- Expand observations and data/information system capabilities.

CCSP Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems

- Reduce uncertainty about the sources and sinks of greenhouse gases, emissions of aerosols and their precursors, and their climate effects.
- Monitor recovery of the ozone layer and improve understanding of the interactions among climate change, ozone depletion, and other atmospheric processes.
- Increase knowledge of the interactions among pollutant emissions, long-range atmospheric transport, climate change, and air quality management.
- Develop information on the carbon cycle, land cover and use, and biological/ecological processes by helping to quantify net emissions of carbon dioxide, methane, and other greenhouse gases, thereby improving the evaluation of carbon sequestration strategies and alternative response options.
- Improve capabilities to develop and apply emissions and related scenarios for conducting "If…, then…" analyses in cooperation with the Climate Change Technology Program.

CCSP Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future

- Improve characterization of the circulation of the atmosphere and oceans and their interactions through fluxes of energy and materials.
- Improve understanding of key "feedbacks" including changes in the amount and distribution of water vapor, extent of ice and the Earth's reflectivity, cloud properties, and biological and ecological systems.
- Increase understanding of the conditions that could give rise to events such as rapid changes in ocean circulation owing to changes in temperature and salinity gradients.
- Accelerate incorporation of improved knowledge of climate processes and feedbacks into climate models to reduce uncertainty about climate sensitivity (i.e., response to radiative forcing), projected climate changes, and other related conditions.
- Improve national capacity to develop and apply climate models.

CCSP Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes

- Improve knowledge of the sensitivity of ecosystems and economic sectors to global climate variability and change.
- Identify and provide scientific inputs for evaluating adaptation options, in cooperation with mission-oriented agencies and other resource managers.
- Improve understanding of how changes in ecosystems (including managed ecosystems such as croplands) and human infrastructure interact over long periods of time.

CCSP Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change

- Support informed public discussion of issues of particular importance to U.S. decisions by conducting research and providing scientific synthesis and assessment reports.
- Support adaptive management and planning for resources and physical infrastructure affected by climate variability and change; build new partnerships with public and private sector entities that can benefit both research and decisions.
- Support policymaking by conducting comparative analyses and evaluations of the socioeconomic and environmental consequences of response options.

CCSP Goal 1: 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 changes

The climate system is highly variable, with average conditions changing significantly over the span of seasons, years, decades, and even longer time scales. Examining the period since the industrial revolution, when human activities started to significantly alter the Earth's land surface and increase the atmospheric concentrations of greenhouse gases (GHGs) and aerosols, an increasing body of evidence gives a picture of a warming world and other related changes. A key issue is whether there is a cause and effect relationship between

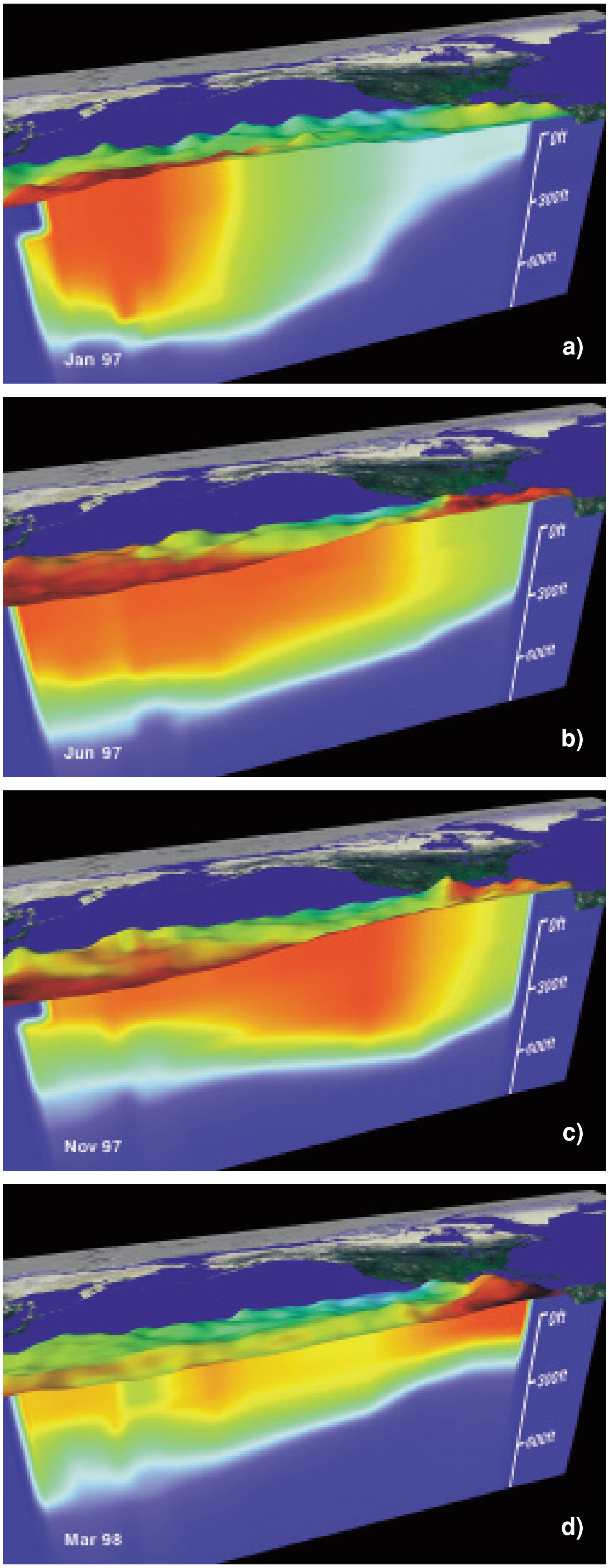


Figure 2-1: Evolution of the 1997-1998 El Niño event. This figure depicts water temperature and sea surface topography in the equatorial Pacific Ocean: (a) January 1997; (b) June 1997; (c) November 1997; (d) March 1998. Source: NASA Goddard Space Flight Center, Scientific Visualization Studio; NOAA Pacific Marine Environmental Laboratory.

these developments. The Intergovernmental Panel on Climate Change (IPCC) and the National Research Council (NRC) have independently concluded (in the words of the NRC) that "changes observed over the last several decades are likely mostly due to human activities," but that "a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed climate changes during the 20th century cannot be unequivocally established" (NRC, 2001a). Uncertainty about natural oscillations in climate on scales of several decades or longer and inconsistencies in the temperature profiles of different data sets are critical scientific questions that must be addressed to improve confidence in the understanding of how and why climate has changed.

El Niño-Southern Oscillation (ENSO) is a widely-recognized, large-scale climate oscillation in the equatorial Pacific Ocean that changes phase every few years, with significant implications for resource and disaster management. There are other climate cycles that last decades, centuries, and even millennia, as revealed in studies of the Earth's climate history. Recently improved (but still imperfect) capacity to forecast ENSO has yielded significant benefits in the United States and other countries, enabling decisionmakers to prepare for impacts.

Improved data and information on the climate system's natural variability and recent changes are needed to increase confidence in studies that seek to detect and attribute changes in climate to particular causes. Expanded observations, modeling, and data/information system capabilities will also improve society's ability to respond to the fluctuations and changes in the environment—whether natural or human-induced—that the nation and the world will face in the next 20 to 30 years and beyond. Substantial amounts of data are already collected through both an extensive observations system developed under the U.S. Global Change Research Program (USGCRP) and a set of operational monitoring systems used for weather forecasting and other uses (that historically were not identified as part of the USGCRP). New technologies can extend existing observation and monitoring networks and improve accessibility to these data, with benefits for both scientific understanding and resource management.

Examples of Key Research Activities

Focus 1.1: Better understand natural long-term cycles in climate [e.g., Pacific Decadal Variability (PDV), North Atlantic Oscillation (NAO)]

- An assessment of potential predictability beyond ENSO (e.g., associated with PDV, NAO) and improvements in the representation of major modes of climate variability in climate change projection models (Chapter 4.2)[1]
- Identification of impacts of natural oscillations in climate on marine fisheries and marine ecosystems (Chapter 8.2)
- Identification of adaptation strategies effective for managing the impacts of seasonal and year-to-year climate variability (Chapter 9.2)

[1] Parenthetical references indicate the chapter and question where additional information on this research can be found.

CCSP GOAL 1

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Temperature trends in the lower atmosphere—steps for understanding and reconciling differences.	Inconsistencies in the temperature profiles of different data sets reduce confidence in understanding of how and why climate has changed.	within 2 years
Past climate variability and change in the Arctic and at high latitudes.	High latitudes are especially sensitive and may provide early indications of climate change; new paleoclimate data will provide long-term context for recent observed temperature increases.	within 2 years
Reanalyses of historical climate data for key atmospheric features. Implications for attribution of causes of observed change.	Understanding the magnitude of past climate variations is key to increasing confidence in the understanding of how and why climate has changed and why it may change in the future.	2-4 years

Focus 1.2: Improve and harness the capability to forecast El Niño-La Niña and other seasonal-to-interannual cycles of variability

- Improved predictions of El Niño-La Niña, particularly the onset and decay phases, and improved probability forecasts of regional manifestations of seasonal climate anomalies resulting from ENSO (Chapter 4.2)
- An assessment of potential predictability of annular modes, tropical Atlantic and Indian Ocean variability and trends, and the monsoons (Chapter 4.2)
- Analyses of societal adjustment to climate variability and seasonal-to-interannual forecasts (Chapter 9.2)

Focus 1.3: Sharpen understanding of climate extremes through improved observations, analysis, and modeling, and determine whether any changes in their frequency or intensity lie outside the range of natural variability

- Improved observational databases, including paleoclimate and historical data records, and model simulations of past climate, to detect and analyze regional trends in extreme events (Chapter 4.4)
- Observational and statistical analyses to assess the relationships between extreme events and natural climate variations, such as ENSO, PDV, NAO/Northern Hemisphere Annular Mode and Southern Hemisphere Annular Mode, and ecosystem response (Chapters 4.4 and 8.2)

Focus 1.4: Increase confidence in the understanding of how and why climate has changed

- Development and extension of critical data sets (including paleoclimatic data) to improve analyses of climate variability and attribution of causes of climate change (Chapter 4.2)
- 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 (Chapter 5.1)

Focus 1.5: Expand observations and data/information system capabilities

- Data requirements analysis and planning
  - Requirements analysis for a global integrated climatological, ecological, and land-use monitoring system, followed by design specifications for the monitoring system (completed with significant international collaboration) (Chapter 12)
  - Definition of the initial requirements for ecosystem observations to quantify feedbacks to climate and atmospheric chemistry, to enhance existing observing systems, and to guide development of new observing capabilities (Chapters 8.1 and 3.5)
  - Definition of the initial requirements for observing systems to monitor the health of ecosystems, including a new suite of indicators of coastal and aquatic ecosystem change (Chapter 8.2)
  - Identification and rescue of data that are at risk of being lost because of media deterioration, poor accessibility, or limited distribution. (Chapter 13)
- Data systems and products
  - Monitoring and data systems for water resources research and management (Chapter 5.4)
  - Development of high-resolution climate data products for climate-sensitive regions, based on monthly instrumental data and annual paleoclimatic data and climate forecasts (Chapter 4.1 and 4.5)
  - 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 (Chapter 13)
  - Global high-resolution satellite remotely sensed data and land-cover databases and global maps of areas of rapid land-use and land-cover change and location and extent of fires (Chapter 6.1)

CCSP Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems

Combustion of fossil fuels, changes in land cover and land use, and industrial activities produce greenhouse gases and aerosols and alter the composition of the atmosphere and important physical and biological properties of the Earth's surface. For example, the atmospheric concentration of carbon dioxide (CO_2) has increased approximately 30 percent since the mid-18th century (see Figure 2-2). The current level of atmospheric CO_2 has not been exceeded during at least the past 420,000 years (the span measurable in ice cores). Atmospheric concentrations of other greenhouse gases [methane (CH_4), tropospheric ozone (O_3), nitrous oxide (N_2O), and halocarbons (e.g., chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs))] have also increased. For example, CH_4 concentrations have more than doubled and the concentrations of industrially produced molecules have increased against a zero natural background. In the case of chlorine, the amount of chlorine in the stratosphere has essentially quintupled due to this human release.

These changes have several important climatic effects. Greenhouse gases (which remain in the atmosphere for years to millennia) have a warming influence on climate, while aerosols (which usually remain in the atmosphere for weeks to months) have both warming and cooling effects that can be quantified only poorly at present (see Figure 2-3). Research conducted as part of CCSP will reduce uncertainty about the sources and sinks of GHGs and emissions of aerosols and their precursors, their climate effects, and the implications of controls on aerosol emissions for both climate and air quality at regional and local scales.

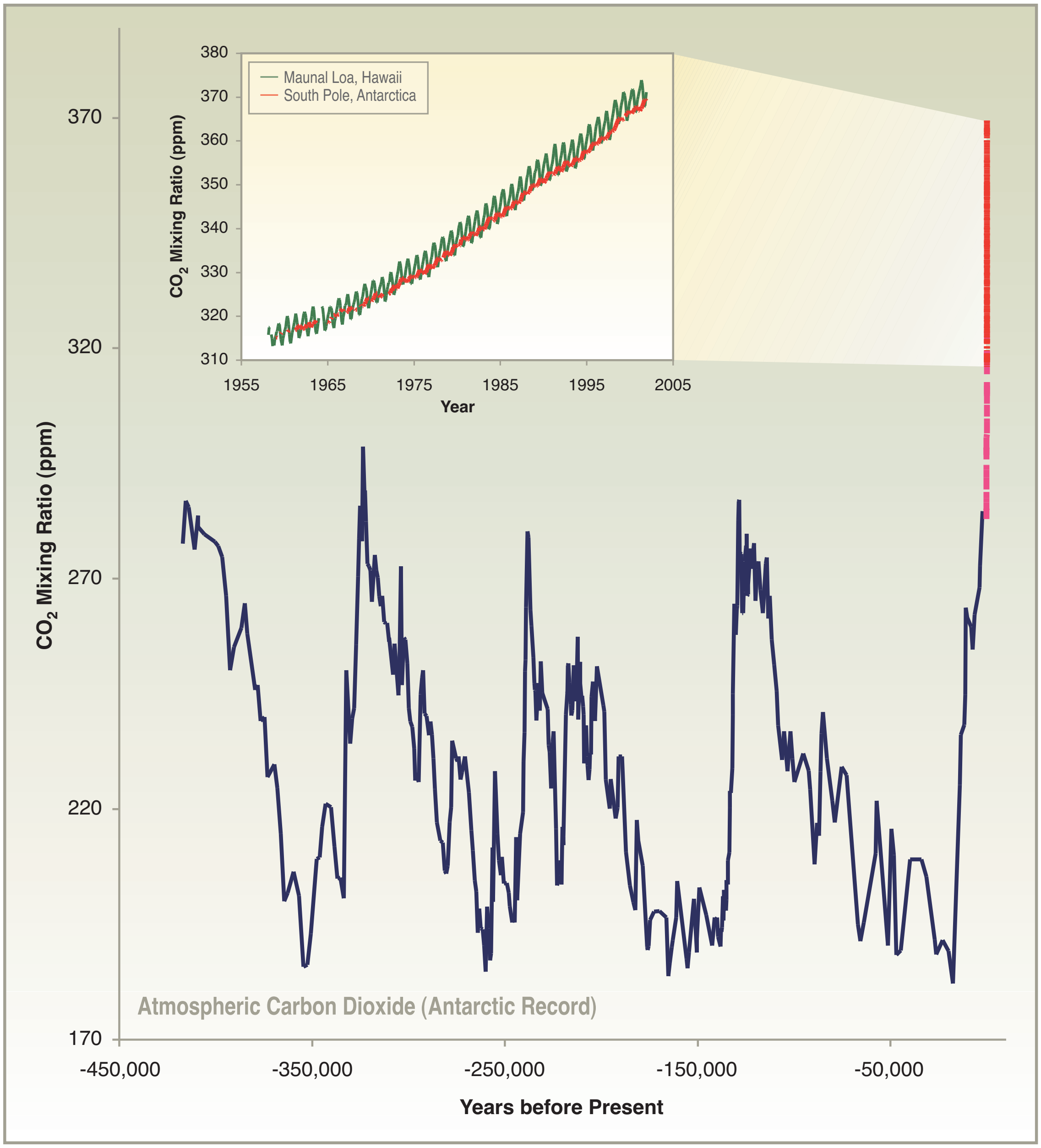


Figure 2-2: Direct measurements of atmospheric CO_2 at Mauna Loa, Hawaii and the South Pole, and CO_2 concentration as derived from the Vostok Antarctic ice core. Source: Adapted from IPCC (2001a), with Mauna Loa record updated by Dave Keeling and Tim Whorf, Scripps Institution of Oceanography.

Changes in land cover and use affect climate directly—for example by altering the Earth's albedo, or reflectivity. They also affect ecosystems and biological processes that contribute to carbon sources and sinks, emissions of other greenhouse gases, and the potential for land use changes to alter regional hydrology. Several CCSP initiatives, including accelerated research on the carbon cycle under the Climate Change Research Initiative (CCRI), will develop needed information for policymaking and improved carbon management.

Emissions of some sets of industrial compounds also contribute to depletion of the stratospheric ozone layer and increased exposure to ultraviolet radiation (which contributes to skin cancers, eye diseases, and possibly other environmental problems). Many of these same ozone-depleting gases are also significant greenhouse gases. CCSP will monitor the recovery of the ozone layer and long-term changes in the industrial compounds and stratospheric conditions that bring about stratospheric ozone depletion.

Future human contributions to climate forcing and potential associated environmental changes will depend on rates and levels of population change, economic growth, development and diffusion of technologies, and other dynamics in human systems. These developments are unpredictable over the long time scales relevant for climate change research. However, "If…, then…" scenario experiments, if carefully constructed, can make it possible to explore the potential implications of different technological, economic, and institutional conditions for future emissions, climate, and living standards. Improving the approach to developing and using these scenarios, in cooperation with

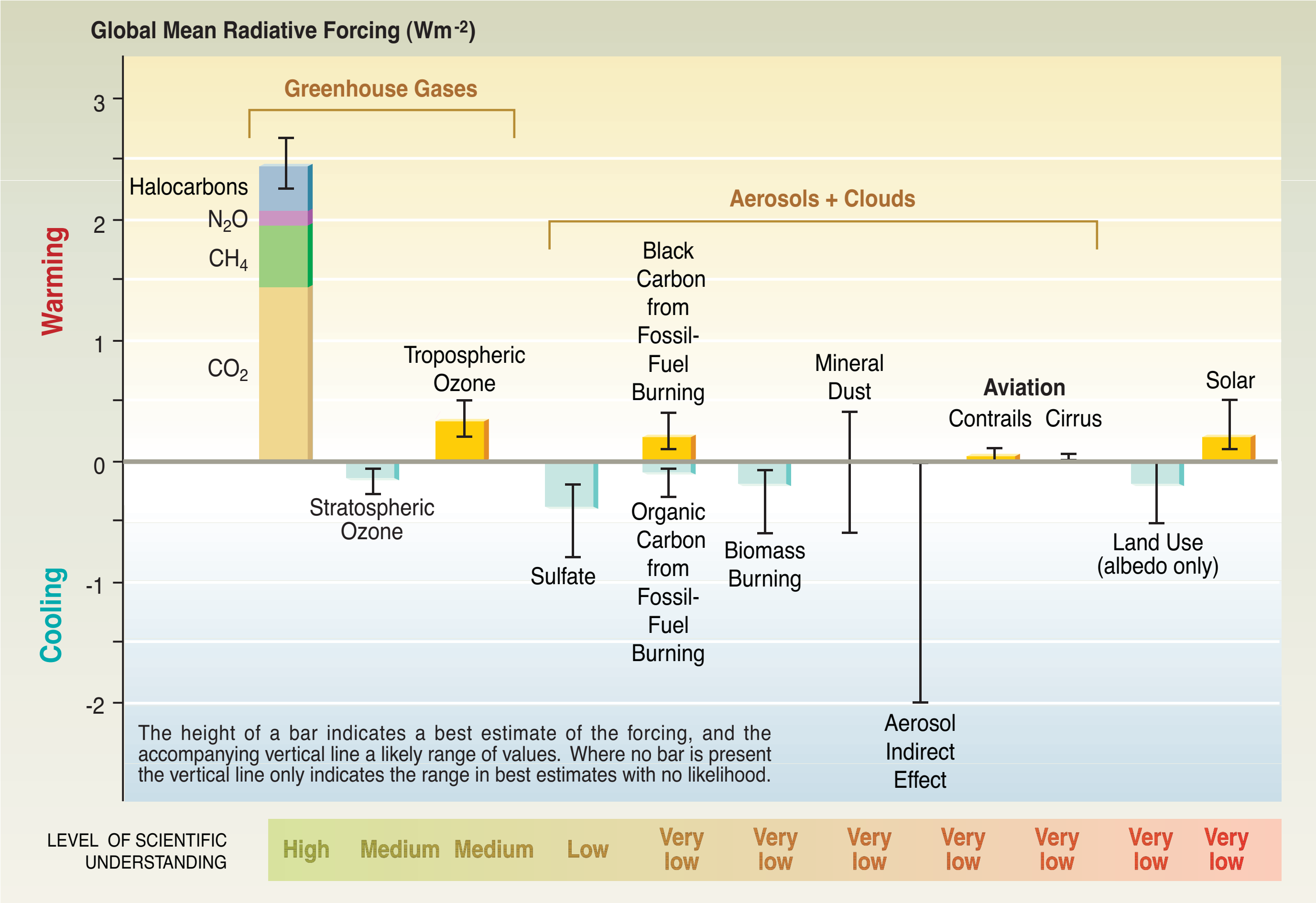


Figure 2-3: Global mean radiative forcing of the climate system and degree of certainty (see Chapter 3 and the Figure 3-2 Annex C entry for more detail). Source: Adapted from IPCC (2001a).

CCTP, is a priority for CCSP. The program will work with CCTP to explore the climate and related implications of different technology portfolios in order to provide information for decisionmaking and to enable the United States to continue its work within the United Nations Framework Convention on Climate Change. In conjunction with research on the carbon cycle and other biogeochemical cycles, improved scenario-based analyses hold the promise of increasing understanding of potential future forcing of climate, as called for by the NRC.

Examples of Key Research Activities

Focus 2.1: Reduce uncertainties about the sources and sinks of GHGs, emissions of aerosols and their precursors, and their climate effects

- Observationally assessed and improved uncertainty ranges of the radiative forcing of the chemically active greenhouse gases (Chapter 3.2)

Focus 2.2: Monitor the recovery of the ozone layer and improve the understanding of the interactions of climate change, ozone depletion, tropospheric pollution, and other atmospheric issues

- Updated trends of stratospheric ozone and ozone-depleting gases in the atmosphere (Chapter 3.4)
- Improved quantitative model evaluation of the sensitivity of the ozone layer to changes in atmospheric transport and composition related to climate change (Chapter 3.4)

Focus 2.3: Increase knowledge of the interactions among emissions, long-range atmospheric transport, and transformations of atmospheric pollutants, and their response to air quality management strategies

- *State of the Atmosphere* report that describes and interprets the status of the characteristics and trends associated with atmospheric composition, ozone layer depletion, temperature, rainfall, and ecosystem exposure (Chapter 3.5)
- A policy-relevant evaluation of the issues related to intercontinental transport, the impact of air pollutants on climate, and the impact of climate change on air pollutants (Chapter 3.5)

Focus 2.4: Develop information on the carbon cycle, land cover and use, and biological/ecological processes by helping to quantify net emissions of carbon dioxide, methane, and other greenhouse gases, thereby improving the evaluation of carbon sequestration strategies and alternative response options

- Improved coupled land-atmosphere models (jointly produced by the Carbon Cycle, Water Cycle, and Land-Use/Land-Cover Change research elements) and enhanced capability to assess the consequences of different land-use change scenarios (Chapters 5.2, 6.4, and 7.3)
- Report on the effects of land-use and land-cover changes on local carbon dynamics and the mitigation and management of greenhouse gases (Chapter 6.4 and 7.3)

CCSP GOAL 2

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with the CCTP. Review of integrated scenario development and application.	Sound, comprehensive emissions scenarios are essential for comparative analysis of how climate may change in the future, as well as for analyses of mitigation and adaptation options.	within 2 years
North American carbon budget and implications for the global carbon cycle.	The buildup of CO_2 and methane in the atmosphere and the fraction of carbon being taken up by North America's ecosystems and coastal oceans are key factors in estimating future climate change.	within 2 years
Aerosol properties and their impacts on climate.	There is a high level of uncertainty about how climate may be affected by different types of aerosols, both warming and cooling, and thus how climate change might be affected by their control.	2-4 years
Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure and climate change.	This information is key to ensuring that international agreements to phase out production of ozone-depleting substances are having the expected outcome (recovery of the protective ozone layer).	2-4 years

- Carbon cycle information to quantify the magnitude and variability of CO_2 sources, sinks, and fluxes to support analysis of carbon sequestration and management in terrestrial and oceanic systems (Chapter 7)
- Interactive global climate-carbon cycle models that explore the coupling and feedbacks between the physical and biogeochemical systems (Chapter 7.4)
- Improved projections of climate change forcings and quantification of dynamic feedbacks among the carbon cycle, human actions, and the climate system, with better estimates of errors and sources of uncertainty (Chapters 3.2 and 7.5)
- Scientific criteria and model tests of carbon management sustainability that take into account system interactions and feedbacks and analysis of options for science-based carbon management decisions and deployment by landowners (Chapters 7.6 and 3.2)

Focus 2.5: Improve capabilities to develop and apply emissions and related scenarios for conducting "If…, then…" analyses in cooperation with CCTP

- Quantify and project possible drivers of land-use change for a range of economic, environmental, and social values and develop regional, national, and global land-use and land-cover change projection models, incorporating advances in our understanding of drivers (Chapter 6.2 and 6.3)
- Linked ecosystem, resource management, and human dimensions models that enable scientific evaluation of a wide range of policy scenarios and assessment of effects on atmospheric CO_2 concentration and carbon sources and sinks (Chapters 7.3 and 8.1)
- Scenarios strengthened by an improved understanding of the interdependence among economic growth; population growth, composition, distribution, and dynamics (including migration); energy use in different sectors (e.g., electric power generation, transportation); advancements in technologies; and pollutant emissions (Chapter 9.1)

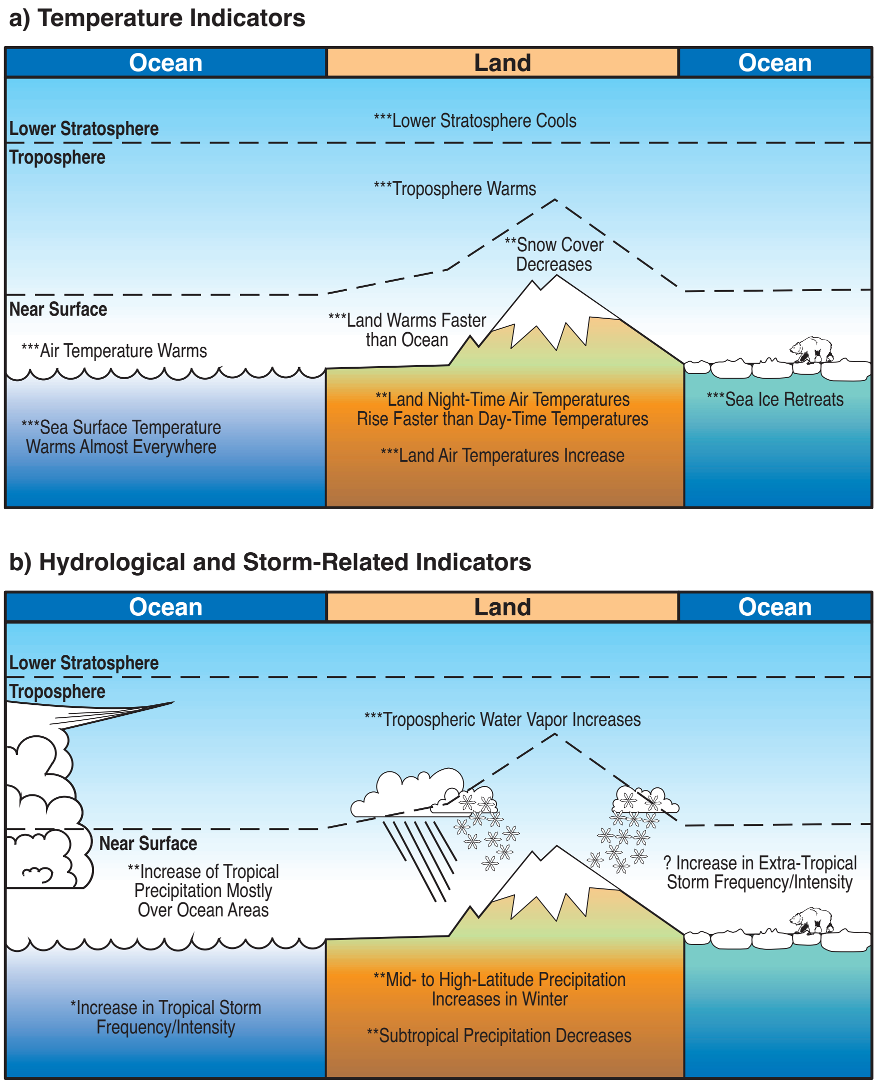
CCSP Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future

While there is a great deal known about the mechanisms that affect the response of the climate system to changes in natural and human influences, many basic questions remain to be addressed. There is also a high level of uncertainty regarding precisely how much climate will change overall and in specific regions (see Figure 2-4). Current models project significantly different increases in global average surface temperature, from approximately 1°C to more than 5°C during the 21st century. This range of uncertainty incorporates both different estimates of climate sensitivity (the increase in temperature that results from a doubling of atmospheric concentrations of CO_2, for example) and a wide range in projections of future greenhouse gas emissions. A primary CCSP objective is to build on existing information and scientific capacity to sharpen qualitative and quantitative understanding through observations, data assimilation, and modeling activities.

CCSP-supported process research will address basic climate system properties and interactions, including improving characterization of the circulation and interaction of energy in the atmosphere and oceans. It will also seek to reduce uncertainties regarding a number of "feedbacks" or secondary changes caused by the initial influence that can either reinforce or dampen the initial effect of greenhouse gases and aerosols. These feedbacks include changes in the amount and distribution of water vapor, changes in extent of ice and the Earth's reflectivity, changes in cloud properties, and changes in biological and ecological systems that could significantly change emissions or absorption of greenhouse gases (see Figure 2-5).

A cause for concern about which there is considerable uncertainty is the potential for changes in extreme events, and rapid, discontinuous changes in climate. Such changes could have profound effects on the environment and human well-being because the time available for adaptation would be limited. The historical record of past climates revealed through the study of ancient ice cores and other paleoclimate data indicates that the climate system can change relatively rapidly in response to internal processes or rapidly changing external forcing. Increasing our understanding of the conditions that could give rise to events such as rapid changes in ocean circulation is a key aspect of CCSP-supported research.

Incorporation of this basic process-level knowledge into climate and ecosystems models holds promise for improving our ability to forecast and project climate phenomena. Climate models seek to quantitatively



*** Virtually Certain
(many models analyzed and all show it)
** Very Likely
(a number of models analyzed show it, or change is physically plausible and could readily be shown for other models)
* Likely
(some models analyzed show it, or change is physically plausible and could be shown for other models)
? Medium Likelihood
(a few models show it or results mixed)

Figure 2-4: Schematic of changes in temperature and hydrological indicators from projections of future climate changes from atmosphere-ocean general circulation models (AOGCMs). Source: Adapted from IPCC (2001a).

simulate the behavior of the climate system and its response to changes in forcing. They vary in complexity and uses, but in the most complex, various components of the climate system (atmosphere, oceans, biosphere, hydrosphere, and cryosphere) are coupled together to study the evolution of the entire Earth system. Research indicates that there are limits to the predictability of regional- and local-scale phenomena. At this point, modeled projections of the future regional impacts of global climate change are often contradictory and are not sufficiently reliable to be used as tools for planning. Alternative methods such as use of climate analog scenarios and weather generators may sometimes be employed for these purposes.

Examples of Key Research Activities

Focus 3.1: Improve characterization of the circulation of the atmosphere and oceans and their interactions through fluxes of energy and materials

- Improved high-resolution three-dimensional ocean circulation models and improved estimates of global air-sea-land fluxes of heat, moisture, and momentum needed to discern characteristics of ocean-atmosphere-land coupling and to assess the global energy balance (Chapters 4.2 and 5.1)
- Models of ocean uptake of carbon that integrate biogeochemistry, ocean circulation, and marine ecosystem responses (Chapters 7.2 and 8.2)

Focus 3.2: Improve understanding of key "feedbacks" including changes in the amount and distribution of water vapor, extent of ice and the Earth's reflectivity, cloud properties, and biological and ecological systems

- Results from process studies related to the indirect effects of aerosols on clouds available for future assessments of climate sensitivity to aerosols (Chapter 3.1 and 3.2)
- Quantification of the potential changes in the cryosphere, including the effects of permafrost melting on regional hydrology and the carbon budget, and the consequences for mountain snowpacks, sea ice, and glaciers (Chapter 5.2)
- Evaluation of the potential for dramatic changes in carbon storage and fluxes and quantification of important feedbacks from ecological systems to climate and atmospheric composition to improve the accuracy of climate projections (Chapters 7.5 and 8.1)

Focus 3.3: Increase understanding of the conditions that could give rise to events such as rapid changes in ocean circulation due to changes in temperature and salinity gradients

- State of understanding on the causes of abrupt changes, and probabilistic estimates of future risks of abrupt global and regional climate-induced changes, including the collapse of the thermohaline circulation, persistent ENSO conditions, abrupt sea-level rises, and the positive feedback associated with high-latitude ice (ice sheets and sea ice) and their impacts on albedo (Chapter 4.3)

Focus 3.4: Accelerate incorporation of improved knowledge of climate processes and feedbacks into climate models to reduce uncertainty in projections of climate sensitivity, changes in climate, and related conditions such as sea level

CCSP GOAL 3

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Climate models and their uses and limitations, including sensitivity, feedbacks, and uncertainty analysis.	Clarifying the uses and limitations of climate models at different spatial and temporal scales will contribute to appropriate application of these results.	within 2 years
Climate projections for research and assessment based on emissions scenarios developed through CCTP.	Production of these projections will help develop modeling capacity and will provide important inputs to comparative analysis of response options.	2-4 years
Climate extremes including documentation of current extremes. Prospects for improving projections.	Extreme events have important implications for natural resources, property, infrastructure, and public safety.	2-4 years
Risks of abrupt changes in global climate.	Abrupt changes have occurred in the past and thus it is important to evaluate what we know about the potential for abrupt change in the future.	2-4 years

- Improved representation of processes (e.g., thermal expansion, ice sheets, water storage, coastal subsidence) in climate models that are required for simulating and projecting sea-level changes (Chapter 4.2)
- Estimates of the spatial and temporal limits of predictability of climate variability and change forced by human activities (Chapter 4.2)
- Incorporation of water cycle and carbon cycle processes, interactions, and feedbacks into an integrated Earth system modeling framework (Chapters 5.2 and 7.5)
- New observationally tested parameterizations for clouds and precipitation processes for use in climate models based on cloud-resolving models developed in part through field process studies (Chapter 5.2)
- National and global models with a coupled climate-land use system (Chapter 6.4)
- Improved capability to include and accurately formulate terrestrial and marine ecosystem dynamics within local and regional climate models

Focus 3.5: Improve national capacity to develop and apply climate models

- Continue support of the two high-end climate modeling centers to respond to the need for scenario-driven

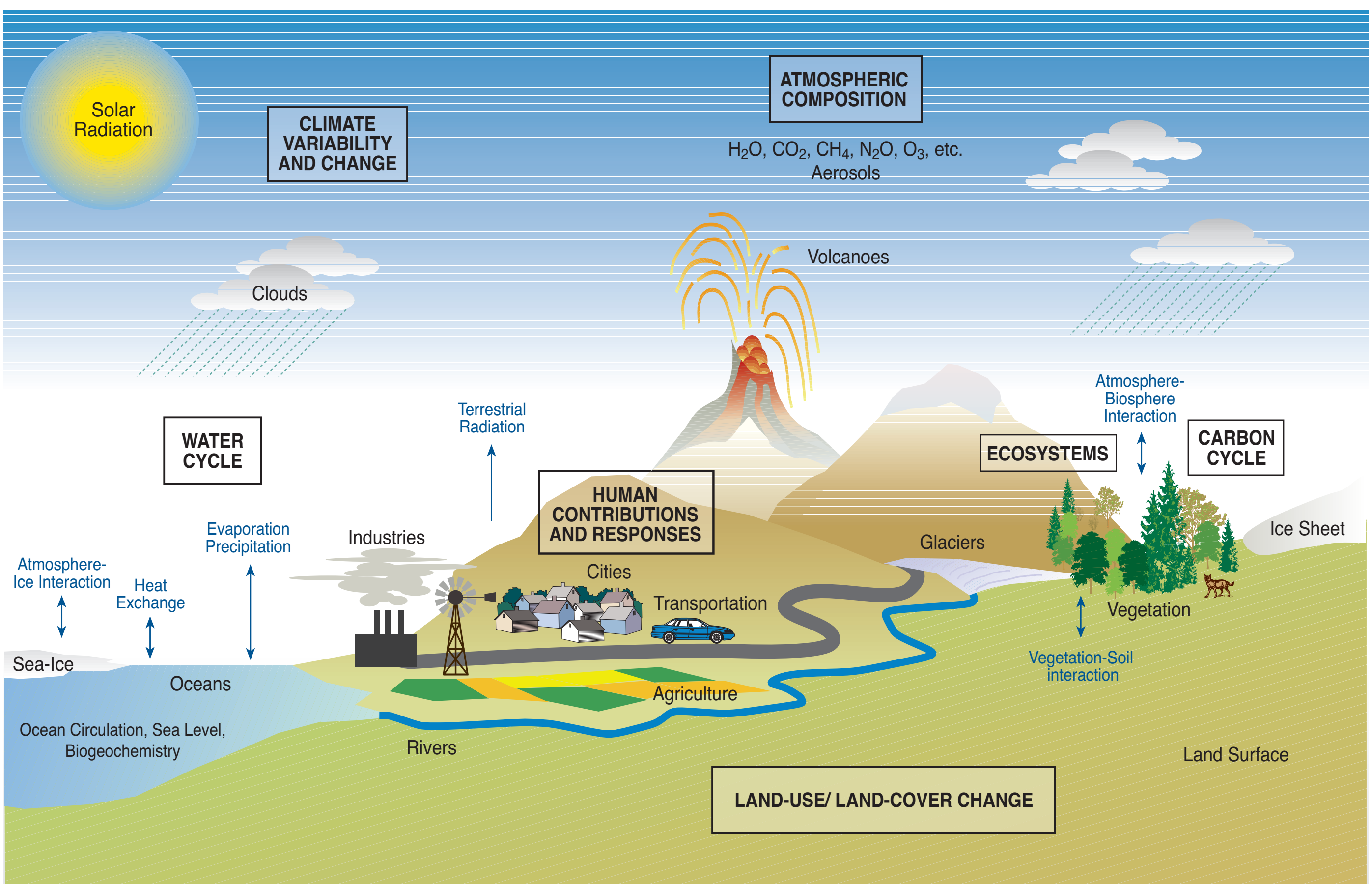


Figure 2-5: Major components needed to understand the climate system and climate change. Source: Adapted from IPCC (2001a).

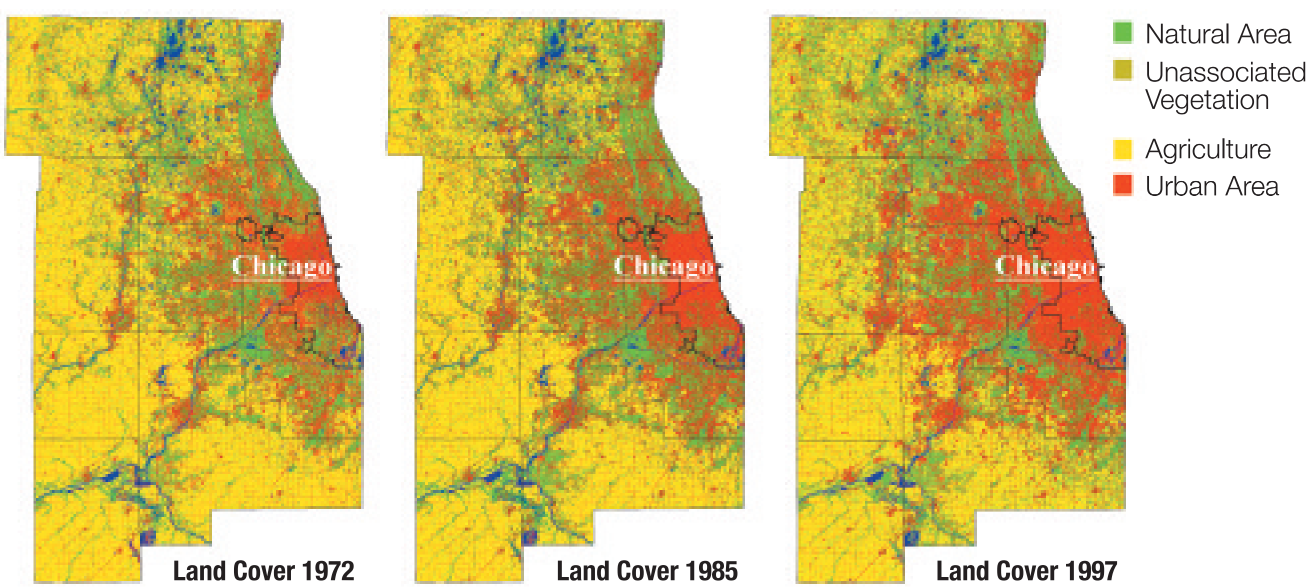
climate modeling in support of assessments (Chapter 10)

- Support for a Common Modeling Infrastructure to optimize modeling resources and enable meaningful knowledge transfer among modelers (Chapter 10)
- Develop a program of focused model intercomparisons and conduct evaluation and analysis of the model sensitivities of major U.S. models as well as model validation with available observational data (Chapter 10)

CCSP Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes

Seasonal-to-annual variability in climate has been connected to impacts on almost every aspect of human life: agricultural yields, water resources, energy demand and supply, transportation, price fluctuations, fishery yields, forest fires, human health and welfare, and many others. Long time scale natural climate cycles and potential future human-induced changes in climate could have additional effects, including altering the lengths of growing seasons, the sustainability of water resource management systems, the geographical ranges of plant and animal species, biodiversity, estuarine and ocean productivity, and the incidence of disturbance regimes that affect both natural and human-made environments. Potential benefits and risks have been identified for a number of systems and activities. Improving our ability to assess potential vulnerability and resilience to future variations and changes in climate and environmental conditions could enable governments, businesses, and communities to reduce negative impacts and seize opportunities to benefit from changing conditions by adapting infrastructure, activities, and plans.

The potential effects of climate variability and change on ecosystems and human activities will not be determined solely by their sensitivity and adaptability, but also by multiple, cumulative interactions among physical, ecological, economic, and social conditions. For example, some crops and plants that might otherwise experience reductions in productivity as a result of changes in climate alone could actually experience increased growth and productivity as a result of increases in atmospheric CO_2 concentrations and nutrients (from deposition and runoff). Other species and ecosystems, which could adjust to climate change alone, might be endangered when land use and other factors interfere with adaptive mechanisms such as migration. Interacting factors must be identified and understood to develop accurate projections of effects. The CO_2 "fertilization effect" (increased plant growth due to higher atmospheric CO_2 concentrations), nitrogen deposition, disturbance (e.g., fire, pest infestations), land-cover fragmentation (see Figure 2-6), air pollution, and other factors affect the functioning (e.g., water use efficiency, biomass allocation) and composition of natural and managed ecosystems over long periods of time. Similarly, estuarine and coastal ecosystems face multiple-stressor problems associated with point source and non-point source pollution, increased sedimentation resulting from upstream land-use practices, invasive species and



Land-Use and Land-Cover Change of Chicago Metropolitan Region between 1972 and 1997

	1972-1985	1985-1997	1972-1997
Urban	+15%	+30%	+49%
Natural Area	-8%	-15%	-21%
Agriculture	-22%	-20%	-37%
Unassociated Vegetation	+147%	+23%	+203%

Figure 2-6: Land-cover maps of the Chicago Metropolitan Region. These maps, created with Landsat imagery from 1972, 1985, and 1997, document changes in several categories of land cover and land use. Source: NASA and Y.Q. Wang, University of Rhode Island.

CCSP GOAL 4

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Coastal elevation and sensitivity to sea-level rise.	Evaluation of how well equipped society is to cope with potential sea-level rise can help reduce vulnerability.	within 2 years
State-of-knowledge of thresholds of change that could lead to discontinuities (sudden changes) in some ecosystems and climate-sensitive resources.	This approach seeks to determine how much climate change natural environments and resources can withstand before being adversely affected.	2-4 years
Relationship between observed ecosystem changes and climate change.	Earlier blossoming times, longer growing seasons, and other changes are being observed, and this report will explore what is known about why these events are happening.	2-4 years
Preliminary review of adaptation options for climate-sensitive ecosystems and resources.	Understanding of adaptation options can support improved resource management—whether change results from natural or human causes—and thus helps realize opportunities or reduce negative impacts.	2-4 years
Scenario-based analysis of the climatological, environmental, resource, technological, and economic implications of different atmospheric concentrations of greenhouse gases.	Knowing how well we can differentiate the impacts of different greenhouse gas concentrations is important in determining the range of appropriate response policies.	2-4 years
State-of-the-science of socioeconomic and environmental impacts of climate variability.	This product will help improve application of evolving ENSO forecasts by synthesizing information on impacts, both positive and negative, of variability.	2-4 years
Within the transportation sector, a summary of climate change and variability sensitivities, potential impacts, and response options.	Safety and efficiency of transportation infrastructure—much of which has a long lifetime—may be increased through planning that takes account of sensitivities to climate variability and change.	2-4 years

sea-level rise. Multiple changes affecting marine ecosystems include natural climate variations (e.g., ENSO cycles and PDV), fishing, and changes in ocean productivity brought on by uncertain causes. The interactions are even more complex when one examines the interactions of biophysical and socioeconomic systems. CCSP research will examine the implications of multiple interacting changes to improve projections of effects.

Evaluation of the potential impacts associated with different atmospheric concentrations of greenhouse gases and aerosols is an important input to weighing the costs and benefits associated with different climate policies. Further research is required to integrate still limited understanding of effects of different concentration levels, and the influence of human activities on concentrations, and to develop methods for aggregating and comparing impacts across different sectors and settings.

Examples of Key Research Activities

Focus 4.1: Improve knowledge of the sensitivity of ecosystems and economic sectors to global climate variability and change

- Results from field and modeling experiments to study the role of mountain environments on precipitation and runoff production (Chapter 5.3)
- Downscaling techniques, such as improved regional climate models, for improved evaluation of potential water resource impacts arising from climate variability and change (Chapter 5.3)
- Reports on past and projected trends in land cover or land use that are attributable to changes in climate (e.g., changes in forest type, changes in agriculture) (Chapter 6.4)
- Ecosystem observations, coupled physical-biological models, indicators, and reports to permit better assessment of the potential consequences of global and climatic changes on selected arctic, alpine, wetland, riverine, and estuarine and marine ecosystems; selected forest and rangeland ecosystems; selected desert ecosystems; and the Great Lakes (Chapter 8.2)
- Development of data and predictive models determining the sensitivity of selected organisms and their assemblages to changes in ultraviolet-B (UV-B) radiation and other environmental variables relative to observations of UV-B radiation in terrestrial, aquatic, and wetland habitats (Chapter 8.2)
- Assessments of the potential economic impacts of climate change on the producers and consumers of food and fiber products (Chapters 8.2 and 9.2)

Focus 4.2: Identify and provide scientific inputs for evaluating adaptation options, in cooperation with mission-oriented agencies and other resource managers

- Data and models demonstrating how different adaptation strategies in croplands and commercial forests affect the sustainability of these ecosystems in changing environmental conditions and their ability to meet human demands (Chapter 8.3)
- Initiation of development of decision support tools relevant to regions where abrupt changes or threshold ecological responses may occur, especially high-altitude and high-latitude ecosystems and transitional zones between ecosystems (i.e., ecotones) such as forest-grassland, agriculture-native prairie, riparian and coastal zones, coastal-oceanic boundaries, and rural-urban interfaces (Chapter 8.3)
- Data sets and spatially explicit models for examining effects of management and policy decisions on a wide range of terrestrial and marine ecosystems to predict the efficacy and tradeoffs of management strategies at varying scales, and preliminary comparisons of the effectiveness of selected management practices (Chapter 8.3)
- Analysis of potential impacts of climate variability and change on transportation infrastructure and operations, and preliminary

development of decision support tools relevant to transportation decisionmakers (Chapter 9.2)

Focus 4.3: Improve understanding of how changes in ecosystems (including managed ecosystems such as croplands) and human infrastructure interact over long periods of time

- Evaluations of the effects of water cycle variability and change on trends in water quality conditions (Chapter 5.4)
- Data from field experiments quantifying aboveground and belowground effects of elevated CO_2 concentration in combination with other environmental changes on the structure and functioning of agricultural, forest, and aquatic ecosystems (Chapters 7.5 and 8.2)
- Examination of responses of ecosystems (including any changes in nutrient cycling) to combinations of elevated CO_2 concentration, warming, and altered hydrology, with data collection underway (Chapter 8.2)
- Analysis of the global occurrence, extent, and impact of major disturbances (e.g., fire, insects, drought, and flooding) on land use and land cover (Chapter 6.1)
- Identification of the regions in the United States where land-use and climate change may have the most significant implications for land management (Chapter 6.5)
- Spatially explicit ecosystem models at regional to global scales, to improve our understanding of contemporary and historical changes in ecosystem structure and functioning, and synthesis of known effects of increasing CO_2, warming, changes in precipitation, and other factors (e.g., increasing tropospheric ozone) on terrestrial ecosystems (Chapter 8.2)
- Estimates of the value of the ancillary benefits (e.g., enhanced wildlife habitat and improved water quality) that could result from implementing various mitigation and adaptation activities within the forestry sector (Chapters 8.3 and 9.2)
- Next phase of assessments of the health effects of combined exposures to climatic and other environmental factors (e.g., air pollution) (Chapter 9.4)

CCSP Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change

The first four CCSP goals focus on the key issues of understanding natural climate conditions and variability, forces that influence climate, climate responses, and implications for human systems and natural environments. CCSP research will focus on this full range of issues in order to lay the basis for informed discussion and decisionmaking. The fifth CCSP goal focuses on the way that this scientific information is used for support of decision needs.

Over the last decade, USGCRP has enlisted federal and external experts to develop a variety of products and resources for decision support. These include methods and tools for integrated assessment (including a variety of quantitative integrated assessment models); state-of-science syntheses and assessments of climate variability and change; international assessments of stratospheric ozone depletion; applications of Earth science observations and data; experiments for application of ENSO forecasts in a variety of regions and economic sectors; and advisory committee assessments of the potential vulnerabilities and opportunities arising from climate change in different regions and sectors of the United States.

These products of the first decade have evoked much commentary, both positive and negative. Formal evaluations of the processes and products of some of these activities have been conducted by the NRC. CCSP's decision support activities will respond to the relevant recommendations of the NRC in reports such as *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). The program will also encourage further evaluation and learning from these experiences in order to structure decision support processes and products that use existing knowledge to the best effect while communicating the limits of this knowledge.

CCSP activities in support of its fifth goal will improve the nation's and global community's understanding of the nature and extent of the challenges inherent in climate change and develop improved resources for evaluating options for adaptation and mitigation. Fulfilling this goal will require development of a variety of resources including observations, databases, data and model products, scenarios, a variety of visualization products, and improved approaches for interacting with users. Research in many of the program elements holds promise of yielding decision support information and products. Improved resources for decision support also require a concerted focus on the processes through which information is developed and applied to support decisionmaking in different areas.

Areas of decisionmaking to be supported by CCSP include adaptive management, planning, and policy. Each of these categories will have its own unique set of stakeholders and will require different decision support processes and tools that will be recognized in the implementation of CCSP decision support activities. CCSP will engage both decisionmakers and members of the research community in the development of processes well suited to both the state-of-science and decisionmaking needs. In addition to supporting decisionmaking, the decision support activities of CCSP will also help to identify key knowledge gaps and provide feedback to researchers that will guide the evolution of the CCSP agenda.

Examples of Key Research Activities

Focus 5.1: Support informed public discussion of issues of particular importance to U.S. decisions by conducting research and providing scientific synthesis and assessment reports

- Contribute to and participate in international assessments on climate change, ozone depletion, and other issues as they arise (multiple chapters)
- Produce a number of synthesis reports and assessments that integrate research results focused on identified science and decision issues in association with stakeholders and researchers to meet the requirements of the Global Change Research Act (multiple chapters)

Focus 5.2: Support adaptive management and planning for resources and physical infrastructure sensitive to climate variability and change; build new partnerships with public and private sector entities that can benefit both research and decisionmaking

- Increased partnerships with existing user support institutions, such as state climatologists, regional climate centers, agricultural

CCSP GOAL 5

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions.	There is a great need for regional climate information; further evaluation of the reliability of current information is crucial in developing new applications.	within 2 years
Best-practice approaches to characterize, communicate, and incorporate scientific uncertainty in decisionmaking.	Improvements in how scientific uncertainty is evaluated and communicated can help reduce misunderstanding and misuse of this information.	within 2 years
Decision support experiments and evaluations using seasonal to interannual forecasts and observational data.	Climate variability is an important factor in resource planning and management; improved application of forecasts and data can benefit society.	within 2 years

extension services, resource management agencies, and state and local governments to accelerate uses of climate knowledge (Chapter 11)

- Assess the adequacy of existing operational climate monitoring networks to provide regional decision support, and to identify major data gaps in addressing critical regional and policy issues, such as drought planning and response (Chapter 4.5)
- Conduct and analyze decision support experiments using observations, integrated data sets, forecasts of seasonal climate variability, and longer term model projections (multiple chapters)
- Develop and apply frameworks for assessing the uses and limits of current regional-scale information (multiple chapters)

Focus 5.3: Support policymaking by conducting comparative analyses and evaluations of the socioeconomic and environmental consequences of response options

- Improve stakeholder involvement in articulating and framing all aspects of policy support activities including question formulation, study design, and transparent review involving stakeholders (Chapter 11)
- Strengthen capacity and conduct "If…, then…" scenario analyses (Chapter 11 and through cooperation with CCTP)
- Develop and apply additional methods for integrated assessment and comparative analyses (Chapters 9 and 11)

"Critical Dependencies" and Approaches to Integration

The interdisciplinary research elements of CCSP partition the overall Earth system and the issue of climate change into discrete and manageable sets of research problems. While partitioning the problem is necessary for both research and program management purposes, it carries with it the potential to divert attention from critical questions that are beyond the scope of the individual research elements, instead emphasizing lower priority issues that reside completely within a single research area. Thus, a key challenge facing CCSP is engaging in integrated planning that "puts back together" the pieces of the Earth system and fosters problem-driven interdisciplinary research. This is especially true for "critical dependencies," topics for which progress in one research element is only possible if related research is first completed in other areas. CCSP will need to foster integration across research elements and disciplines; among basic research and supporting activities such as observations, modeling, and data management; in the development of comprehensive climate models; and between participating departments and agencies if it is to achieve its objectives.

"Critical Dependencies" among the Research Elements

Scientifically, integration is essential for understanding how the Earth system functions and will evolve in response to future forcing. This is because of the inherent interconnectedness among components of the Earth system. In particular, the existence of feedback loops in the Earth system creates the need to work across disciplinary boundaries. For some issues, it will be necessary to coordinate and integrate across all of the CCSP program elements. One example that illustrates how the different research elements may help address a key uncertainty is given in Box 2-2, focused on the question of the evolution of the global distribution of atmospheric methane.

Because the components of the Earth system interact continuously, research in one program element often has a *critical dependency* with work in other elements. Critical dependencies can involve insights from process studies, data flows, model components, and other research and operational activities.

The most obvious set of critical dependencies is in the area of observational data. In many cases, observations of the underlying physical state of the Earth system (e.g., temperature, precipitation history) are required before questions about climate or global change can be addressed. Another example is information on land cover and land use, which also forms the basis for many studies of hydrology, biogeochemical cycling, and ecosystems research. Chapters 3-9 describe both the inputs that each research element needs from other program elements and the products that each expects to produce to support goals in other research areas. A challenge for CCSP will be to coordinate production of information required to satisfy these critical dependencies so that they meet requirements and are sequenced properly. CCSP will coordinate development of implementation plans for the research elements to meet this challenge. Box 2-3 lists illustrative examples of "critical dependencies" from the research elements.

BOX 2-2

INTEGRATING ACROSS RESEARCH ELEMENTS TO IMPROVE PROJECTIONS OF METHANE EMISSIONS AND CONCENTRATIONS

In order to improve understanding of current and projected atmospheric concentrations of methane, it is essential to integrate results obtained through the different CCSP science elements. This includes pulling together information on the initial concentration, the sources of additional emissions, the processes that transport it, and the removal processes. Each of the research elements will contribute the following information:

- **Atmospheric Composition**. Measurement of methane's distribution in the atmosphere is by definition the starting point for assessing the evolution of its future concentrations. Since the major removal process for methane from the atmosphere is its oxidation by hydroxyl (OH), assessment of the distribution of OH, including its spatial and temporal variation, is also required. The inverse modeling that is used to help infer source distributions is also part of this research element.
- **Climate Variability and Change**. The climate system circulates methane from its source regions and distributes it uniformly around the globe. Climate also determines temperature, which affects both methane emissions and the rate at which it is removed through oxidation by OH (one of the more temperature-dependent reactions that affects atmospheric composition). This research element also provides estimates of future changes in surface temperatures at high latitudes. These estimates are important for determining the likelihood that methane tied up in the surface at high latitudes could be released.
- **Carbon Cycle**. Although methane is less abundant than carbon dioxide, its contribution to atmospheric radiative forcing is significant due to its much greater radiative impact per molecule. Carbon cycle studies estimate the overall release and uptake of methane, provide the context necessary for interpreting measurements and estimates of methane release and removal, and incorporate advanced understanding of process controls on methane uptake and release from the land and oceans into carbon cycling models.
- **Water Cycle**. Water plays a crucial role in helping to establish the conditions under which methane is emitted, and it also is a crucial precursor to OH, which removes methane from the atmosphere. Water availability also affects the magnitude and rate of emissions from agricultural sources (e.g., rice cultivation), landfills, and other land-based sources.
- **Land-Cover/Land-Use Change**. Some land uses are associated with methane emissions. For example, methane is emitted from rice cultivation and natural wetlands, and is removed from the atmosphere by vegetation and soils. Improved understanding of how land is used in different locations, as well as how land uses might change over time, is crucial to estimating current and projecting future emissions.
- **Ecosystems**. The production of methane from biological processes can be traced to microbial processes, and the ecosystems research element provides the knowledge base for carrying out relevant studies of the biology that underlies methane production and its emission to the atmosphere.
- **Human Impacts**. Methane is emitted by many human activities, including agricultural practices such as raising livestock and growing rice, waste disposal practices in landfills and other sites, and the production and transportation of coal, natural gas, and oil. The amount of methane emitted by these activities depends on basic characteristics of the emission processes as well as the management practices that are employed. These have changed and will continue to change over time and hence must be considered in estimating current and projecting future emissions.

Coordination of Research and Supporting Activities

Just as meeting CCSP objectives will require integration across the research elements described in Chapters 3-9, so will it require coordination and integration of the different approaches employed by the scientific community in addressing these major challenges—basic research, surface-based networks, field-based process studies, global satellite observations, computational modeling, data management, assessment, and decision support. It is worth emphasizing that many of the surface-based networks and some of the global satellite observations are carried out as part of operational monitoring programs not previously considered as part of USGCRP, and which may not even now be identified in the CCSP budget. Clearly, our nation's effort to provide comprehensive, integrated answers to the questions posed in this plan will require integrated use of all such data and approaches.

Basic research provides the intellectual framework of the entire global change research enterprise. From laboratory descriptions of critical physical, chemical, and biological processes, to determination of appropriate standards and calibration procedures, to approaches for simulation, analysis, visualization, etc., of data, research serves as the basis on which advances in observing and modeling depend. It also includes the necessary social science and related research that provides the data and models needed to include effects of human inputs and response into the CCSP program.

BOX 2-3

SELECTED EXAMPLES OF CRITICAL DEPENDENCIES TO BE SUPPORTED BY EACH RESEARCH ELEMENT

Chapter 3. Atmospheric Composition
- Radiative forcing input parameters to climate model simulations—*Climate Variability and Change*
- Characterization of other composition-climate processes (e.g., impact of aerosols on cloud formation and precipitation)—*Water Cycle*

Chapter 4. Climate Variability and Change
- Cloud/water vapor feedback processes in the context of the coupled climate system models—*Water Cycle*
- Environmental condition predictions/estimates—*Land-Use/Land-Cover Change, Carbon Cycle, and Ecosystems*

Chapter 5. Water Cycle
- Long-range prediction capability for drought and flood risks (seasonal-to-interannual time scales)—*Climate Variability and Change*
- Quantification of the potential impact of changes in permafrost on regional hydrology and the carbon budget—*Carbon Cycle*

Chapter 6. Land-Use/Land-Cover Change
- Analysis of the effects of historical and contemporary land use on carbon storage and release across environmental gradients—*Carbon Cycle*
- Quantification and projection of possible drivers of land-use change for a range of economic, environmental, and social values—*Ecosystems, Carbon Cycle, and Human Contributions and Responses*

Chapter 7. Carbon Cycle
- Quantitative estimates of carbon fluxes from managed and unmanaged ecosystems in North America and surrounding oceans, with regional specificity—*Water Cycle, Ecosystems, Land-Use/Land-Cover Change, and Climate Variability and Change*
- Evaluation of the environmental effects of mitigation options—*Ecosystems, Human Contributions and Responses, and Land-Use/Land-Cover Change*

Chapter 8. Ecosystems
- Information about ecological inputs to atmospheric composition through greenhouse gas exchanges between the atmosphere and ecosystems—*Atmospheric Composition*
- Information about energy exchanges between ecosystems and the atmosphere for inclusion in general circulation models—*Climate Variability and Change*
- Analysis of effects of global change on ecosystem goods and services—*Human Contributions and Responses*

Chapter 9. Human Contributions and Responses to Environmental Change
- Improved modeling frameworks that better link general circulation, ecological, and economic models of the agricultural and forestry sectors—*Water Cycle, Ecosystems, Land-Use/Land-Cover Change, and Climate Variability and Change*

Surface-based monitoring networks provide a distributed, accurate, and potentially high-frequency method for obtaining environmental data. They also allow the network managers to concentrate observing power in regions where it is most needed. As noted above, many of these are managed as part of operational monitoring programs and do not report as part of USGCRP. They also provide critical validation information for satellite-derived observations.

Field-based process studies allow the combined use of surface-based measurements and transportable platforms (ships, aircraft, balloons, etc.), and also provide opportunities to define intermediate spatial scales between the local scales best studied with surface-based networks and the larger spatial scales typically observed with satellite instruments. By virtue of being able to comprehensively sample a large number of environmental variables associated with a particular issue, they are excellent for providing data sets that can be used to quantitatively test process models that ultimately support the development of parameterizations that can be incorporated into larger scale models.

Global satellite observations allow for frequent observations over most if not all of the Earth's surface, and allow one to make measurements in regions for which *in situ* data are not available. Successful implementation of satellite observing programs requires validation with surface-based networks and with more focused *in situ* observations. Process representation in models will be derived from knowledge gained in the field-based process studies. It is important that research observations be integrated with those of operational monitoring programs not traditionally considered part of USGCRP.

Computational modeling provides a way in which information about the potential future of one or more elements of the Earth system can be expected to evolve, based on assumptions about naturally occurring and human-induced forcings. The models to be used in this way can be tested in a retrospective sense by comparing observed data on Earth system evolution (obtained from surface- and space-based observing systems as well as field-based process studies) and the known forcings; conversely, the models can also be used in an inverse set with the observations to infer present and historical forcings. Computational models can also be integrated with observational data in data assimilation systems to provide accurate and geophysically (and increasingly biogeochemically) consistent data sets of the distribution and fluctuations of key environmental variables. The assimilation process is also critical for initializing the global models and for their evaluation.

Data management is a critically important CCSP component for two reasons. First, it is necessary to provide active, long-term stewardship for the large volumes and multiplicity of types and sources of data. Second, it provides the means to distribute the data to a growing group of users, going far beyond the traditional scientific research community to the broader set of users who are making the policy and resource management decisions.

Scientific assessment provides the opportunity for researchers to go back and critically assess the status of their knowledge, sharpen the questions they are trying to answer, then provide a "feedback loop" to the research process so that the research of the future will better identify and address key uncertainties and knowledge gaps. Part of the assessment process may involve detailed study of the observational data sets, process knowledge, or modeling systems developed under CCSP to resolve discrepancies and competing approaches. End-to-end assessment is broader in that it can involve going back to the basic building blocks of a research area, assessing status and progress, and then looking at the implications of the results of this analysis for a variety of end states, including many relevant decision support applications. Assessment used to support decisions is an iterative analytic process that engages both researchers and interested stakeholders in the evaluation and interpretation of the interactions of natural and socioeconomic systems. These assessments typically consist of four elements: problem formulation, analysis, characterization of consequences, and communication of results.

Decision support is the set of processes that includes interdisciplinary research, product development, communication, and operational services that provide timely and useful information to address challenges and questions confronting those who need to make policy and/or resource management decisions. In addition to the emphasis on the quality and robustness of scientific information for providing decision support, there is typically a premium on timeliness, resolution, comprehensiveness, and effective communication of levels of scientific confidence and certainty.

Models as Integrating Tools

Computational models are particularly important in integrating our knowledge of the Earth system, providing both a quantitative way of assessing the accuracy of the system and of projecting its future evolution (see Figure 2-7). It is important that the models used for projecting future conditions include the full range of processes linking the Earth system's components, and thus the feedback processes that are so important in determining the Earth's behavior. Such models become complex, requiring the integration efforts of large teams of scientists (both Earth system scientists and computational scientists), and require significant amounts of computing capability, together with human and data resources for the archiving and distributing of their results.

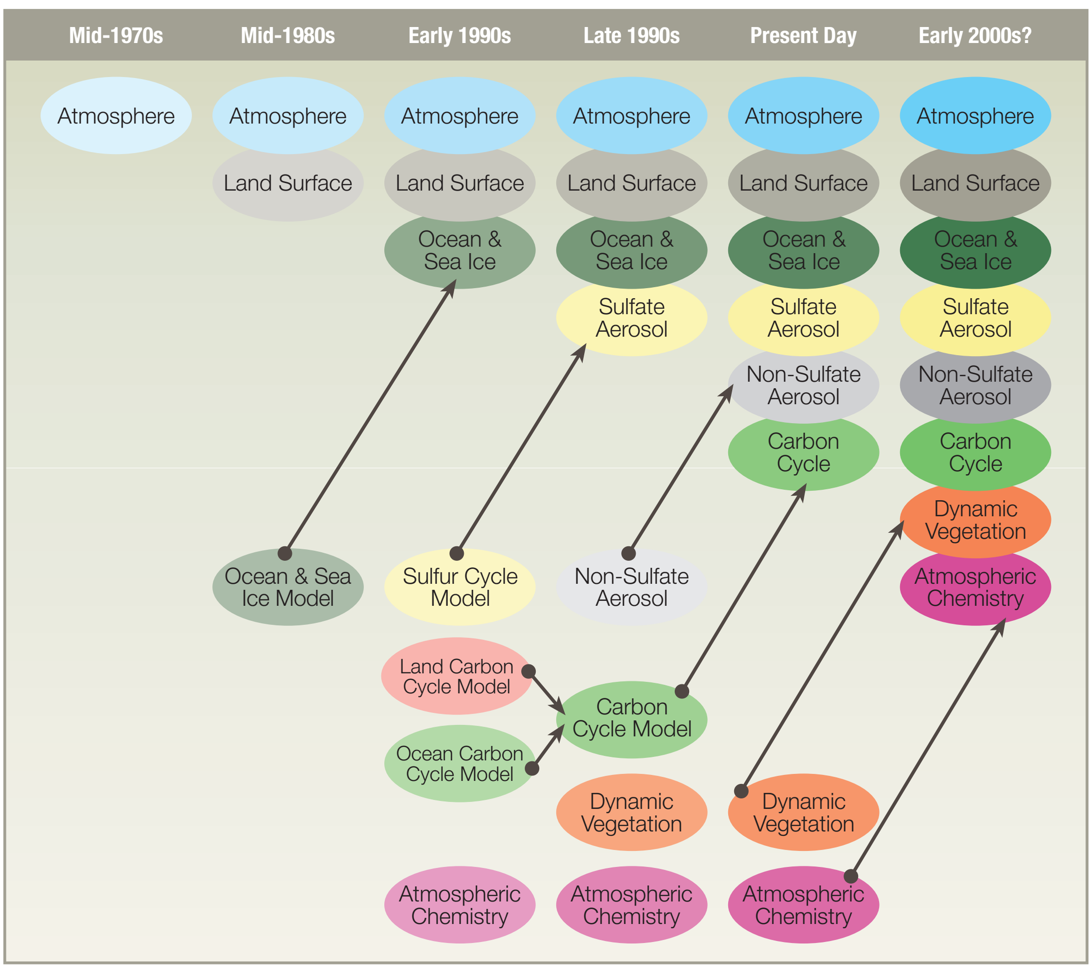


Figure 2-7: The development of climate models over the last 25 years showing how the different components are first developed separately and later coupled into comprehensive climate models. Source: IPCC (2001a).

TABLE 2-1

Summary of Synthesis and Assessment Products – Topics to be Covered

CCSP GOAL 1	Extend knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed changes
within 2 years	Temperature trends in the lower atmosphere—steps for understanding and reconciling differences.
within 2 years	Past climate variability and change in the Arctic and at high latitudes.
2-4 years	Re-analyses of historical climate data for key atmospheric features. Implications for attribution of causes of observed change.
CCSP GOAL 2	Improve quantification of the forces bringing about changes in the Earth's climate and related systems
within 2 years	Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with CCTP. Review of integrated scenario development and application.
within 2 years	North American carbon budget and implications for the global carbon cycle.
2-4 years	Aerosol properties and their impacts on climate.
2-4 years	Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure and climate change.
CCSP GOAL 3	Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future
within 2 years	Climate models and their uses and limitations, including sensitivity, feedbacks, and uncertainty analysis.
2-4 years	Climate projections for research and assessment based on emissions scenarios developed through CCTP.
2-4 years	Climate extremes including documentation of current extremes. Prospects for improving projections.
2-4 years	Risks of abrupt changes in global climate.
CCSP GOAL 4	Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes
within 2 years	Coastal elevation and sensitivity to sea-level rise.
2-4 years	State-of-knowledge of thresholds of change that could lead to discontinuities (sudden changes) in some ecosystems and climate-sensitive resources.
2-4 years	Relationship between observed ecosystem changes and climate change.
2-4 years	Preliminary review of adaptation options for climate-sensitive ecosystems and resources.
2-4 years	Scenario-based analysis of the climatological, environmental, resource, technological, and economic implications of different atmospheric concentrations of greenhouse gases.
2-4 years	State-of-the-science of socioeconomic and environmental impacts of climate variability.
2-4 years	Within the transportation sector, a summary of climate change and variability sensitivities, potential impacts, and response options.
CCSP GOAL 5	Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change
within 2 years	Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions.
within 2 years	Best-practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decisionmaking.
within 2 years	Decision support experiments and evaluations using seasonal-to-interannual forecasts and observational data.

These models should have a number of important attributes:

- They should adequately represent the state of the Earth system and its prior evolution, in particular over the recent past, when there is a more comprehensive set of observations with which to compare the models and where better knowledge of the types and amounts of naturally occurring and human-induced forcings is available.
- They should be sufficiently comprehensive that they can be applied confidently over the period of interest. This is particularly crucial for longer simulations. For example, detailed representation of the partitioning of carbon among the atmosphere, the ocean, and terrestrial ecosystems will be crucial to representing future distributions of atmospheric carbon dioxide and its concomitant contribution to radiative forcing and climate change. Human interactions must also be included in models operating over time scales that are influenced by human activities. The CCSP strategy for adding comprehensiveness to these models is outlined in some detail in Chapter 10 of this plan.
- They should be constructed to provide information at the desired spatial resolution.
- They should be able to be run in sufficient number and in sufficiently short time that their results can be provided to scientific, policy, and decisionmaking users.

Integration between and among Agencies

Within CCSP, multiple agencies have responsibilities in a number of the areas outlined above, so it is crucial that the agencies work together to optimize results, minimize duplication, and capitalize on their expertise, experience, and capabilities. The way in which this will be done is outlined in detail in Chapter 16 for federal agencies, while the relationship between U.S. and international activities is discussed in Chapter 15. The details of the CCSP structure, including the creation of interagency working groups, community-based science steering groups, and management-level interactions within the CCSP agencies and at higher levels are explained in Chapter 16.

In this section we note as examples some of the things that agencies working together through CCSP will strive to do to assure the necessary linkages between program elements:

- Make integrated use of infrastructure, especially for surface-based networks, airborne campaigns, and ship-based expeditions, to both reduce cost and maximize return by enhancing the availability of integrated data sets
- Ensure common data formats and interoperable data systems so that scientific, management, and policy-oriented data users can integrate desired data sets with minimal difficulty
- Collaborate on calibration systems and relevant intercomparisons to be sure that related observing capability can be consistently tied to measurement activities and to recognized laboratory standards
- Integrate process-oriented, surface- and airborne-based studies and network observations with calibration and validation activities for satellite programs
- Develop integrated modeling frameworks that will enhance opportunities for interchange of components and intercomparison of model results (both with other models and with observations)
- Issue joint solicitations where the optimal way to engage the research community in addressing issues of scientific importance.

Synthesis and Assessment Products

CCSP will provide a variety of synthesis and assessment products on an ongoing basis as discussed. These products will support both policymaking and adaptive management. The overall approach to decision support is described in Chapter 11 of this plan. This section integrates the earlier discussion in this chapter and summarizes the synthesis and assessment products that CCSP will generate.

The 1990 Global Change Research Act provides the overall framework for the conduct and management of the interagency research program on climate and global change, and Section 106 of the act defines requirements for scientific assessments.[2] To comply with the terms of Section 106, CCSP will produce 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 CCSP will complete over the next 4 years. The subjects to be addressed are listed in Table 2-1. This approach takes account of the need for assessments on the full range of issues spanning all CCSP objectives and will provide a "snapshot" of knowledge of the environmental and socioeconomic aspects of climate variability and change. The products will support specific groups or decision contexts across the full range of issues addressed by CCSP, and where appropriate, CCTP.

National policymaking focuses on many issues, but in this case involves integrating information from forcings and climate response to impacts and the costs and benefits of different response strategies. Synthesis of scientific data and results with economic information, demographic trends, technical specifications, etc., is essential for producing useful information on responding to the challenges posed by climate variability and change. How much information needs to be integrated depends on the specific issue or question that is being addressed and the type of decision that is being supported.

One highly important issue to be addressed at a national level is the challenge of developing new technologies to reduce the projected growth in greenhouse gas emissions. This requires integrating information from the natural sciences, engineering, and the economic and social sciences. CCSP will work closely with CCTP in incorporating information on portfolios of different technologies in evaluations of the implications of different response options through "If…, then…" scenario analyses, integrated assessment, and other approaches to comparative evaluation. This will facilitate understanding needs for development of new technologies.

There are uncertainties associated with all of this information, so when knowledge is integrated, information about the degree of certainty/uncertainty associated with it must also be carried forward. CCSP's decision support activities will address this essential requirement by communicating uncertainties in a manner appropriate to the decision context. CCSP's work program also includes research to improve methods for taking account of uncertainty in research and analysis, assessing the implications of uncertainty for decisionmaking, and communicating uncertainty to different audiences.

The comprehensive structure of CCSP's goals will help to ensure that the program sponsors research and provides support for decisionmaking on the full range of issues associated with variability and change in climate and related systems.

[2]"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."

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