8

Research and Systematic Observation

Investments in climate science over the past several decades have greatly increased understanding of global climate change, including its attribution mainly to human influences. The air and oceans are warming, mountain glaciers are disappearing, sea ice is shrinking, permafrost is thawing, the great land ice sheets on Greenland and Antarctica are showing signs of instability, and sea level is rising. The consequences for human well-being are already being felt: more heat waves, floods, droughts, and wildfires; tropical diseases reaching into the temperate zones; vast areas of forest destroyed by pest outbreaks linked to warming; alterations in patterns of rainfall on which agriculture depends; and coastal property increasingly at risk from the surging seas. All of these impacts are being experienced in the United States and globally, as extensively documented in the recently released U.S. Global Change Research Program report *Global Climate Change Impacts in the United States* (Karl et al. 2009).

RESEARCH ON GLOBAL CHANGE

The latest and best scientific information forms the bedrock on which effective policy to combat and cope with climate change must be built. To assist the government and society as a whole with understanding, mitigating, and adapting to climate change, U.S. government agencies deploy a wide range of powerful science and technology resources. Each agency has different sets of key specialists and capabilities, different networks and relationships with the external research community, and separate program and budget authorities.

U.S. Global Change Research Program

The U.S. Global Change Research Program (USGCRP) brings together into a single interagency program the essential capacities for research and observations that are widely distributed across U.S. government agencies.[1] An essential component of success in delivering the information necessary for decision making is coordination of the programmatic and budgetary decisions of the 13 agencies that make up the USGCRP.

Growing out of interagency activities and planning beginning in about 1988, creation of the USGCRP energized cooperative interagency activities, with each agency bringing its strength to the collaborative effort. In 1990, USGCRP received congressional support under the Global Change Research Act (GCRA). The act called for the development of a research program "...to understand, assess, predict, and respond to human-induced and natural processes of global change," and guided federally supported global change research for the next decade.[2] In 2001, President Bush established the Climate Change Research Initiative (CCRI) to investigate uncertainties and set research priorities in climate change science, aiming to fill gaps in understanding within a few years.[3] In the following year, it was announced that the USGCRP and CCRI together would become the Climate Change Science Program (CCSP). The USGCRP label remained attached to many of the program's activities; now, consistent with the statutory language of the GCRA, the whole effort is going forward in the Obama administration as the USGCRP.

The USGCRP is managed by a director from one of the participating agencies (currently from the National Aeronautics and Space Administration [NASA]), with the help of the USGCRP Integration and Coordination Office (ICO) and interagency working groups that plan future research and cross-cutting activities, such as communications, decision support, and information and data concerns. The Office of Science and Technology Policy (OSTP) and Office of Management and Budget work closely with the ICO and the working groups to establish research priorities and funding plans to ensure the program is aligned with the administration's priorities and reflects agency planning.

The fiscal year 2011 budget provides $2.1 billion for USGCRP/CCSP programs—an increase of about 3 percent, over the 2009 level (excluding American Recovery and Reinvestment Act of 2009 [ARRA] funds).[4] USGCRP programs also received $604 million in ARRA funding based on preliminary agency allocations, including $237 million for NASA climate activities. ARRA funding also includes $170 million for the National Oceanic and Atmospheric Administration's (NOAA's) climate modeling activities. The 2011 budget supports research activities, including the goals set forth in the program's strategic plan. These activities can be grouped under the following areas: increase society's knowledge of Earth's past and present climate variability and change; improve understanding of natural and human forces of climate change; accelerate the capability to model and predict future conditions and impacts; assess the nation's vulnerability to current and anticipated impacts of climate change; and improve the nation's ability to respond to climate change by providing climate information and decision-support tools that are useful to policymakers and the general public.

Although the USGCRP continues to support a variety of research activities to gain more detailed predictive understanding of climate change, increased emphasis is being placed on bridging the significant gaps between estimating how much climate may change and the effects these changes may have on ecosystem services, water resources, natural resource utilization, human health, and societal well-being. The USGCRP is making a strong commitment to provide information that will reduce vulnerabilities and improve resilience to variability and change.

A recent National Academy of Sciences National Research Council report recommended restructuring the USGCRP around "...the end-to-end climate change problem, from understanding causes and processes to supporting actions needed to cope with the impending societal problems of climate change" (NAS/NRC 2009). The USGCRP is committed to supporting a balanced portfolio of fundamental and application-oriented research activities, from expanded modeling efforts to studies of coupled human-natural systems and institutional resilience. Plans are being developed to boost adaptation research; to bolster the capacity to monitor change and its impacts (including not only enhancing monitoring networks on land and at sea but also strengthening our system of Earth observation satellites); to produce the integrated assessments of the pace, patterns, and regional impacts of climate change that will be needed by decision makers as input into their deliberations on the metrics and goals to be embraced for both mitigation and adaptation; and to make climate data and information accessible to those who need it.

Adaptation Research

Knowledge is currently limited about the ability of communities, regions, and sectors to adapt to a changing climate. To address this shortfall, research on climate change impacts and adaptation must address complex human dimensions, such as economics, management, governance, behavior, and equity. Interdisciplinary research on adaptation that takes into account the interconnectedness of the Earth system and the complex nature of the social, political, and economic environment in which adaptation decisions must be

[1]See http://www.usgcrp.gov/.

[2]See http://www.gcrio.org/gcact1990.html.

[3]See http://www.climatescience.gov/about/ccri.htm.

[4]See http://www.gpoaccess.gov/usbudget/.

made is central to this effort. Given the relationships between climate change and extreme events, the communities of researchers, engineers, and other experts who work on reducing risks from natural and human-caused disasters have an important role to play in framing climate change adaptation strategies and in providing information to support decision making during implementation. For example, assessments of emergency preparedness and response systems, insurance systems, and disaster-relief capabilities are an important component of a society's adaptive capacity.

Integrated Assessment

Preparing for and adapting and responding to the impacts of climate change at the national level must begin with an integrated assessment that cuts across regional and sectoral lines. Any national assessment activity must engage localities and sectors to aggregate information into a national picture of climate impacts, and should also use this engagement to gather information on the "demand side" of adaptation, where people live and work, to re-orient research and observation investments. While national policy may be warranted for addressing certain climate change issues, individuals, public- and private-sector organizations, local communities, states, and regions will need to respond to many challenges as well. Future USGCRP activities will serve these different scales and stakeholders, providing the information and capabilities they need to prepare for and adapt and respond to future conditions.

Climate Services

Coordinated climate information and services are needed to assist decision making across public and private sectors. Local planners need information on likely changes in precipitation amount and flooding rains; farmers and farm cooperatives need information on changes in season length and temperature, not just for their own farms, but for those of their local and distant competitors; coastal zone managers need information on likely changes in sea level, storms, and estuarine temperatures; water resource managers need information on likely changes in snowpack and runoff, and the chance of floods and drought; community health planners need information on changes in the location of freezing conditions and the frequency of extreme heat waves; industry needs information on changes in extremes that might affect their businesses and shipping; and economic analysts need information across the region.

Just as the nation's climate research efforts require and benefit from interagency and academic partnerships, so too will the development and communication of climate change information benefit citizens and researchers. Providing this information requires sustained federal agency partnerships and collaboration with climate service providers and end users.

While much work has been done to evaluate the need for climate services and a National Climate Service, the Obama administration believes that additional assessment and analysis of existing climate-service capabilities and user needs for climate services are necessary. A National Climate Service and, more broadly, our nation's approach to delivering climate services will require that such analysis and assessment are ongoing, science-based, user-responsive, and relevant to all levels of interest—e.g., local, regional, national, and international. Such a framework must also be able to adapt to new developments in the scientific understanding of climate change and resultant impacts to serve the needs of decision makers and the public.

To address the nation's need for reliable and accurate climate information, OSTP is working to convene a task force with representation from a diverse group of key agencies whose charge will be to examine national assets, existing data and information gaps, and costs related to the development of a cohesive framework for delivering accurate climate-related information to the public. This process is intended to result in a more detailed functional and organizational approach for delivering climate services to the nation, in concert with a broad authorizing framework.

SYSTEMATIC OBSERVATIONS

Long-term, high-quality observations of the global environmental system are essential for defining the current state of the Earth's system, discovering past trends, and measuring 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. A full documentation of all U.S. systematic climate observational activities can be found in *The United States National Report on Systematic Observations for Climate for 2008: National Activities with Respect to the Global Climate Observing System (GCOS) Implementation Plan* (U.S. CCSP 2008). The following input will summarize, and where appropriate, update that information.

Past reports have categorized observing systems as being either satellite-based or *in situ*, to indicate a ground-based system. However, the term *in situ* is somewhat misleading, as it appears to include all non-satellite measurements (i.e., remote sensing from the ground, balloons, or aircraft), which it does not. For example, atmospheric observations necessary for climate studies include both real *in situ* measurements (which directly sample the air mass surrounding the instrument) as well as non-satellite remote-sensing measurements. Therefore, this report distinguishes observing systems as being either non-satellite or satellite in nature.

Satellite observations provide a unique perspective of the global integrated Earth system and are necessary for good global climate coverage. Non-satellite 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). Non-satellite 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.

NOAA has provided leadership in the *in situ* long-term measurement of atmospheric greenhouse gases (GHGs) for 40 years. Flask, tower. and aircraft measurements are routinely made by NOAA's Earth System Resources Laboratory, and ocean carbon inventory and exchange observations are routinely made by NOAA's Pacific Marine Environmental Laboratory. NOAA maintains the global observational networks and field programs on which society will increasingly depend for reliable information.

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 (CO_2), global surface temperature, and global sea level. 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 NASA and the U.S. Geological Survey (USGS).[5] The LDCM is currently planned for launch in December 2012 and is expected to have a 5-year mission life with 10-year expendable provisions.

The USGS Landsat 35-year record of the Earth's surface is available to users at no charge. Under a transition toward the National Land Imaging Program, USGS is pursuing an aggressive schedule to provide users with electronic access to any Landsat scene held in the USGS-managed national archive of global scenes dating back to Landsat 1, launched in 1972. As of February 2009, any Landsat archive scene selected by a user will be automatically processed, at no charge. In addition, newly acquired scenes meeting a cloud cover threshold of 20 percent or below will be processed and placed online for at least three months, after which time they will remain available for selection from the archive.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS)[6] program has undergone a major restructuring in order to put this critical program on a more sustainable pathway toward success. The satellite system is a national priority that is essential to meeting both civil and military weather-forecasting, storm-tracking, and climate-monitoring requirements. The restructured program, now known as the Joint Polar Satellite System (JPSS), will consist of platforms based on the NPOESS Preparatory Project (NPP) satellite scheduled for launch in September 2011. The JPSS is designed to monitor global environmental conditions, and collect and disseminate data related to weather, atmosphere, oceans, land, and near-space environment with a planned launch in 2015. The first JPSS satellite will host some of the sensors that were planned for the first NPOESS satellite, including the Visible Infrared Imaging Radiometer Suite, the Cross-track Infrared Sounder, the Advanced Technology Microwave Sounder, the Ozone Mapping and Profiling Suite, and the Cloud and Earth Radiant Energy System instrument.

Remotely sensed observations continue to be a cornerstone of the overall U.S. climate-observing program as coordinated by the USGCRP. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite mission and CloudSat radar instruments are providing an unprecedented examination of the vertical structure of aerosols and clouds over the entire Earth. These data—when combined with data from the Aqua, Aura, and Parasol satellites orbiting in formation (the "A-Train")—will enable systematic pursuit of key issues, including the effects of aerosols on clouds and precipitation, the strength of cloud feedbacks, and the characteristics of difficult-to-observe polar clouds. The increasing volume of data from remote-sensing and non-satellite observing systems presents a continuing challenge for USGCRP agencies to ensure that data management systems are able to handle the expected increases.

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

[5] See http://landsat.gsfc.nasa.gov/ and http://landsat.usgs.gov.

[6] See http://www.ipo.noaa.gov/.

[7] See http://www.earthobservations.org/.

(GEOSS)[7] for applications that benefit society has been a focus of efforts coordinated by the intergovernmental Group on Earth Observations (GEO)[8] and the U.S. Group on Earth Observations (USGEO).[9] The United States continues to be a very active participant in the development of GEOSS. The purpose of GEOSS is to achieve *comprehensive, coordinated, and sustained* observations of the Earth system in order to improve monitoring of the changing state of the planet, to increase understanding of complex Earth processes, and to enhance the prediction of the impacts of environmental change, including climate change. Finally, GEOSS provides the overall conceptual and organizational framework to build toward integrated global Earth observations to meet user needs and to support decision making in an increasingly complex and environmentally stressed world. It is a "system of systems" consisting of existing and future Earth observation systems, supplementing—not supplanting—the mandates and governance arrangements of those systems, such as GCOS.[10] The established Earth observation systems, through which many countries cooperate as members of the United Nations (UN) Specialized Agencies and as contributors to international scientific programs, provide essential building blocks for GEOSS.[11]

Potential benefits of Earth observations were detailed in the U.S. Integrated Earth Observation System 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). The importance of this global collaborative effort was evident at the November 2009 GEO-VI Plenary Meeting, and a regional implementation of GEOSS, known as GEOSS in the Americas*,* continues to be an effort strongly supported by the United States.[12] The first significant GEOSS in the Americas project involved the shifting of the Geostationary Operational Environmental Satellites GOES-10 satellite in 2006 to a new orbit, to greatly improve environmental satellite coverage of the Western Hemisphere, especially over South America.[13] By significantly enhancing satellite detection of such natural hazards as severe storms, floods, drought, landslides, and wildfires, the shift helps protect lives and property in both South America and the United States, and allows for improved prediction, response, and follow-up and expanded understanding of Earth system processes. Planning is underway to continue this South America coverage after GOES-10's service is completed, by using GOES-12. Since 2006, other collaborative activities in the region have been taken on, including the North American Drought Monitoring Program[14] and a coastal zone management effort discussed at a special forum in concert with the 2009 GEO-VI Plenary Meeting.

Documentation of U.S. Climate Observations

The United States supports a large number of remote-sensing satellite platforms, as well as a broad network of Earth-based global atmospheric, ocean, and terrestrial observation systems that are essential to climate monitoring. The United States contributes to the development and operation of several global observing systems, both research and operational, that collectively provide a comprehensive measure of climate system variability and climate change processes. These systems are a baseline Earth-observing system and include NASA, NOAA, and USGS Earth-observing satellites and extensive non-satellite observational capabilities. The USGCRP also supports several ground-based measurement activities that provide the data used in studies of the various climate processes necessary for better understanding of climate change. U.S. observational and monitoring activities contribute significantly to several international observing systems, including the GCOS, principally sponsored by the World Meteorological Organization (WMO); the Global Ocean Observing System (GOOS),[15] sponsored by the UN Educational, Scientific, and Cultural Organization's Intergovernmental Oceanographic Commission;[16] and the Global Terrestrial Observing System (GTOS), sponsored by the UN Food and Agriculture Organization.[17] The latter two have climate-related elements being developed jointly with GCOS. For example, NOAA has provided leadership in the *in situ* long-term measurement of atmospheric GHGs for 40 years. Flask, tower, and aircraft measurements are routinely made by NOAA's Earth System Resources Laboratory, and ocean carbon inventory and exchange observations are routinely made by NOAA's Pacific Marine Environmental Laboratory.

U.S. priorities for advancement of the atmospheric, oceanic, and terrestrial observing components of GCOS include (1) reducing the uncertainty in the global carbon inventory (in the atmospheric, oceanic, and terrestrial domains), sea-level change, and sea surface temperature; (2) continuing support for existing non-satellite atmospheric networks in developing nations; and (3) planning for surface and upper-air GCOS reference observations consistent with the USGCRP Synthesis and Analysis Report 1.1 (Karl et al. 2006). As such, the GOOS will make incremental advances, building out to 60 percent completion in 2010, in which 50 surface drifters will be equipped with salinity sensors for satellite validation and salinity budget calculations, particularly in the polar regions; a new reference array will be added across the Atlantic basin, to measure changes in the ocean's overturning circulation—an indicator of possible abrupt climate change; a pilot U.S. coastal carbon-observing network will enter sustained service, to help quantify North American carbon sources and sinks and to measure ocean acidification caused by CO_2 sequestration in

[8] See http://www.earthobservations.org/.

[9] See http://www.usgeo.gov/.[10] See http://www.gosic.org/ios/GCOS-main-page.htm.

[11] See http://earthobservations.org.

[12] See http://www.ssd.noaa.gov/PS/SATS/GOES/TEN/.

[13] See http://www.strategies.org/EOPA.html.

[14] See http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/nadm/.

[15] See http://www.ioc-goos.org/.

[16] See http://ioc-unesco.org/.

[17] See http://www.fao.org/gtos/.

the ocean; and dedicated ships will target deployments of Argo and surface drifters in undersampled regions of the world oceans. The North American Carbon Program (NACP), under the auspices of the USGCRP, aims heavily at terrestrial uncertainties that are supported by a growing set of atmospheric measurements to place constraints on flux estimates.[18] These observations are ongoing and involve participation from numerous agencies and institutions.

Non-Satellite Atmospheric Observations

The United States supports 75 stations in the GCOS Surface Network, 21 stations in the GCOS Upper Air Network,[19] and 4 stations in the Global Atmospheric Watch (GAW).[20] 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 UN Framework Convention on Climate Change (UNFCCC), the United States has continued to field and commission a system known as the U.S. Climate Reference Network (USCRN).[21] The USCRN 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 beginning in 2002, and as of September 2008, 114 USCRN stations have been commissioned in the continental United States. In 2008, work was begun on expanding that network to include 29 additional commissioned USCRN stations in Alaska; as of September 2009, 2 new USCRN stations had been installed in Alaska. The USCRN concept is also being applied toward expanding reference surface observing on an international basis as resources allow. After a few years of planning, an effort is underway to install a USCRN station at the Russian Arctic observing station in Tiksi as part of a U.S.–Russia bilateral effort.

In addition, the Cooperative Observer Program (COOP) is the nation's largest and oldest weather network, with nearly 10,250 observations taken daily, mostly by volunteers, over the course of the past 121 years. The COOP is the primary source for monitoring U.S. climate variability, including measuring weekly to interannual time frames on national, regional, and local scales. These data are also the primary basis for assessments of century-scale climate change. The network is in stable locations of urban, suburban, and rural settings in flat, mountainous, and beach areas where people live, work and play. The COOP is designed to provide weather, water, and climate information. Due to the density of this observation network, the information collected by the COOP can clarify how the U.S. climate has changed in the past 120 years or more, on a national, regional, and local level. The USCRN installed the final station in 2008, and uses historic data from the COOP network to develop pseudo-normals. Each year these data help to inform decisions related to Federal Disaster Declarations based on weather, insurance industry claims, water resource management, drought declarations, transportation issues, legal issues, computing model guidance to daily weather forecasts, normals and extremes, and energy consumption.

The Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) is a scientific user facility for obtaining continuous, long-term measurements of radiative fluxes, cloud and aerosol properties, and related atmospheric characteristics in diverse climate regimes.[22] The ACRF paradigm of long-term continuous measurements is essential to the evaluation and enhancement of climate models that must simulate the evolution of atmospheric properties for long continuous periods, from decades to centuries. The ACRF expands its geographic coverage through deployments of a mobile facility and includes aerial measurements that complement the ground measurements. In 2008, the mobile facility was deployed to China to examine aerosol indirect effects. In 2009, the mobile facility began a two-year deployment to the Azores to study processes controlling the radiative properties and microphysics of marine boundary layer clouds, a high-priority science question. An International Polar Year (IPY)[23] experiment was conducted using combinations of ground and aerial measurements. Data from the IPY experiment will be used as a case study by the Global Energy and Water Cycle Experiment Cloud Systems Study.[24]

The U.S. GCOS program's primary mission is support of non-satellite reference observational efforts, including developing the GCOS Reference Upper-Air Network (GRUAN). The GRUAN is intended to aid in enhancing the quality of upper-tropospheric and lower-stratospheric water vapor measurements at a subset of 30-40 global stations. The GRUAN began operation on January 1, 2009, and is led by the GRUAN Lead Center in Lindenberg, Germany; seven U.S. stations (including five ACRF sites, one NOAA/National Center for Atmospheric Research site, and one site from Howard University) have been invited to be part of the initial configuration of stations. The GRUAN is a key contributing network to GCOS; contributes to the GEOSS goal of "understanding, assessing, predicting, mitigating, and adapting to climate variability and change"; and is a key element supporting the Global Space-Based Inter-Calibration System effort. Long-term surface-based reference climate sites are essential for creating a continuous and homogeneous climate data record, such as those used by the Intergovernmental Panel on Climate Change and the UNFCCC, in global climate assessments. A reference climate data record is also essential for use by least-developed nations for local and regional planning related to protecting and monitoring water resources

[18] See http://www.nacarbon.org/.

[19] See http://www.ncdc.noaa.gov/oa/hofn/guan/guan-intro.html.

[20] See http://www.wmo.ch/web/arep/gaw/gaw_home.html.

[21] See http://www.ncdc.noaa.gov/crn/.

[22] See http://www.arm.gov/acrf/.

[23] See http://www.ipy.org/.

[24] See http://www.gewex.org/gewex_overview.html.

(e.g., drought forecasting), for understanding the effects of climate change on human health, and for understanding, assessing, predicting, mitigating and adapting to climate variability and change. Additionally, this kind of data record is a key element in reducing uncertainties in global temperature and precipitation variances, providing reference ground-truth data to aid in the evaluation of climate model simulations and in the provision of quality data for the calibration and validation of satellite data.

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)[25] provides a consistent data set 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. Another key system along these lines is the AErosol RObotic NETwork (AERONET),[26] which is a federation of ground-based remote-sensing aerosol networks established in part by NASA and France's Centre National de la Recherche Scientifique.

AERONET provides a long-term, continuous, and readily accessible public domain database of aerosol optical properties for research and characterization of aerosols, validates satellite retrievals, and provides synergy with other databases. AERONET collaboration provides 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)[27] 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 on Substances That Deplete the Ozone Layer* and almost all of the significant non-CO_2 gases in the *Kyoto Protocol* to mitigate climate change. Also, both NASA and NOAA demonstrate great collaborative research efforts in this key climate monitoring activity.[28]

AERONET retrievals of atmospheric particulate absorption will continue to be utilized in climate-forcing studies and in the validation of current and future satellite missions, such as the Glory satellite (late 2010 launch), which will measure aerosol light absorption from space. Network expansion will continue, with focus on regions that are not adequately sampled and that are important for understanding of global climate change, such as Asia. An experimental effort is underway to investigate the possibility of measuring sunlight reflected off the moon to make aerosol measurements at night. In addition, an experimental algorithm is under development for measurements of atmospheric CO_2. In the future, light detection and ranging (LIDAR) data will be used in studies of the influence of polar stratospheric clouds on ozone formation over the South Pole, Arctic haze impacts on polar climate, and generation of climatological aerosol and cloud properties at several Micro Pulse Lidar (MPL)[29] Network (MPLNET)[30] sites. To enhance data value, MPL instrument designs and hardware will be continually improved. In addition, several new MPLNET data products will be made available to the research community.

Non-Satellite Ocean Observations

The climate requirements of GOOS are the same as those for GCOS. Also like GCOS, GOOS is based on a number of non-satellite and space-based observing components. The United States supports the Integrated Ocean Observing System's (IOOS's) surface and marine observations through a variety of components, including fixed and surface-drifting buoys, subsurface floats, and volunteer observing ships.[31] It also supports the Global Sea Level Observing System (GLOSS) through a network of sea level tidal gauges.[32]

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. At present, the United States is the world leader in implementing the non-satellite elements of GOOS for climate, and sponsors the majority of the IOOS Global Component, which is the U.S. contribution to the international GOOS program and the ocean baseline of the GEOSS. The United States sponsors nearly half of the platforms presently deployed in the global ocean (3,860 of 7,723), with 72 other countries providing the remainder. The United States has historically contributed about half of the international system, and has been a leader in fostering an international systems approach to the implementation of GOOS.

Expanding in coverage, currently 60 percent of the initial GOOS design is complete. The demand for ocean data and the products and forecasts derived from these data require international cooperation with other nations to complete deployment as soon as possible.

In 1998, an international consortium presented plans for Argo, a global array of 3,000 autonomous instruments that would revolutionize the collection of critical, climate-relevant information from the upper 2 kilometers (km) (1.2 miles [mi]) of the world's oceans.[33] These instruments drift at depth, periodically

[25] See http://croc.gsfc.nasa.gov/shadoz/.

[26] See http://aeronet.gsfc.nasa.gov/data_frame.html.

[27] See http://agage.eas.gatech.edu/.

[28] See http://www.strategies.org/EOPA.html.

[29] See http://www.arm.gov/instruments/instrument.php?id=mpl.

[30] See http://www.mplnet.com/.

[31] See http://www.ocean.us/what_is_ioos.

[32] See http://www.gloss-sealevel.org/.

[33] See http://www.argo.ucsd.edu/.

rising to the sea surface, collecting data along the way, and report their observations in real time via satellite communications. The initial deployment objective of 3,000 instruments distributed homogenously throughout the world's oceans has been attained, and Argo now provides over 100,000 high-quality temperature and salinity profiles annually, along with global-scale velocity data, all without a seasonal bias. The Argo array has been deployed through the collaboration of more than 40 countries plus the European Union.

A guiding principle of Argo is that the program should benefit everyone. Thus, the data are openly and immediately available to anyone wishing to use them. Argo data coupled with global-scale satellite measurements from radar altimeters have made possible huge advances in the representation of the oceans in coupled ocean-atmosphere models for climate forecasts and the routine analysis and forecasting of the state of the subsurface ocean. Argo data are being used in an ever-widening range of research applications that have led to new insights into how the ocean and atmosphere interact in extreme as well as normal conditions. Two examples are the processes in polar winters when the deep waters that fill most of the ocean basins are formed, and the transfer of heat and water to the atmosphere beneath tropical cyclones. Both conditions are crucial to global weather and climate, and could not be observed by ships.

The present generation of instruments has a design life of four years when profiling to 2-km (1.2-mi) depth every 10 days. Maintaining the array will require annual deployments of around 800 floats. Having deployed the array and built the data delivery system, the challenge is to maintain the full array for a decade in a pre-operational "sustained maintenance" phase, including ensuring the availability of the platform resources to maintain the array. This will allow Argo's design to be optimized and its value fully demonstrated. The United States has committed to maintaining half of the array, and other contributing nations are striving to continue the array's strong international nature.

Continued upgrading of the GLOSS tidal gauge network from 43 to 170 stations is planned for the period 2006–2010. 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).[34] From 2005 to 2007, 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 38 TAO buoys in the Indian Ocean by 2013, which will form the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) network. RAMA is a multinationally supported element of the Indian Ocean Observing System, a combination of complementary satellite and non-satellite measurement platforms for climate research and forecasting purposes. NASA is currently investing in the development of new prototype geodetic instruments for deployment later this decade to support the creation of a next-generation geodetic network for the improvement of the terrestrial reference frame.

IOOS is the U.S. coastal observing component of the GOOS. It 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. The IOOS observing subsystem employs both remote and non-satellite sensing. Remote sensing includes satellite-, aircraft- and land-based sensors, power sources, and transmitters. Non-satellite sensing includes platforms (ships, buoys, gliders, etc.), non-satellite sensors, power sources, sampling devices, laboratory-based measurements, and transmitters.

Non-Satellite Terrestrial Observations

For terrestrial observations, GCOS and 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 and 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.[35] SCAN, which began as a pilot program, now consists of more than 120 sites.[36] 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

[34] See http://www.pmel.noaa.gov/tao/proj_over/pubs/overview.html.

[35] See http://www.wcc.nrcs.usda.gov/snow/.

[36] See http://www.wcc.nrcs.usda.gov/scan/.

and ground truthing satellite data, monitoring drought development, forecasting water supply, and predicting sustainability for cropping systems.

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.[37] Its objectives are to collect critical new information to help define the current global CO_2 budget, to enable improved projections of future concentrations of atmospheric CO_2, and to enhance the understanding of carbon fluxes, net ecosystem production, and carbon sequestration in the terrestrial biosphere.

North American Carbon Program

NACP, a major focus of the USGCRP, is a multidisciplinary research program established to obtain the scientific understanding of North America's carbon sources, sinks, and changes in carbon stocks needed to meet societal concerns and provide tools for decision makers. NACP is supported by a number of federal agencies through a variety of intramural and extramural funding mechanisms and award instruments. NACP relies upon a rich and diverse array of existing observational networks, monitoring sites, and experimental field studies in North America and its adjacent oceans. The program's goals are to develop quantitative scientific knowledge, robust observations, and models to determine: the emissions and uptake of CO_2, methane (CH_4), and carbon monoxide (CO); the changes in carbon stocks; and the factors regulating these processes for North America and adjacent ocean basins. NACP also aims to develop the scientific basis to implement full carbon accounting on regional and continental scales. This is the knowledge base needed to design monitoring programs for natural and managed CO_2 sinks and emissions of CH_4; to support long-term quantitative measurements of fluxes, sources, and sinks of atmospheric CO_2 and CH_4; and to develop forecasts for future trends.

Glacier Monitoring

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. The approach has been to establish long-term mass balance monitoring programs at three widely spaced U.S. glacier basins to clearly sample different climate-glacier-runoff regimes—South Cascade Glacier in Washington State, and Gulkana and Wolverine Glaciers in Alaska. Mass balance data are available beginning in 1959 for the South Cascade Glacier, and beginning in 1966 for the Gulkana and Wolverine Glaciers.[38]

Land Cover Characterization Program

This program was begun in 1995 to develop land cover and other land characterization databases to address national and international requirements that were becoming increasingly sophisticated and diverse. To meet these requirements, USGS develops multi-scale land cover characteristics databases used by scientists, resource managers, planners, and educators (Global and National Land Cover Characterization), and contributes to the understanding of the patterns, characteristics, and dynamics of land cover across the United States and the globe (Urban Dynamics and Land Cover Trends). The program also conducts research to improve the utility and efficiency of large-area land cover characterization and land cover characteristics databases.

The initial goal to develop a global 1-km (0.6-mi) land cover characteristics database was achieved in 1997. Current efforts focus on revising the database utilizing input from users around the world. USGS, the University of Nebraska-Lincoln, and the European Commission's Joint Research Centre generated the initial 1-km (0.6-mi) resolution Global Land Cover Characteristics database using NOAA Advanced Very-High-Resolution Radiometer data from April 1992 through March 1993. The database was built on a continent-by-continent basis using standard map projections and 1-km (0.6-mi) nominal spatial resolution; each continental database contains unique elements based on the geographic aspects of the specific continent. The continental databases are combined to make seven global data sets, each representing a different landscape based on a particular classification legend.[39]

National Ecological Observatory Network

NEON is a planned continental-scale research platform for discovering and understanding the impacts of climate change, land-use change, and invasive species on ecology.[40] NEON would be a national observatory, not a collection of regional observatories. It is currently in the planning and development stages.

NEON would consist of distributed sensor networks and experiments, linked by advanced cyber infrastructure to record and archive ecological data for at least 30 years. Using standardized protocols and an open data policy, NEON would gather long-term data on ecological responses of the biosphere to changes in land use and climate, and on feedbacks from the geosphere, hydrosphere, and atmosphere. NEON would be designed to serve as a U.S. terrestrial contribution to GEOSS.

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 capa-

[37] See http://public.ornl.gov/ameriflux/.

[38] See http://ak.water.usgs.gov/glaciology/.

[39] See http://edcdaac.usgs.gov/glcc/glcc.html.

[40] See http://www.neoninc.org/.

bility 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 GOES and Polar-orbiting Operational Environmental Satellites (POES),[41] the series of Earth Observing System (EOS) satellites,[42] the Landsats 5 and 7,[43] and the Jason satellite[44] measuring sea-surface height, wind speed, and waves. Additional satellite missions in support of GCOS include (1) the Active Cavity Radiometer Irradiance Monitor for measuring solar irradiance;[45] (2) the EOS Terra, Aqua, and Aura series; (3) the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) for studying ocean and productivity, as well as aerosols;[46] (4) the Shuttle Radar Topography Mission;[47] and (5) the Tropical Rainfall Measuring Mission for measuring rainfall, clouds, sea-surface temperature, radiation, and lightning.[48] A major upgrade to the GOES system, known as GOES-R, is under development, with a first launch scheduled for 2015.[49]

POES

Since 1979, the NOAA POES system has provided the nation with the longest time series of essential climate variables, including atmospheric temperature, water vapor, clouds, ozone, vegetation, and sea and land surface temperature.

GOES

Since the 1980s GOES has provided essential information on the diurnal cycle of clouds, and has been used as a key data set for the International Satellite Cloud Climatology Project. GOES has also been used to study the diurnal cycle of sea surface temperature.

Jason Altimeter Series

Global sea level rise is the most obvious manifestation of climate change in the ocean. It directly threatens coastal infrastructure through increased erosion, more frequent storm-surge flooding, and loss of habitat through drowned wetlands. The only feasible way to accurately determine global sea level rise is through satellite altimetry, the systematic collection of sea level observations, gathered today by the ongoing Jason series of satellite missions. These observations suggest that sea level rise is accelerating; in particular, the value of approximately 3.1 millimeters (0.12 inches) per year from altimeters over the past 15 years is almost twice the estimate of approximately 1.7 mm (0.07 in) per year from tide gauges over the past century.

The Jason series is being transitioned as a research endeavor from NASA and the Centre National d'Etudes Spatiales (the French Space Agency) to NOAA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT, NOAA's operational satellite counterpart in Europe) for joint implementation as a sustained operational capability. NOAA and EUMETSAT have already assumed responsibility for the ground system and operation of the Jason-2 satellite launched in June 2008. Additionally, with funding requested in the President's fiscal year (FY) 2010 budget (OMB 2009), NOAA plans to begin developing Jason-3, a joint mission with EUMETSAT. Assuming resources are made available on schedule, a joint Jason-3 could be launched in late 2013, in time to overlap at least the last 6 months of the design life of Jason-2, thus helping ensure the continuity of the climate record of global sea level.

Ocean Surface Vector Wind Measurements

NASA's QuikSCAT (or Quick Scatterometer) scans the ocean surface to measure wind speed and direction, providing observations over the open ocean where other tools, such as buoys, ships, and reconnaissance flights, are sparse or unavailable. Over time, these data have proved useful to NOAA for marine and tropical cyclone forecasts. In November 2009, NASA announced performance degradation of the QuikSCAT satellite.

NOAA and NASA continue to pursue short-term and long-term strategies to replace these space-based scatterometry measurements. NOAA is using data from the Advanced Scatterometer (ASCAT) onboard the Meteorological Operational (MetOp) satellite operated by EUMETSAT. NOAA and NASA have signed a letter of intent to collaborate on science and obtain Oceansat-2 data from the Indian Space Research Organisation. NOAA and NASA have also had discussions with the Japanese Aerospace Exploration Agency (JAXA) about flying a U.S.-developed scatterometer instrument on a future JAXA satellite.[50]

The Afternoon Train ("A-Train")

A collaboration between NASA and the space agencies of Canada and France, the A-Train (Afternoon Train) is a key Sun-synchronous, Earth-orbiting satellite formation that studies the atmosphere.[51] The A-Train constellation consists of five satellites flying in close proximity to each other. A sixth satellite, the Orbiting Carbon Observatory (OCO), was to have been added to the A-Train constellation in early 2009, but experienced a launch failure in February 2009.

[41] See http://www.oso.noaa.gov/poes/.

[42] See http://eospso.gsfc.nasa.gov/.

[43] See http://landsat.usgs.gov/.

[44] See http://topex-www.jpl.nasa.gov/mission/jason-1.html.

[45] See http://acrim.jpl.nasa.gov/.

[46] See http://oceancolor.gsfc.nasa.gov/SeaWiFS/.

[47] See http://www2.jpl.nasa.gov/srtm/.

[48] See http://trmm.gsfc.nasa.gov/.

[49] See http://www.goes-r.gov/.

[50] See http://www.jaxa.jp/projects/sat/gcom/index_e.html.

[51] See http://nasascience.nasa.gov/earth-science/a-train-satellite-constellation.

The first satellite in the A-Train constellation, Aqua, was launched in 2002; the second satellite, Aura, was launched in July 2004; and the CloudSat, CALIPSO, and PARASOL satellites were launched in April 2006. The A-Train satellites cross the equator within a few minutes of one another at around 1:30 p.m. local solar time. By combining the different sets of observations from the A-Train, a better understanding of atmospheric composition, clouds, and aerosols has led and is leading to major advances in atmospheric knowledge. More details on the five A-Train components follow.

NASA Aura—The NASA Aura satellite was launched with four instruments to extensively monitor the composition of the atmosphere.[52] Two of these instruments, the Microwave Limb Sounder and High-Resolution Dynamics Limb Sounder, obtain highly resolved altitude profiles of the stratosphere and upper troposphere for understanding photochemical and dynamical processes in these altitude ranges. The Tropospheric Emission Spectrometer obtains column and partial altitude profiles for ozone and tropospheric trace gases, while the Ozone Monitoring Instrument obtains nearly daily global ozone column maps, as well as columns for other important air quality parameters. Aura observes the atmosphere to answer the following three high-priority environmental questions: (1) Is the Earth's ozone layer recovering? (2) Is air quality getting worse? and (3) How is the Earth's climate changing?

PARASOL—A French Centre National d'Etudes Spatiales microsatellite project,[53] PARASOL has improved the characterization of cloud and aerosol microphysical and radiative properties. This advance has substantially increased our understanding of the radiative impact of clouds and aerosols, which in turn has led to improving numerical modeling of these processes in general circulation models.

CALIPSO and CloudSat—NASA's highly complementary CALIPSO[54] and CloudSat[55] satellites provide new, three-dimensional perspectives of how clouds and aerosols form, evolve, and affect weather and climate. Both satellites fly in formation as part of the NASA A-Train constellation, providing the benefits of near simultaneity and thus the opportunity for synergistic measurements made with complementary techniques.

NASA Aqua—The NASA Aqua satellite is designed to acquire precise atmospheric and oceanic measurements that provide a greater understanding of these components in the Earth's climate.[56] Other instruments on Aqua, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, provide regional-to-global land cover, sea surface temperature, and ocean color. Data from the A-Train instruments will help answer these important questions: (1) What are the aerosol types, and how do satellite observations match global emission and transport models? (2) How do aerosols contribute to the Earth radiation budget, and to what extent are they a climate forcing? (3) How does cloud layering affect the Earth radiation budge? (4) What is the vertical distribution of cloud water/ice in cloud systems? and (5) What is the role of polar stratospheric clouds in ozone loss and denitrification of the Arctic vortex?

AIRS—Additional advances have been achieved by exploiting new thermal sounder measurements from the Atmospheric InfraRed Sounder (AIRS). Global retrievals from AIRS have proven valuable to understand the distribution as well as the transport mechanisms of CO, CH_4, and CO_2 in the middle troposphere with respective precisions of 10, 1.5, and 0.5 percent. NOAA has incorporated the lessons learned from AIRS into operational carbon products from the EUMETSAT Infrared Atmospheric Sounding Interferometer (IASI), which launched aboard the MetOp-A satellite in 2006. NOAA is planning to continue these products with the NPOESS Cross-track Infrared Sounder (CrIS). The currently scheduled IASI and CrIS missions will allow the creation of a 20-year record of satellite thermal sounder-derived carbon trace gases, along with self-consistent ozone, temperature, moisture, and cloud information.

Other Recent NASA Missions

Other recent NASA missions include the following:

ICESat—The Ice, Cloud, and Land Elevation Satellite, 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.[57] 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 of ice melt to global sea level rise.

SORCE—The Solar Radiation and Climate Experiment satellite, also 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.[58]

GRACE—The Gravity Recovery and Climate Experiment (GRACE) twin satellites celebrated their seventh anniversary in orbit in March 2009, completing a successful primary mission that has provided improved ongoing estimates of the Earth's gravity field.[59] 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.

[52] See http://aura.gsfc.nasa.gov/.

[53] See http://smsc.cnes.fr/PARASOL/.

[54] See http://www.nasa.gov/mission_pages/calipso/main/.

[55] See http://cloudsat.atmos.colostate.edu/.

[56] See http://aqua.nasa.gov/.

[57] See http://icesat.gsfc.nasa.gov/.

[58] See http://lasp.colorado.edu/sorce/index.htm.

[59] See http://www.csr.utexas.edu/grace/.

Planned Missions

NASA plans to launch the following four missions over the next several years:

Glory—2010 launch: Glory will measure black carbon soot and other aerosols, as well as total solar irradiance.

Aquarius—2010 launch: Aquarius will measure global sea surface salinity.

NPOESS Preparatory Project—2011 launch: This project will demonstrate advanced technology for atmospheric sounding, providing continuity of weather and climate observations following EOS-PM (Terra) and EOS-AM (Aqua). It will supply data on atmospheric and sea surface temperatures, humidity soundings, land and ocean biological productivity, and cloud and aerosol properties.

Global Precipitation Measurement—2013 launch: The Global Precipitation Measurement mission will study global precipitation (rain, snow, and ice).

Data Management

Data management is an important aspect of any systematic observing effort. U.S. agencies have 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.

Integrated Earth Observations

Cooperative efforts by USGCRP and USGEO agencies are moving toward providing integrated and more easily accessible Earth observations. Currently operating USGCRP 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 the U.S. Department of Energy's (DOE's) Carbon Dioxide Information Analysis Center (USGCRP and SGCR 2006). DOE's Carbon Dioxide Information Analysis Center (CDIAC) provides comprehensive, long-term data management support, analysis, and information services to the global climate research community and the general public. The CDIAC data collection is designed to answer questions pertinent to both the present-day carbon budget and temporal changes in carbon sources and sinks. The data sets provide quantitative estimates of anthropogenic CO_2 emission rates, atmospheric concentration levels, land-atmosphere fluxes, ocean-atmosphere fluxes, and oceanic concentrations and inventories. The data holdings also support the NACP. NOAA's Climate Services Portal aggregates NOAA climate data, products, and services and serves as a touchstone for inquiries, interactive public dialogue, education, climate assessment information, and user requests.

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 included the IPY participation through a focus on polar climate observations via NCDC's World Data Center for Meteorology.[60] Finally, efforts are being explored to improve climate data integration in the Pacific Islands region and produce more useful, end-user-driven climate products.

PRICIP AND PaCIS

The Pacific Region Integrated Climatology Information Products (PRICIP) project[61] is an example of a region-wide collaborative activity under the auspices of the Pacific Climate Information System (PaCIS).[62] PRICIP is a regional path-finding activity with the goal of developing a national comprehensive coastal climatology program. It aims to improve our understanding of patterns and trends of storm frequency and intensity—"storminess"—within the Pacific region and develop a suite of integrated information products that can be used by emergency managers, mitigation planners, government agencies, and decision makers in key sectors, including water and natural resource management, agriculture and fisheries, transportation and communication, and recreation and tourism.

PRICIP is exploring how the climate-related processes that govern extreme storm events are expressed within and between three thematic areas: heavy rains, strong winds, and high seas. It involves analyses of historical records collected throughout the Pacific region, and the integration of these climatological analyses with near-real-time observations to put the current weather into a longer-term perspective. PaCIS provides a programmatic framework to integrate ongoing and future climate observations, operational forecasting services, and climate projections, research, assessment, data management, outreach, and education to address the needs of American Flag and U.S.-Affiliated Pacific Islands.

Integrated Data and Environmental Applications Center

NOAA's Integrated Data and Environmental Applications (IDEA) Center helps meet critical regional needs for ocean, climate, and ecosystem information to protect lives and property, support economic development, and enhance the resilience of Pacific Island communities in the face of changing environmental conditions.[63] This region-wide data integration activity (1) integrates regional observations, research, assessment, and services, and provides a prototype for a next-generation NOAA data center; (2) strengthens the delivery of ocean, climate, and ecosystem data products and information services to the diverse Pacific Island user community; (3) supports NOAA research and service programs in the Pacific; (4) supports the emergence of regional ocean- and climate-observing systems and information services that are responsive to the needs of Pacific Island com-

[60] See http://www.ncdc.noaa.gov/oa/wdc/.

[61] See http://www.pricip.org/.

[62] See http://www.ideademo.org/pacis.

[63] See http://www.ideademo.org/.

munities, governments, and businesses via the evolving PaCIS program; (5) supports integrated ecosystem science and services needed for Pacific Island ocean and coastal resource management programs; and (6) continues NOAA/U.S. leadership in the emergence of a global environmental observing system (e.g., GCOS, GOOS, IOOS, and GEOSS).

National Integrated Drought Information System

Droughts have far-reaching impacts on many aspects of our daily lives, from water management to health to energy consumption and conservation. To mitigate these impacts, NOAA, other federal and state agencies, partners, and countries developed the plan for the National Integrated Drought Information System (NIDIS). NIDIS is a dynamic and accessible drought-risk information system that was created in response to extended drought conditions, especially in the western United States, over the past decade.

In 2007, the United States unveiled a new, interactive Web site called the U.S. Drought Portal (USDP) that allows the public and civic managers to monitor U.S. drought conditions, get forecasts, assess the impacts of drought on their communities, and learn about possible mitigation measures.[64] This Web site is useful internationally as nations work to coordinate drought preparedness, response, mitigation, and recovery activities, and it fits in well with drought-related bilateral activities the United States is engaged in with partners in Canada and Mexico.

In 2008, NOAA, along with its partners, including the U.S. Department of Agriculture (USDA), began to institute geographic information system (GIS) mapping capabilities into the USDP. In 2009, the program will work to integrate enhanced GIS capabilities into the USDP. Additionally, communities will be unveiled in the portal, serving as a location for subject matter experts to share improvements in drought monitoring, forecasting, and mitigation. These communities will also serve as a coordinating and communications mechanism for NIDIS regional pilot projects. NIDIS was featured at the 2007 GEO-IV Plenary Session as a major contribution to GEOSS.

State of the Climate Report

Produced in partnership with WMO and numerous national and international partners, the annual *State of the Climate Report–Using Earth Observations to Monitor the Global Climate*,[65] consists of operational monitoring, analysis, and reporting on atmosphere, ocean, and land surface conditions from the global to local scale. By combining historical data with current observations, this report places today's climate in historical context and provides perspectives on the extent to which the climate continues to vary and change, as well as the effect that climate is having on societies and the environment.

More than 150 scientists from over 30 countries are now part of an annual process of turning raw observations collected from the global array of observing systems into information that enhances the ability of decision makers to understand the state of the Earth's climate and its variation and change during the past year, with context provided by decades to centuries of climate information. Many observational and analytical systems are unique to countries or regions of the world. Nevertheless, through this effort, the information from each system is openly shared, which is essential to transitioning data to operational use and filling critical gaps in current knowledge about the state of the global climate system. A State of the Climate Report is distributed through publication in the *Bulletin of the American Meteorological Society* each year,[66] and is translated into other languages and distributed to all 187 WMO member nations. The report seeks to provide details on as many of the essential climate variables (ECVs) as possible, as identified in the GCOS Second Adequacy Report.[67] Since this report began monitoring ECVs in 2001, and in line with the recently published 2008 edition, the number of reported ECVs has more than doubled to nearly 25.

Earth Observing System Data and Information System

NASA's Earth Observing System Data and Information System (EOSDIS) provides convenient mechanisms for locating and accessing products of interest either electronically or via orders for data on media. EOSDIS facilitates collaborative science by providing sets of tools and capabilities, such that investigators may provide access to special products (or research products) from their own computing facilities. EOSDIS has an operational EOS Data Gateway (EDG) that provides access to the data holdings at all the Distributed Active Archive Centers (DAACs) and participating data centers from other U.S. and international agencies. Currently, there are 14 EDGs around the world that permit users to access Earth science data archives, browse data holdings, select data products, and place data orders.

Eight NASA DAACs, representing a wide range of Earth science disciplines, comprise the data archival and distribution functions of EOSDIS. The DAACs carry out the responsibilities for processing certain data products from instrument data, archiving and distributing NASA's Earth science data, and providing a full range of user support. More than 2,100 distinct data products are archived at and distributed from the DAACs. These institutions are custodians of Earth science mission data until the data are moved to long-term archives. They ensure that data will be easily accessible to users.

NASA and NOAA have initiated a pilot project to develop a prototype system for testing candidate ap-

[64] See http://drought.gov.

[65] See http://www.noaa.gov/features/climate/climatemonitoring2.html.

[66] See http://www.ametsoc.org/PUBS/bams/.

[67] An archive of these reports from 2000 to 2007 can be found at http://www.ncdc.noaa.gov/oa/climate/research/state-of-climate.

proaches for moving MODIS data into long-term NOAA archives. This pilot project is part of the evolution of NOAA's Comprehensive Large Array-data Stewardship System (CLASS). Acting in concert with their users, DAACs provide reliable, robust services to those whose needs may cross traditional discipline boundaries, while continuing to support the particular needs of their respective discipline communities. The DAACs are currently serving a broad and growing user community at an increasing rate. CLASS is NOAA's online facility for the distribution of NOAA and U.S. Department of Defense (DOD) POES data, NASA mission data, NOAA GOES data, and derived data. CLASS is an electronic library of NOAA environmental data that provides capabilities for finding and obtaining such satellite data.[68]

Global Observing System Information Center

The transition of the Global Observing System Information Center (GOSIC) 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; facilitates easier access to data and information produced by GCOS, GOOS, and GTOS and their partner programs; provides explanations of the various global data systems, as well as an integrated overview of the myriad global observing programs, which includes online access to their data, information, and services; and offers a search capability across international data centers, to enhance access to a worldwide set of observations and derived products.[69]

TECHNOLOGY FOR GLOBAL CHANGE

The United States has committed not only to improving the science to better understand global climate change, but also to promoting the development and deployment of technologies to reduce GHG emissions. These efforts are targeted at increasing energy end-use efficiency and supplying energy with greatly reduced GHG emissions to meet the nation's goals of reducing GHG emissions and stabilizing GHG atmospheric concentrations at a level that avoids dangerous human interference with the climate system. To address these challenges, the Obama administration and Congress are working together to spur a revolution in clean energy technologies.

U.S. Climate Change Technology Program

The U.S. Climate Change Technology Program (CCTP) was established administratively in 2002, and authorized by the Energy Policy Act of 2005.[70] CCTP developed its August 2005 *Vision and Framework for Strategy and Planning* (CCTP 2005) 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 end 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. DOE serves as the lead agency for the CCTP effort. Twelve agencies participate in the interagency coordination efforts of CCTP. Eight of these fund activities are included in the CCTP portfolio.

In FY 2009, approximately $5.2 billion was appropriated for CCTP activities. ARRA provided over $25 billion in additional funding for CCTP research and development (R&D) activities across a broad portfolio of GHG mitigation options, including high-performance buildings; efficient manufacturing; advanced vehicles; clean biofuels; wind, solar, geothermal, and nuclear power; carbon capture and sequestration; advanced energy storage; a more intelligent electric grid; and techniques for reducing emissions and/or increasing uptake of CO_2 in agriculture and forestry. ARRA also provided $400 million for establishing the Advanced Research and Projects Agency–Energy (ARPA-E) within DOE to overcome the long-term and high-risk technological barriers to the development of clean energy technologies.[71]

Energy End Use and Infrastructure

Major sources of GHGs are closely tied to the use of energy in transportation, residential and commercial buildings, and industrial processes. Improving energy efficiency and reducing the intensity of GHG emissions in these sectors 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 expanded use and grid access of low-emission electricity from renewable energy technologies, including wind, solar, and geothermal power.

Key research activities include DOE's nationwide plan to modernize the electric grid, enhance the security of the U.S. energy infrastructure, and ensure reliable electricity delivery to meet growing demand. The R&D program is focused on technologies that reduce GHG emissions and contribute to energy independence and economic growth by improving the reliability, efficiency, flexibility, functionality, and security of the nation's electricity delivery system. The emphasis is on development of advanced transmission technologies, including more efficient cables and conductors to reduce energy loss; strengthening the reliability of the electric grid by enhancing real-time visualization tools; and developing a "smart grid" system with enhanced intelligence and connectivity.

Several U.S. agencies (DOE, Department of Transportation [DOT], DOD, Environmental Protection Agen-

[68] See http://www.nsof.class.noaa.gov/saa/products/welcome.

[69] See http://gosic.org.

[70] See http://www.climatetechnology.gov/.

[71] See http://arpa-e.energy.gov/.

cy [EPA], and NASA) are working on cost-effective automotive technologies that increase fuel efficiency and produce ultra-low pollution and GHG emissions. Under the Clean Automotive Technology Program, EPA facilitates collaboration with the automotive industry through innovative research to achieve ultra-low-pollution emissions, increase fuel efficiency, and reduce GHGs. By developing cost-effective technologies, the program encourages manufacturers to produce cleaner and more fuel-efficient vehicles. The DOT Federal Transit Administration's National Fuel Cell Bus Program develops and demonstrates fuel cell transit bus technology.[72] In addition, DOE's Vehicle Technologies Program supports R&D to make vehicles more efficient and capable of operating on non-petroleum fuels.[73]

Other DOT programs include efforts to improve travel activity, reduce vehicle miles traveled, and enhance vehicle and system operations. Aviation yields GHG emissions that have the potential to influence global climate. To identify opportunities for GHG emission reductions in the aviation sector, DOT's Federal Aviation Administration (FAA) recently launched the Aviation Climate Change Research Initiative. Currently, measuring and tracking fuel efficiency from aircraft operations provide the data for assessing the improvements in aircraft and engine technology, operational procedures, and the airspace transportation system that reduce aviation's contribution to CO_2 emissions. The FAA's Commercial Aviation Alternative Fuels Initiative is a government–private-sector coalition that focuses the efforts of commercial aviation to engage the emerging alternative fuels industry.[74] With support from NASA, the FAA recently launched the Continuous Lower Energy Emissions and Noise Program to advance maturing engine and aircraft technologies for quick fusion into the fleet in order to achieve increases in fuel efficiency (which is directly related to CO_2 emissions) and reduction in nitrogen oxide emissions (which affects distributions of ozone and methane—both of which are GHGs). These strategies to improve the transportation system can reduce GHG emissions, lead to environmental benefits, reduce oil use, improve America's energy security, and benefit the economy.

Reducing energy consumption and transforming the carbon footprint of the built environment through the development of technologies that will enable cost-competitive, zero-energy buildings, and supporting the advancement of clean and efficient industrial technologies and processes are other areas of research that could yield significant emission reductions both domestically and globally. At the July 9, 2009, Group of Eight (G8) meetings in L'Aquila, Italy, the Major Economies Forum countries (G8 + China, India, South Africa, Brazil, Mexico, and Indonesia) announced a Global Partnership to drive transformational low-carbon, climate-friendly technologies. A commitment was made to dramatically increase and coordinate public-sector investments in research, development, and demonstration (RD&D) of these technologies, with a view to doubling such investments by 2015, while recognizing the importance of private investment, public-private partnerships and international cooperation, including regional innovation centers. The United States will lead on "efficiency," which includes both buildings and industrial sector efficiency. Technology Action Plans and roadmaps will be developed along with recommendations for further progress. Drawing on global best practice policies, the Global Partnership will undertake to remove barriers, establish incentives, enhance capacity building, and implement appropriate measures to aggressively accelerate deployment and transfer of key existing and new low-carbon technologies, in accordance with national circumstances.

Energy Supply

Global and domestic energy supplies are dominated by fossil fuels that emit CO_2 when burned. The transition to a low-carbon energy future will require the availability of cost-competitive low- or zero-carbon energy supply technologies.

Renewable energy includes a range of different technologies that can play an important role in reducing GHG emissions. The United States currently invests considerable resources in wind, wave, tidal, hydropower, solar photovoltaics, and biomass technologies. In FY 2009, CCTP-related investments in renewable energy technologies included a combined $800 million. For example, DOE is helping meet America's increasing energy needs by working with wind industry partners to develop clean, domestic, innovative wind energy technologies that can compete with conventional fuel sources. DOE's Wind and Hydropower Technologies Program efforts have culminated in some of industry's leading products today and have contributed to record-breaking industry growth.[75] DOE's Biomass Program also conducts R&D in four key areas of technology required to produce biomass feedstocks and convert them to useful biofuels and value-added products: feedstocks, processing and conversion, integrated biorefineries, and infrastructure.[76]

USDA's Biomass Research and Development Initiative addresses feedstock development, biofuels and bio-based product development, and biofuel development analysis.[77] All projects are implemented in accordance with a life-cycle perspective that considers both direct and indirect environmental and economic impacts. USDA's Rural Development program provides (1) loan guarantees for the development, construction, and retrofitting of commercial-scale biorefineries; (2) grants to help pay for the development and construction costs of demonstration-scale biore-

[72] See http://www.nrel.gov/hydrogen/proj_fc_bus_eval.html.

[73] See http://www1.eere.energy.gov/vehiclesandfuels/.

[74] See http://www.caafi.org/.

[75] See http://www1.eere.energy.gov/windandhydro/.

[76] See http://www1.eere.energy.gov/biomass/.

[77] See http://www.brdisolutions.com/default.aspx.

fineries; (3) payments to biorefineries to replace fossil fuels used to produce heat or power with renewable biomass; and (4) loan guarantees to rural residents, agricultural producers, and rural businesses for energy efficiency and renewable energy systems, energy audits, and technical assistance for projects ranging from biofuels to wind, solar, geothermal, methane gas recovery, advanced hydro, and biomass.[78]

Advanced fossil -based power and fuels are areas of particular interest for the United States. With coal likely to remain one of the nation's most widely used energy resources for the foreseeable future, the United States is actively funding applied R&D of advanced coal technologies that improve efficiency and reduce the intensity of CO_2 emissions. These activities are conducted through such programs as the Clean Coal Power Initiative, a cost-shared partnership between the government and industry to develop and demonstrate advanced coal-based power generation technologies.[79]

Concerns about resource availability, energy security, air quality, and climate change suggest a larger role for nuclear power as an energy supply choice. A key mission of DOE's nuclear energy R&D program is to plan and conduct applied research in advanced reactor and fuel and waste management technologies. The aim of these efforts is to enable nuclear energy to be used as a safe, advanced, cost-effective source of reliable energy that will help address climate change by reducing GHG emissions. The Generation IV Nuclear Energy Systems program is investigating the next-generation reactor and fuel-cycle systems, which represent a significant leap in economic performance, safety, and proliferation resistance.[80] Fusion energy 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.

Carbon Capture and Sequestration

Carbon capture and sequestration (CCS) is a central element of CCTP's strategy, because for the foreseeable future, fossil fuels will continue to be the world's most widely used forms of energy. Global energy models suggest that with current global coal use patterns, it will not be possible to stabilize atmospheric GHG concentrations at acceptable levels. Thus, a realistic approach is to find ways to "sequester" the CO_2 produced when fossil 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. These include capturing carbon (or CO_2), geologic storage of CO_2, and terrestrial sequestration in natural environs.

Advanced techniques to capture gaseous CO_2 from energy and industrial facilities and store it permanently in geologic formations are under development. In 2008, the G8 nations called for advancing CCS internationally, resulting in 20 major demonstrations by 2020; the United States agreed to sponsor at least 10 of these. Central to these U.S. demonstrations is DOE's core Carbon Sequestration Program, which 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. The Carbon Sequestration Program is complemented by other DOE programs that seek to significantly reduce the overall cost of integrated plants that will produce electricity and other co-products while capturing and sequestering CO_2.[81] The focus is on CO_2 capture from both new and existing coal plants.

In 2003, DOE launched a nationwide network of seven Regional Carbon Sequestration Partnerships that include 43 U.S. states, four Canadian provinces, three Native American nations, and over 350 organizations.[82] The partnerships' main focus is on determining the best approaches for sequestration in their regions and taking the initial steps to develop the infrastructure that will be needed for eventual large-scale deployment. This includes examination of regulatory needs. Small-scale validation testing of 35 sites involving terrestrial and geologic sequestration technologies began in 2005. During 2009–2012, CO_2 injection will begin for nine large-scale geologic storage tests that will be carried out by the seven regional partnerships. These tests will be of sufficient scale to allow the partnerships to address the kinds of challenges that will be encountered for commercial projects.

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. In addition, USDA's Agricultural Research Service operates the Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network (GRACEnet) at 31 locations around the country to measure and predict carbon sequestration and GHG emissions across a range of agricultural systems, land and animal management practices, soils, and climate zones.[83] Elements of GRACEnet include the development and use of standardized measurement methods, process model development, data base development, and the development of guidelines for producers.

Other Greenhouse Gases

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

[78] See http://www.rurdev.usda.gov/.

[79] See http://www.netl.doec.gov

[80] See http://www.ne.doe.gov/GenIV/neGenIV1.html.

[81] See http://www.netl.doe.gov/technologies/carbon_seq/.

[82] See http://fossil.energy.gov/sequestration/partnerships/index.html.

[83] See http://www.ars.usda.gov/research/programs/programs.htm?np_code=204&docid=17271.

Improvements in methods and technologies to detect and either collect or prevent CH_4 emissions from various sources—such as landfills, coal mines, 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 reuse, recycle, and reduce the leakage of 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, in some cases, can reduce 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.

The U.S. Department of Commerce's National Institute of Standards and Technology is testing, developing, and making available to researchers a wide variety of measurement and monitoring tools and techniques to aid in the development of technologies to mitigate climate change.

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. President Obama has committed to doubling federal investment in the basic sciences.

DOE will continue to support the 46 Energy Frontier Research Centers (EFRCs) that are addressing current fundamental scientific roadblocks to clean energy and energy security.[84] These centers will address the full range of energy research challenges in renewable and low-carbon energy, energy efficiency, energy storage, and cross-cutting science. The EFRCs will take advantage of new capabilities in nanotechnology, light sources that are a million times brighter than the sun, supercomputers, and other advanced instrumentation.

DOE's multidisciplinary Energy Innovation Hubs will also address basic science, technology, and economic and policy issues. The hubs will support cross-disciplinary R&D focused on the barriers to transforming energy technologies into commercially deployable materials, devices, and systems. They will advance promising areas of energy science and technology from their early stages of research to the point where the risk level will be low enough for industry to deploy them into the marketplace.

Established by DOE in 2009, ARPA-E is modeled after the Defense Advanced Research Projects Agency, which was created during the Eisenhower administration in response to the Russian Sputnik program, which launched the world's first artificial satellite. The purpose of ARPA-E is to advance high-risk energy research projects that can yield revolutionary changes in how energy is produced, distributed, and used.[85] ARRA has provided $400 million for ARPA-E.

Multilateral Research and Collaboration

The United States believes that well-designed multilateral collaborations focused on achieving practical results can accelerate development and commercialization of new technologies. Thus, 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). The following initiatives are examples of U.S. multinational collaboration.

Carbon Sequestration Leadership Forum

The Carbon Sequestration Leadership Forum (CSLF) is a multilateral U.S. initiative that provides a framework for international collaboration on sequestration technologies.[86] Established at a June 2003 ministerial meeting held in Washington, D.C., CSLF consists of 23 members, including 22 national governments representing both developed and developing countries, as well as the European Commission. 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 20 international research projects, five of which involve the United States.

[84] See http://www.science.doe.gov/bes/EFRC.html.

[85] See http://arpa-e.energy.gov/.

[86] See http://www.cslforum.org/.

Generation IV International Forum

The Generation IV International Forum (GIF) is a multilateral partnership of 10 countries and the European Commission that is fostering international cooperation in R&D for the next generation of safer, more affordable, and more proliferation-resistant nuclear energy systems.[87] This new generation of nuclear power plants could produce electricity and hydrogen with substantially less waste and without emitting any air pollutants or GHG emissions. Since its creation in July 2001, GIF has established a legal basis for collaboration through a treaty-level Framework Agreement (2005) and implementing arrangements (2007 onward). The United States supports collaboration in two of the systems: the Very-High-Temperature Reactor (VHTR) and the Sodium Fast Reactor (SFR). The primary mission of the VHTR is to provide carbon-free process heat for cogeneration and many potential industrial applications, including hydrogen production, while the SFR's primary mission is the closing of the nuclear fuel cycle.

ITER

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.[88] The goal of this collaborative project is to demonstrate the scientific and technological feasibility of fusion as an energy source. If successful, ITER will advance progress toward producing clean, abundant, commercially available fusion energy by the end of the century. Toward this goal, the seven ITER partners signed an agreement in November 2006 to construct the project; site preparation began in Saint-Paul-lez-Durance, France, in January 2007; and construction began in 2009.

Asia-Pacific Partnership on Clean Development and Climate

The Asia-Pacific Partnership on Clean Development and Climate (APP) is an innovative effort to accelerate the development and deployment of clean energy technologies.[89] The seven APP partner countries (Australia, Canada, China, India, Japan, Korea, and the United States) collectively account for more than half of the world's economy, population, and energy use. They produce about 65 percent of the world's coal, 62 percent of the world's cement, 52 percent of world's aluminum, and more than 60 percent of the world's steel. They have committed to collaborate and work with the private-sector partners to meet goals for energy security, national air pollution reduction, and climate change in ways that promote sustainable economic growth and poverty reduction. The APP focuses on expanding investment and trade in cleaner energy technologies, goods, and services in key market sectors. The partners have approved eight public–private-sector task forces covering aluminum, buildings and appliances, cement, coal mining, power generation and transmission, renewable energy and distributed generation, steel, and cleaner fossil energy technologies.

[87] See http://www.gen-4.org/.

[88] See http://www.iter.org/.

[89] See http://www.asiapacificpartnership.org/.