NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Principal Areas of Focus

The National Aeronautics and Space Administration (NASA) conducts a program of breakthrough research to advance fundamental knowledge on the most important scientific questions on the global and regional integrated Earth system. NASA's program encompasses all themes of the *Strategic Plan for the U.S. Climate Change Science Program*. NASA's investment in the 13-agency CCSP is 58% of the total amount of the President's 2009 Budget Request for CCSP. In addition, NASA contributes substantially to other interagency initiatives complementary with CCSP, including the *U.S. Ocean Action Plan* and the *Strategic Plan for the U.S. Integrated Earth Observation System*.

NASA continues to enhance its worldwide leadership in interdisciplinary science of the global integrated Earth system. The research encompasses the global atmosphere; the global oceans including sea ice; land surfaces including snow and ice; ecosystems; and interactions between the atmosphere, oceans, land and ecosystems, including humans. NASA's goal is to understand the changing climate, its interaction with life, and how human activities affect the environment. In association with national and international agencies, NASA applies this understanding for the well-being of society.

NASA presently operates 14 on-orbit satellites: ACRIMSAT, Aqua, Aura, CALIPSO, CloudSat, EO, GRACE, ICESat, Jason, Landsat-7, QuikSCAT, SORCE, Terra, and TRMM. Table 1 lists primary CCSP themes of the operating missions. NASA has seven missions in development (Aquarius, Glory, GPM, LDCM, NPP, OCO, and OSTM) for launch from 2008 to 2013, with OSTM, OCO, and Glory planned for launch in the 2008-2009 period. The President's 2009 Budget Request contains National Research Council (NRC) *Decadal Survey* recommendations, including the start of two new missions (ICESat-II and SMAP), pre-formulation activities on two additional missions, and initiating competitive Venture-class mission activities to ensure flexibility and community input into the evolving satellite constellation.

NASA aircraft- and surface-based instruments are used to calibrate and enhance interpretation of high-accuracy, climate-quality, stable satellite measurements. NASA supports state-of-the-art computing capability and capacity for extensive global integrated Earth system modeling. NASA, in recording approximately 4 terabytes of data every day, maintains the world's largest scientific data and information system for collecting, processing, archiving, and distributing Earth system data to worldwide users.

Program Highlights for 2009

NASA will make significant progress in 2009 in every theme of the *Strategic Plan of the U.S. Climate Change Science Program*. The examples below also demonstrate progress in all nine CCSP priorities for 2009.

Atmospheric Composition

NASA, in pioneering the understanding of the role of atmospheric chemistry and composition in the global integrated Earth system, adopted an overall research approach of sustained, systematic satellite observations with laboratory, aircraft, and ground-based measurements. Field campaigns are an important extension of satellite measurements.

CORRELATION OF NASA OPERATING SATELLITE MISSIONS WITH CCSP SCIENTIFIC THEMES

Satellite	Launch Date	CCSP Science Focus Areas
ACRIMSAT	December 1999	Climate variability and change
Aqua	May 2002	Atmospheric composition; carbon cycle; ecosystems; climate variability and change; water cycle
Aura	July 2004	Atmospheric composition
CALIPSO	April 2006	Atmospheric composition; water cycle
Cloudsat	April 2006	Water cycle
EO	November 2000	Carbon cycle; ecosystems
GRACE	March 2002	Water cycle; climate variability and change
ICESat	January 2003	Climate variability and change; water cycle
Jason	December 2001	Climate variability and change; water cycle
Landsat-7	April 1999	Carbon cycle; ecosystems
QuikSCAT	June 1999	Climate variability and change
SORCE	January 2003	Atmospheric composition; climate variability and change; water cycle
Terra	December 1999	Atmospheric composition; carbon cycle; ecosystems; climate variability and change; water cycle
TRMM	November 1997	Climate variability and change; water cycle

Analyses of 'historical' satellite data are combined with observations recorded from Aqua, Aura, CALIPSO, Cloudsat, and Terra, which are the primary on-orbit satellites for studies of atmospheric chemistry and composition. These missions provide data for studies of stratospheric ozone recovery, tropospheric chemistry and air quality, aerosol characterization, long-range transport of pollution, and cloud formation processes. For 2009, measurements from Aqua, Aura, CALIPSO, and Cloudsat—four of the five satellites flying in close formation in the A-Train yielding an unprecedented variety of data in a 15-minute interval on the same groundtrack—data set will be used to determine the impact of gas constituents on aerosol properties and the interactions of aerosols with clouds. Analyses of combined satellite, aircraft, and surface measurements from the Tropical Composition, Cloud, and Climate Coupling (TC4) experiment will continue to elucidate the roles of boundary layer gases and aerosols in the formation and radiative properties of cirrus clouds. The Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) data analyses will begin. ARCTAS will investigate effects of pollution transport, haze, halogen chemistry, and boreal forest fires on the Arctic climate. In 2009, NASA will deploy a Global Hawk unattended airborne system for calibration and validation of Aura data.

Climate Variability and Change

This research element includes ocean circulation, sea ice, ice sheets, and abrupt climate change. Feedbacks by clouds and water vapor are discussed under *Global Water Cycle*. Climate models, which have a central integrating role, are discussed under *Modeling Strategy*.

With the 2008-scheduled launch of OSTM, NASA will continue high accuracy, stable measurements of global mean sea level, which has been rising at about 3.3 mm yr^{-1} since 1993. In 2009, NASA will

select a new science team to evaluate and exploit data from the Aquarius sea surface salinity mission scheduled for launch in 2010. NASA continues to lead the *U.S. Ocean Action Plan* Near-Term Opportunity to assess Atlantic meridional overturning circulation for rapid climate change.

Large changes in the Arctic and Antarctic focused scientific attention on these environments, and on the impact of these changes for the global integrated Earth system. In 2009, NASA will formulate a new satellite mission, ICESat-II, recommended in the NRC *Decadal Survey*. ICESat-II will accurately measure ice topography allowing estimation of ice sheet volume changes and sea ice thickness. An ICESat-II Science Definition Team will be established in 2009.

Global Water Cycle

The water cycle involves water in all three of its phases, exchanges large amounts of energy through phase changes, and is ubiquitous: clouds and precipitation; ocean-atmosphere, cryosphere-atmosphere, and land-atmosphere interactions; mountain snow; and groundwater.

NASA researchers continue satellite data analyses to quantify and monitor the processes, which comprise the Earth's hydrologic cycle and its variability in space and time. In 2009, investigations will focus on the components of the global water cycle (e.g., precipitation pattern) in order to examine possible changes that may occur as atmospheric water storage becomes larger with increased global warming.

In 2009, NASA will initiate a new research opportunity to better understand tropical cyclone genesis and intensification processes through the combination of satellite observations, model simulations, and airborne field campaigns. Research during the next 5 years will focus on understanding the relative roles of different rapid intensification processes ranging in scale from the synoptic environment to the convective scale.

In 2009, NASA will start the *Decadal Survey* mission SMAP to measure soil moisture and determine the freeze/thaw state of the soil when launched in 2012. SMAP data will contribute to determining water fluxes between the atmosphere, the land surface, and the subsurface of the land; extending the capabilities of medium-range weather forecast models and seasonal climate models; and understanding whether the soil is a carbon sink or source in cold regions.

Land-Use and Land-Cover Change

Land-use dynamics depends on understanding past and present land-use practices. Land-use and land-cover change drive climate change, and climate change itself drives land use and land cover.

In 2009, NASA and USGS will release a new global land survey (GLS) data set produced from Landsat-5 and Landsat-7 images recorded during 2004-2007. Land-cover changes over 30 years will be determined from comparative analyses of the new GLS data with previous GLS data sets constructed for 1975, 1990, and 2000. In 2009, NASA will support the NRC in a study of the state of knowledge and future research needs for land change modeling approaches. NASA will continue to support scientific investigations on land-use and land-cover change impacts on ecosystems in the Northern Eurasia Partnership Initiative.

Global Carbon Cycle

Research on the global carbon cycle addresses the distribution and cycling of carbon among the terrestrial, oceanic, and atmospheric reservoirs.

In 2009, NASA will continue analyses of ship and satellite measurements recorded in 2008 in the Southern Ocean to estimate air-sea exchange of carbon dioxide and other gases in high sea and high wind conditions. In 2009, NASA, in partnership with ONR and NSF, will develop advanced *in situ* technologies to calibrate satellite ocean color data. The new instrumentation will replace MOBY—a 15-year old marine optical buoy—and will support calibration of ocean color measurements from the on-orbit MODIS on Aqua and from VIIRS on NPP, which is scheduled for launch in 2010.

NASA will continue developing continental-scale data products for the North America Carbon Program (NACP) and continue modeling and synthesis activities for the NACP mid-continent intensive field campaign. In 2009, research will continue on carbon storage and emissions in northern high latitudes. In 2009, research will be initiated to evaluate atmospheric carbon dioxide measurements from the OCO satellite mission scheduled for launch in December 2008.

Ecosystems

Ecosystems affect the climate system through large exchanges of greenhouse gases. The goals of this research element are to document and understand how terrestrial and marine ecosystems are changing and to quantify carbon budgets for key ecosystems.

In 2009, NASA will combine satellite and *in situ* observations with Earth system and ecological models. New studies include those that relate land surface warming to phytoplankton productivity, characterize climate change affects on bird habitats and bird survival, and address terrestrial ecosystem response in high latitudes to climate change. In 2009, NASA will develop algorithms to analyze satellite observations of three-dimensional vegetation structure in support of *Decadal Survey* missions DESDynI and ICESat-II. Research will continue with multi-sensor observations of biological impacts of a changing climate on coral reefs.

Human Contributions and Responses

In 2009, NASA will support the evaluation and assessment of potential policy-, market-, and technology-based approaches to adapting to or mitigating the impacts of climate change. Also, NASA will address the impact of climate change to exposure and severity of infectious diseases.

Modeling Strategy

Our quantitative understanding of Earth system processes and feedbacks is codified in climate models. Climate models are rapidly improving in accuracy and sensitivity through incorporation of new understandings of the physics, chemistry, and biology and their interactions. New infrastructure and advanced computing capacity and computing capabilities are an important component of improved climate models.

The Earth System Modeling Framework (ESMF)—which was initiated in 2002 by NASA and now is an interagency activity—enables shared infrastructure and interoperability of model components and interface. In 2009, optimized data transfer, hierarchical attributes, regridding interface, and multi-tile grids will be completed. In 2009, ESMF will demonstrate interfaces for coupling ESM components on different computers.

During 2009, NASA will enhance its Earth System Model (ESM) by incorporating chemistry-physics coupling throughout the atmosphere. The ESM will include a non-hydrostatic finite volume dynamical core allowing evaluation across temporal scales from weather to climate.

Decision Support Resources Development

NASA will demonstrate the utility of NASA research capabilities for decision-support needs over many sectors likely to be impacted by climate change, such as agriculture, air quality, disaster management, ecosystems, public health, water resources, and weather. The focus in 2009 will be on applications to policy and decisions the Nation will consider in responding to climate change (e.g., policy frameworks, technology and market approaches, decisionmaking on national and regional climate adaptation and mitigation, and carbon and energy management).

Observing and Monitoring the Climate System

Global measurements to understand the physical, biological, chemical, and ecosystem processes responsible for changes in the Earth system on all relevant space and time scales are critical to understand past and present climate changes and predict future climate change. NASA is the world's leading organization recording sustained, high accuracy, stable, global observations with high spatial and temporal resolutions for studies of global and regional climate change.

The table on page 209 describes briefly the operating satellite missions and their relationship to CCSP research themes. In FY2009, NASA will launch two new missions. The OCO mission is scheduled for launch in December 2008, and will measure carbon dioxide concentrations in the atmosphere. These data will elucidate carbon dioxide sources and sinks on regional scales of about 1,000 km. The Glory mission, scheduled for launch in March 2009, will measure microphysical properties of aerosols to determine how aerosols contribute to net cooling or warming. Glory will join the A-Train to improve understanding of the interactions between aerosols and clouds and other phenomena. Also, Glory will extend the time series of total solar irradiance at the top of the atmosphere.

The June 2006 Nunn-McCurdy recertification of NPOESS de-manifested and de-scoped instruments that were intended to extend the climate data records of many important variables. In 2007, NASA and NOAA announced that the OMPS-Limb instrument would be placed on NPP set to launch in 2010 to mitigate the potential gap in ozone data to understand stratosphere ozone recovery in response to the Montreal Protocol. The OMPS-Limb instrument will provide the first vertically resolved ozone measurements. In 2008, NASA and NOAA agreed to incorporate a CERES instrument on NPP to mitigate the potential gap in nearly 30 years of Earth's radiant budget measurements. NASA is working to ensure continuity of the 29-year total solar irradiance time series with measurements by Glory, which is set to launch in 2009 to overlap with SORCE. In 2008, NASA and NOAA plan to recommend a satellite option to continue total solar irradiance measurements after those made by Glory.

NASA research satellites are typically designed for 3- to 5-year lifetimes. The primary mission objectives focus on demonstrating new measurement techniques and acquiring data to advance understanding of relatively short-term Earth system processes. Many NASA research satellite missions continue to operate well beyond their design lives, thus extending the data sets and enabling examination of longer period phenomena. In 2009, NASA will evaluate the extension of on-orbit missions that have completed their primary mission or will complete their primary mission in the 2 years following the evaluation.

Data Management and Information

NASA has led development of integrated data management and information systems to enhance interdisciplinary studies of the global Earth system. The goal is seamless, platform-independent, timely, and open access to integrated data, products, and information to address the science of climate change.

The first phase of a major upgrade to NASA's Earth Observing System Data and Information System (EOSDIS), which acquires nearly 4 terabytes of satellite data per day, was completed in 2008. Upgrades envisioned for 2009 and beyond include research on connectivity of NASA data with other relevant data sources and systems, and on seamless integration of multiple data and metadata. Research investigations continuing in 2009 will link together data from multiple satellites, create Earth system data records, and develop new data system tools that improve the access, use, and interoperability of satellite data.

NASA continues populating the Global Change Master Directory (GCMD)—a 20,000-metadata directory—at the rate of about 900 descriptions per month. A new version of GCMD software will be released in 2008 with updates planned in 2009.