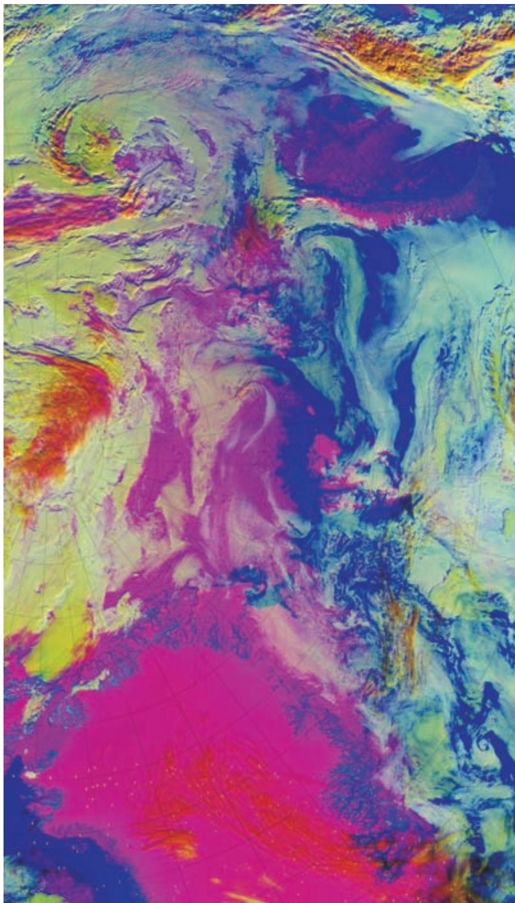


8 | Observing and Monitoring the Climate System

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

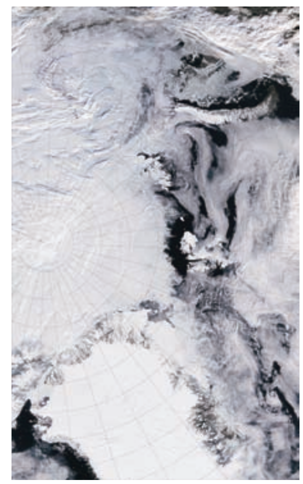
Goal 13.1: Collect and manage data in multiple locations.
Goal 13.2: Enable users to discover and access data and information via the Internet.
Goal 13.3: Develop integrated information data products for scientists and decisionmakers.
Goal 13.4: Preserve data and information.

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" (Chapter 12) and "Data Management and Information" (Chapter 13):

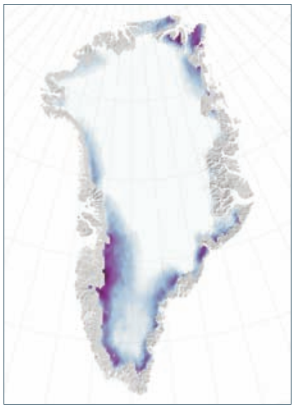
- How can we provide active stewardship for an observation system that will document the evolving state of the climate system, allow for improved understanding of its changes, and contribute to improved predictive capability for society?
- How can we provide seamless, platform-independent, timely, and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

Long-term, high-quality observations of the global environment 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 are collected consistently over a long period of time; (2) observations collected as part of research investigations to elucidate processes to maintain 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.

The importance of ongoing climate observations for detecting unusual changes over small time intervals has recently been emphasized for the Arctic. The Arctic region is experiencing unprecedented large and rapid changes. For example, the area and elevation of melting on the Greenland ice sheet have increased; glacier area, thickness, and volume in Alaska have decreased; permafrost temperatures have risen and thawing is occurring in many areas; Eurasian rivers' discharge into the Arctic Ocean has increased, and sea ice extent, thickness, and volume have decreased; and shrubs and "greenness" have increased on the North Slope of Alaska while boreal forest "greenness" has decreased and fires have increased due to drought. A specific subset of the GCOS observing activities for 2007 and 2008 are the CCSP-sponsored polar climate observations made in cooperation with the International Polar Year (IPY). IPY plans to advance polar observations by establishing a new level of multidisciplinary observatory using the latest technology in sensor web (i.e., a network of spatially distributed sensor platforms that

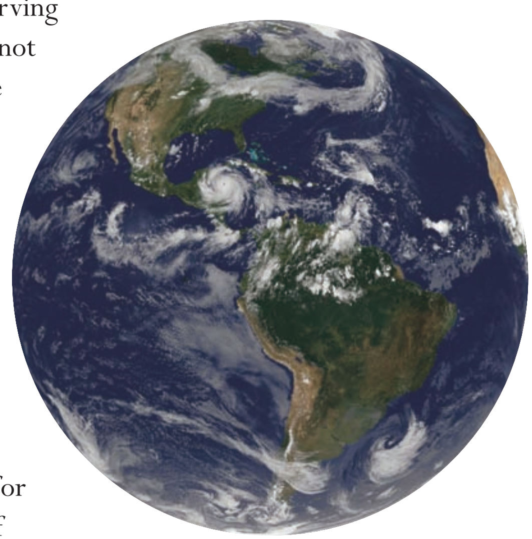


wirelessly communicate with each other) and power-efficient design. Data from these, and more traditional surface- and space-based observatories, will provide high-quality records needed to detect potential future climate change. The United States will increase its efforts on observations of the polar atmosphere, ice, and ocean, as well as leverage its investments in polar research with international partners.

Remotely sensed observations continue to be a cornerstone of CCSP. For example, 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 and called 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. With increases in data volume from a number of remote-sensing and *in situ* observing systems, a continuing challenge for CCSP agencies will be to ensure that data management systems are able to keep up with increases over the next several years. It is imperative that users can effectively make use of an increasing and diverse range of data products that include *in situ*, model output, and satellite data, which is expected to triple in volume by FY 2013.

Highlights of Recent Research

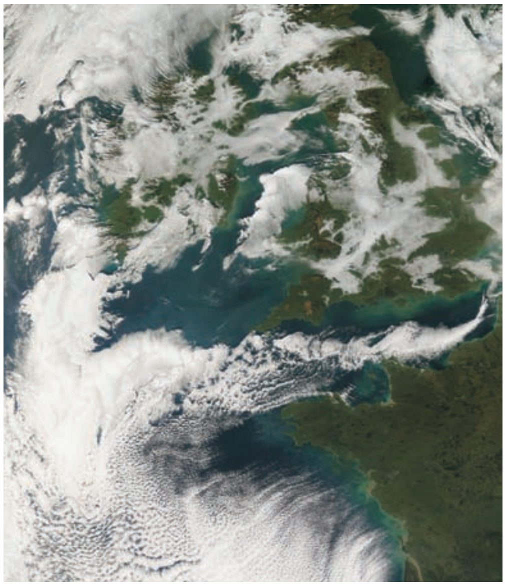
Selected highlights of observation and monitoring activities supported by CCSP-participating agencies follow. The principal focus of this chapter is on describing progress in implementing the observations that contribute to the CCSP mission. As a result, the chapter touches on some observing systems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



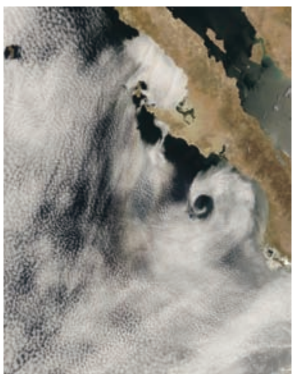
Observations and Monitoring

Tropical Moored Buoy Network Extended into the Indian Ocean. Working in close collaboration with Indian Ocean and Asian partners, a series of moored buoys have been deployed in the Indian Ocean for measurement of a comprehensive suite of ocean-atmosphere climate variables. This westward extension of the equatorial Pacific Tropical Atmosphere Ocean/Triangle Trans-Ocean (TAO) array, whose long-term data have revolutionized understanding of the evolution of El Niño, is necessary to understand changes in Indian Ocean sea surface temperatures, which have recently been shown to influence regional climate variability and change (including prolonged drought in the mid-latitudes, including the United States). Since 2005, eight 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.

Global Coverage Achieved by the Argo Profiling Array. Argo profiling floats, measuring upper ocean temperature and salinity, have now been deployed in all oceans. The United States operates approximately half of the global array in cooperation with 22 countries operating the other half. The floats drift at depth and periodically rise to the sea surface, collecting data along the way, and report their observations in real-time via satellite communications. This global data set is used together with complementary data from satellites and other *in situ* systems to document ocean heat content and global sea-level change.

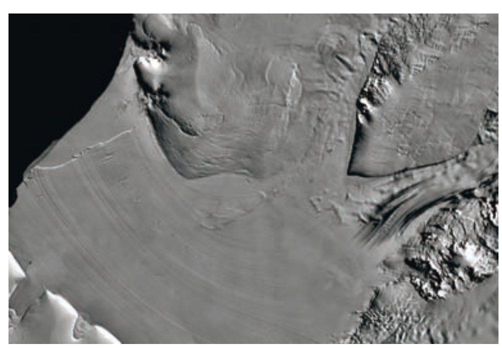


Satellite Observations of Atmosphere, Land, and Oceans. The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument has been operating successfully on NASA's Earth Observing System (EOS) Terra mission for over 6 years and on the Aqua mission for over 4 years. The MODIS instruments have provided daily global observations of atmospheric, land, and ocean features with unprecedented detail, due to the 250- to 1,000-m spatial resolution coupled with multi-spectral capability in 36 carefully selected spectral bands extending from the visible to the thermal infrared portions of the electromagnetic spectrum. Observing the atmosphere, MODIS has produced advanced, detailed observations of the global and regional extent of aerosols from natural and anthropogenic activity. Analysis not only produces accurate determinations of the extent of cloudiness—including that associated with thin, wispy cirrus—that profoundly affects Earth's radiation balance, but also cloud properties such as cloud phase (water or ice), optical depth (i.e., cloud thickness), and effective droplet radius. The MODIS instruments are also providing more detailed observations of land features such as surface reflectance (albedo), surface temperature, snow and ice cover, and the variability of vegetation type and vigor associated with seasonal and climatic (e.g., above and below average moisture) variability. The capability of MODIS to classify vegetation types and the photosynthetic activity of vegetation over the land as well as in the surface waters of the world's oceans (i.e., phytoplankton) is leading to more accurate evaluation of spatial and seasonal changes in the global net productivity of Earth's biosphere. The capability of MODIS to observe global processes and trends is leading to better understanding of natural and anthropogenic effects on the Earth-atmosphere system, and to better performance of general circulation models (GCMs). An example of the latter is the use of atmospheric winds derived from MODIS observations over the polar regions of the globe. These observations have been shown to improve the global predictive skill of several GCMs, both in the polar regions that are undergoing rapid change, and in the mid-latitudes.



Climate Sensitivity, Cloud Feedback, and Global Albedo.[1,2] Recent analyses of state-of-the-art climate model simulations show that uncertainties in cloud feedback continue to dominate uncertainties in climate sensitivity. These studies have also shown that cloud feedback is linearly proportional to changes in cloud radiative forcing, and that low cloudiness appears to dominate the cloud feedback uncertainty. The combination of studies suggests that changes in Earth's albedo through changing low-altitude cloudiness are one of the most critical observations. Analysis of global albedo using broadband satellite observations made from the Clouds and the Earth's Radiant Energy System (CERES) instrument showed that the interannual variations in global albedo are dominated by changes in the tropics. Examination of the year-to-year variability of tropical and global cloud properties observed by CERES and MODIS identified the need for a highly accurate satellite data set of 20 years or more to achieve a sufficient signal-to-noise ratio to estimate decadal changes in cloud radiative forcing representative of cloud feedback in the climate system. These studies have highlighted the increased capability of simultaneous measurements of a wide range of climate variables to allow the clarification of key relationships in major portions of the climate system.

QuikSCAT.[3,4] The SeaWinds instrument aboard the Quick Scatterometer (QuikSCAT) satellite has measured the speed and direction of wind over the surface of the oceans since 1999. Although launched as an experimental instrument, it has been assimilated pre-operationally into atmospheric weather prediction models (NOAA's National Centers for Environmental Prediction, the European Centre for Medium-Range Weather Forecasts, and others) for the past 2 years. It is providing new insights on air-sea exchanges. Furthermore, the underlying radar backscatter data have been applied to climate change research concerning terrestrial high latitudes through studies of ice layer formation.

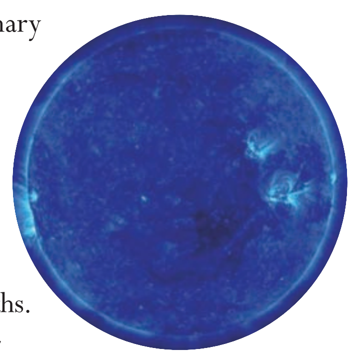


Clues to Variability in Arctic Minimum Sea Ice Extent.[5] Polar systems are especially sensitive to changing conditions and provide early indications of climate change. Perennial sea ice is a primary indicator of Arctic climate change. From 1979 to 2007, it decreased in extent by about 40%. Analysis of new satellite-derived fields of winds, radiative forcing, and transported heat energy reveals distinct regional differences in the relative roles of these parameters in explaining variability in the position of the northernmost ice edge. In all six peripheral seas studied, downwelling longwave radiation flux anomalies explain the most variability—approximately 40%—while northward wind anomalies are important in areas north of Siberia, particularly earlier in the melt season. Anomalies in the amount of solar energy absorbed by the surface are negatively correlated with perennial ice retreat in all regions, suggesting that the effect of solar flux anomalies is overwhelmed by the long-wave influence on ice edge position. This work has taken on new urgency with the 2007 Arctic sea ice minimum extent being the lowest in the 1978 to 2007 satellite record.

ICESat.[6] The Ice, Cloud, and Land Elevation Satellite (ICESat), launched in 2003, has made significant contributions to CCSP's polar observations. The lidar instrument on ICESat measures 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 determination of the present-day mass balance of the ice sheets, study of associations between observed ice changes and polar climate, and improvement of estimates of the present and future contributions to global sea-level rise. ICESat has achieved remarkable successes with first-of-their-kind observations:

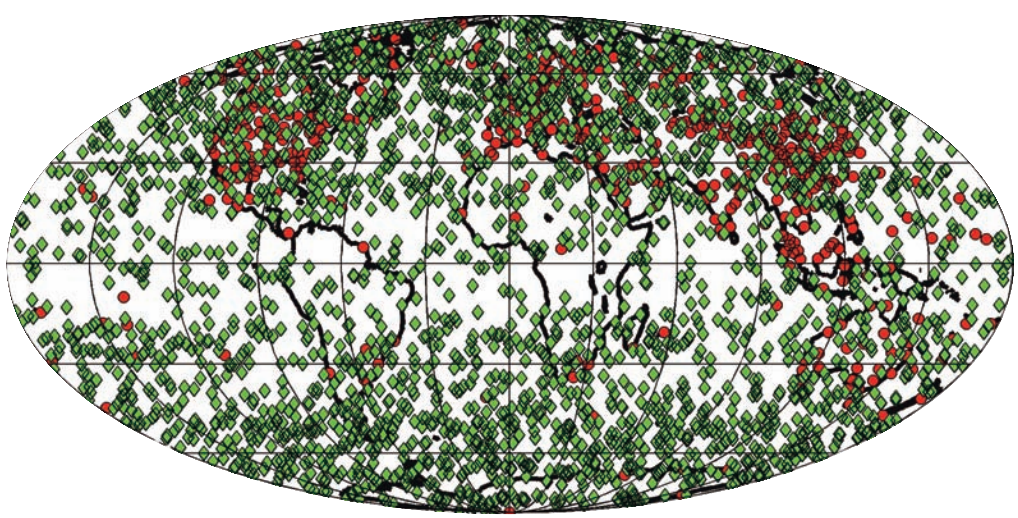
- The most accurate elevation maps to date of the Greenland and Antarctic Ice Sheets (centimeters per year)
- Detection of changes in the Greenland and Antarctic Ice Sheets
- Demonstrated ability to characterize detailed topographic features of ice sheets, ice shelves, and ice streams
- Pioneering sea ice thickness mapping (distributions and means).

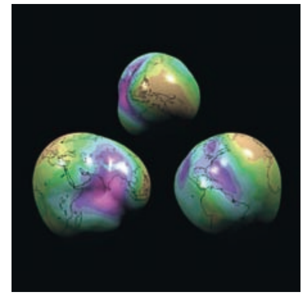
Solar Variability: SORCE Mission.[7] The Sun is the Earth's primary energy source and external driver of climate variability. The Solar Radiation and Climate Experiment (SORCE) satellite, launched in 2003, is equipped with four instruments that measure variations in solar radiation much more accurately than previous instruments. SORCE is now making the first contiguous observations of solar variability across the full solar spectrum, from far ultraviolet to near-infrared wavelengths. SORCE's operational life extends across the 2006-2007 solar



minimum, a crucial period for estimating any long-term trend, such as that indicated by indirect measurements of past solar forcing. The mission is expected to overlap with the Glory mission that will carry forward the total solar irradiance record after 2008. The continued measurements previously planned by the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) through the Total Solar Irradiance Sensor (including a Total Solar Irradiance Monitor and Spectral Irradiance Monitor) were deleted from the NPOESS program during the Nunn-McCurdy recertification process completed in June 2006. Agencies are currently assessing the impacts of this decision for solar irradiance monitoring.

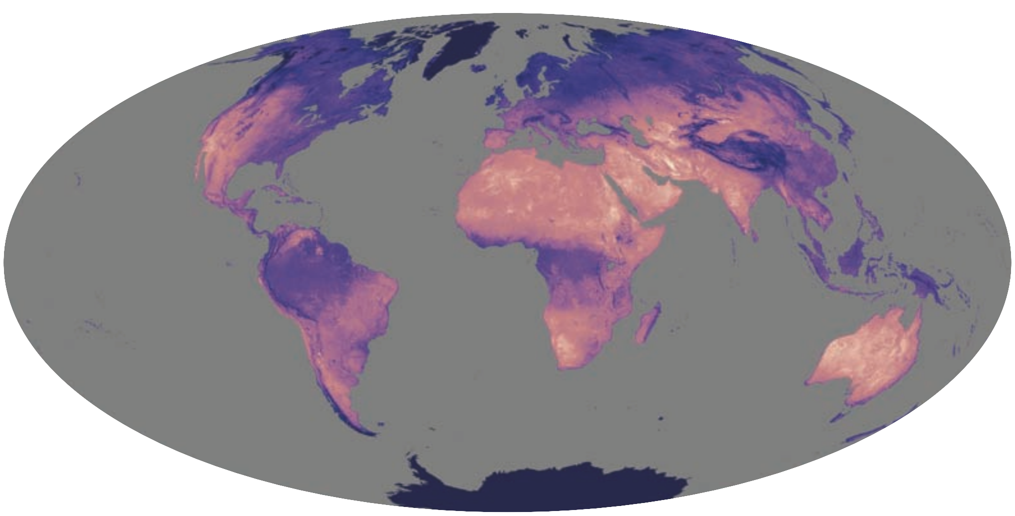
High-Resolution Vertical Profiles of Atmospheric Temperature and Moisture.[8] The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) relies on radio occultation of signals from the Global Positioning System satellites. COSMIC satellites take 2,500 vertical profile measurements every 24 hours in a nearly uniform distribution around the globe, filling in current data gaps over vast stretches of the oceans. The data's high vertical resolution complements the high horizontal resolution of other conventional weather satellite measurements. This is the first time that the technique of radio occultation has been used on a global scale and in real-time to provide continuous monitoring of worldwide atmospheric conditions. COSMIC builds on a series of previous research-oriented satellites, which were used to develop the measurement technique and establish the usefulness of the data in operational forecast systems. The remarkable stability, consistency, and accuracy of the measurements are a new precision tool to help scientists in quantifying long-term climate change trends. COSMIC was successfully launched on 14 April 2006, and its constellation of six small satellites will be transmitting atmospheric data to Earth for the next 5 or more years.





Observing Earth's Mass Distribution Changes from Space.[9] The Gravity Recovery and Climate Experiment (GRACE) is a two-spacecraft mission, developed under a partnership between NASA and the German Aerospace Center. After five successful years of mission operation, 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 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 and snow stored on land. Analyses of these time variable gravity fields provide global observations of changes in total water storage (vertically integrated water content), averaged over scales of a few hundred kilometers and greater. Usefully accurate surface water storage estimates from GRACE allow quantitative comparisons to be made on seasonal and longer time scales. A recent study compared GRACE surface water storage estimates to the outputs of five models. All of the models reproduce the global annual pattern of storage amplitude and the seasonal cycle. However, global average agreements were found to mask systematic model biases at low latitudes. Identifying these errors in the models will allow improved parameterization of water stores in the land models and alleviate precipitation biases. Both processes are difficult to formulate and the satellite data will greatly aid in improving the veracity of the models.

Surface-Based Observatories of Clouds and Radiation.[10,11] The primary goal of the Atmospheric Radiation Measurement (ARM) program is to improve the treatment of cloud and radiation physics in global climate models in order to improve the climate simulation capabilities of these models. These efforts have been enhanced by the



addition of the ARM mobile facility (AMF) to study cloud and radiation processes in multiple climatic regimes. The AMF can be deployed to sites around the world for durations of 6 to 18 months. Data streams produced by the AMF 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 from January through December 2006 and measured radiation, cloud, and aerosol properties during the monsoon and dry seasons. Using measurements from the ARM Mixed-Phase Arctic Cloud Experiment (M-PACE), a data set has been created that allows climate and cloud models to simulate Arctic weather allowing for direct comparison of observations and model simulations.

Baseline Surface Radiation Network. The Baseline Surface Radiation Network has acquired 15 years of surface radiation budget data at its original half-dozen sites and has since expanded to more than 38 international sites. These observations combined with historic records have detected interdecadal annual mean variations on the order of about 2%, which exceeds previous expected variations that are not replicated in climate models. Contributing effects from clouds and aerosols are suspected to be the most likely cause of these variations.

Data Management and Information

Selected data management and information activities supported by CCSP-participating agencies follow.

REASoN Program.[12] Forty Cooperative Agreement projects that are part of NASA's Earth Science Research, Education, and Applications Solutions Network (REASoN) have completed their first year. The REASoN projects are part of NASA's strategy to work with its partners to improve its existing data systems, guide the development and management of future data systems, and focus performance outcomes to further Earth science research objectives. In order to achieve these goals, the REASoN projects are organized to engage the science community and peer review process in the development of higher level science products; to use these products to advance Earth system research; to develop and demonstrate new technologies for data management and distribution; and to contribute to interagency efforts to improve the maintenance and accessibility of data and information systems.

Global Change Master Directory.[13] 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. 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 desired. 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 Earth Observation System of Systems (GEOSS).

Highlights of Plans for FY 2008

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 2008 and beyond follow.

Global Climate and Ocean Observing Systems. FY 2008 priorities for advancement of 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 Report 1.1. As such, the global ocean observing system will make incremental advances, building out to 59% completion. In addition to the Argo array reaching global coverage, the TAO array in the Pacific will begin to be refreshed with redesigned mooring technologies, and the TAO tropical system will be expanded further in the Indian Ocean. Three new ocean reference stations will be added to the system, for improved forecasts and modeling validation, assessments of climate impacts on ecosystems, and monitoring for possible rapid climate change. The tide gauge network will continue to be upgraded for real-time reporting, also contributing to the international tsunami warning system. Continued support will be given to the activities, database development, and data delivery systems of the international Global Sea-Level Observing System. The drifting arrays will be augmented with salinity sensors to better capture sea surface salinity and to provide calibration for the planned Aquarius satellite mission; and additional carbon dioxide (CO_2) sensors will be added to moored arrays and ships to analyze seasonal variability and exchange of CO_2 between the ocean and atmosphere. Work is underway on developing biological sensors as part of Ocean Observing Systems. 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 GRUAN.

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

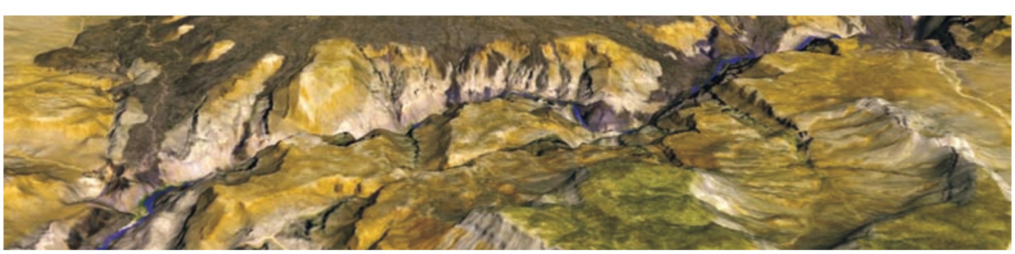
Polar Region Observations: International Polar Year. Polar climate observations will continue to be a CCSP focus in FY 2008. As a part of IPY, CCSP research will investigate the possible connections between Arctic haze aerosols and the melting of polar ice in the region. The investigation will involve multiple agencies in cooperation with scientists and facilities from several other countries. In addition to a wide variety of surface measurements, *in situ* and remote-sensing measurements will be made from balloons and aircraft. Satellite observations will include CALIPSO and Cloudsat, using lidar and radar instruments to provide three-dimensional distributions of aerosols and layered clouds. Surface field teams from many nations will be supported by a wealth of satellites contributed for polar research by multiple space agencies.

These activities will address Goals 12.1 and 12.5 and Questions 3.1 and 3.3 of the CCSP Strategic Plan.

In Situ Observations: International Polar Year. The Arctic Observing Network (AON) is envisioned as a system of atmospheric, land- and ocean-based environmental monitoring capabilities—from ocean buoys to satellites—that will significantly advance observations of Arctic environmental conditions. Developed largely as a research system under the leadership of NSF and NOAA, it is hoped that data from AON will eventually enable the interagency U.S. government initiative—the Study of Environmental Arctic Change—to better understand the wide-ranging series of significant and rapid changes occurring in the Arctic. From April to July 2008, 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 new NASA CALIPSO Lidar and CloudSat radar 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 A-train configuration of the Aqua, Aura, and Parasol satellites orbiting in formation—will enable systematic observation of the key climate forcing of aerosol indirect effects, climate sensitivity of cloud feedbacks, and polar climate response of difficult-to-observe polar clouds. The last of these capabilities will also directly support IPY activities. Finally, a U.S. Climate Reference Network system will be deployed at the Russian Arctic site of Tiksi at latitude 71.5°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.

Data Fusion. As the length of record in the database of global observations increases, increased effort will be placed on assimilating Earth observations into GCMs, to produce an integrated view of the climate system and to better provide this view to users as part of decision-support and resource management systems. The value of the data itself will benefit by increased "data fusion" in which, for example, MODIS observations will be joined with the complementary capabilities of other Earth-observing instruments, to provide much improved, more accurate and rigorous observations of key phenomena such as sea surface temperature, cloud characteristics, and land surface features. Data fusion efforts will include instruments on existing EOS missions such as Terra, Aqua, ICESat, Aura, Landsat, and SORCE, and on recently launched missions such as CloudSat and CALIPSO and, farther in the future, Earth System Science Pathfinder missions and the Global Precipitation Measurement (GPM) Mission. The fusion of space-borne observations with *in situ* biological and physical observations, such as those gathered through the National Ecological Observatory



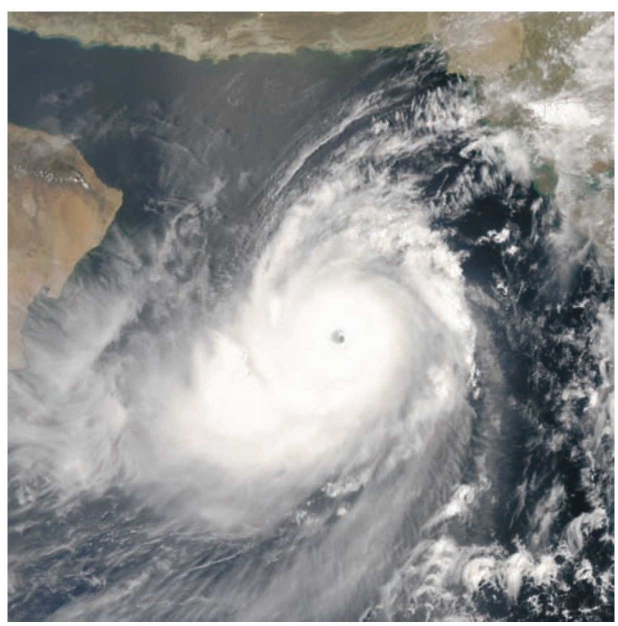
Network and the Ocean Observing Initiative, is crucial for gaining a better understanding of trends and associated consequences of the variability in the atmosphere-land-ocean system. This activity is closely related to the CCSP Climate Variability and Change research element's priority of improving Earth system analysis capabilities.

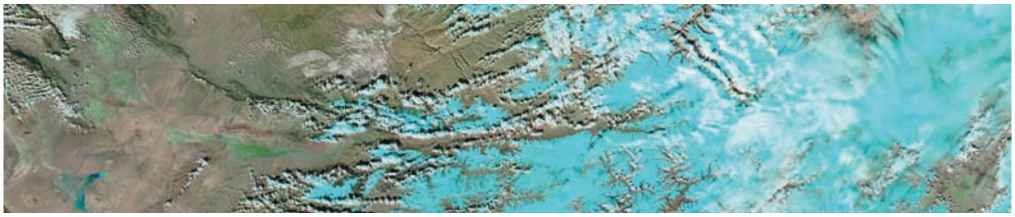
These activities will address Goals 13.2 and 13.3 of the CCSP Strategic Plan.

Solar Variability: Glory.[14] The Glory mission will continue to be developed in FY 2008, and is planned to launch in 2009. It will carry a Total Irradiance Monitor (TIM) based on the SORCE TIM design, with the same high-precision phase-sensitive detection capability. Glory will also carry an Aerosol Polarimeter Sensor (APS), which will improve ability to distinguish among aerosol types by measuring the polarization state of reflected sunlight. Both TIM and APS will provide key measurements of 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. A fundamental scientific goal of the GPM Mission 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 record of precipitation has been extended in recent years to include oceanic as well as land areas using satellite measurements from TRMM. This is an example





of a key climate data set to be maintained and extended into the future. 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.

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. The average ocean salinity is about 35 parts per 1,000. The instruments that are part of this satellite mission will measure changes in sea surface salinity over the global oceans to a precision of 0.2 parts per 1,000 (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 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 CONAE, the Argentine space agency, with an expected launch date in 2010.

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 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 of global sea-level rise. Ocean topography measurements from these missions have elucidated the role of tides in ocean mixing and maintaining deep ocean circulation. Furthermore, quantitative determination of ocean heat storage from satellite measurements together with measurements from the global array of temperature/salinity profiling floats known as Argo 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 CNES, and the European meteorological agency EUMETSAT, and has a planned 2008 launch.

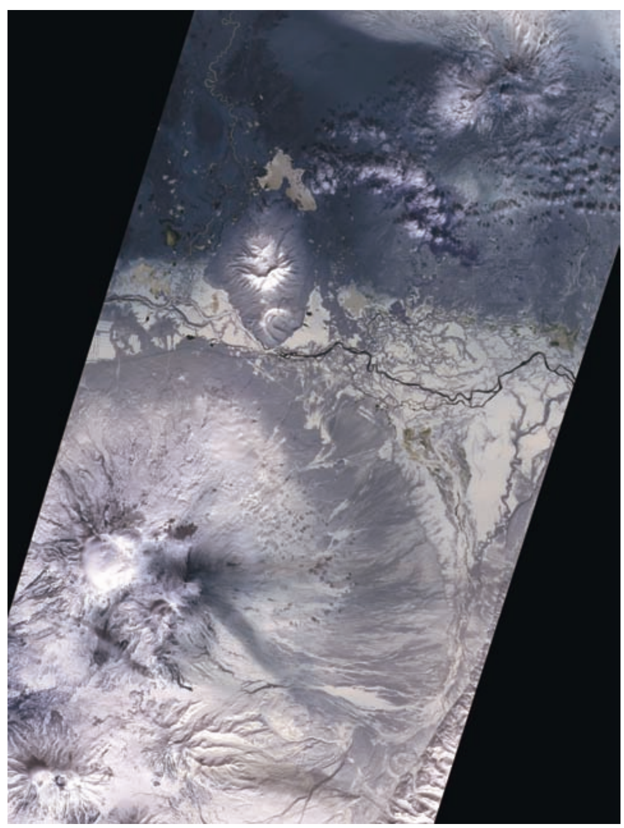
These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

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 the Earth's climate.

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

Continuity of Climate Measurements.[15,16] As new satellite instruments bring new measurement capabilities, the challenge becomes establishing priorities for the right mix of existing observing capabilities and new capabilities to support the goals of CCSP. Continuity of measurement of several key climate variables are being carefully considered including stratospheric ozone, radiative energy fluxes of the Sun and Earth, atmospheric CO_2 and methane concentrations, global surface temperature, and global land cover (e.g., as measured by Landsat).

The long-term record of global land cover was begun by Landsat 1 in 1972 and continues through the collection of data from Landsats 5 and 7. Launched in 1984, with a design life of 3 years, Landsat 5 continues to provide near-global coverage through a network of international ground station cooperators. Landsat 7 was launched in 1999, and continues to acquire global observations on a daily basis although in a degraded operating mode. The combined assets of Landsats 5 and 7 permit repeat coverage as frequently as every eight days over ground-receiving station sites. 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)



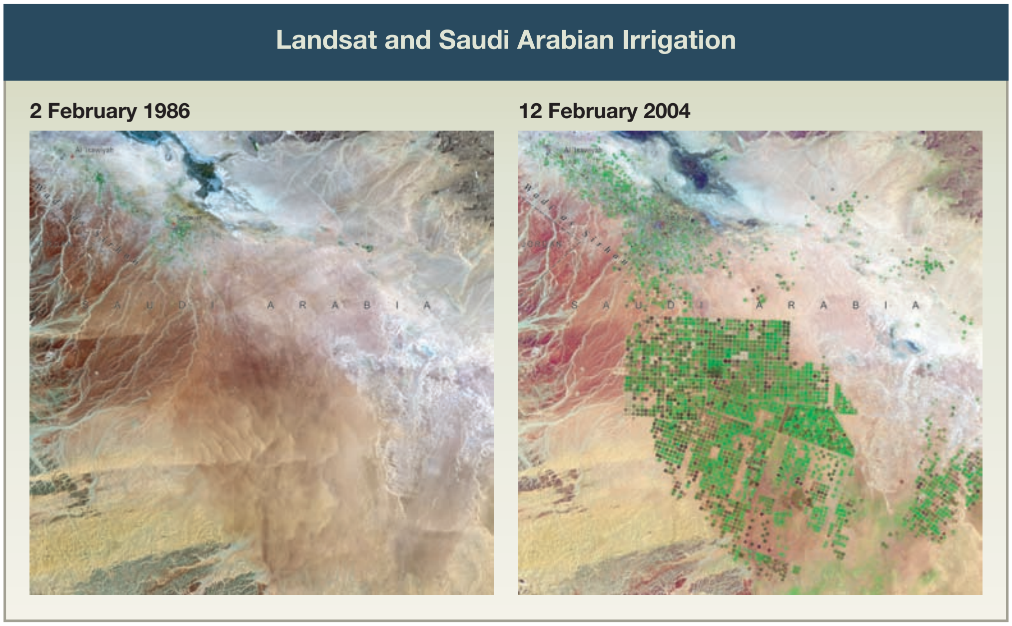


Figure 14: Landsat and Saudi Arabian Irrigation. Landsat images, from 1986 and 2004, reveal the effects of center-pivot irrigation in a desert region in Saudi Arabia known as Wadi As-Sirhan. In the satellite images, these irrigated fields appear as green dots. This region was once so barren that it could barely support the towns Al'Isawiyah and Tubarjal shown in the upper left of each image. Following the introduction of center-pivot irrigation, the barren desert was gradually transformed into a greener, food-producing landscape. The irrigation system draws water from an ancient underground aquifer. *Credit: USGS / EROS Data Center.*

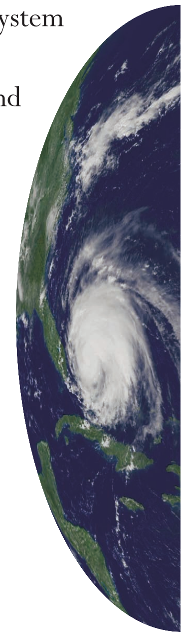
being planned by NASA and USGS. LDCM is expected to have a 5-year mission life with 10-year expendable provisions. The National Land Imaging Program Plan provides long-term planning for a stable, operational, space-based land imaging capability. See Figure 14 for an example of the usefulness of the Landsat data record.

Planning continues on deploying component sensors from NPOESS. A decision was made in June 2006 to delete 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. Agencies are currently assessing the impacts of this decision and evaluating options. The NPOESS Preparatory Project is scheduled as a bridge mission between NASA's EOS program in 2009, and NPOESS, now scheduled for its first launch in 2013.

The record of precipitation that has been extended in recent years to include oceanic as well as land areas using measurements from TRMM is another example of a key climate data set that needs to be considered as priorities are set for the future. These examples of key climate variables are elements of the comprehensive observing system to monitor changes in the cycles of carbon, energy, water, and related biogeochemical processes that drive Earth's climate.

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

Integrated Ocean Observing System.[17] The Integrated Ocean Observing System (IOOS) is the U.S. coastal-observing component of the Global Ocean Observing System (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 is being established by NOAA via a national IOOS Program Office co-located with the <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.



These activities will address Goals 12.1, 12.3, and 12.6 of the CCSP Strategic Plan.

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