

Howard J. Diamond *
NOAA National Climatic Data Center, Silver Spring, Maryland

1. BACKGROUND

The U.S. has been involved with GCOS since its inception. Since 1992, a considerable amount of work has been done by various federal agencies. In particular, federal agencies have supported the international GCOS Steering Committee, and the work of the GCOS data, space, and science panels, as they have engaged in planning GCOS, defining its requirements, and contributing parts of the initial system. NOAA's National Climatic Data Center (NCDC) in Asheville, North Carolina, supports a number of GCOS data management activities and hosts the U.S. GCOS Program Office based in Silver Spring, Maryland.

The primary focus of this office is to coordinate the development of a national GCOS program that involves all U.S. federal agencies with a role in climate observing and monitoring. As part of this effort, the U.S. national program has taken a three-tiered approach to fostering the GCOS program. This approach involves providing support: (1) Internationally to improve and enhance monitoring stations in developing nations that require assistance as identified by the international GCOS Atmospheric Observations Panel for Climate; (2) regionally for workshops and projects such as those in the Pacific Ocean region for ensuring a robust and sustainable GCOS observing program; and (3) on a bi-lateral basis with nations that have entered into agreements with the U.S. on improving climate observing activities. The U.S. GCOS Program Office is currently involved in funding bi-lateral climate projects with Australia, China, New Zealand, and South Africa. Like other developed nations, the U.S. was required to submit a report on the status of its systematic observations for climate. The full report is available at the U.S. National GCOS home page at <http://www.ncdc.noaa.gov/oa/usgcos/index.htm>, and while the report was written in 2001, it still remains viable and relevant with respect to describing the diverse array of in-situ climate observing networks; however, since there have been considerable changes with respect to remote sensing platforms, this paper will attempt to fill some of the gaps related to that.

Meteorological surface-based networks, utilized for climate purposes, make observations of important climate factors, atmospheric profiles, and pollutant emissions, aerosols, and ozone. These surface-based networks are intended to provide the basic observational set needed to define the status and trends

in climate of the world, and also to calibrate and validate satellite-based observations. Although hundreds of millions of dollars are spent each year on developing and operating space-based observation systems, surface-based meteorological networks are "under reporting" their observations in many parts of the developing world. This is because of declining economies and the lack of understanding of how these observations contribute to the global effort to monitor climate. Consequently, these networks are operating substantially below their design standards and important observations are either not being made, or are not being communicated to users. Workshops are being conducted to define GCOS deficiencies and, during the next several years, more detailed activities to improve the networks will be identified. The implementation of a GCOS Cooperation Mechanism (GCM) was begun in 2004 as a way of identifying resources (both financial and in-kind) to aid in improving the operation of GCOS monitoring stations in developing nations. The GCM is being used to implement an overall global GCOS Improvement Program. Support, both in funds and in-kind support, has been provided, in addition to the U.S. by Australia, New Zealand, South Africa, Spain, and the United Kingdom. International support for GCOS has been growing over the past couple of years and a second formal meeting of the GCM Donor Board was held in Montreal in November 2005.

At its summit in Gleneagles, Scotland, July 2005, the G8 reiterated its commitment made in 2003 in Evian, France, to strengthen international cooperation on global Earth observations. In their 2005 statement the G-8 said:

"We will continue to exercise leadership in this area, and welcome the adoption of the 10-year implementation plan for development of the Global Earth Observation System of Systems (GEOSS) at the Third Earth Observations Summit which took place in Brussels in February this year. We will: (a) move forward in the national implementation of GEOSS in our member states; (b) support efforts to help developing countries and regions obtain full benefit from GEOSS, including from the Global Climate Observing System (GCOS) such as placement of observational systems to fill data gaps, developing of in country and regional capacity for analyzing and interpreting observational data, and development of decision-support systems and tools relevant to local needs; (c) in particular, work to strengthen the existing climate institutions in Africa, through GCOS, with a view to developing fully operational regional climate centres in Africa."

As such, NOAA's U.S. GCOS Program Office, which represents the U.S. on the GCOS Cooperation

* Corresponding author address: Howard J. Diamond, NOAA/NCDC, 1100 Wayne Avenue, Suite 1202, Silver Spring, MD 20910; e-mail: howard.diamond@noaa.gov.

Board, has committed to leading the way for facilitating improvements in the management and operation of GCOS and GCOS-related atmospheric networks. The U.S. GCOS Program Office has taken leadership, working with our partners at the WMO, in further GCOS improvements. This work began in Fiscal Year (FY) 2003 and plans are for continued efforts in this area for the foreseeable future. However, improvements in the various international GCOS networks cannot be done by NOAA alone, and are dependent on matching contributions from other developed nations via the GCM to aid in leveraging and implementing improvements to GCOS networks, and sustaining them. The program reflects a broad-based approach that looks at supporting observing and data management activities at the international, regional, and bi-lateral levels. In addition, support for Pacific Islands Ocean and Climate observing regional coordinators in Fiji and Samoa to aid in coordinating these observing activities among developing countries in the region has been a great boost towards capacity building in that critical region.

The support for developing nations has primarily been for retrofitting surface and upper air observing stations that have up-to-now been silent but yet are key to global climate monitoring activities. Countries that have received new equipment and expendables over the past three years include: Argentina, Armenia, Congo, Cook Islands, Costa Rica, Ecuador, Ivory Coast, Kenya, Maldives, Namibia, the Philippines, and Zimbabwe. In addition to equipment, in cooperation with the U.S. State Department, a number of workshops for enhancing climate change monitoring in support of the Intergovernmental Panel on Climate Change (IPCC) have or are being staged in South Africa, southern South America, northern South America and Central America, Southwest Asia, and Southern Asia. These are all hands-on workshops involving seminars and hands-on work with data from the various countries in attendance. In addition, the State Department has been instrumental in aiding in the establishment of regional GCOS maintenance facilities which have been established in the Pacific and the Caribbean. Another one is being planned for Southern and Eastern Africa in order to further the sustainability of the GCOS network in the developing nations of that region.

2. ORGANIZATION OF THE GCOS CLIMATE OBSERVATIONS PROGRAM IN THE U.S.

Climate observation activities in the U.S. are coordinated via a federal interagency organization known as the Climate Change Science Program Office (CCSPO). The CCSPO was created in 2001 as part of the President's Climate Change Research Initiative and includes membership from 17 U.S. federal Government agencies. More information on the CCSPO's efforts can be found via their web site at <http://climatescience.gov>. In its initial strategic plan published in 2003, one of the three main aims of the CCSP was to "Enhance and Expand Observations of the Earth System". The intent of this aim was to help "implement an international,

integrated, sustained, and comprehensive global Earth observation system to minimize data gaps and maximize the utility of existing observing networks". This goal fits in quite nicely with the goals of GCOS, and as such an interagency Observations Working Group (OWG) was formed under the auspices of the CCSP to aid in that effort. The key agencies participating in the OWG are NOAA, the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the U.S. Geological Survey (USGS). While other agencies are members of the OWG, these 4 agencies form the basis for the bulk of sustained climate observing activities in the U.S. and on behalf of GCOS on an international basis. The OWG is co-chaired by NOAA and NASA, and is the coordinating body that helps set observing priorities, as well as in coordinating GCOS activities in the U.S.

In particular, the OWG is tasked with coordinating the development of strategies to:

- Design, develop, deploy, integrate and sustain the climate observational components of a comprehensive earth observing system;
- Develop and demonstrate new technology for the innovation of new observations;
- Accelerate the development and deployment of observing and monitoring elements needed for decision support;
- Integrate modeling requirements with the observing system;
- Coordinate the management of observing system components with an effective interagency structure;
- Provide data and information in a timely and seamless manner with a management and distribution system that employs interoperability and standards, and
- Foster international cooperation that contributes to a more robust global climate observing system.
- Systematic Observations

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

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

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

Planning continues on deploying the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The potential contribution of NPOESS to climate monitoring over the next decade has been significantly degraded due to cost and complexity constraints. A decision was made in June 2006 to de-manifest many of the climate related instruments from NPOESS. These sensors included those for earth radiation budget, solar irradiance (total and spectrally resolved), high resolution ozone vertical profile, aerosol optical properties, and sea surface topography. While the prospect of this may lead to termination and/or gaps in several climate parameters the potential for restoring some of these sensors is currently being evaluated by NASA and NOAA. While this is obviously a concern for maintaining climate observing continuity on a global scale, it is an issue that the United States takes seriously. An NPOESS Preparatory Project mission is scheduled for launch in 2009, and the first NPOESS spacecraft is now scheduled for launch in 2013.

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

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

A key regional effort of GEOSS in the Western Hemisphere is known as GEOSS in the Americas. The vision of this effort is to build partnerships with countries and organizations in the Americas and the Caribbean to strengthen the ability to utilize each other's research and operational Earth observations. The first significant GEOSS in the Americas project involved the shifting of the GOES-10 satellite in December 2006 to a new orbit, to greatly improve environmental satellite coverage of the Western Hemisphere, especially over South America. By significantly enhancing satellite detection of such natural hazards as severe storms, floods, drought, landslides, and wildfires, the shift will help protect lives and property in both South America and the United States, and will allow for improved prediction, response, and follow-up and expanded understanding of Earth system processes [see <http://www.strategies.org/EOPA.html>]. Since 2002, the United States has entered into a number of important bilateral climate agreements, funding projects with Australia, China, New Zealand, and South Africa. These wide-ranging projects deal with climate prediction, ocean observation, stratospheric detection, water vapor measurements, capacity building and training, and communication of information, and focus the attention and resources of these countries on developing a more sustainable and robust GCOS program.

3. DOCUMENTATION OF U.S. CLIMATE OBSERVATIONS

The U.S. supports a broad network of in-situ global atmospheric, ocean, and terrestrial observation systems, as well as a large number of remote sensing satellite platforms that are essential to climate monitoring.

3.1 *In-Situ Atmospheric Observations*

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

States has begun fielding and commissioning a system known as the Climate Reference Network (CRN). The CRN is designed to answer the question: How has the U.S. climate changed over the past 50 years at national, regional, and local levels? Since 2002, 100 CRN stations have been put into operation out of a planned 115 stations in the Continental U.S. [see <http://www.ncdc.noaa.gov/oa/climate/uscrn>]. The full complement of 115 sites should be completely implemented by May 2008. Beginning in 2008, the CRN program will also be expanded into Alaska with an eventual plan for 29 sites (to date 4 pilot sites have already been installed). A prime emphasis of the U.S. GCOS program centers on reference observations for both surface and upper air sites. As such, the CRN system also forms the basis for a number of U.S. efforts to pursue the installation of reference surface observing in unique high latitude, high elevation, and tropical sites with partners from the World Bank, various universities, and the Smithsonian Tropical Research Institute. Finally, planning activities will continue on developing a GCOS Reference Upper Air Network (GRUAN) to aid in enhancing the quality of upper tropospheric and lower stratospheric water vapor measurements at a subset of present GCOS Upper Air Network stations and the U.S. has been a large supporter of the work done to date by the AOPC's Working Group on Atmospheric Reference Observations, and as such we are helping to support a planned workshop tentatively scheduled to take place in Lindenberg, Germany, in the February 2008 timeframe.

Since water vapor is the most important greenhouse gas in our atmosphere, exhibiting large gradients in concentration and mixing ratio between the Earth's surface and the upper troposphere/lower stratosphere (UT/LS). Fitting in with the GRUAN planning work outlined above, understanding changes in the distribution of water vapor, whether due to natural or anthropogenic causes, is essential to understanding the potential for climate change. Even small increases in stratospheric water vapor (1% per year) could cause significant surface radiative forcing and stratospheric cooling. Stratospheric water vapor amounts are controlled by dehydration processes driven by low temperatures in the tropopause region of the tropics. Our understanding of the dehydration process and its variability is incomplete. Of particular importance is the extent and frequency of ice-supersaturated conditions in the UT/LS. These shortfalls in our knowledge have made accurate and precise water vapor measurements in the tropopause region a required component of future climate research, particularly at the low water vapor mixing ratios in the UT/LS where measurement discrepancies currently exist. A number of research efforts will be continued or initiated to help resolve the observed discrepancies in in situ water vapor observations. These activities are being conducted jointly by NASA and NOAA with the involvement of US and international investigators from a wide range of government and academic institutions. The planned efforts include: (1) single instrument laboratory studies designed to better characterize and understand

instrument performance and calibration under a variety of atmospheric conditions; (2) the possible selection and use of a water vapor calibration standard to establish and/or confirm measurement accuracy and precision; and (3) multiple-instrument intercomparisons in the laboratory and field involving an independent referee to coordinate and presents the results of each formal laboratory and flight intercomparison that includes instruments from different research groups. Field intercomparisons will include aircraft-borne, balloon-borne, and satellite instruments.

The U.S. GCOS program supports a number of climate observing systems and projects in developing nations. In 2002, there were 20 non-transmitting GUAN stations around the globe. Through focused projects, the number of non-transmitting stations has dropped to 1 as of June 2007. The GCOS program continues to ensure the long-term sustainability of all stations through the establishment of regional technical and maintenance support centers for southern and eastern Africa, the Caribbean, and the Pacific Islands. Related to this capacity-building activity, the program will be supporting an intensive upper-air campaign as part of the African Monsoon Multidisciplinary Analysis, with the installation of a new hydrogen generator at the upper-air site in Dakar, Senegal.

While it is difficult to list all observing campaigns and systems, there are several others that need to be noted here for their global climate significance. The Southern Hemisphere ADDitional OZonesondes (SHADOZ) [see <http://croc.gsfc.nasa.gov/shadoz/>] provides a consistent dataset from balloon-borne ozonesondes for ground verification of satellite tropospheric ozone measurements at 12 sites across the tropical and subtropical regions of the southern hemisphere. Another key system along these lines is the Aerosol Robotic NETwork (AERONET) [see http://aeronet.gsfc.nasa.gov/data_frame.html] which is a federation of ground based remote sensing aerosol networks established in part by NASA and France's CNRS. AERONET provides a long-term, continuous and readily accessible public domain database of aerosol optical properties for research and characterization of aerosols, validation of 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) and NOAA's Flask Monitoring Network have been instrumental in measuring the composition of the global atmosphere continuously since 1978. The AGAGE is distinguished by its capability to measure over the globe at high frequency almost all of the important species in the Montreal Protocol to protect the ozone layer and almost all of the significant non-CO₂ gases in the Kyoto Protocol to mitigate climate change, and both NASA and NOAA demonstrate great collaborative research efforts in this key climate monitoring activity [see

<http://agage.eas.gatech.edu/>
<http://www.esrl.noaa.gov/>.

The primary goal of the Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) is to provide the infrastructure needed for studies investigating atmospheric processes in several climatic regimes and for climate model development and evaluation. The ACRF consists of three stationary facilities, an ARM Mobile Facility, and the ARM Aerial Vehicles Program (AAVP). The stationary sites provide scientific testbeds in three climatically significant regions (mid-latitude, polar, and tropical), and the AMF provides a capability to address high priority scientific questions in regions other than the stationary sites. The AAVP provides a capability to obtain in situ cloud and radiation measurements that complement the ground measurements. Data streams produced by the ACRF will be available to the atmospheric community for use in testing and improving parameterizations in global climate models. The AMF was deployed in [Niamey, Niger](#) in 2006 measuring radiation, cloud, and aerosol properties during the monsoon and dry seasons.

The Micro Pulse Lidar (MPL) Network (MPLNET) [see <http://mplnet.gsfc.nasa.gov>] is a federated network of MPL systems designed to measure aerosol and cloud vertical structure continuously, day and night, over long time periods required to contribute to climate change studies and provide validation for models and satellite sensors in NASA's Earth Observing System. At present, thirteen permanent sites are operational worldwide, and five more to be completed soon. Numerous temporary sites have been established in support of various field campaigns. Most MPLNET sites are co-located with sites in NASA's AERONET to provide both column and vertically resolved aerosol and cloud data, such as: optical depth, absorption, size distribution, aerosol and cloud heights, planetary boundary layer structure and evolution. Recent MPLNET accomplishments include contributions to the development of a novel approach to retrieve the height and optical depth of low, thick cloud layers (such as stratus). Such clouds can contain vast amounts of water and reflect significant amounts of sunlight. However, these clouds are extremely difficult to analyze from space due to their low altitude and high drop concentration (opaque). In another recent study, MPLNET contributed to the most comprehensive assessment of aerosol profiling capability to date. The study concluded that measured aerosol extinction profile uncertainty is approximately 20% on average. The profile of aerosol extinction is used to determine aerosol radiative effects. The accuracy with which we are able to estimate aerosol extinction translates directly to our ability to quantify aerosol impacts on climate understand impacts on climate.

3.2 In-Situ Ocean Observations

The climate requirements of the Global Ocean Observing System (GOOS) are the same as those for GCOS. Also like GCOS, GOOS is based on a number

of in situ and space-based observing components. The United States supports the Integrated Ocean Observing System's surface and marine observations through a variety of components, including fixed and surface-drifting buoys, subsurface floats, and volunteer observing ships. It also supports the Global Sea Level Observing System through a network of sea level tidal gauges.

The U.S. currently provides satellite coverage of the global oceans for sea-surface temperatures, surface elevation, ocean-surface vector winds, sea ice, ocean color, and other climate variables. The first element of the climate portion of GOOS, completed in September 2005, is the global drifting buoy array, which is a network of 1,250 drifting buoys measuring sea-surface temperature and other variables as they flow in the ocean currents. Continued upgrading of the Global Sea Level Observing System (GLOSS) tidal gauge network from 43 to 170 stations is planned for 2006–10. Ocean carbon inventory surveys in a 10-year repeat survey cycle help determine the anthropogenic intake of carbon into the oceans. Plans for advancement of the global Tropical–Atmosphere–Ocean (TAO) network of ocean buoys include an expansion of the network into the Indian Ocean (the Pacific Ocean has a current array of 70 TAO buoys). During 2005–07, 8 new TAO buoys were installed in the Indian Ocean in collaboration with partners from India, Indonesia, and France. Plans call for a total of 39 TAO buoys in the Indian Ocean by 2013. These moorings will enhance the tropical networks currently monitoring above-surface, surface, and subsurface conditions in the Pacific and Atlantic Oceans. As of the end of 2006, 57 percent of the GOOS suite of ocean climate observing platforms had been fielded; the full system of ocean climate sensors is scheduled for completion by 2010.

The Integrated Ocean Observing System (IOOS) is the U.S. coastal observing component of the Global Ocean Observing System and 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 collocated with the Ocean.US [<http://www.ocean.us/>] consortium of offices consisting of NASA, NSF, NOAA, and the Navy. The IOOS observing subsystem employs both remote and in situ sensing. Remote sensing includes satellite-, aircraft- and land-based sensors, power sources and transmitters. In situ sensing includes platforms (ships, buoys, gliders, etc.), in situ sensors, power sources, sampling devices, laboratory-based measurements, and transmitters.

3.3 In-Situ Terrestrial Observations

For terrestrial observations, GCOS and the Global Terrestrial Observing System (GTOS) have identified permafrost thermal state and permafrost active layer as

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

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

Polar Climate Observations—Polar climate observations will continue to be a focus of U.S. activities as preparations are made for the International Polar Year beginning in 2007. Currently, the United States maintains soil-moisture climate stations in both Alaska and Antarctica, and plans to increase efforts on observations of the Arctic atmosphere, sea ice, and ocean. Working with a number of Arctic nations via the International Arctic Systems for Observing the Atmosphere (IASOA), the United States will deploy and/or participate in a number of observing activities to produce a higher-resolution characterization of clouds and aerosols and of both incoming and outgoing radiation, to provide the high-quality records needed to detect climate change and to improve calibration of broad-scale satellite observations in the Arctic. For example, through the IASOA process, the United States will be working with its international partners in establishing a super-site climate observatory in the Russian Arctic in Tiksi, north of the Arctic Circle at latitude 71.5° North.

The AmeriFLUX Network—The AmeriFLUX network endeavors to establish an infrastructure for guiding, collecting, synthesizing, and disseminating long-term measurements of CO₂, water, and energy exchange from a variety of ecosystems. Its objectives are to collect critical new information to help define the current global CO₂ budget, enable improved projections of future concentrations of atmospheric CO₂, and enhance the understanding of carbon fluxes, net

ecosystem production, and carbon sequestration in the terrestrial biosphere.

The North American Carbon Program (NACP)—The NACP is a major focus of the US CCSP, to measure and understand the source and sinks of CO₂, CH₄, and CO in North America and in adjacent ocean regions.

3.4 Space-Based Observations

Space-based, remote-sensing observations of the atmosphere–ocean–land system have evolved substantially since the early 1970s, when the first operational weather satellite systems were launched. Over the last decade satellites have proven their observational capability to accurately monitor nearly all aspects of the total Earth system on a global basis. Currently, satellite systems monitor the evolution and impacts of El Niño and La Niña, weather phenomena, natural hazards, and vegetation cycles; the ozone hole; solar fluctuations; changes in snow cover, sea ice and ice sheets, ocean surface temperatures, and biological activity; coastal zones and algal blooms; deforestation and forest fires; urban development; volcanic activity; tectonic plate motions; aerosol and 3-dimensional cloud distributions; water distribution; and other climate-related information.

A number of U.S. satellite operational and research missions form the basis of a robust national remote-sensing program that fully supports the requirements of GCOS (U.S. DOC/NOAA 2001). These include instruments on the Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellites (POES), the series of Earth Observing Satellites (EOS), the Landsats 5 and 7, and the Jason satellite measuring sea-surface height, winds, and waves. Additional satellite missions in support of GCOS include (1) the Active Cavity Radiometer Irradiance Monitor for measuring solar irradiance; (2) the EOS-Terra, Aqua, and Aura series; (3) QuickSCAT; (4) the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) for studying ocean and productivity, as well as aerosols; (5) the Shuttle Radar Topography Mission; and (6) the Tropical Rainfall Measuring Mission for measuring rainfall, clouds, sea-surface temperature, radiation, and lightning. A major upgrade to the GOES system, known as GOES-R, is under development, with a first launch scheduled for late 2012. It should also be noted that a number of new missions will be launched over the next several years as follows [launch year in brackets]: (1) Orbiting Carbon Observatory [2008] mission to measure CO₂; (2) Glory mission [2008] which will measure black carbon soot and other aerosols, as well as total solar irradiance; (3) Ocean Surface Topography Mission [2008] which is an altimetry mission to provide sea surface heights for determining ocean circulation, climate change and sea-level rise; (4) Aquarius [2009] intended to measure global sea surface salinity; and (5) Global Precipitation Measurement (GPM) mission [2012]. Some recent missions since the last report to the UNFCCC include:

The Ice, Cloud, and Land Elevation Satellite (ICESat), launched in 2003, has been measuring surface elevations of ice and land, vertical distributions of clouds and aerosols, vegetation-canopy heights, and other features with unprecedented accuracy and sensitivity. The primary purpose of ICESat has been to acquire time series of ice-sheet elevation changes for determining the present-day mass balance of the ice sheets, to study associations between observed ice changes and polar climate, and to improve estimates of the present and future contributions to global sea level rise.

The Solar Radiation and Climate Experiment (SORCE) satellite, launched in 2003, is equipped with four instruments that measure variations in solar radiation much more accurately than previous measurements and observe some of the spectral properties of solar radiation for the first time.

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and CloudSat satellites were successfully launched in April 2006. CALIPSO and CloudSat are highly complementary and together will provide new, three-dimensional perspectives of how clouds and aerosols form, evolve, and affect weather and climate. Both Calipso and CloudSat fly in formation as part of the NASA A-Train constellation (e.g., along with Aqua, Aura, and the French PARASOL spacecraft), providing the benefits of near simultaneity and thus the opportunity for synergistic measurements made with complementary techniques.

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

3.5 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.

Cooperative efforts by CCSP and USGEO agencies are moving toward providing integrated and more easily accessible Earth observations. Currently operating CCSP systems for data management and distribution highlighted in the 2007 Our Changing Planet report include NASA's Global Change Master Directory and Earth Observing System Data and Information System, and DOE's Carbon Dioxide Information Analysis Center (CCSP and SGCR 2006a). NOAA's

The National Climatic Data Center's (NCDC) Climate Data Online site provides climate data from multiple stations around the world. Plans for 2007 and 2008 include the International Polar Year (IPY) participation through a focus on polar climate observations via NCDC's World Data Center for Meteorology [see <http://www.ncdc.noaa.gov/oa/wdc/>].

Carbon Dioxide Information Analysis Center (CDIAC). DOE's CDIAC provides comprehensive, long-term data management support, analysis, and information services to DOE's climate change research programs, 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 CO₂ emission rates, atmospheric concentration levels, land-atmosphere fluxes, ocean-atmosphere fluxes, and oceanic concentrations and inventories. In 2008, CDIAC will augment its ocean holdings by offering CO₂ measurements from buoys, research cruises, and Volunteer Observing Ships lines along U.S. coastlines to support the NACP. In 2008, CDIAC will also release the final CARINA synthesis database including both discrete and underway measurements. CDIAC will release of the final PICES synthesis database, which will replace the previous North Pacific discrete measurement component of the [Global Ocean Data Analysis Project](http://www.globalocean.org/).

Quality Assurance for the Global Atmosphere Watch (GAW) Precipitation Chemistry Program. Precipitation chemistry remains as a major environmental issue due to concerns over eutrophication, ecosystem health, biogeochemical cycling, and global climate change. Although global modeling assessments require data of high and known quality, many of the laboratories supporting the approximately 200 site global network require expert assistance and ongoing oversight. The NOAA Air Resources Laboratory, in close cooperation with the State University of New York at Albany, Environment Canada, European, East Asian, and other scientists, has addressed these problems through the development and provision of a guidance manual for program participants, and the development of a tool for rapid assessment of laboratory quality by data users. Global laboratory intercomparison data are presently posted at <http://www.gasac-americas.org/> and may be displayed by clicking on the "Data" link and then on "Ring Diagram Assessments". Intercomparisons have been conducted annually beginning in 1985 and biannually beginning in 2001. In addition to complete quality assurance information, it is the goal of this program to make all GAW precipitation chemistry data freely downloadable on the Web.

3.6 Global Change Master Directory

The Global Change Master Directory (GCMD) is an extensive directory of descriptive and spatial information about data sets relevant to global change research. The GCMD provides a comprehensive resource where a researcher, student, or interested individual can access sources of Earth science data and related tools and services. At present the GCMD database contains over 18,200 metadata descriptions of data sets from approximately 2,800 government agencies, research institutions, archives, and universities worldwide; updates are made at the rate of 900 descriptions per month. The GCMD contains descriptions of data sets covering all disciplines that produce and use data to help understand our changing planet. Although much research is focused on climate change, the GCMD includes metadata from disciplines including atmospheric science, oceanography, ecology, geology, hydrology, and human dimensions of climate change. This interdisciplinary approach is aimed at researchers exploring the interconnections and interrelations of multidisciplinary global change variables (e.g., how climate change may affect human health). The GCMD has made it easier for such data users to locate the information they desire. The latest version of the GCMD software was released in May 2007 as MD9.7. Software upgrades are made in response to user needs and to capitalize on new technology. A portal has been created in support of the Global Environmental System Of Systems (GEOSS). [See <http://globalchange.nasa.gov> or <http://gcmd.nasa.gov>]

3.7 NOAA Virtual Data System (NVDS)

NVDS is a distributed web-based system to support customer requirements for NOAA's global climatological, geophysical, and oceanographic data from the three NOAA National Data Centers at the National Climatic Data Center, National Geophysical Data Center, and National Oceanographic Data Center. NVDS provides online access to a climate data archive of radar, satellite, model, and other data (over 1.5 petabytes accessible online), thereby allowing 99% of all data orders to be placed and filled online. Some examples of data usage include engineering design projects to calculate: (1) ice loads for towers, cables, and wires; 2) wind loads for buildings; (3) heating and cooling requirements; and (4) drainage and runoff extremes for pipes and culverts. Other climate related applications involve aircraft operations for runway design and instrument landing systems (wind climatologies); accident investigations; ship routing and oil rig placement; global re-analyses for climate trends assessment used by the IPCC; HAZMAT operations and studies related to oil spills and toxic releases; weather risk management; insurance investigations and verification; court cases and criminal investigations; and wind energy studies related to the siting of wind farms.

NOAA Integrated Data and Environmental Applications (IDEA) Center. Efforts are being explored

to improve climate data integration in the Pacific Islands region and produce more useful, end-user-driven climate products. The newly created NOAA IDEA Center is developing more customer-focused, integrated environmental products. Operating under the auspices of NOAA's NCDC, the IDEA Center is partnering with academic institutions and other federal and local agencies in the region to provide information on (1) issues related to Pacific islands, including past, current, and future trends in patterns of climate- and weather-related extreme events (e.g., tropical cyclones, flooding, drought, and ocean temperature extremes); (2) their implications for key sectors of the economy, such as agriculture, tourism, and fisheries; and (3) options for coastal communities and marine ecosystem managers to adapt to and manage the effects of variable and changing environmental conditions [see <http://www.apdrc.soest.hawaii.edu/PRIDE>].

The Global Observing Systems Information Center (GOSIC) at <http://goscic.org> serves as a central data integration facility for the data and information requirements related to global observing data access and retrieval. The GOSIC began as a developmental activity at the University of Delaware in 1997, and as of January 2007, has fully transitioned to an operational global data facility operated by NCDC on behalf of, and with the concurrence of, the global observing community. The GOSIC provides information, and associated tools, to facilitate better access to data and information produced by the Global Climate, Ocean, and Terrestrial Observing Systems (GCOS, GOOS and GTOS) and their partner programs. The distributed nature of this vast system of global and regional data and information systems is best served by such a single entry point for users. GOSIC provides that entry point by performing such functions as providing global data system documentation and metadata, providing an integrated overview of the various global observing programs, and facilitating on-line access to their data, information, and related data services. GOSIC offers a search capability across international data centers in order to better facilitate access to a worldwide set of observations and derived products that provide the end user with a consistent interface across all centers. In addition to supporting the global observing community's data and information needs, it also supports the data management operations of the World Data Center (WDC) for Meteorology, Asheville. Furthermore, the GOSIC assists NCDC's internal data management work by providing a focus for improving key data management facilities within NCDC which all contribute to various aspects of GEOSS. The GEO Secretariat, recognizing the value of GOSIC's suite of data integration and retrieval tools, has invited it to participate in the scenario development and build-out of the GEOSS Architecture Implementation Pilot; additionally GOSIC will also be working with the U.S. GEO-IDE Program Manager to assist that effort in providing data integration and retrieval assistance. An example involving climate data access is that via GOSIC's efforts, NCDC's data can now be viewed in the GeoNetwork at

<http://www.fao.org/geonetwork/srv/en/main.home> and this is a direct result of GOSIC's proactive and flexible data integration efforts.

4. ANNUAL STATE OF THE CLIMATE REPORT— USING EARTH OBSERVATIONS TO MONITOR THE GLOBAL CLIMATE

NOAA, in partnership with the WMO along with numerous national and international partners established a State of the Climate program, which 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 program 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 observing and analysis systems are unique to countries or regions of the world, but through this effort, the information from each system is openly shared and has proven 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. Working with the WMO this report is also translated into other languages and distributed to all 187 WMO member nations. The State of the Climate Report seeks to report on as many of the Essential Climate Variables as possible as identified by GCOS Second Adequacy Report.

5. CONCLUSION

The U.S. has been very supportive of the overall international GCOS program effort and has provided considerable support on both a global, regional, as well as bi-lateral basis. It is believed that support for GCOS should be global in nature and the U.S. is working to be a leader in helping to make GCOS a sustainable and robust system both regionally and globally, and that can serve the needs of an improved global climate monitoring system that is part of GEOSS) being planned internationally by more than 70 nations and over 40 international organizations; see the following URL for more details: <http://earthobservations.org>.

The U.S. GCOS Program Office at NCDC has identified high elevation and high latitude surface observing sites as being a high priority for filling critical gaps in global surface observing. The partnerships and associated activities identified here have been keys in

beginning to address these gaps on a long-term and sustainable basis.