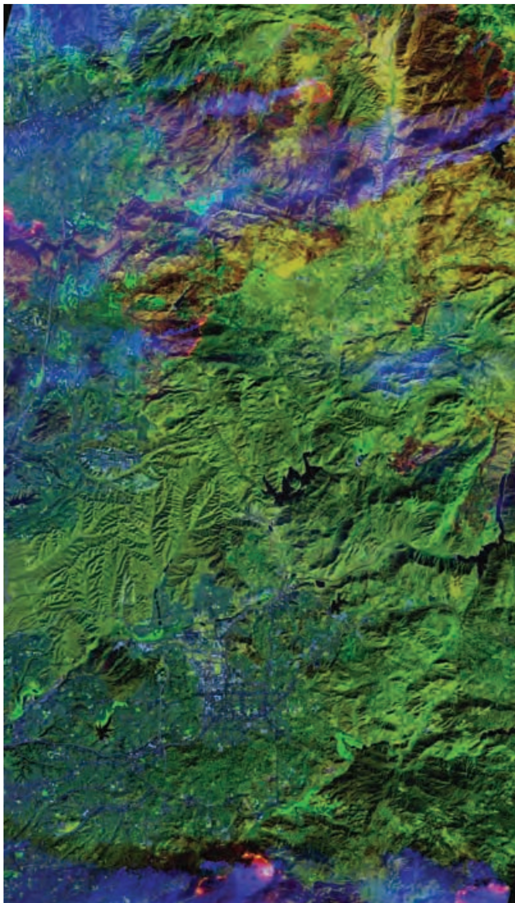


8 | Observing and Monitoring the Climate System

Observing and Monitoring the Climate System

Goal 12.1: Design, develop, deploy, and integrate observation components into a comprehensive system.
Goal 12.2: Accelerate the development and deployment of observing and monitoring elements needed for decision support.
Goal 12.3: Provide stewardship of the observing system.
Goal 12.4: Integrate modeling activities with the observing system.
Goal 12.5: Foster international cooperation to develop a complete global observing system.
Goal 12.6: Manage the observing system with an effective interagency structure.

Data Management and Information

Goal 13.1: Collect and manage data in multiple locations.
Goal 13.2: Enable users to discover and access data and information via the Internet.
Goal 13.3: Develop integrated information data products for scientists and decisionmakers.
Goal 13.4: Preserve data and information.

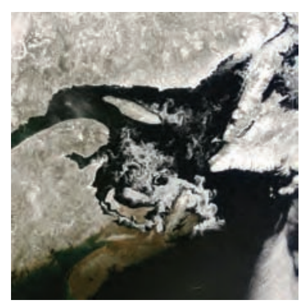
See Chapters 12 and 13 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these goals.

Two overarching questions are identified in the CCSP Strategic Plan for "Observing and Monitoring the Climate System" and "Data Management and Information". These questions continue to offer guidance to these elements of the program:

- How can we provide active stewardship for an observation system that will document the evolving state of the climate system, allow for improved understanding of its changes, and contribute to improved predictive capability for society?
- How can we provide seamless, platform-independent, timely, and open access to integrated data, products, information, and tools with sufficient accuracy and precision to address climate and associated global changes?

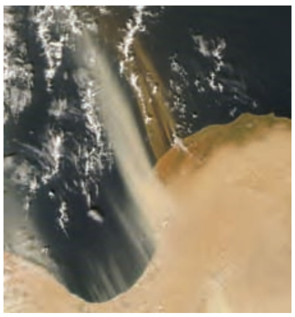
High-quality, long-term observations of the global environment are essential for defining the current state of the Earth's environmental system, its history, and its variability. This task requires both space- and surface-based observation systems. Climate observations encompass a broad range of environmental observations, including (1) routine weather observations, which are collected consistently over a long period of time; (2) observations collected as part of research investigations to elucidate processes that contribute to maintaining climate patterns or 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.

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 *in situ* observational capabilities. CCSP 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 Global Climate Observing System (GCOS) principally sponsored by the World Meteorological Organization (WMO); the Global Ocean Observing System sponsored by the United Nations Educational, Scientific, and Cultural Organization's Intergovernmental Oceanographic Commission (IOC); and the Global Terrestrial Observing System sponsored by the United Nations Food and Agriculture Organization. The latter two have climate-related elements being developed jointly with GCOS.



A specific subset of the GCOS observing activities for 2007 and 2008 (and into 2009) are the CCSP-sponsored polar climate observations made in cooperation with the International Polar Year (IPY). During 2009, IPY will come to a formal conclusion; however, many polar observing systems will continue to operate. Several agencies are working together to establish an Arctic Observing Network that will build on systems deployed during IPY and provide for coordinated efforts to sustain key climate observations. This cooperation will extend to international partners to encourage a pan-Arctic approach to observation and data sharing.

Remotely sensed observations continue to be a cornerstone of CCSP. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) lidar 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 *in situ* observing systems presents a continuing challenge for CCSP agencies to ensure that data management systems are able to handle the expected increases.



Highlights of Recent Research—Observations and Monitoring

The following are selected highlights of observation and monitoring activities supported by CCSP-participating agencies. The principal focus of this chapter is on describing progress in implementing the observations that contribute to the CCSP mission. As a result, the chapter touches on some observing systems that are crucial to CCSP but are not included within the CCSP budget because they primarily serve other purposes.

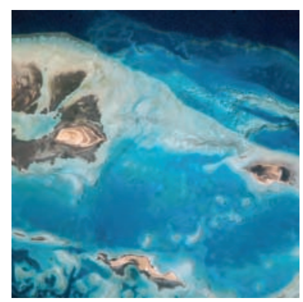
Integrated Surface Climate Observations. The integration of a series of surface observing system networks is intended to sustain the Nation's record of land surface measurements essential to monitor and assess the surface climate. This project integrates land surface observations from regional, national, and international sources. Three major surface climate networks cover the U.S. region: (1) the U.S. Climate Reference Network (CRN) sites; (2) the Surface Energy Budget Network; and (3) a modernized Historical Climate Network. CCSP's automated observing systems, voluntary cooperative observing systems, mesonet observing systems, and private sector observations are also integrated into the system. These surface observing systems contribute measurements of 10 key GCOS essential climate variables: air temperature, precipitation, atmospheric pressure, surface radiation, vector winds, water vapor, clouds, soil temperature, soil moisture, and snow depth.

Initial Ocean Observing System for Climate Reaches 59% Completion. CCSP agencies cooperate with 66 nations in implementing the internationally vetted design of an initial ocean observing system for climate, articulated in the WMO/IOC/UNEP plan for GCOS. Deployment of the observing system, planned for completion in 2013, is proceeding, with the United States currently supporting nearly 50% of the ocean-based observing platforms.

Tropical Moored Buoy Network Extended into the Indian Ocean. CCSP continues to provide leadership in the development of the Indian Ocean Observing System (IndOOS), a multi-national, multi-platform network designed to support climate forecasting and

research. IndOOS is a regional cornerstone of the Global Earth Observing System of Systems (GEOSS) and has been endorsed by committees of the World Climate Research Programme and the IOC. By the end of FY 2008, the array of moorings will consist of 12 sites (four new sites in FY 2008), bringing the total moored buoy array, including all international contributions, to 43% completion.

GCOS Tide Gauge Network Expands Real-Time Reporting Capacity. The GCOS tide gauge network is a subset of the global sea-level observing system, providing high-precision, geo-located tide gauge records appropriate for monitoring long-term climate trends in sea level. Plans call for a network of 180 stations across the globe. As of the beginning of FY 2008, the United States and its partners had added, upgraded, or maintained 127 stations in support of the international goal. The reference-level data sets are used in conjunction with operational numerical models for the calibration of satellite altimeter data, the compilation of oceanographic data products, and research on interannual to decadal climate fluctuations and short-term extreme events. They are also used by various national tsunami warning agencies for tsunami monitoring.



Global Coverage Achieved by the Argo Profiling Array. In 1998, an international consortium presented plans for an array of 3,000 autonomous instruments that would revolutionize the collection of climate-relevant information from the upper 2 km of the world's oceans—the Argo array. These instruments drift at depth, periodically 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 the array 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 has made possible huge advances in the representation of the oceans in coupled ocean-atmosphere models used 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.

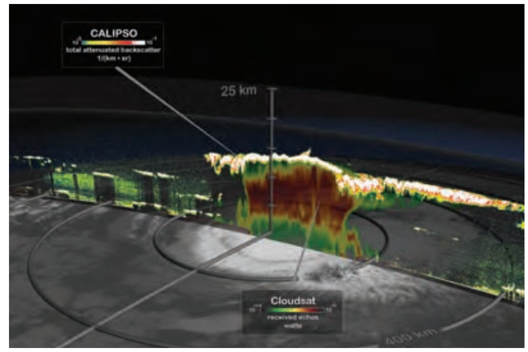
Global Network of Automated Surface-Based Aerosol Measurements.[1] The Aerosol Robotic Network (AERONET) continued expansion of monitoring coverage of the optical properties of atmospheric aerosols (pollution, smoke, desert dust) to a global network of approximately 230 automated sites. Key additional sites were added on the Tibet plateau and in the Ganges floodplain of India to monitor the potential impacts of atmospheric particulates on the region, including possible impacts on atmospheric circulation. New data analysis techniques have been developed that provide a more accurate measure of particle size. In addition, the determination of aerosol light absorption has been improved, which is critical for reducing the current large uncertainties in aerosol radiative forcing of climate. Analysis of data collected in 2004 in the United Arab Emirates with these newly enhanced techniques demonstrated this improved ability to measure aerosol absorption, which leads to a better understanding of the dynamics of desert dust and pollution aerosols over a variety of environments, including Arabian Peninsula desert and over the Persian Gulf. AERONET has also recently included measurements made on ships of opportunity with hand-operated instruments, to better characterize marine environments where no islands exist for automated monitoring. From June through August 2007, AERONET organized numerous ground-based measurements under the CALIPSO satellite flight track in order to validate the satellite products and also to make use of the combined information from both upward- and downward-viewing remote-sensing measurements.

Surface-Based Micro Pulse Lidar Network.[2,3,4] The Micro Pulse Lidar Network (MPLNET) 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 (see <mplnet.gsfc.nasa.gov>). At present, 13 permanent sites are operational worldwide, with 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 AERONET sun photometer sites to provide both column and vertically resolved aerosol and cloud data, such as optical depth, absorption, size distribution, aerosol and cloud heights, and 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 (opacity). 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 researchers can estimate aerosol extinction directly affects ability to quantify aerosol impacts on climate.

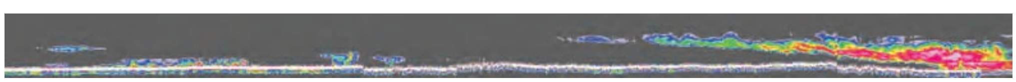
Multi-Platform Field Experiment to Study Tropical Clouds and Climate. CCSP scientists completed the Tropical Composition, Cloud, and Climate Coupling (TC4) field experiment in Costa Rica (July to August 2007), which focused on identifying and quantifying chemical and dynamical processes occurring in the tropical tropopause layer. This region of the Earth's atmosphere plays a key role in both climate change science and atmospheric ozone depletion. One of the specific goals of TC4 was to study the composition, formation, and radiative properties of clouds (cirrus and sub-visible cirrus) in this region, thereby assessing the contributions of such clouds, aerosols, and water vapor to climate forcing. Other aspects of the campaign focused on understanding the convective processes that control the transport of air from the lower atmosphere into the tropical tropopause layer (the coldest layer of the atmosphere, at 14 to 18 km altitude) and thence into the stratosphere where they can influence stratospheric ozone. This campaign combined the unique observations from the A-Train satellites and three ground-based and balloon sonde stations in the inter-tropical convergence zone together with three instrumented aircraft flying in a stacked formation (NASA's DC-8, WB-57, and ER-2). Through such coordinated measurements, the TC4 campaign not only sought to address processes controlling the composition of the upper troposphere but also to validate and enhance satellite data analysis. The ER-2 contained downward-looking remote-sensing instruments and flew at an altitude of 20 km, similar to some satellite instruments. The WB-57 contained *in situ* instruments and flew within the upper-troposphere cloud layers to characterize the composition simultaneously observed remotely from above. The DC-8 contained both *in situ* and remote-sensing instruments to quantify the composition of gases, aerosols, and clouds below and into the upper-atmosphere cloud layers transported upward by convection. Numerous research efforts using TC4 data will improve understanding of this important atmospheric region.

CloudSat Measurements. Data from the CloudSat radar have provided scientists with new insights into clouds and their structure, and have also provided entirely new insights into Earth's most vital source of freshwater and revealed fascinating views of the massive weather systems that form and die as they circle Earth. Some of the new discoveries offered over the first 12 months of CloudSat operations include:

- The first real information on the fraction of clouds that produce precipitation. These observations indicate that almost 15% of clouds over oceans produce precipitation that reaches the surface. Thus, CloudSat has shown precipitation to be much more common than previously thought, because precipitation over oceans is extremely hard to measure and light rain that often falls has been completely missed by satellite observations until now. Weather and climate models currently fail to predict this precipitation and it is expected that CloudSat observations will lead to direct improvements in these predictions.



- For the first time, the ability to peer inside major damaging storms, revealing cloud structures and rainfall of hurricanes for the very first time. These observations have provided scientists with new satellite-based estimates of hurricane intensity. These observations are important as they uniquely test theories that shape understanding of how storm intensity might change due to climate change.
- Weather and climate-prediction models indicate that the majority of rainfall comes from deep thunderstorms. However, CloudSat observations now show that a large proportion of rain falls from much shallower clouds.
- New insights on the greenhouse effects of clouds, identifying where and when clouds trap heat in the atmosphere and increase heat lost from the atmosphere to space. This dynamic tradeoff between heating and cooling is one of the basic controls on global climate and this new knowledge gives scientists better tools with which to predict future climate.
- Observations of clouds over polar regions during winter. These clouds have been largely invisible to earlier satellites because of the lack of sunlight and the difficulty of sensing a difference between cold clouds and cold ice-covered surfaces. The polar regions are extremely sensitive to climate warming and the complex interplay between the polar surface and polar clouds can now be studied for the first time.



Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). Like CloudSat, the CALIPSO mission celebrated its first year of operation in June 2007, and is providing new observations of the global distribution and vertical structure of aerosols and thin clouds with unprecedented detail. CALIPSO's innovative measurement capabilities, together with those from the A-Train satellite constellation (see Figure 20), are helping to better understand how aerosols modify Earth's climate by cooling the surface or warming the atmosphere; how they affect cloud lifetimes and precipitation; and how they are lofted into the free troposphere, transported long distances, and affect air quality. CALIPSO's measurements of thin tropical clouds are also providing new insight into processes that maintain the humidity distribution in the upper troposphere. In addition,

CALIPSO and MODIS Composite Product

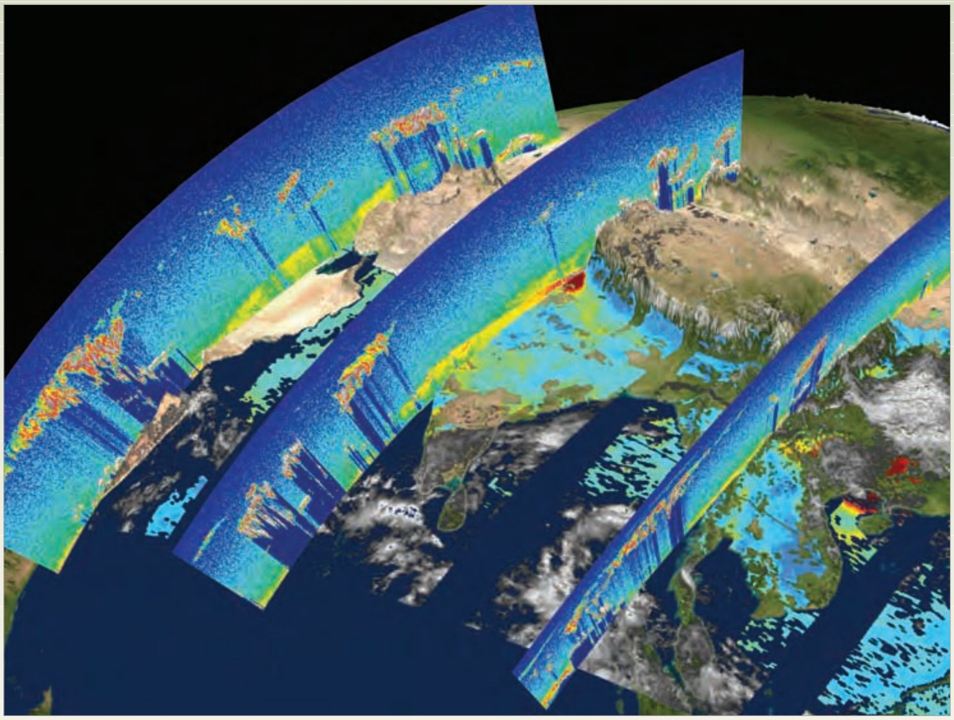
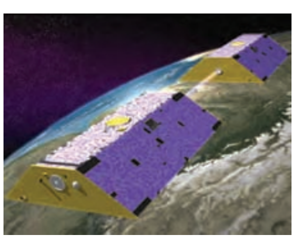


Figure 20: CALIPSO and MODIS Composite Product. A composite image showing CALIPSO observations of lidar backscatter superimposed with aerosol optical measurements from Aqua MODIS over south central Asia on 25 October 2006. CALIPSO measurements show aerosols pooling next to the Himalayan mountains (seen by bright yellow and red colors). These data aid studies of aerosols over India and the aerosol-induced warming of the atmosphere, which contribute to retreat of Himalayan glaciers. *Credit: C.R. Trepte, NASA / Langley Research Center*.

these data are being combined with observations from CloudSat to produce a composite survey of the vertical distribution of clouds of varying thickness and layering, especially in the difficult-to-measure polar night. In concert with observations from the Aura satellite, CALIPSO is further aiding in understanding of changes in atmospheric composition by providing new perspectives on the formation and evolution of polar stratospheric clouds that play a key role in the development of the ozone hole.

Surface-Based Observatories of Clouds and Radiation.[5,6,7,8,9,10,11] The Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) provides the infrastructure needed for studies investigating atmospheric processes and for climate model development and evaluation. The ACRF observation resources consist of several highly instrumented stationary facilities, a mobile facility, and aerial vehicles for studying cloud formation processes and their influence on radiative transfer, and for measuring other parameters that determine the radiative properties of the atmosphere. The stationary sites provide scientific test beds in three climatically significant regions (mid-latitude, polar, and tropical), and the mobile facility provides a capability to address high-priority scientific questions in regions not covered by the stationary sites. The aerial vehicles provide a capability to obtain *in situ* cloud and radiation measurements that complement the ground measurements. The ACRF data archive is available to the atmospheric community for climate research in near-real-time. In 2007, the mobile facility was deployed in the Black Forest region of Germany, where scientists studied rainfall resulting from atmospheric uplift (convection) in mountainous terrain (orographic precipitation). Coordinated observations using combinations of mobile and aerial facilities at the ARM fixed sites in the tropics and the Arctic have provided a rich source of information on processes in these regions. Research results have recently been published using these Tropical Warm Pool-International Cloud Experiment and Mixed-Phase Arctic Cloud Experiment coordinated observations. In 2008, the mobile facility will be deployed to China to examine aerosol indirect effects.

Testing Cloud Models by Cloud Type and Atmospheric Conditions.[12,13] Accurate modeling of clouds in climate prediction models remains the largest uncertainty in climate sensitivity over the next century. Typical climate data sets use monthly mean observations at a 100-km spatial scale to reach sufficient sampling for climate accuracy and then test the ability of climate models to reproduce the monthly gridded observations over the globe. A major limitation in this approach is the inability to relate cause and effect in fast climate processes like clouds. During a month of weather in any particular 100-km grid box on the Earth, many different types of clouds, surface, and atmospheric conditions will have occurred, confounding the ability to decide which clouds need fixing, for what types of atmospheric conditions, and for which processes. Meanwhile, typical field experiments can obtain only a few carefully chosen case studies that have insufficient sampling to test models at climate accuracy. New approaches have been developed to obtain the specificity of field experiments by cloud type and/or atmospheric conditions using global satellite observations such as Clouds and the Earth's Radiant Energy System (CERES), Moderate Resolution Imaging Spectrometer (MODIS), and International Satellite Cloud Climatology Project (ISCCP) combined with global weather data. Early results from these new studies used more than 10,000 cloud systems to study what happens when clouds change on climate time scales such as an El Niño event. The results showed that the physical properties of each cloud type (stratus, cumulus, cumulonimbus) remained remarkably stable, but that the frequency of occurrence of each cloud type changed.



Observing Mass Distribution Changes from Space. The Gravity Recovery and Climate Experiment (GRACE) is a two-spacecraft tandem mission, developed under a partnership between NASA and the Deutsches Zentrum für Luft- und Raumfahrt (DLR) of Germany. After 5 successful years of mission operation, many significant multidisciplinary results using GRACE observations have been reported. The unprecedented accuracy of the measurements provides the opportunity to observe time variability in the Earth's gravity field due to changes in mass distribution. The

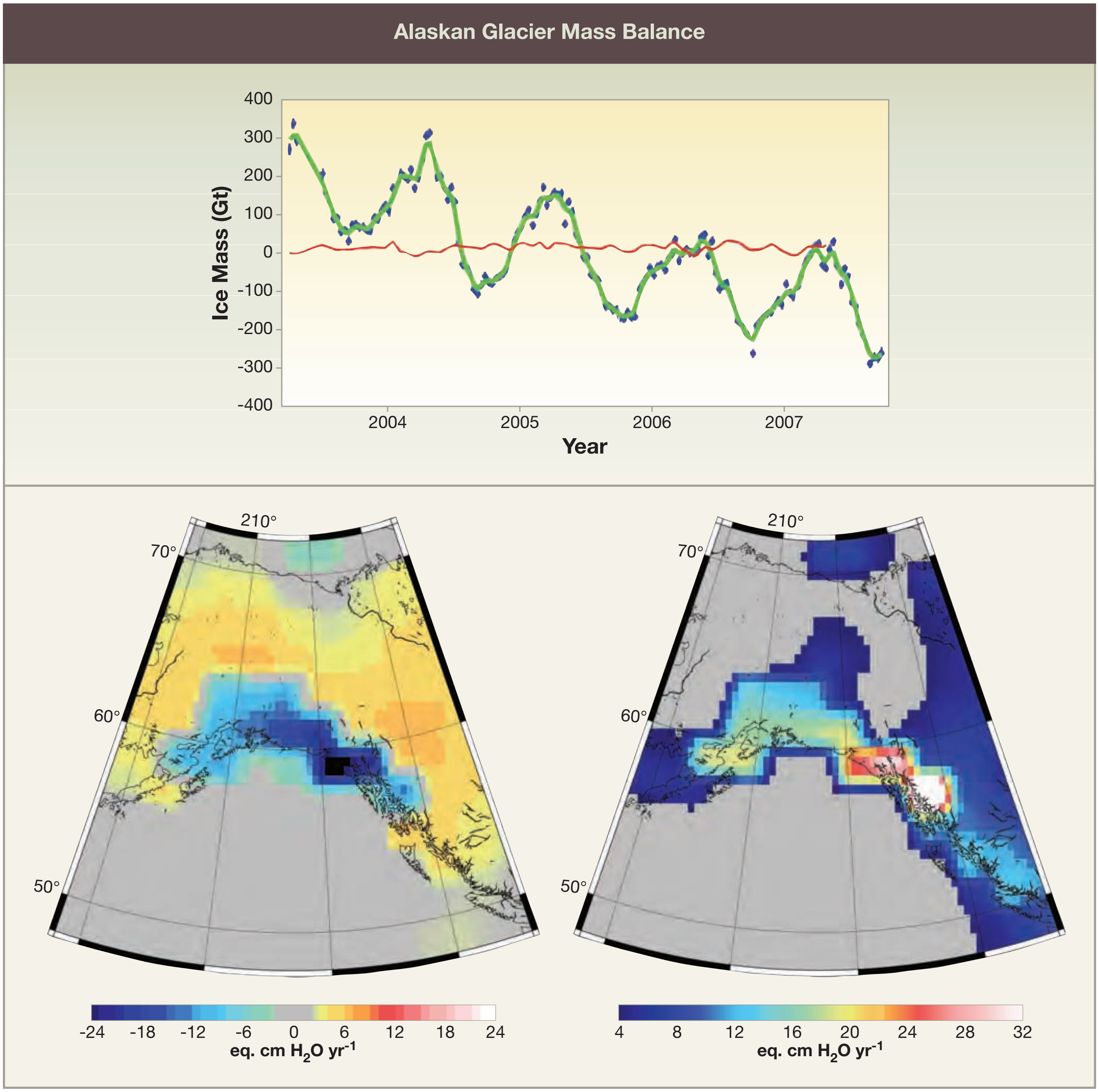
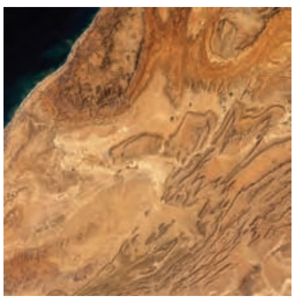


Figure 21: Alaskan Glacier Mass Balance. Alaskan glacier mass balance is provided by analyses of measurements from the GRACE mission's inter-satellite range-rate data (April 2003 through September 2007). The top panel shows the annual variation and overall trend in ice mass for the blue-colored areas in the lower left image (ice mass units are Gt, i.e., 10^{15} g). The lower left image presents the spatial distribution of the surface ice mass trends for the period April 2003 to March 2007. The lower right image shows the spatial distribution of surface annual ice mass change. The greatest negative net balance rates are found in the Yakutat and Glacier Bay regions, while the largest annual amplitudes are found in the southeast glacier regions. Note that surface mass variation contributions from the atmosphere, oceans, tides, terrestrial water storage, and glacial isostatic adjustment have been removed. *Credit: S.B. Luthcke, NASA / Goddard Space Flight Center*.

month-to-month gravity variations obtained from GRACE provide information about changes in the distribution of mass within the Earth and at its surface. The largest time variable gravity signals are the result of changes in the distribution of water, snow, and ice stored on land. Recently GRACE results have been produced on a month-to-month basis for all the major glacier areas of the Earth with areas as small as <50,000 km^2. These results have shown the losses of ice mass in Greenland, Antarctica, and Alaska to be consistent with the observed sea-level rise for the same time period. An example of this exciting work appears as Figure 21 on the previous page. Precise measurements made from satellite orbit may be used to monitor large ice sheets and glacier areas, providing glacier mass balance variations at monthly resolution. GRACE data have emerged as one of the critical climate observations provided by CCSP.



Highlights of Recent Research—Data Management and Information

The following are selected data management and information activities supported by CCSP-participating agencies.

Data Fusion for Climate Sensitivity.[14,15] One of the prime challenges in understanding climate is to unscramble cause and effect in this complex climate system. The Earth's energy balance of heat absorbed and emitted can be changed by changes in any one or more of a range of different surface and atmospheric components including snow, ice, vegetation, cloud, temperature, water vapor, carbon dioxide (CO_2), methane, and aerosols. Recent advances in CCSP global satellite instruments have allowed merging of these many different properties into consistent climate-quality data sets allowing analysis of cause and effect in changing the Earth's energy balance. For example, the NASA CERES energy balance data products now merge data from up to 11 instruments on seven spacecraft from NASA, NOAA, and international partners. The fused CERES data describe energy flow from the surface through the atmosphere to the top of atmosphere and out into deep space. Critical testing of this NASA-developed global radiation balance data is performed against a wide range of DOE- and NOAA-operated surface radiation sites. The new fusion data products are being used to determine what part of climate changes over the course of Earth's reflectance of solar energy back to space are caused by clouds or by snow and ice—both key feedbacks that determine climate sensitivity.

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 CO_2 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 CO_2 measurements from buoys, research cruises, and volunteer observing ship lines along U.S. coastlines to support the North American Carbon Program (NACP). In 2008, CDIAC will also release the final Carbon Dioxide in the Atlantic Ocean (CARINA) synthesis database including both discrete and underway measurements. CDIAC will release the final North Pacific Marine Science Organization (PICES) synthesis database, which will replace the previous North Pacific discrete measurement component of the Global Ocean Data Analysis Project.

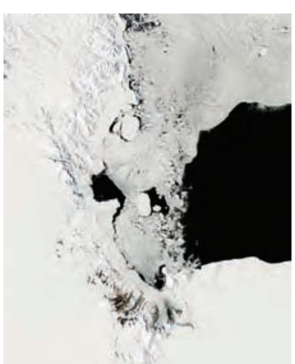
Quality Assurance for the Global Atmosphere Watch (GAW) Precipitation Chemistry Program. Precipitation chemistry remains a major environmental issue due to concerns over eutrophication, ecosystem health, biogeochemical cycling, and global climate change. Although global modeling assessments require data of high and known quality, many of the laboratories supporting the approximately 200-site global network require expert assistance and ongoing oversight. CCSP agency scientists—in close cooperation with the State University of New York at Albany, Environment Canada, and 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. Intercomparisons have been conducted annually since in 1985 and biannually since 2001.[a] In addition to complete quality assurance information, it is the goal of this program to make all GAW precipitation chemistry data freely downloadable from the Internet.

Global Observing System Information Center. The Global Observing System Information Center (GOSIC) began as a developmental activity at the University of Delaware in 1997, and as of January 2007 had been fully converted to an operational global data facility through CCSP agency support on behalf of and with the concurrence of the global observing community. GOSIC provides information, and facilitates easier access to data and information produced by GCOS, the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (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 explanations of the various global data systems, as well as providing an integrated overview of the

[a] Global laboratory intercomparison data are presently posted at <qasac-americas.org> and may be displayed by clicking on the “Data” link and then on “Ring Diagram Assessments.”

various global observing programs, which includes on-line access to data, information, and 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. See <gosic.org> for more detail.

Annual State of the Climate Report—Using Earth Observations to Monitor the Global Climate. In partnership with WMO, along with numerous national and international partners, a State of the Climate monitoring effort has been established, 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 present-day 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 decisionmakers 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 moving data into operational use and filling critical gaps in current knowledge about the state of the global climate system (see <ncdc.noaa.gov/oa/climate/research/state-of-climate> for more detail). A State of the Climate report is distributed through publication in the *Bulletin of the American Meteorological Society* each year. Working with 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 the GCOS Second Adequacy Report.



Polar Ice Albedo and Cloud Feedback.[15,16,17] The International Polar Year is underway in 2007 and 2008. One of the key elements to understand is the role of snow and ice albedo feedback in amplifying the sensitivity of climate. As snow and ice retreat in a warming climate, they expose darker, less reflective surfaces that can allow additional absorption of solar radiation, and therefore further amplify polar and global warming. New global satellite observations since 2000 allow the data fusion of climate accuracy snow data (MODIS), sea-ice cover [Advanced Microwave Scanning Radiometer (AMSR)], cloud properties (MODIS), and global albedo/reflectance (CERES) to study this key feedback with an accuracy never before available. A key advance has been the ability of MODIS to derive more accurate satellite-measured polar snow cover and clouds verified against the DOE Barrow Alaska surface site, and the ability of CERES to derive more accurate polar reflectance to space as a function of snow and cloud changes as well as

new estimates of surface radiation verified against the U.S. Baseline Surface Radiation Network (BSRN) and DOE ARM surface sites. The new data confirm that snow and ice retreat are significantly increasing Earth's absorption of solar energy by reducing its reflectance to space. These new data also include the darkening effects of increasing vegetation in polar regions. At the same time that clear-sky conditions show lower Earth reflectance (warming effect), the data show that much of the drop in reflectance of the Earth due to snow and ice retreat has been offset by an increased reflectance from increasing cloud cover during polar summer (cooling effect). But these same clouds can act to reduce the polar surface emission of thermal radiation to space (especially in polar winter), and further research will look at the total effect of solar and thermal infrared energy in summer and winter seasons.

Highlights of Plans for FY 2009

CCSP will continue to develop and implement integrated systems for observing and monitoring global change, and the associated data management and information systems. Selected key planned activities for FY 2009 and beyond follow.

Global Climate and Ocean Observing Systems. FY 2009 priorities for advancing the atmospheric and ocean observing components of GCOS include: (1) reducing the uncertainty in the carbon inventory of the global ocean, sea-level change, and sea surface temperature; (2) continuing support for existing *in situ* atmospheric networks in developing nations; and (3) planning for surface and upper air GCOS reference observations consistent with CCSP Synthesis and Assessment Product 1.1. As such, the global ocean observing system will make incremental advances, building up to 62% completion: 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 the ocean; and dedicated ships will be deployed to target deployments of Argo and surface drifters in undersampled regions of the world oceans.

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.

These activities will address Goals 12.3 and 12.5 of the CCSP Strategic Plan.

Extended Examination and Intercomparison of Water Vapor Measurements from Aircraft, Balloons, and Satellites. Water vapor is the most important greenhouse gas in the 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, 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. 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 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. CCSP agencies are jointly conducting these activities with the involvement of U.S. 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 present the results of each formal laboratory and flight intercomparison that includes instruments from different research groups. Field intercomparisons will include aircraft-, balloon-, and satellite-borne instruments.

These activities will address Goals 12.3 and 12.5 of the CCSP Strategic Plan.

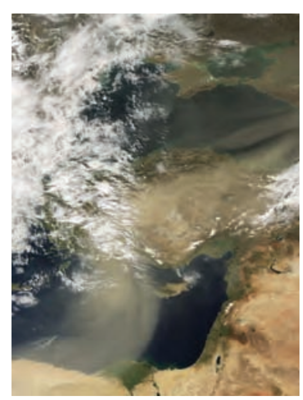
International Polar Year Observations. The United States will conduct aircraft flights over the North Slope of Alaska to measure temperature, humidity, total particle number, aerosol size distribution, cloud condensation nuclei concentration, ice nuclei concentration, optical scattering and absorption, vertical velocity, cloud liquid water and ice contents, cloud droplet and crystal size distributions, cloud particle shape, and

cloud extinction. These data, coupled with ground-based measurements, will be used to evaluate model simulations of Arctic climate. The CALIPSO lidar and CloudSat radar are providing satellite measurements of the difficult-to-observe polar clouds. The last of these capabilities will also directly support IPY activities.

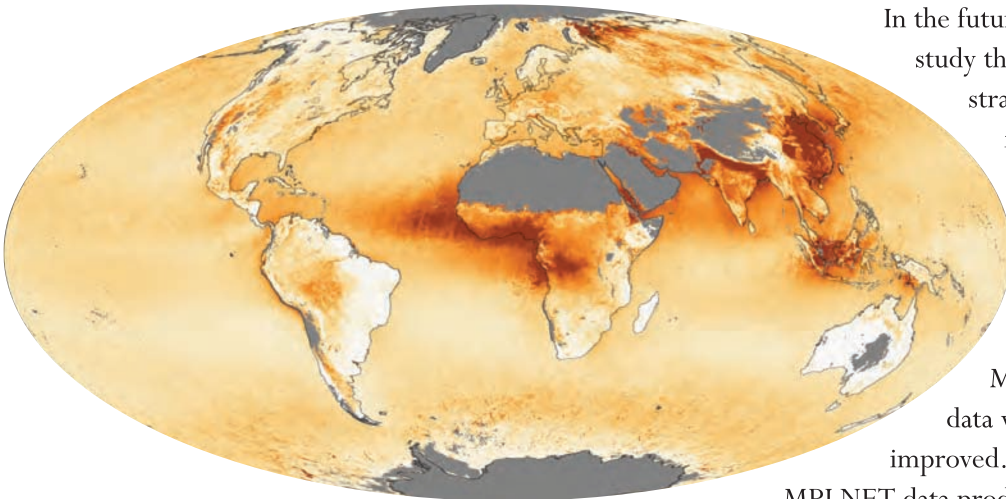
CCSP researchers will begin analysis of data from a series of FY 2008 airborne field campaigns addressing Arctic climate. These analyses of data from aircraft flights, ground measurements, and satellites will contribute to a larger international effort called POLARCAT (Polar Study using Aircraft, Remote Sensing, Surface Measurements, and Models of Climate, Chemical Aerosols, and Transport). Spring observations will be analyzed to assess the long-range transport of anthropogenic pollution to the Arctic and its contribution to Arctic haze and tropospheric ozone chemistry. Summer observations will be analyzed to assess boreal fire emissions. These analyses will ultimately improve the ability of current models to simulate the influence of anthropogenic pollution and boreal fires on the Arctic atmosphere and climate as it relates to changing atmospheric composition, radiative forcing of trace gases and aerosols, and aerosol-cloud interactions.

Finally, two U.S. Climate Reference Network systems will be deployed at the Russian arctic sites of Tiksi (72.5°N) and Yakutsk (63.0°N) in order to provide long-term reference measurements of temperature, precipitation, wind, pressure, and surface radiation in support of IPY and beyond.

These activities will address Goals 12.3 and 12.5 of the CCSP Strategic Plan.



Surface-Based Measurements of Aerosols and Clouds. 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 (early 2009 launch), which will measure aerosol light absorption from space. Network expansion will continue, with a focus on inadequately sampled regions that are important for understanding global climate change, such as China (both the polluted eastern regions and the western deserts that are a source of dust storms). 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 to make measurements of atmospheric CO_2.



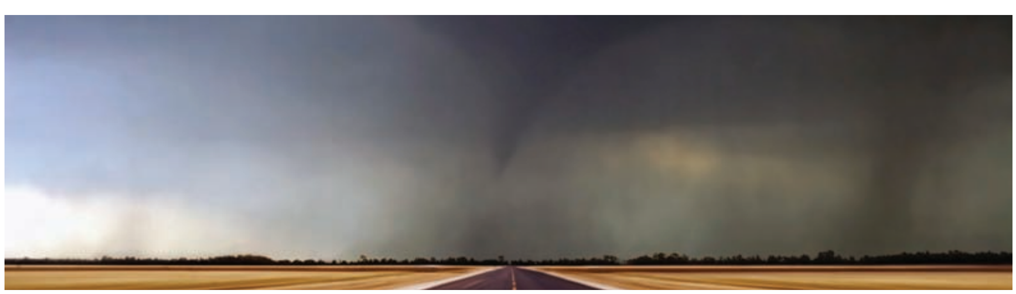
In the future, lidar data will be used to study the influence of polar stratospheric clouds on ozone formation over the South Pole, to study Arctic haze impacts on polar climate, and to generate climatological aerosol and cloud properties at several MPLNET sites. To enhance data value, MPL instrument improved. In addition, several new MPLNET data products will be made available to the research community.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Solar Variability: Glory. The Glory mission is planned to launch in 2009. It will carry a Total Irradiance Monitor (TIM) based on the Solar Radiation and Climate Experiment (SORCE) TIM design, with the same high-precision phase-sensitive detection capability. Glory will also carry an Aerosol Polarimeter Sensor (APS), which will improve the ability to distinguish among aerosol types by measuring the polarization state of reflected sunlight. Both TIM and APS will provide key measurements beginning in 2009 during the minimum of solar cycle 24. This less-active portion of the 11-year solar cycle is especially crucial in estimating any long-term trends in solar output—a key to understanding the 20th-century context of global change, as the Sun is the single entirely "external" forcing of the climate system that is unaffected by climate change itself.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Global Precipitation Measurement Mission. Motivated by the successes of the Tropical Rainfall Measuring Mission (TRMM) satellite and recognizing the need for a more comprehensive global precipitation measuring program, NASA and the Japan Aerospace Exploration Agency conceived a new Global Precipitation Measurement (GPM) mission



that is still in the formulation phase. A fundamental scientific goal of GPM is to make substantial improvements in global precipitation observations, especially in terms of measurement accuracy, sampling frequency, spatial resolution, and coverage, thus extending TRMM's rainfall time series. To achieve this goal, the mission will consist of a constellation of low-Earth-orbiting satellites carrying various passive and active microwave measuring instruments. The GPM mission will be used to address important issues central to improving the predictions of climate, weather, and hydrometeorological processes; to stimulate operational forecasting; and to underwrite an effective public outreach and education program, including near-real-time dissemination of televised regional and global rainfall maps. Assessment of how natural and anthropogenic aerosols affect precipitation variability (and therefore the water cycle) is a complex and important problem. The capability to monitor the diurnal cycle of rainfall globally with GPM is expected to enable significantly improved understanding of the links between aerosols, climate variability, weather changes, hydrometeorological anomalies, and small-scale cloud macrophysics and microphysics.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Aquarius. Aquarius is a satellite mission to measure global sea surface salinity. Its instruments will measure changes in sea surface salinity over the global oceans to a precision of 2 parts in 10,000 (equivalent to about 1/6 of a teaspoon of salt in 1 gallon of water). By measuring global sea surface salinity with good spatial and temporal resolution, Aquarius will answer long-standing questions about how the oceans respond to climate change and the water cycle, including changes in freshwater input and output to the ocean associated with precipitation, evaporation, ice melting, and river runoff. Aquarius is a collaboration between NASA and the Comison Nacional de Actividades Espaciales (CONAE), the Argentine space agency, with an expected launch date in 2009.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Ocean Surface Topography Mission. The accurate, climate-quality record of sea surface topography measurements, started in 1992 with TOPography EXperiment (TOPEX)/Poseidon and continued in 2001 by the Jason satellite mission, will be extended with the Ocean Surface Topography Mission (OSTM). These missions have provided accurate estimates of regional sea-level change and global sea-level rise unbiased by the uneven distribution of tide gauges. Ocean topography measurements from these missions have elucidated the role of tides in ocean mixing and maintaining deep ocean circulation. Further, quantitative determination of ocean heat storage from satellite measurements together with measurements from the Argo global array of temperature/salinity profiling floats have confirmed climate model predictions of the Earth's energy imbalance that is primarily due to greenhouse gas forcing. The high levels of absolute accuracy and cross calibration make these missions uniquely suited for climate research. OSTM is a collaboration among NASA, NOAA, the French space agency Centre National d'Etudes Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Orbiting Carbon Observatory. The Orbiting Carbon Observatory (OCO) is a new mission, expected to launch in 2008, that will provide the first dedicated, space-based measurements of atmospheric CO_2 (total column) with the precision, resolution, and coverage needed to characterize carbon sources and sinks on regional scales and to quantify their variability. Analyses of OCO data will regularly produce precise global maps of CO_2 in the Earth's atmosphere that will enable more reliable projections of future changes in the abundance and distribution of atmospheric CO_2 and studies of the effect that these changes may have on Earth's climate.

These activities will address Goals 12.2 and 12.5 of the CCSP Strategic Plan.

Integrated Ocean Observing System (IOOS). IOOS is the U.S. coastal observing component of GOOS 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 has been established by CCSP via a national IOOS Program Office co-located with the <Ocean.US> consortium of offices consisting of NASA, NSF, NOAA, and the Navy (see <ocean.us>). 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.

These activities will address Goals 12.3 and 12.6 of the CCSP Strategic Plan.

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