8 Research and Systematic Observation

Climate change and climate variability play important roles in shaping the environment, infrastructure, economy, and other aspects of life worldwide. The United States continues to lead the world in research on climate and other global environmental changes, funding a significant portion of the world's climate change research to provide a sound scientific basis for national and international decisions regarding these changes.

With the goal of improving understanding of the science behind climate change, President Bush launched the interagency Climate Change Science Program (CCSP) in February 2002, building on strong U.S. commitment to research on global change. With its $1.5 billion annual investment in monitoring and predicting global change, CCSP is improving understanding of the natural and human-induced changes in the Earth's global environmental system.

The United States also conducts a robust technology research, development, demonstration, and commercialization effort coordinated through the multi-agency Climate Change Technology Program (CCTP). Since 2003, the United States has invested nearly $3 billion annually to facilitate more rapid development and commercialization of advanced and cost-competitive technologies to help meet the Nation's long-term goal of reducing, and eventually reversing, greenhouse gas (GHG) emissions. CCSP and CCTP collaborate to address issues at the intersection of science and technology, such as the evaluation of approaches to sequestration, anthropogenic GHG emissions monitoring, and energy technology development and market penetration scenarios.

Long-term, high-quality observations of the global environmental system are essential for understanding and evaluating Earth system processes. The United States contributes to the development and operation of global observing systems that combine data streams from both research and operational observing platforms to provide a comprehensive measure of climate system variability and climate change. The United States supports multiple oceanic, atmospheric, terrestrial, and space-based systems, working with international partners to enhance observations and improve data quality and availability.

In developing the roadmap for CCSP, the United States recognized the need for enhanced observations and the importance of international cooperation in this area. To address these issues, the United States initiated the first intergovernmental, ministerial-level Earth Observation Summit, which was held in July 2003. At the third Earth Observation Summit, in Brussels in 2005, nearly 60 countries adopted a 10-year plan for implementing a Global Earth Observation System of Systems (GEOSS), that addresses multiple environmental data needs, including climate, weather, biodiversity, natural disasters, and water and energy resource management (GEO 2005). With its focus on climate science, technology, and Earth observations, the United States is at the forefront of finding long-term answers to the complicated issue of global climate change.

THE U.S. CLIMATE CHANGE SCIENCE PROGRAM

CCSP[1] is a collaborative interagency program that integrates the U.S. Global Change Research Program (USGCRP) with the Administration's Climate Change Research Initiative (CCRI). CCSP adds value to the individual Earth and climate science missions of its 13 participating federal agencies and their national and international partners by coordinating research and information to achieve results that no single agency, or small group of agencies, could attain. In addition to integrating research and observational approaches across disciplinary boundaries, CCSP is working to create a more seamless approach among the theory, modeling, observations, and applications that are required to address the multiple scientific challenges posed by climate change and variability.

Development of the CCSP Strategic Plan

In July 2002, CCSP began a process to create a 10-year strategic plan, soliciting and comprehensively examining the research and observation needs of national and international climate change scientists and stakeholders. In November 2002, the Bush Administration released a "discussion" draft of the CCSP strategic plan for public review (CCSP 2002). Guided by the priority information needs identified by scientists and stakeholders, the discussion draft outlined a comprehensive, collaborative approach for developing a more accurate understanding of climate change and its potential impacts.

External comments, obtained through well-attended workshops, public review periods, and multiple reviews by the National Academies' National Research Council (NRC), played an important role in revising the draft plan. After consideration of all of the external input and extensive comments from the internal U.S. government review process, the Bush Administration released the final *Strategic Plan for the U.S. Climate Change Science Program* in July 2003 (CCSP and SGCR 2003a), along with its shorter companion document, *The U.S. Climate Change Science Program—Vision for the Program and Highlights of the Scientific Strategic Plan* (CCSP and SGCR 2003b). The *Strategic Plan* is the first comprehensive update of a U.S. national plan for climate and global change research since the original USGCRP strategy was issued at the program's inception in 1990.

In February 2004, the NRC review committee issued its second public report on the plan, *Implementing Climate and Global Change Research: A Review of the Final U.S. Climate Change Science Program Strategic Plan* (NRC 2004). This report expressed the committee's conclusions on the content, objectivity, quality, and comprehensiveness of the final *Strategic Plan*, on the process used to produce it, and on the proposed process for developing subsequent findings to be reported by CCSP. The NRC review made a number of recommendations on implementing the plan, concluding:

> *The Strategic Plan for the U.S. Climate Change Science Program articulates a guiding vision, is appropriately ambitious, and is broad in scope. It encompasses activities related to areas of long-standing importance, together with new or enhanced cross-disciplinary efforts. It appropriately plans for close integration with the complementary Climate Change Technology Program. The CCSP has responded constructively to the National Academies review and other community input in revising the strategic plan. In fact, the approaches taken by the CCSP to receive and respond to comments from a large and broad group of scientists and stakeholders, including a two-stage independent review of the plan, set a high standard for government research programs. As a result, the revised strategic plan is much improved over its November 2002 draft, and now includes the elements of a strategic management framework that could permit it to effectively guide research on climate and associated global changes over the next decades. Advancing science on all fronts identified by the program will be of vital importance to the nation.*

CCSP Vision

Over the past 15 years, the United States has invested heavily in scientific research, monitoring, data management, and assessment for climate change analyses to build a foundation of knowledge for decision making. The seriousness of the issues and the unique role that science can play in helping to inform society's course give rise to CCSP's guiding vision: *A nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems.*

CCSP Mission

The core precept that motivates CCSP is that the best possible scientific knowledge should be the foundation for the information required to manage climate variability and change, and related aspects of global change. Thus, CCSP's mission is to: *Facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication.*

CCSP Core Approaches

CCSP employs the following core approaches in working toward its goals:[2]

Scientific Research: Plan, Sponsor, and Conduct Research on Changes in Climate and Related Systems—The greatest percentage of the CCSP budget is devoted to continuing the essential ongoing investment in scientific knowledge, facilitating the discovery of the unexpected, and advancing the frontiers of science. CCSP agencies coordinate their work through seven interdisciplinary research elements and four cross-cutting elements, which together support scientific research across a wide range of interconnected issues of climate and global change. The CCSP research elements are: (1) Atmospheric Composition, (2) Climate Variability and Change (including Climate Modeling), (3) Global Water Cycle, (4) Land-Use/Land-Cover Change, (5) Global Carbon Cycle, (6) Ecosystems, and (7) Human Contributions and Responses/Decision Support. The four cross-cutting elements are: (1) Observations, (2) Modeling, (3) Communications, and (4) International Research

[1] See <http://www.climatescience.gov>.

[2] For greater detail, see <http://www.climatescience.gov/Library/stratplan2003/final/default.htm>.

and Cooperation. CCSP encourages evolution of the research elements over the coming decade in response to new knowledge and societal needs.

Observations: Enhance Observations and Data Management Systems to Generate a Comprehensive Set of Variables Needed for Climate-Related Research—Prior and current investments in new Earth observations will significantly enhance knowledge of environmental variables in the coming years. But enhanced global and regional integration of observation and data management systems, especially to help generate new and improved decision-support products, will also be needed. CCSP is working to increase the capacity to prioritize, ensure the quality of, archive, and disseminate (in useful format) the large quantity of available observations.

The intergovernmental Group on Earth Observations (GEO) is committed to continuing progress toward the development of a comprehensive, coordinated, and sustained GEOSS. In February 2005, the GEO released a 10-year implementation plan summarizing the essential steps to be taken by a global community of nations and intergovernmental, international, and regional organizations (GEO 2005). The U.S. contribution to GEOSS is the Integrated Earth Observation System (IEOS). In March 2005, the National Science and Technology Council's Committee on Environment and Natural Resources (CENR) released the *Strategic Plan for the U.S. Integrated Earth Observation System* (IWGEO and NSTC/CENR 2005). The plan addresses the policy, technical, fiscal, and societal benefit components of this integrated system, and created the U.S. Group on Earth Observations (USGEO) as a standing subcommittee of CENR. CCSP is coordinating its observation priorities with USGEO as IEOS is developed.

Decision Support: Develop Improved Science-Based Resources to Aid Decision Making—CCSP is encouraging improved interactions with stakeholders and is developing resources to support public discussion and planning, adaptive management, and policymaking. The program is also encouraging development of new methods, models, and other resources that facilitate economic analysis, decision making under conditions of uncertainty, and integration and interpretation of information from the natural and social sciences in particular decision contexts.

Communications: Communicate Results to Domestic and International Scientific and User Communities, Stressing Openness and Transparency—CCSP has a responsibility to communicate with interested partners in the United States and throughout the world, and to learn from these partners on a continuing basis. CCSP aims to improve dialogue with public- and private-sector constituencies and to provide users of climate change information with adequate opportunities to help frame important scientific research activities. This dialogue is an essential component of the development of decision-support tools.

CCSP Scientific Goals

In its *Strategic Plan*, CCSP adopted five overarching scientific goals (CCSP and SGCR 2003a). By developing information responsive to these goals, the program ensures that it addresses the most important climate-related issues. The following five goals frame what might be termed an "end-to-end" approach to climate and global change research, including observations, understanding processes, projections of future change, understanding potential consequences of change, and applications of knowledge to management decisions.

- *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.
- *Goal 2*—Improve quantification of the forces bringing about changes in the Earth's climate and related systems.
- *Goal 3*—Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.
- *Goal 4*—Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.
- *Goal 5*—Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

Synthesis and Assessment Products

CCSP is producing synthesis and assessment products to support informed discussion and decision making on climate variability and change by policymakers, resource managers, stakeholders, the media, and the general public. These products provide current evaluations of the identified science foundation that can be used for informing public debate, policy development, and adaptive management decisions, and for defining and setting the program's future direction and priorities.

U.S. government and nongovernmental researchers are producing 21 synthesis and assessment (S&A) products. Each product will undergo a rigorous peer review by scientists, stakeholders, and the general public, as well as final approval by the U.S. government. These products constitute an important new form of topic-driven integration of U.S. global change assessment efforts and will be disseminated by the U.S. government at various dates between 2006 and 2008. Box 8-1 presents the list of products associated with the five CCSP goals.

The first of these products, S&A Product 1.1—*Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*—was released on May 9, 2006 (CCSP and SGCR 2006b). S&A Product 1.1 addresses some of the long-standing difficulties that have impeded understanding changes in atmospheric temperatures and the basic causes of these changes. It is an important contribution toward improving understanding of climate change and human influences on temperature trends. S&A Product 1.1 and other S&A products to follow will

BOX 8-1 Summary of the 21 Climate Change Science Program Synthesis and Assessment Products

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.

1.1 Temperature trends in the lower atmosphere: Steps for understanding and reconciling differences. (Released on May 9, 2006).

1.2 Past climate variability and change in the Arctic and at high latitudes.

1.3 Re-analyses of historical climate data for key atmospheric features. Implications for attribution of causes of observed change.

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

2.1 (A) Scenarios of greenhouse gas emissions and atmospheric concentrations, and (B) global change scenarios: their development and use.

2.2 North American carbon budget and implications for the global carbon cycle.

2.3 Aerosol properties and their impacts on climate.

2.4 Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet exposure and climate change.

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

3.1 Climate models: an assessment of strengths and limitations for user applications.

3.2 Climate projections based on emission scenarios for long-lived radiatively active trace gases and future climate impacts of short-lived radiatively active gases and aerosols.

3.3 Weather and climate extremes in a changing climate.

3.4 Abrupt climate change.

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

4.1 Coastal elevations and sensitivity to sea level rise.

4.2 State-of-knowledge of thresholds of change that could lead to discontinuities in some ecosystems and climate-sensitive resources.

4.3 The effects of climate change on agriculture, land resources, water resources, and biodiversity.

4.4 Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources.

4.5 Effects of climate change on energy production and use in the United States.

4.6 Analyses of the effects of global change on human health and welfare and human systems.

4.7 Impacts of climate variability and change on transportation systems and infrastructure: Gulf Coast study.

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

5.1 Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions.

5.2 Best-practice approaches for characterizing, communicating, and incorporating scientific uncertainty in climate decision making.

5.3 Decision-support experiments and evaluations using seasonal-to-interannual forecasts and observational data.

constitute a valuable source of information for policymakers, researchers, and other interested parties.

International Research and Cooperation

International coordination and cooperation are essential to improve understanding of climate variability and change. As described in the CCSP *Strategic Plan*, an international approach to research is required because of the global scope of the climate system, as well as limitations to the scientific capacity and financial resources of any one nation (CCSP and SGCR 2003a).

The goals of the U.S. efforts to promote international cooperation in support of CCSP are:

- Actively promote and encourage cooperation between U.S. scientists and scientific institutions and agencies and their counterparts around the globe.
- Expand observing systems to provide global observational coverage of variability and change in the atmosphere and oceans and on land.
- Ensure that the data collected are of the highest quality possible, suitable for both research and forecasting, and that these data are exchanged and archived on a timely and effective basis among all interested scientists and end users.
- Support development of scientific capabilities and the application of results in developing countries to promote the fullest possible participation by scientists and scientific institutions in these countries.

On behalf of the U.S. government and the scientific community, CCSP participates in and provides input to, major international scientific and related organizations. In addition, CCSP provides support to maintain the central coordinating infrastructure of major international research programs and activities that complement CCSP and U.S. government goals and objectives for climate science.

The U.S. government also supports the environmental programs of other countries that have reduced GHG emissions, while promoting energy efficiency, forest protection, biodiversity conservation, and other development goals. This "multiple benefits" approach to climate change helps developing and transition countries expand economically without sacrificing environmental protection.

CCSP has provided scientific resources and/or direct funding support for international projects and programs, including the Arctic Climate Impact Assessment, the International Geosphere-Biosphere Programme, Diversitas, the International Human Dimensions Programme, the World Climate Research Programme, SySTem for Analysis Research and Training, the Intergovernmental Panel on Climate Change, and the Northern Eurasia Earth Science Partnership Initiative. The United States has also established bilateral (climate-related) partnerships with Australia, Brazil, Canada, China, Central America (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama), the European Union, Germany, India, Italy, Japan, Mexico, New Zealand, the Republic of Korea, the Russian Federation, and South Africa.

CCSP Workshop: Climate Science in Support of Decision Making

CCSP has committed to support public discussion and planning, adaptive management, and policymaking. In November 2005, the program reported on its progress and future plans regarding these three decision-support goals at a CCSP-sponsored public workshop, *Climate Science in Support of Decision Making* (CCSP 2005). The more than 700 participants included an international audience of climate scientists, decision makers, and users of information on climate variability and change, and more than 260 abstracts were submitted. A variety of sessions addressed recent and ongoing global change assessments, the application of climate science to adaptive management (e.g., water, ecosystems, energy systems, coastal and air quality management), and the use of climate information in analyses of policy options.

Participants provided positive feedback on the opportunity to learn about CCSP's activities and exchange information with other scientists and decision makers. CCSP will use insights from the workshop to guide current and future CCSP programs, and intends to provide additional forums for future communication about this aspect of the program.

CLIMATE CHANGE TECHNOLOGY PROGRAM

In addition to laying a strong foundation in climate science, the United States is moving ahead on realistic technology options to meet the United Nations Framework Convention on Climate Change's (UNFCCC's) ultimate objective of stabilizing GHG atmospheric concentrations at a level that avoids dangerous human interference with the climate system.

The United States is leading the development of advanced technologies that have the potential to reduce, avoid, or sequester GHG emissions. CCTP[3] was created to coordinate and prioritize the U.S. government's investment in climate-related technology research, development, demonstration, and commercialization—which was about $3 billion in fiscal year 2006—and to further the President's National Climate Change Technology Initiative, a suite of discrete activities that, if successful, could advance technologies to avoid, reduce, or capture and store GHG emissions on a large scale.

CCTP developed its August 2005 *Vision and Framework for Strategy and Planning* (CCTP 2005b) and September 2006 *Strategic Plan* (CCTP 2006) to guide and prioritize the federal government's climate technology efforts. CCTP's strategic vision has six complementary goals: (1) reducing emissions from energy use and infrastructure; (2) reducing emissions from energy supply; (3) capturing and sequestering CO_2; (4) reducing emissions of other GHGs; (5) measuring and monitoring emissions; and (6) bolstering the contributions of basic science. Figure 8-1 provides a schematic roadmap for the technologies being pursued under these goals. A fuller explanation of these technologies is available in CCTP's *Research and Current Activities* (CCTP 2003) and *Technology Options for the Near and Long Term* (CCTP 2005a) reports.

Energy Use and Infrastructure

Improving energy efficiency and reducing GHG emissions intensity in transportation, buildings, and industrial processes can significantly reduce overall GHG emissions. In addition, improving the infrastructure of the electricity transmission and distribution grid can reduce GHG emissions by making power generation more efficient and by providing greater grid access for wind and solar power.

Key research activities include the U.S. Department of Energy's (DOE's) Freedom CAR (Cooperative Automotive Research)[4] program, a cost-shared, government–industry partnership that is pursuing research and development in technologies needed to enable the mass production of affordable, practical hybrid vehicles, such as hydrogen-powered fuel-cell vehicles. The U.S. Environmental Protection Agency's Clean Automotive Technology[5] program is working on cost-effective automotive technologies that increase fuel efficiency and produce ultra-low pollution and GHG emissions. Advanced heavy-duty-vehicle technologies, zero-energy homes and commercial buildings, solid-state lighting, and high-temperature superconducting wires that virtually eliminate electricity transmission losses are other areas of research that could yield significant emission reductions.

[3] See <http://www.climatetechnology.gov>.
[4] See <http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/freedomcar/index.html>.
[5] See <http://www.epa.gov/otaq/technology/>.

FIGURE 8-1 **Roadmap for Climate Change Technology Development**

	NEAR-TERM GOALS	MID-TERM GOALS	LONG-TERM GOALS
GOAL 1 Energy End Use and Infrastructure	• Hybrid & Plug-In Hybrid Electric Vehicles • Engineered Urban Designs • High-Performance Integrated Homes • High-Efficiency Appliances • High-Efficiency Boilers & Combustion Systems • High-Temperature Superconductivity Demonstrations	• Fuel Cell Vehicles and H_2 Fuels • Low-Emission Aircraft • Solid-State Lighting • Ultra-Efficient HVACR • "Smart" Buildings • Transformational Technologies for Energy-Intensive Industries • Energy Storage for Load Leveling	• Widespread Use of Engineered Urban Designs & Regional Planning • Energy-Managed Communities • Integration of Industrial Heat, Power, Processes, & Techniques • Superconducting Transmission & Equipment
GOAL 2 Energy Supply	• IGCC Commercialization • Stationary H_2 Fuel Cells • Cost-Competitive Solar PV • Demonstrations of Cellulosic Ethanol • Distributed Electric Generation • Advanced Fission Reactor & Fuel Cycle Technology	• FutureGen Scale-Up • H_2 Co-Production From Coal/Biomass • Low-Wind-Speed Turbines • Advanced Biorefineries • Community-Scale Solar • Gen IV Nuclear Plants • Fusion Pilot Plant Demonstration	• Zero-Emission Fossil Energy • H_2 & Electric Economy • Widespread Renewable Energy • Bio-Inspired Energy & Fuels • Widespread Nuclear Power • Fusion Power Plants
GOAL 3 Capture, Storage, & Sequestration	• CSLF & CSRP • Post-Combustion Capture • Oxy-Fuel Combustion • Enhanced Hydrocarbon Recovery • Geologic Reservoir Characterization • Soils Conservation • Dilution of Direct-Injected CO_2	• Geologic Storage Proven Safe • CO_2 Transport Infrastructure • Soils Uptake & Land Use • Ocean CO_2 Biological Impacts Addressed	• Track Record of Successful CO_2 Storage Experience • Large-Scale Sequestration • Carbon- & CO_2-Based Products & Materials • Safe, Long-Term Ocean Storage
GOAL 4 Other Gases	• Methane to Markets • Precision Agriculture • Advanced Refrigeration Technologies • PM Control Technologies for Vehicles	• Advanced Landfill Gas Utilization • Soil Microbial Processes • Substitutes for SF_6 • Catalysts That Reduce N_2O to Elemental Nitrogen in Diesel Engines	• Integrated Waste Management System With Automated Sorting, Processing, & Recycling • Zero-Emission Agriculture • Solid-State Refrigeration/AC Systems
GOAL 5 Measure & Monitor	• Low-Cost Sensors and Communications	• Large-Scale, Secure Data Storage System • Direct Measurement to Replace Proxies & Estimators	• Fully Operational Integrated MM Systems Architecture (Sensors, Indicators, Data Visualization & Storage, Models)

Energy Supply

Fossil fuels, which emit CO_2 when burned, remain the world's energy supply of choice. Therefore, a transition to a low-carbon energy future would require the availability of cost-competitive low- or zero-carbon energy supply options. When combined with improved energy carriers, such as electricity and hydrogen, these options could offer the prospect of considerable reductions in GHG emissions.

Renewable energy includes a range of different technologies that can play an important role in reducing GHG emissions. The United States invests considerable resources in wind, solar photovoltaics, and biomass technologies. In fiscal year 2006, DOE and the U.S. Department of Agriculture (USDA) spent a combined $247.5 million on wind, solar, and biomass programs. Although the price competitiveness of many of these technologies has improved significantly, there still is a need to reduce their manufacturing, operating, and maintenance costs.

There will be a continuing need for portable, storable energy carriers for heat, power, and transportation. Hydrogen is an excellent energy carrier, generates no emissions when used in a fuel cell, and can be produced from diverse sources, including renewable, nuclear, and fossil fuel power (the last of which could be combined with carbon capture). President Bush's $1.2 billion Hydrogen Fuel Initiative[6] is exploring these production options, as well as the infrastructure needed to store and deliver hydrogen economically and safely. Current CCTP research is expected to make possible an industry decision to commercialize hydrogen fuel-cell vehicles in 2015, and possibly bring them to market by 2020.

Advanced fossil-based power and fuels is an area of special interest for the United States, because about half of the Nation's

[6] See <http://www.eere.energy.gov/hydrogenandfuelcells/presidents_initiative.html>.

electricity demand is generated from its vast coal reserves. FutureGen[7] is a 10-year, $1 billion government–industry collaboration to build the world's first emission-free, coal-fired power plant. This project, which includes India and the Republic of Korea, will incorporate the latest technologies in carbon sequestration, oxygen and hydrogen separation membranes, turbines, fuel cells, and coal-to-hydrogen gasification. Through this research, clean coal can remain part of a diverse, secure energy portfolio well into the future.

Concerns about resource availability, energy security, and air quality as well as climate change suggest a larger role for nuclear power as an energy supply choice. The Generation IV Nuclear Energy Systems Initiative[8] is investigating the next-generation reactor and fuel-cycle systems, which represent a significant leap in economic performance, safety, and proliferation resistance. One promising system being developed under the Nuclear Hydrogen Initiative[9] would pair very-high-temperature reactor technology with advanced hydrogen production capabilities that could produce both electricity and hydrogen on a scale to meet transportation needs. Complementing these programs is the Advanced Fuel Cycle Initiative—Advanced Burner Reactor,[10] which is developing advanced, proliferation-resistant nuclear fuel technologies that can improve the fuel cycle, reduce costs, and increase the safety of handling nuclear wastes.

Fusion energy[11] is a potential major new source of energy that, if successfully developed, could be used to produce electricity and possibly hydrogen. Fusion has features that make it an attractive option from both environmental and safety perspectives. However, the technical hurdles of fusion energy are very high, and with a commercialization objective of 2050, its impact will not be felt until the second half of the century.

Recent Initiatives

In his 2006 State of the Union Address, President Bush outlined plans for an Advanced Energy Initiative (AEI).[12] AEI aims to accelerate the development of advanced technologies that could change the way American homes, businesses, and automobiles are powered. AEI is designed to take advantage of technologies that with a little push could play a big role in helping to reduce both the Nation's use of foreign sources of energy and its pollution and GHG emissions. AEI includes greater investments in zero-emission coal-fired plants, solar and wind power, nuclear energy, better battery and fuel cell technologies for pollution-free cars, and cellulosic biorefining technologies for biofuels production. One component of AEI is the Global Nuclear Energy Partnership, a groundbreaking effort to develop a worldwide consensus on enabling expanded use of economical, carbon-free nuclear energy to meet growing electricity demand. This initiative is discussed in greater detail later in the Multilateral Research section, which begins on the following page.

Carbon Capture and Sequestration

Carbon capture and sequestration is a central element of CCTP's strategy, because for the foreseeable future, fossil fuels will continue to be the world's most reliable and lowest-cost form of energy. Thus, a realistic approach is to find ways to "sequester" the CO_2 produced when these fuels—especially coal—are used. The term *carbon sequestration* describes a number of technologies and methods to capture, transport, and store CO_2 or remove it from the atmosphere.

Advanced techniques to capture gaseous CO_2 from energy and industrial facilities and store it permanently in geologic formations are under development. DOE's core Carbon Sequestration Program[13] emphasizes technologies that capture CO_2 from large point sources and store the emissions in geologic formations capable of holding vast amounts of CO_2. In 2003, DOE launched a nationwide network of seven Regional Carbon Sequestration Partnerships[14] that include 40 states, four Canadian provinces, three Indian nations, and over 300 organizations. The partnerships' main focus is on determining the best approaches for sequestration in their regions. They are also examining regulatory and infrastructure needs. Small-scale validation testing of 35 sites involving terrestrial and geologic sequestration technologies began in 2005, and will continue until 2009.

Terrestrial sequestration—removing CO_2 from the atmosphere and sequestering it in trees, soils, or other organic materials—has proven to be a low-cost means for long-term carbon storage. The DOE-supported Carbon Sequestration in Terrestrial Ecosystems consortium provides research on mechanisms that can enhance terrestrial sequestration.[15] In addition, USDA operates the Greenhouse Gas Reduction Through Agricultural Carbon Enhancement Network at 30 locations around the country to measure and predict carbon sequestration and GHG emissions across a range of agricultural systems, soils, and climate zones.

Other Greenhouse Gases

A main component of the U.S. strategy is to reduce other GHGs, such as methane (CH_4), nitrous oxides (N_2O), sulfur hexafluoride (SF_6), and fluorocarbons.

Improvements in methods and technologies to detect and either collect or prevent CH_4 emissions from various sources—such as landfills, coal mines,

7 See <http://fossil.energy.gov/programs/powersystems/futuregen/index.html>.
8 See <http://gen-iv.ne.doe.gov>.
9 See <http://nuclear.gov/hydrogen/hydrogenOV.html>.
10 See <http://www.gnep.energy.gov/gnepAdvancedBurnerReactors.html>.
11 See <http://www.sc.doe.gov/Program_Offices/fes.htm>.
12 See <http://www.whitehouse.gov/stateoftheunion/2006/energy/index.html>.
13 See <http://fossil.energy.gov/programs/sequestration/index.html>.
14 See <http://fossil.energy.gov/programs/sequestration/partnerships/index.html>.
15 Another option being explored is using biotechnology to enhance the ability of plants to take up CO_2, and thus sequester additional carbon.

natural gas pipelines, and oil and gas exploration operations—can prevent this GHG from escaping to the atmosphere. Reducing CH_4 emissions may also have a positive benefit in reducing local ozone problems, as CH_4 is a long-lived ozone precursor. In agriculture, improved management practices for fertilizer applications and livestock waste can reduce CH_4 and N_2O emissions appreciably.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and SF_6 are all high global warming potential (GWP) gases. HFCs and PFCs are used as substitutes for ozone-depleting chlorofluorocarbons and are used in or emitted during complex manufacturing processes. Advanced methods to reduce the leakage of, reuse, and recycle these chemicals and to use lower GWP alternatives are being explored.

Programs aimed at reducing particulate matter have led to significant advances in fuel combustion and emission control technologies to reduce U.S. black carbon aerosol emissions. Reducing emissions of black carbon, soot, and other chemical aerosols can have multiple benefits, including better air quality and public health and reduced radiative forcing.

Measuring and Monitoring

To meet future GHG emission measurement requirements, a wide array of sensors, measuring platforms, monitoring and inventorying systems, and inference methods are being developed. Many of the baseline measurement, observation, and sensing systems used to advance climate change science are being developed as part of CCSP. CCTP's efforts focus primarily on validating the performance of various climate change technologies, such as in terrestrial and geologic sequestration.

Basic Science

Basic scientific research is a fundamental element of CCTP. Tackling the dual challenges of addressing climate change and meeting growing world energy demand is likely to require discoveries and innovations that can shape the future in often unexpected ways. The CCTP framework aims to strengthen the basic research enterprise through strategic research that supports ongoing or projected research activities and exploratory research involving innovative concepts.

Multilateral Research

The United States believes that well-designed multilateral collaborations focused on achieving practical results can accelerate development and commercialization of new technologies. The United States has initiated or joined a number of multilateral technology collaborations in hydrogen, carbon sequestration, nuclear energy, and fusion that address many energy-related concerns (e.g., energy security, climate change, and environmental protection).

International Partnership for the Hydrogen Economy[16]

In November 2003, representatives from 16 governments gathered in Washington, D.C., to launch the International Partnership for the Hydrogen Economy (IPHE), a vehicle to coordinate and leverage multinational hydrogen research programs. IPHE will develop common recommendations for internationally recognized standards and safety protocols to speed market penetration of hydrogen technologies. An important aspect of IPHE is maintaining communications with the private sector and other stakeholders to foster public–private collaboration and address the technological, financial, and institutional barriers to hydrogen.

Carbon Sequestration Leadership Forum[17]

The Carbon Sequestration Leadership Forum (CSLF) is a multilateral U.S. initiative that provides a framework for international collaboration on sequestration technologies. Established at a June 2003 ministerial meeting held in Washington, D.C., CSLF consists of members from 22 governments representing both developed and developing countries.

The CSLF's main focus is assisting the development of technologies to separate, capture, transport, and store CO_2 safely over the long term; making carbon sequestration technologies broadly available internationally; and addressing broader issues relating to carbon capture and storage, such as regulation and policy. To date, CSLF has endorsed 17 international research projects, five of which involve the United States.

Generation IV International Forum[18]

In July 2001, under U.S. leadership, nine other countries and Euratom chartered the Generation IV International Forum (GIF), to fulfill the objective of the Generation IV Nuclear Energy Systems Initiative. GIF's goal is to develop a fourth generation of advanced, economical, safe, and proliferation-resistant nuclear systems that can be adopted commercially by 2030. Six technologies have been selected as the most promising candidates for future designs, some of which could be commercially ready by 2015. GIF countries are jointly preparing a collaborative research program to develop and demonstrate the projects.

ITER[19]

In January 2003, President Bush announced that the United States was joining the negotiations for the construction and operation of the international fusion experiment ITER. The goal of this proposed multilateral $5 billion collaborative project is to design and demonstrate a fusion energy production system. If successful, ITER

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16 See <http://www.iphe.net>. IPHE members include the United States, Australia, Brazil, Canada, China, European Commission, France, Germany, Iceland, India, Italy, Japan, New Zealand, Norway, Republic of Korea, Russian Federation, and United Kingdom.

17 See <http://www.cslforum.org>. CSLF members include the United States, Australia, Brazil, Canada, China, Colombia, Denmark, European Commission, France, Germany, Greece, India, Italy, Japan, Republic of Korea, Mexico, Netherlands, Norway, Russian Federation, Saudi Arabia, South Africa, and United Kingdom.

18 See <http://www.ne.doe.gov/genIV/neGenIV2.html>. GIF member countries include the United States, Argentina, Brazil, Canada, France, Japan, Republic of Korea, South Africa, Switzerland, and United Kingdom.

19 See <http://www.iter.org>. ITER members include the United States, China, European Union, India, Japan, Republic of Korea, and Russian Federation.

will advance progress toward producing clean, abundant, commercially available fusion energy by the middle of the century. In November 2006, the seven ITER partners signed an agreement to construct the project.[20]

Global Nuclear Energy Partnership[21]

The Global Nuclear Energy Partnership (GNEP), a component of AEI, has two major goals: (1) expand carbon-free nuclear energy to meet growing electricity demand worldwide, and (2) promote nonproliferation objectives through the leasing of nuclear fuel to countries that agree to forgo enrichment and reprocessing. GNEP partner countries would consist of both fuel-supplier nations and reactor nations. Fuel-supplier nations would provide reliable nuclear fuel services to reactor nations through an independent nuclear fuel broker, such as the International Atomic Energy Agency.

SYSTEMATIC OBSERVATIONS

Long-term, high-quality observations of the global environmental system are essential for defining the current state of the Earth's system, its history, and its variability. This task requires both space- and surface-based observation systems. The term *climate observations* can encompass a broad range of environmental observations, including (1) routine weather observations, which, when collected consistently over a long period of time, can be used to help describe a region's climatology; (2) observations collected as part of research investigations to elucidate chemical, dynamic, biological, or radiative processes that contribute to maintaining climate patterns or to their variability; (3) highly precise, continuous observations of climate system variables collected for the express purpose of documenting long-term (decadal-to-centennial) change; and (4) observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time to provide information on climate change for millennial and longer time scales.

Satellite observations provide a unique prespective of the global integrated Earth system and are necessary for good global climate coverage. *In situ* observations are required for the measurement of parameters that cannot be estimated from space platforms (e.g., biodiversity, groundwater, carbon sequestration at the root zone, and subsurface ocean parameters). *In situ* observations also provide long time series of observations required for the detection and diagnosis of global change, such as surface temperature, precipitation and water resources, weather and other natural hazards, the emission or discharge of pollutants, and the impacts of multiple stresses on the environment due to human and natural causes.

One critical challenge to the Earth observation field is to maintain existing observation capabilities in a variety of areas. For example, maintaining the observational record of stratospheric ozone is essential in discerning the effects of climate change on the nature and timing of ozone recovery. Other key areas include radiative energy fluxes of the Sun and Earth, atmospheric carbon dioxide, and global surface temperature. Efforts to create a long-term record of global land cover, started by Landsat in the 1970s, are currently being prepared for the transition to a Landsat Data Continuity Mission (LDCM) being planned by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey.[22] The LDCM is expected to have a 5-year mission life with 10-year expendable provisions.

Planning continues on deploying the National Polar-orbiting Operational Environmental Satellite System (NPOESS). This satellite system is designed to monitor global environmental conditions, and to collect and disseminate data related to weather, atmosphere, oceans, land, and near-space environment. NPOESS will maintain a continuous global climate record for a subset of the environmental parameters measured on current U.S. research and operational satellites. The United States is currently evaluating the impacts of the current configuration, and is addressing options that could enhance future U.S. satellite-based climate monitoring. An NPOESS Preparatory Report mission is scheduled for launch in 2009, and the first NPOESS spacecraft is scheduled for launch in 2013.

To meet the long-term needs for the documentation of global changes, the United States integrates observations from both research and operational systems. The United States supports the need to improve global observing systems for climate, and to exchange information on national plans and programs that contribute to the global capacity in this area.

Providing for wide access to information from the Global Earth Observation System of Systems (GEOSS) for applications that benefit society has been a focus of efforts coordinated by the intergovernmental Group on Earth Observations (GEO) and the U.S. Group on Earth Observation (USGEO). An international framework for open access to GEOSS data was established, and a U.S. strategic plan was drafted to provide a basis for international cooperation. At the third Earth Observation Summit in February 2005, the United States joined nearly 60 countries and the European Commission in endorsing to a plan that, over the next 10 years, will revolutionize the understanding of Earth system processes.[23]

A key regional effort of GEOSS in the Western Hemisphere is known as GEOSS in the Americas. The vision of this effort is to build partnerships with countries and organizations in the Americas and the Caribbean to strengthen the ability to utilize each other's research and operational Earth observations. The first significant GEOSS in the Americas project involved the shifting of the GOES-10 satellite in 2006 to a new orbit, to greatly improve environmental satellite coverage of the Western Hemisphere, especially over South America. By

[20] The seven ITER partners are the European Union, India, Japan, People's Republic of China, Republic of Korea, Russian Federation, and United States.

[21] See <http://www.gnep.energy.gov>.

[22] See <http://landsat.gsfc.nasa.gov/>.

[23] For more details, see <http://earthobservations.org>.

significantly enhancing satellite detection of such natural hazards as severe storms, floods, drought, landslides, and wildfires, the shift will help protect lives and property in both South America and the United States, and will allow for improved prediction, response, and follow-up and expanded understanding of Earth system processes.[24]

Potential benefits of Earth observations were detailed in the IEOS 10-year strategic plan that covered climate and eight other related areas—agriculture, disasters, ecology, energy, health, integration, ocean resources, water resources, and weather (IWGEO and NSTC/CENR 2005). Similarly, the CCSP *Strategic Plan* (CCSP and SGCR 2003a) has identified several overarching questions for observing and monitoring the climate system, such as: *How can we provide stewardship for open access to integrated data and products with sufficient accuracy and precision to address climate and associated global changes?*

Documentation of U.S. Climate Observations

As part of its continuing contributions to systematic observations in support of climate monitoring, the United States submitted *The United States Detailed National Report on Systematic Observations for Climate* to the UNFCCC Secretariat on September 6, 2001 (U.S. DOC/NOAA 2001). The report documents the U.S. systematic climate observing program and includes information on *in situ* atmospheric observations, *in situ* oceanographic observations, *in situ* terrestrial observations, and satellite-based observations. The report attempted to cover all relevant observation systems and is representative of the larger U.S. effort to collect environmental data. The United States supports a broad network of *in situ* global atmospheric, ocean, and terrestrial observation systems, as well as a large number of remote-sensing satellite platforms that are essential to climate monitoring.

In Situ *Atmospheric Observations*

The United States supports 75 stations in the Global Climate Observing System (GCOS) Surface Network (GSN), 21 stations in the GCOS Upper Air Network (GUAN), and 4 stations in the Global Atmospheric Watch (GAW). These stations are distributed geographically as prescribed in the GCOS and GAW network designs. The data (metadata and observations) from these stations are shared according to GCOS and GAW protocols.

Since publishing its last report to the UNFCCC, the United States has begun fielding and commissioning a system known as the Climate Reference Network (CRN). The CRN is designed to answer the question: *How has the U.S. climate changed over the past 50 years at national, regional, and local levels?* Since 2002, 74 CRN stations have been commissioned out of a planned 110 stations.[25]

The U.S. GCOS program supports a number of climate observing systems and projects in developing nations. In 2002, there were 20 nontransmitting GUAN stations around the globe. Through focused projects, the number of nontransmitting stations has dropped to 6. The GCOS program continues to ensure the long-term sustainability of all stations through the establishment of regional technical and maintenance support centers for southern and eastern Africa, the Caribbean, and the Pacific Islands. Related to this capacity-building activity, the program will be supporting an intensive upper-air campaign as part of the African Monsoon Multidisciplinary Analysis, with the installation of a new hydrogen generator at the upper-air site in Dakar, Senegal.

While it is difficult to list all observing campaigns and systems, several others should be noted for their global climate significance. The Southern Hemisphere ADditional OZonesondes (SHADOZ) provides a consistent dataset from balloon-borne ozonesondes for ground verification of satellite tropospheric ozone measurements at 12 sites across the tropical and subtropical regions of the southern hemisphere.[26] Another key system along these lines is the Aerosol Robotic NETwork (AERONET), which is a federation of ground-based, remote-sensing aerosol networks established in part by NASA and France's Centre Nationale de Recherche Scientifique (CNRS).[27] AERONET provides a long-term, continuous, and readily accessible public domain database of aerosol optical properties for research and characterization of aerosols and for validation of satellite retrievals. AERONET provides synergy with other databases, along with a series of globally distributed observations of spectral aerosol optical depth, inversion products, and precipitable water in diverse aerosol regimes.

The collaborative effort between NASA's Advanced Global Atmospheric Gases Experiment (AGAGE) and NOAA's Flask Monitoring Network has been instrumental in measuring the composition of the global atmosphere continuously since 1978. The AGAGE is distinguished by its capability to measure globally and at high frequency most of the important gases in the *Montreal Protocol* to protect the ozone layer and almost all of the significant non-CO_2 gases in the *Kyoto Protocol* to mitigate climate change. This key climate monitoring activity demonstrates NASA's and NOAA's significant collaborative research efforts.[28]

The primary goal of the Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) is to provide the infrastructure needed for studies investigating atmospheric processes in several climatic regimes and for climate model development and evaluation. The ACRF consists of three stationary facilities, an ARM Mobile Facility (AMF), and the ARM Aerial Vehicles Program (AAVP). The stationary sites provide scientific test beds in three climatically significant regions (mid-latitude, polar, and tropical), and the AMF provides a capability to address high-priority scientific questions in

[24] See <http://www.strategies.org/EOPA.html>.
[25] See <http://www.ncdc.noaa.gov/oa/climate/uscrn>.
[26] See <http://croc.gsfc.nasa.gov/shadoz/>.
[27] See <http://aeronet.gsfc.nasa.gov/data_frame.html>.
[28] See <http://agage.eas.gatech.edu/> and <http://www.esrl.noaa.gov/>.

regions other than the stationary sites. The AAVP provides a capability to obtain *in situ* cloud and radiation measurements that complement the ground measurements. Data streams produced by the ACRF will be available to the atmospheric community for use in testing and improving parameterizations in global climate models. The AMF was deployed in Niamey, Niger, in 2006 measuring radiation, cloud, and aerosol properties during the monsoon and dry seasons.

In Situ *Ocean Observations*

The climate requirements of the Global Ocean Observing System (GOOS) are the same as those for GCOS. Also like GCOS, GOOS is based on a number of *in situ* and space-based observing components. The United States supports the Integrated Ocean Observing System's surface and marine observations through a variety of components, including fixed and surface-drifting buoys, subsurface floats, and volunteer observing ships. It also supports the Global Sea Level Observing System through a network of sea level tidal gauges.

The United States currently provides satellite coverage of the global oceans for sea-surface temperatures, surface elevation, ocean-surface vector winds, sea ice, ocean color, and other climate variables. The first element of the climate portion of GOOS, completed in September 2005, is the global drifting buoy array, which is a network of 1,250 drifting buoys measuring sea-surface temperature and other variables as they flow in the ocean currents.

Continued upgrading of the Global Sea Level Observing System (GLOSS) tidal gauge network from 43 to 170 stations is planned for 2006–10. Ocean carbon inventory surveys in a 10-year repeat survey cycle help determine the anthropogenic intake of carbon into the oceans. Plans for advancement of the global Tropical–Atmosphere–Ocean (TAO) network of ocean buoys include an expansion of the network into the Indian Ocean (the Pacific Ocean has a current array of 70 TAO buoys). During 2005-07, 8 new TAO buoys were installed in the Indian Ocean in collaboration with partners from India, Indonesia, and France. Plans call for a total of 39 TAO buoys in the Indian Ocean by 2013. These moorings will enhance the tropical networks currently monitoring above-surface, surface, and subsurface conditions in the Pacific and Atlantic Oceans. As of the end of 2006, 57 percent of the GOOS suite of ocean climate observing platforms had been fielded; the full system of ocean climate sensors is scheduled for completion by 2010.

The Integrated Ocean Observing System (IOOS) is the U.S. coastal observing component of GOOS. IOOS is envisioned as a coordinated national and international network of observations, data management, and analyses that systematically acquires and disseminates data and information on past, present, and future states of the oceans. A coordinated IOOS effort is being established by NOAA via a national IOOS Program Office co-located with the Ocean.US consortium of offices consisting of NASA, NOAA, the National Science Foundation, and the U.S. Navy.[29] The IOOS observing subsystem employs both remote and *in situ* sensing. Remote sensing includes satellite-, aircraft-, and land-based sensors; power sources; and transmitters. *In situ* sensing includes platforms (ships, buoys, gliders, etc.); *in situ* sensors; power sources; sampling devices; laboratory-based measurements; and transmitters.

In Situ *Terrestrial Observations*

For terrestrial observations, GCOS and the Global Terrestrial Observing System (GTOS) have identified permafrost thermal state and permafrost active layer as key variables for monitoring the state of the cryosphere. The United States operates a long-term "benchmark" glacier program to intensively monitor climate, glacier motion, glacier mass balance, glacier geometry, and stream runoff at a few select sites. The data collected are used to understand glacier-related hydrologic processes and improve the quantitative prediction of water resources, glacier-related hazards, and the consequences of climate change. Long-term, mass-balance monitoring programs have been established at three widely spaced U.S. glacier basins that clearly sample different climate-glacier-runoff regimes.

SNOTEL and SCAN Networks—The SNOTEL (SNOpack TELemetry) and SCAN (Soil Climate Analysis Network) monitoring networks provide automated comprehensive snowpack, soil moisture, and related climate information designed to support natural resource assessments. SNOTEL operates more than 660 remote sites in mountain snowpack zones of the western United States. SCAN, which began as a pilot program, now consists of more than 120 sites. These networks collect and disseminate continuous, standardized soil moisture and other climate data in publicly available databases and climate reports. Uses for these data include inputs to global circulation models, verifying and ground truthing satellite data, monitoring drought development, forecasting water supply, and predicting sustainability for cropping systems.

Polar Climate Observations—Polar climate observations will continue to be a focus of U.S. activities as preparations are made for the International Polar Year beginning in 2007. Currently, the United States maintains soil-moisture climate stations in both Alaska and Antarctica, and plans to increase efforts on observations of the Arctic atmosphere, sea ice, and ocean. Working with a number of Arctic nations via the International Arctic Systems for Observing the Atmosphere (IASOA), the United States will deploy and/or participate in a number of observing activities to produce a higher-resolution characterization of clouds and aerosols and of both incoming and outgoing radiation, to provide the high-quality records needed to detect climate change and to improve calibration of broad-scale satellite observations in the Arctic. For example, through the IASOA process, the United States will be working

[29] See <http://www.ocean.us/>.

with its international partners in establishing a super-site climate observatory in the Russian Arctic in Tiksi, north of the Arctic Circle at latitude 71.50° North.

The AmeriFLUX Network—The AmeriFLUX network endeavors to establish an infrastructure for guiding, collecting, synthesizing, and disseminating long-term measurements of CO_2, water, and energy exchange from a variety of ecosystems. Its objectives are to collect critical new information to help define the current global CO_2 budget, enable improved projections of future concentrations of atmospheric CO_2, and enhance the understanding of carbon fluxes, net ecosystem production, and carbon sequestration in the terrestrial biosphere.

North American Carbon Program—A major focus of the U.S. CCSP, the North American Carbon Program measures and studies the sources and sinks of CO_2, CH_4, and CO in North America and in adjacent ocean regions.

Space-Based Observations

Space-based, remote-sensing observations of the atmosphere–ocean–land system have evolved substantially since the early 1970s, when the first operational weather satellite systems were launched. Over the last decade satellites have proven their observational capability to accurately monitor nearly all aspects of the total Earth system on a global basis. Currently, satellite systems monitor the evolution and impacts of El Niño and La Niña, weather phenomena, natural hazards, and vegetation cycles; the ozone hole; solar fluctuations; changes in snow cover, sea ice and ice sheets, ocean surface temperatures, and biological activity; coastal zones and algal blooms; deforestation and forest fires; urban development; volcanic activity; tectonic plate motions; aerosol and three-dimensional cloud distributions; water distribution; and other climate-related information.

A number of U.S. satellite operational and research missions form the basis of a robust national remote-sensing program that fully supports the requirements of GCOS (U.S. DOC/NOAA 2001). These include instruments on the Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellites (POES), the series of Earth Observing Satellites (EOS), the Landsats 5 and 7, the Total Ozone Mapping Spectrometer satellite, and the Jason satellite measuring sea-surface height, winds, and waves. Additional satellite missions in support of GCOS include (1) the Active Cavity Radiometer Irradiance Monitor for measuring solar irradiance; (2) the EOS-Terra, Aqua, and Aura series; (3) QuickSCAT; (4) the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) for studying ocean and productivity, as well as aerosols; (5) the Shuttle Radar Topography Mission; and (6) the Tropical Rainfall Measuring Mission for measuring rainfall, clouds, sea-surface temperature, radiation, and lightning. A major upgrade to the GOES system, known as GOES-R, is under development, with a first launch scheduled for late 2012.

Also, several new missions will be launched during the next few years: (1) the Orbiting Carbon Observatory mission will measure CO_2 (2008 launch); (2) Glory mission will measure black carbon soot and other aerosols, as well as total solar irradiance (2008 launch); (3) the altimetry Ocean Surface Topography mission will provide sea-surface heights for determining ocean circulation, climate change, and sea level rise (2008 launch); (4) Aquarius will measure global sea surface salinity (2009 launch); and (5) the Global Precipitation Measurement mission will monitor worldwide precipitation (2012 launch).

Some recent missions since the last report to the UNFCCC include:

- The Ice, Cloud, and Land Elevation Satellite (ICESat), launched in 2003, has been measuring surface elevations of ice and land, vertical distributions of clouds and aerosols, vegetation-canopy heights, and other features with unprecedented accuracy and sensitivity. The primary purpose of ICESat has been to acquire time series of ice-sheet elevation changes for determining the present-day mass balance of the ice sheets, to study associations between observed ice changes and polar climate, and to improve estimates of the present and future contributions to global sea level rise.
- The Solar Radiation and Climate Experiment (SORCE) satellite, launched in 2003, is equipped with four instruments that measure variations in solar radiation much more accurately than previous measurements and observe some of the spectral properties of solar radiation for the first time.
- The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and CloudSat satellites were successfully launched in April 2006. CALIPSO and CloudSat are highly complementary and together will provide new, three-dimensional perspectives of how clouds and aerosols form, evolve, and affect weather and climate. Both Calipso and CloudSat fly in formation as part of the NASA A-Train constellation (e.g., along with Aqua, Aura, and the French PARASOL spacecraft), providing the benefits of near simultaneity and, thus, the opportunity for synergistic measurements made with complementary techniques.

NASA's Gravity Recovery and Climate Experiment (GRACE) twin satellites celebrated their fifth anniversary on orbit in March 2007, completing a successful primary mission that has provided improved estimates of the Earth's gravity field on an ongoing basis. In conjunction with other data and models, GRACE has provided observations of terrestrial water storage changes, ice-mass variations, ocean bottom pressure changes, and sea level variations.

Data Management

Data management is an important aspect of any systematic observing effort. U.S. agencies have separate and unique mandates for climate-focused and -related systematic observations, and for the attendant data processing, archiving, and use of the important information from these observing systems.

Cooperative efforts by CCSP and USGEO agencies are moving toward providing integrated and more easily accessible Earth observations. Currently operating CCSP systems for data management and distribution highlighted in the 2007 *Our Changing Planet* report include NASA's Global Change Master Directory and Earth Observing System Data and Information System, and DOE's Carbon Dioxide Information Analysis Center (CCSP and SGCR 2006a). NOAA's National Climatic Data Center's (NCDC's) Climate Data Online site provides climate data from multiple stations around the world. Plans for 2007 and 2008 include the International Polar Year (IPY) participation through a focus on polar climate observations via NCDC's World Data Center for Meteorology.[30] Data management for IPY is coordinated among multiple U.S. agencies and throughout the world.

U.S. agencies and participants in CCSP and USGEO are working with their partners in Earth observation for climate action on local, state, regional, and national levels and in government, academia, and the private sector.

Finally, efforts are being explored to improve climate data integration in the Pacific Islands region and produce more useful, end-user-driven climate products. The Pacific Region Integrated Data Enterprise (PRIDE), currently underway in Hawaii, is efficiently using existing resources via a newly created NOAA Integrated Data and Environmental Applications (IDEA) Center, which is developing more customer-focused, integrated environmental products. Operating under the auspices of NOAA's NCDC, the IDEA Center is partnering with academic institutions and other federal and local agencies in the region to provide information on (1) issues related to Pacific islands, including past, current, and future trends in patterns of climate- and weather-related extreme events (e.g., tropical cyclones, flooding, drought, and ocean temperature extremes); (2) their implications for key sectors of the economy, such as agriculture, tourism, and fisheries; and (3) options for coastal communities and marine ecosystem managers to adapt to and manage the effects of variable and changing environmental conditions.[31]

International and Regional Support and Cooperation for Sustained Climate Observations

The Regional Implementation Workshop, initiated by GCOS in response to Decision 6/CP.5 of the UNFCCC, expanded on the Secretariat of the Pacific Regional Environment Program's needs analysis. Held in Apia, Samoa, in August 2000 with the support and active participation of Australian and U.S. experts, the workshop provided the basis for development of a Pacific Island-GCOS (PI-GCOS) program[32] to implement high-priority actions required to restore and improve observing systems in the region, to effectively monitor and detect trends and changes in the region's climate. The U.S. GCOS Program Office at NOAA's NCDC supports and contributes resources to the PI-GCOS effort.

Since 2002, the United States has entered into a number of important bilateral climate agreements, funding projects with Australia, China, New Zealand, and South Africa. These wide-ranging projects deal with climate prediction, ocean observation, stratospheric detection, water vapor measurements, capacity building and training, and communication of information, and focus the attention and resources of these countries on developing a more sustainable and robust GCOS program.

Finally, the transition of the Global Observing System Information Center (GOSIC)[33] from a developmental activity at the University of Delaware to an operational global data facility at NOAA's NCDC was completed on behalf of and with the concurrence of the global observing community in October 2006. GOSIC provides information, and facilitates easier access to data and information produced by GCOS, GOOS, and GTOS and their partner programs. The distributed nature of this vast system of global and regional data and information systems is best served by this single entry point for users. GOSIC provides explanations of the various global data systems, as well as an integrated overview of the myriad global observing programs, which includes on-line access to their data, information, and services. GOSIC offers a search capability across international data centers, to enhance access to a worldwide set of observations and derived products.

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30 See <http://www.ncdc.noaa.gov/oa/wdc/>.

31 See <http://www.apdrc.soest.hawaii.edu/PRIDE>.

32 See <http://pi-gcos.org>.

33 For more details, see <http://gosic.org>.