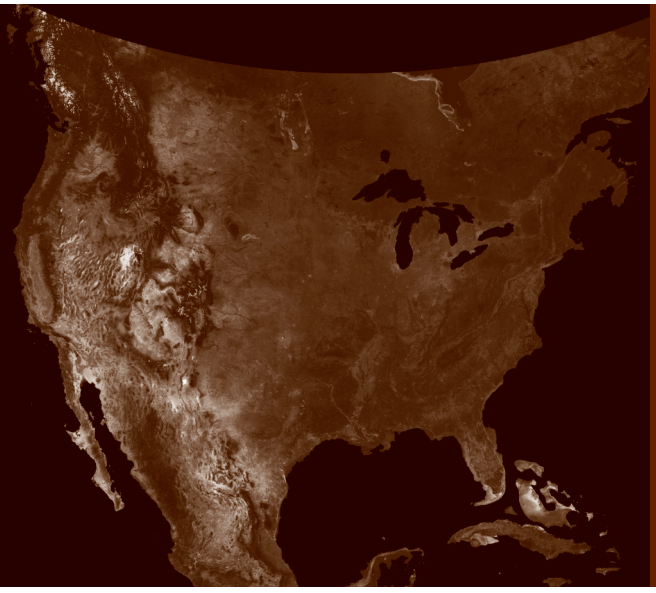
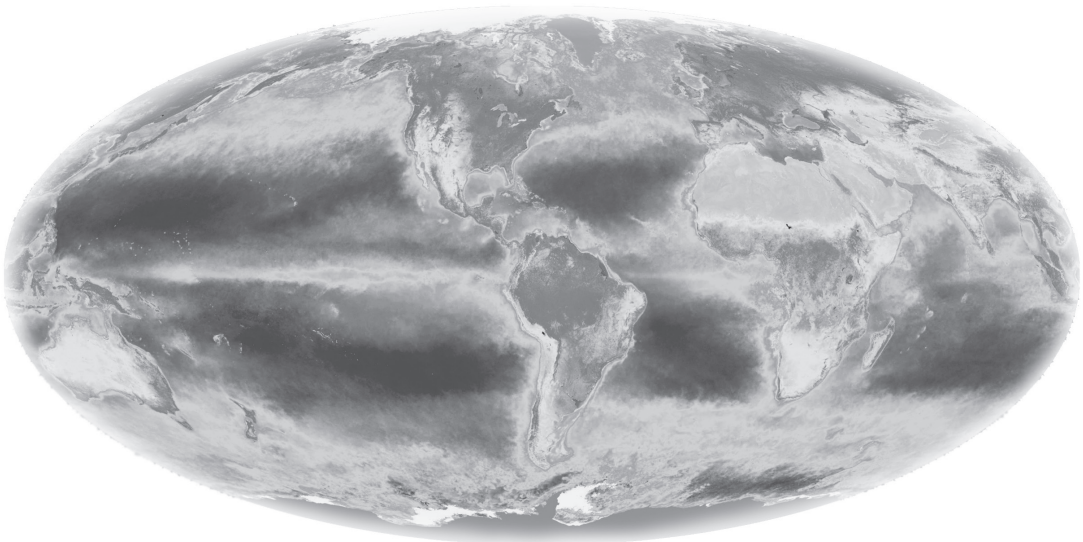
Aeronautics and Space Report of the President



Fiscal Year 2009 Activities

Aeronautics and Space Report of the President



Fiscal Year 2009 Activities

The National Aeronautics and Space Act of 1958 directed the annual Aeronautics and Space Report to include a "comprehensive description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities during the preceding calendar year." In recent years, the reports have been prepared on a fiscal-year basis, consistent with the budgetary period now used in programs of the Federal Government. This year's report covers activities that took place from October 1, 2008, through September 30, 2009.

Table of Contents

National Aeronautics and Space Administration

NASA

Exploration Systems Mission Directorate

Advanced Capabilities Division

Advanced Capabilities

In fiscal year 2009 (FY 09), the Exploration Systems Mission Directorate's (ESMD) Advanced Capabilities Division (ACD) provided critical research and technology products that reduced operational and technical risks for the flight systems being developed by the Constellation Program.[1] These products addressed high-priority technology requirements for lunar exploration; risk mitigation related to astronaut health and performance; basic research in life and physical sciences using the International Space Station (ISS), free-flying spacecraft, and ground-based laboratories; and lunar robotic missions to gather data relevant to future human lunar missions.

Lunar Precursor Robotic Program

The Lunar Precursor Robotic Program (LPRP) developed and executed robotic missions to the moon to prepare for future human exploration. Precursor activities included topographical mapping, characterizing the distribution of lunar resources, and measuring the radiation and temperature environments on the

1. President Barack Obama's FY 11 budget request, announced in February 2010, cancelled the Constellation Program. However, the FY 10 Consolidated Appropriations Act prohibited the cancellation of Constellation while the 2010 NASA Authorization Act directed NASA to develop a new approach to human spaceflight. Parts of Constellation were carried into the development of the new program, but please note that this report reflects a historical approach to the data available at the time.

lunar surface. Data from Lunar Precursor Robotic Program missions were critical to the Constellation Program's efforts to return humans to the moon and supported astronaut safety issues, landing site selection, and engineering requirements for lunar surface hardware.

The first lunar robotic mission was the Lunar Reconnaissance Orbiter (LRO), which provided detailed mapping for human landing site selection, valuable information about the lunar radiation and thermal environments, and the identification of lunar resource availability. A comanifested mission to LRO, the Lunar CRater Observation and Sensing Satellite (LCROSS), impacted a permanently shadowed crater on the lunar surface to investigate the possible presence of water and other volatiles.

During FY 09, LRO was successfully launched and the spacecraft was commissioned in lunar orbit. All seven scientific instruments on board the spacecraft were activated and returned data. High-resolution optical and radar images of the lunar surface were acquired, including photos of the Apollo landing sites. The LRO spacecraft also measured extremely low temperatures in polar craters, mapped the distribution of hydrogen on the lunar surface, and determined the elevation of terrain features with its laser altimeter. After commissioning, the spacecraft was maneuvered into its mapping orbit to return data for one year.

The Lunar Mapping and Modeling Project (LMMP) completed formulation, systems requirements, and preliminary design audits in FY 09. The Project's goals were to create a comprehensive data archive and portal for all lunar data, including data from LRO and previous missions, such as Lunar Prospector and the Apollo missions, for use by the Constellation Program mission planners for future human and robotic exploration. The lunar data will be presented via an intuitive, integrated, reliable set of mapping and modeling tools.

Human Research Program

The Human Research Program (HRP) investigates and mitigates the highest risks to astronaut health and performance in support of the National Aeronautics and Space Administration's (NASA) exploration missions. The program's primary goal is to develop and provide human health and performance countermeasures,

knowledge, technologies, and tools that enable safe, reliable, and productive human space exploration.

During FY 09, HRP recommended potassium citrate as a renal stone countermeasure for ISS astronauts. Flight medical personnel can use potassium citrate as a mitigation strategy for the buildup of calcium in the urine that causes the development of renal stones during long-term exposure to microgravity. The recommendation was reviewed and approved for medical practice by the NASA Chief Health and Medical Officer.

HRP also completed two important food system studies in thermostabilized food and nutrient stability. The thermostabilized food study was a three-year accelerated shelf-life test of 13 thermostabilized food items to determine shelf life for extended-duration exploration. Egg products had a shelf life of zero months, indicating that thermostabilized processing cannot be used for egg products. Currently, egg products are freeze-dried, with a shelf life of approximately 12 months. Vegetable dishes had a shelf life of 12 to 50 months, while grilled pork chops and salmon were acceptable for 87 to 96 months. Shelf life values were extrapolated for NASA's 65 thermostabilized items. Results indicated that greater than 50 percent of the current menu items would have a shelf life of less than three years. These analyses suggested that new processing technologies will be needed to improve initial quality and extend the shelf life of food products for use in long-duration missions.

The nutrient stability study determined the stability of food and nutritional items, representative of the types and classes typically provided on space missions, after prolonged exposure to the spaceflight environment. Kits were exposed to space for a period of up to 19 months and returned to Earth for nutritional analysis. Results of the study indicated that long-duration storage has a much greater effect on nutrient stability than does spaceflight. This emphasized the need for improved packaging or other means to increase the shelf life of nutrients in the food system and mitigate time-related nutrient degradation.

HRP completed the *Space Flight Human-System Standard Volume 2* and the *Human Integration Design Handbook* to support the development of Constellation space vehicles, including the Orion capsule. The handbook contains human-system integration data and lessons learned from previous human programs. Its

purpose is to aid interpretation of Volume 2 standards by providing guidance to space vehicle and habitat designers.

HRP completed behavioral health and performance studies during the Russian Academy of Sciences' 105-day Chamber Study, late March through July, in partnership with the National Space Biomedical Research Institute (NSBRI). The isolation chamber study served as a simulation of a six-person ISS crew. Three studies sponsored by the National Space Biomedical Research Institute were conducted: operational evaluation of a photic countermeasure to improve alertness, performance, and mood during night-shift work; objective monitoring of crew neurobehavioral functions and crew interactions; and autonomy during long-duration isolation and confinement.

HRP delivered a new model of the acute risks from solar particle events, developed in collaboration with the Department of Defense Special Weapons Agency (formerly the Nuclear Agency). The acute radiation risks body organ dose model predicts possible early health effects on crews from exposure to some historically large solar events possible on lunar and/or Mars missions. Based on model assumptions, exposure to these historical events would cause early moderate health effects to crewmembers inside a typical spacecraft or during extravehicular activities if effective shielding and medical countermeasure tactics were not provided.

HRP began several new ISS experiments during 2009, including the bisphosphonates experiment to examine a countermeasure for bone loss, an integrated cardiovascular experiment to measure the effects of microgravity on heart function, a maximum oxygen uptake (VO2 Max) experiment to measure changes to astronaut aerobic capacity, a functional task test to examine the ability of crews to carry out mission functions while transitioning from low gravity to partial gravity or 1 g-force, a Pro-K experiment to evaluate a dietary countermeasure for bone loss in astronauts, and a reaction self-test to examine astronaut performance while in space.

Exploration Technology Development Program

The Exploration Technology Development Program (ETDP) developed new technologies that will enable NASA to conduct future human and robotic exploration missions with reduced mission risk and cost. ETDP's primary customers were the designers of flight systems in the Constellation Program. ETDP matured

near-term technologies to enable the first flight of Orion and developed long-lead technologies needed for lunar exploration missions. ETDP worked to reduce the risk of infusing new technologies into flight projects by maturing them to the level where they can be demonstrated in a relevant environment.

During FY 09, ETDP conducted airplane flight tests of terrain-relative navigation sensors for the lunar lander's autonomous precision landing system. The optical sensors were designed to image features on the lunar surface during the lander's descent phase and compare the features with an on-board terrain map to determine the lander's position along its trajectory. This technology would assist the crew during piloted landings and allow unpiloted cargo landers to autonomously navigate to a landing site near a lunar outpost.

ETDP continued the development of a deep-throttling, liquid oxygen–liquid hydrogen rocket engine for the lunar lander's descent stage. A series of engine firings were conducted to demonstrate stable operations of the engine at low-thrust levels. A prototype 5,500–pound force (lbf) thrust liquid oxygen–liquid methane engine for the lander's ascent stage was also tested. This engine could help reduce the risk for future exploration missions since methane is a non-toxic propellant that does not require special ground handling procedures. Also, it could be produced from the atmosphere of Mars to reduce the mass of propellant that must be launched from Earth.

Two prototype systems for producing oxygen from the lunar regolith were field tested in Hawaii. The chemical composition of the volcanic soil in Hawaii is similar to that of the lunar regolith. Both systems used a similar process in which the soil was heated to a high temperature inside a reaction chamber, and then hydrogen gas was passed through it. The hydrogen reacted with the oxygen in the soil to form water vapor. The water vapor was then condensed and split into hydrogen and oxygen using electrolysis. These in-situ resource utilization systems would reduce the amount of consumables needed to sustain the life support systems at a lunar outpost.

To help assemble a lunar outpost, ETDP developed and tested a new type of lunar rover called the Tri-ATHLETE—a large, six-legged rover with wheels that can walk or roll over rough terrain. It stands about 20 feet tall when the legs are fully extended and can split into two halves. Each half has three legs, which can operate independently. The two halves of the Tri-ATHLETE can work together to lift a large payload module off the lunar lander and transport it to the outpost

assembly site. The Tri-ATHLETE demonstrated offloading a habitat module at the Desert Research and Technology Studies (RATS) field test in Arizona.

During the field test, ETDP also demonstrated an improved version of the Lunar Electric Rover (LER). The second-generation Lunar Electric Rover had two airlock interfaces in its crew cabin so that it could dock with other rovers; it also had a retractable dust cover to protect the spacesuits attached to the rear of the crew cabin. A laser navigation sensor developed by the Canadian Space Agency was tested on the rover during the field test.

ETDP made progress in the development of advanced energy storage technology. A new lithium-ion battery with higher energy density was developed for the Lunar Electric Rover to increase its driving range. A new type of fuel cell that used capillary forces to wick away the water produced was demonstrated in the laboratory. These "non-flow through" fuel cells are more robust than conventional fuel cells because they do not require a pump to remove the water. In a conventional fuel cell, the pump uses some of the power generated and could be prone to failure.

The ETDP Fission Surface Power Systems project tested key components of a nuclear power system for a lunar outpost, including a two-kilowatt Stirling power conversion system integrated with a liquid metal coolant loop and an annular linear induction pump to circulate the coolant using electromagnetic forces. A high-temperature radiator was also tested. The project is working toward a non-nuclear demonstration of an integrated fission surface power system using a reactor simulator.

In partnership with the NASA Engineering Safety Center (NESC), ETDP completed the fabrication of an all-composite crew module for Orion and began structural testing. Composite materials could reduce the module's mass and manufacturing costs. An alternate concept for the Orion launch abort system called the Max Launch Abort System (MLAS) was successfully flight tested at Wallops Flight Facility. Unlike the Orion launch abort system, the Max Launch Abort System vehicle does not require additional rocket motors to stabilize it during flight and reorient it during recovery. Instead, it is passively stabilized using drag fins. The crew module is reoriented using drogue parachutes.

The Electronic Nose instrument that is designed to monitor atmospheric contamination events on the ISS completed six months of continuous on-orbit

operations. ETDP also delivered to the ISS Program a more comprehensive atmosphere analyzer called the Vehicle Cabin Atmosphere Monitor. This instrument is a Gas Chromatograph-Mass Spectrometer, capable of measuring the full complement of atmospheric constituents.

International Space Station Research

With the deployment of additional research facilities and increased crew time, the International Space Station (ISS) and the Space Shuttle offer more opportunities to conduct research in life and physical sciences in microgravity.

In FY 09, the Fluids and Combustion Facility (FCF), which includes the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR), was installed on the ISS and commissioned. Experiments to study the combustion of small droplets were performed using the Multi-User Droplet Combustion Apparatus on the Combustion Integrated Rack. The Light Microscopy Module was integrated with the Fluids and Combustion Facility to allow the characterization of fluids, colloids, and two-phase media. Experiments in combustion, fluids' behavior in microgravity, and materials sciences were successfully conducted using both U.S. and international partner facilities.

Many plant, microbiology, cellular biology, and animal science research investigations were conducted using the ISS, Space Shuttle, and free-flyer platforms. These research investigations provided new insight into the effects of microgravity on microbial virulence, plant growth, and animal biology.

In order to continually utilize these facilities on the ISS and other microgravity research platforms, new openly solicited, peer-reviewed investigations in fluid physics, combustion sciences, cellular biology, microbiology, and plant and animal research were selected.

Constellation Systems Division

Constellation Program

In accordance with the Authorization Acts of 2005 and 2008, NASA's Constellation Program (CxP) focused on the next generation of spacecraft for human exploration beyond low-Earth orbit (LEO). Since its inception in 2005, CxP has made tremendous strides toward achieving the goal of extending human

presence in space. Likewise, 2009 was an exceptional year for the CxP, marked by the successful conclusion of program- and project-level major design reviews as well as the completion of high-profile and important testing. In August 2009, CxP passed a significant milestone when NASA granted approval for CxP to proceed from Key Decision Point I, which allowed the program to proceed toward the next milestone of transitioning the program into the implementation phase.

There were five Initial Operational Capabilities projects within the highly integrated (or "tightly coupled") CxP: Ares I, Orion, Ground Operations, Mission Operations, and Extravehicular Activity. The Ares I Project completed the initial First Stage Development Motor 1 test firing, which demonstrated significant risk reduction for the Ares I launch vehicle. The test firing was also a significant project milestone as it marked the first test of full-scale flight hardware in the development of the Ares I. The Ares team also successfully conducted three Ares I First Stage parachute tests during 2009. The parachute tests tested the rocket's deceleration system, designed to slow the rapid descent of the spent first-stage motor. All parachute systems performed as designed, and all hardware was recovered from the drop zone without damage.

Project Orion completed its internal project Preliminary Design Review in August 2009 and proceeded with detailed designs. Critical Design Review was planned for spring 2011. The procurement of components for engineering development units was initiated, and excellent progress was made on test hardware fabrication, such as the Ground Test Article. The Pad Abort 1 test was planned for spring 2010, and the assembly of the flight test vehicle was nearly completed. Static test firings of all three solid rocket motors, part of the launch abort system, were successfully completed. Project Orion also made substantial progress in construction of the Systems Environmental Test Facility at Plum Brook Station, Ohio, where Orion systems level qualification testing will be performed. Orion also completed a key facility renovation on Kennedy Space Center's Apollo-era Operations and Checkout Building on January 26, 2009. This marked the activation of the High Bay Facility—the culmination of a two-year renovation led by Lockheed Martin, with investments from the state of Florida, to prepare the facility to support the manufacturing of the new Orion crew exploration vehicle.

The Ground Operations Project made significant progress in facility modifications for the Constellation Program. The Ground Operations Project completed

the construction of three new 600-foot lightning masts at Launch Pad B to protect the new Ares I rockets and implemented key modifications to the Shuttle launch pad to support the future Ares launches. The Ground Operations Project also began the fabrication of the new Ares I Mobile Launcher (ML), stacking the first of 10 tiers of the new launch tower on the launcher. Having the tower on the Mobile Launcher (reminiscent of Apollo launch towers) will facilitate a clean pad concept.

Commercial Crew and Cargo Program Office

Commercial Crew and Cargo Program Office FY 09 Highlights

Administered by the Commercial Crew and Cargo Program Office, the Commercial Orbital Transportation Services (COTS) project progressed toward its goal of demonstrating an orbital capability to service the ISS and encourage a commercial market for ISS resupply. During FY 09, NASA maintained two unfunded and two funded Space Act Agreements (SAAs) with private companies. Unfunded SAAs included PlanetSpace and Sierra Nevada Corporation (formerly SpaceDev); funded SAAs included Space Exploration Technologies (SpaceX) and Orbital Sciences Corporation (Orbital). SpaceX made significant progress, completing qualification testing of the Dragon capsule, the Merlin rocket engines, and launch vehicle structures, as well as the construction of its Cape Canaveral launch facility. During 2009, SpaceX developed and flew the Dragon Eye, a proximity operations sensor that will be used to guide the Dragon capsule to the ISS. The SpaceX COTS Ultra High Frequency Communication Unit was also flown to, and physically integrated into, the ISS, providing a future communications link between the ISS and the Dragon Capsule.

Additionally, SpaceX began manufacturing flight hardware to be used for the first NASA demonstration mission, planned for 2010. SpaceX experienced delays that are common within the aerospace community and that resulted in the renegotiation of milestones related to the NASA demonstration missions.

NASA's other funded SAA partner, Orbital, also made significant progress by completing its COTS system preliminary design review, major element critical design reviews, and ISS Safety Review Panel review, in addition to groundbreaking at its Wallops Flight Facility launch site. The Orbital systems-level critical design review is planned for early fiscal year 2010 (FY 10).

SpaceX plans to conduct orbital demonstrations in 2010, and Orbital plans to conduct its ISS demonstration mission in 2011.

Space Operations Mission Directorate

Space Shuttle/International Space Station (Integrated)

FY 09 was a milestone in the history of the ISS program, the year when the majority of major construction activities on board the ISS were completed. The final set of truss and solar array elements (which now stretch as wide as a football field) were installed. So, too, were the final pieces of the Japan Aerospace Exploration Agency's (JAXA) Kibo laboratory module, which completed the International Partners' (IP) laboratories. During FY 09, the ISS supported over 100 research experiments station-wide, including 50 U.S. experiments, involving over 400 scientists, even while station construction was rapidly underway. In May, the station crew size doubled to six, allowing more crew time for research. By the end of FY 09, the ISS was 81 percent complete, with an on-orbit mass of over 689,500 pounds. The ISS International Partnership celebrated eight years of continuous human presence in space on November 2, 2008, as well as the 10th anniversary of the launch of Zarya, the first ISS element on orbit, on November 20, 2008.

For the past 11 years, NASA has applied the full capabilities of the Space Shuttle to the mission for which this unique vehicle was originally conceived—the assembly of a large, advanced research station in low-Earth orbit, one that can serve as a critical international way station for further missions beyond low-Earth orbit. In FY 09 alone, the Space Shuttle lofted nearly 150,000 pounds of hardware, equipment, and supplies to the ISS and hosted 16 spacewalks over four highly successful missions at the station. An additional three spacewalks were performed by the ISS crew from the Russian Pirs airlock. The Space Shuttle's four ISS assembly flights were punctuated by another historic mission in FY 09—the fifth servicing mission to the Hubble Space Telescope (HST) in May 2009, a mission marked by some of the most intense and intricate extravehicular activity (EVA) work in the history of space exploration.

Crew exchanges continued in FY 09, with the launch of Soyuz 17S TMA-13 from Baikonur Cosmodrome, Kazakhstan, on October, 12, 2008, carrying Expedition

18 crewmembers Mike Fincke and Yuri Lonchakov, as well as spaceflight participant Richard Garriott. Soyuz 16S TMA-12 left the ISS on October 23, 2008, and landed safely, carrying returning Expedition 17 crewmembers Sergei Volkov and Oleg Kononenko and spaceflight participant Garriott.

The crew of Space Shuttle Endeavour flew the first Shuttle mission of the fiscal year with the launch of STS-126 to the ISS on November 14, 2008. There were two primary goals for the mission: to deliver equipment and supplies that would enable an increase of the ISS crew capability from three to six and to repair the station's starboard Solar Alpha Rotary Joint (SARJ). Preparing the ISS to permanently host six crewmembers was vital to bringing the full research capabilities of the station online. To that end, the 124th Space Shuttle flight carried over 32,000 pounds of hardware aboard the Multi-Purpose Logistics Module Leonardo, including crew quarters, wastewater reclamation hardware, a galley, a toilet, exercise equipment, and other equipment needed for a doubling of the ISS crew. Leonardo also carried hardware to repair the SARJ over a series of four spacewalks. The SARJ (a ten-foot-diameter, wagon-wheel-shaped gear mechanism on the starboard truss) had been locked in a stationary position since the joint mechanisms were found to be contaminated with debris in 2007. Locking the starboard solar arrays prevented further damage until the repair could be effected but also meant that the starboard arrays could not track the sun during the station's orbit and, therefore, could not provide all the electrical power the ISS laboratories would require. Replacing the Trundle Bearing Assemblies on the SARJ allowed the starboard solar arrays to once again rotate and track the sun. The SARJ repair again demonstrated that a well-trained, prepared, and adaptable team of astronaut crews and ground controllers provides the ultimate in flexibility and capability in space—a lesson that will serve the U.S. and the IP well as NASA continues to explore beyond low-Earth orbit. STS-126 also served as a taxi flight, bringing NASA astronaut Sandra Magnus to the ISS and returning Expedition 17/18 flight engineer Greg Chamitoff back to Earth.

The hardware delivered by Endeavour included the Water Recovery System portion of the station's Regenerative Environmental Control and Life Support System. The Oxygen Generator had been delivered earlier. This system, besides being necessary to support six-crew operations by reducing the need for water resupply from the ground, is critical to future long-duration spaceflight beyond low-Earth

orbit where water resources and resupply opportunities are severely constrained. After activation and a safety check of the water processing and analysis systems, the first drink of on-board reprocessed urine occurred on May 20, 2009. With the Regenerative Environmental Control and Life Support System operational, the ISS will be capable of meeting about 78 percent of its oxygen and water needs through reclamation and reprocessing. Space exploration provides an opportunity to demonstrate these kinds of revolutionary technologies in an extremely demanding operational environment.

With the starboard SARJ successfully repaired on STS-126, the STS-119 mission was clear to proceed with the delivery and installation of the Starboard 6 (S6) truss and solar arrays, the last piece of the ISS backbone completing the ISS electrical power system. The 31,060-pound Starboard 6 truss is the size of a school bus and completely filled Space Shuttle Discovery's cargo bay at launch on March 15, 2009. Based on operational experience and lessons learned from previous flights, deployment of the two 115- by 38-foot solar arrays proceeded without incident. With eight solar array wings now fully deployed, the ISS became one of the brightest objects in the sky. The ISS solar arrays can supply about 708,000 kilowatt-hours of electrical power per year, enough to meet the electrical needs of about 50 Houston-area homes. STS-119 also served as a crew rotation flight, carrying Japanese astronaut Koichi Wakata to the ISS to relieve Expedition 18 flight engineer Sandra Magnus.

On March 26, 2009, 18 Soyuz TMA-14 was launched from Baikonur Cosmodrome carrying Expedition 19 crewmembers Gennady Padalka and Michael Barratt, as well as spaceflight participant Charles Simonyi. Expedition 18 crewmembers Mike Fincke and Yuri Lonchakov and spaceflight participant Simonyi returned to Earth on 17 Soyuz TMA-13 on April 7, 2009, without incident. On May 27, Expedition 20 crewmembers Roman Romanenko, Frank De Winne, and Robert Thirsk lifted off from Baikonur on 19 Soyuz TMA-15. Two days later, on May 29, 2009, they docked with the ISS, beginning six-crewmember ISS operations. This also marked the first time that all five ISS International Partner agencies were represented on-orbit at the same time.

One of the most anticipated Space Shuttle missions of the year was the STS-125 mission to the HST, launched on May 11, 2009. The primary objective of Space Shuttle Discovery and her seven-member crew was to carry out the fifth and last

HST servicing mission, upgrading and refurbishing the 19-year-old telescope with new equipment and new scientific instruments. Four spacewalking astronauts conducted five EVAs during the mission, each lasting between seven to eight hours, on five consecutive days, often using real-time fixes to complete complex tasks. The crew installed the new Wide Field Camera 3, which allows the HST to take large-scale, extremely clear and detailed pictures at ultraviolet and infrared wavelengths, a dramatic improvement over all previous HST cameras. They installed the Cosmic Origins Spectrograph, which can observe faint, faraway light sources that provide clues to the evolution of galaxies and the origin of stellar and planetary systems. The STS-125 crew also performed a tune-up on the venerable instrument, replacing old gyroscopes, batteries, and a fine guidance sensor, which locks onto stars as part of the telescope's extraordinarily accurate pointing and tracking system.

With mission STS-127 and the delivery of the Kibo Japanese Experiment Module Exposed Facility, installation of the IP laboratories on the ISS is complete. The Kibo Exposed Facility can accommodate up to 10 research experiments exposed to the space environment providing physical, electrical, and data communications support. Experiments can be handled by the Kibo robotic arm and brought inside or taken outside of the ISS through the Kibo airlock. Launched on July 15, 2009, Space Shuttle Endeavour also delivered a pallet of large spare parts to the ISS (including a space-to-ground antenna, a linear drive unit, and a pump module), as well as six replacement batteries for the station's oldest solar array. STS-127 also served as a test of the DragonEye navigation sensor system being developed by SpaceX of Hawthorne, California. DragonEye will be used by the SpaceX Dragon cargo vehicle for proximity operations around the ISS when SpaceX begins demonstrating a commercial resupply capability to the ISS in FY 11. In addition to these critical outfitting and testing objectives, STS-127 set a record for the largest group of people ever to live and work in space at the same time. Tim Kopra replaced Japanese astronaut Koichi Wakata as a permanent crewmember aboard the ISS, and the thirteen members of the Endeavour and ISS crew worked together to prepare the ISS for research and operations in the post-Shuttle era.

With STS-127 having finished construction on the last of the IP research modules, the crew of Space Shuttle Discovery on STS-128 focused on outfitting the ISS for sustained operations and an intensified program of scientific research. Launched

on August 28, 2009, STS-128 delivered nearly seven tons of equipment and hardware carried inside the Multi-Purpose Logistics Module Leonardo. Research capabilities delivered on STS-128 included the Materials Science Research Rack, a second Minus Eighty-Degree Laboratory Freezer for the ISS, and the Fluids Integrated Rack. STS-128 also carried the Combined Operational Load Bearing External Resistance Treadmill (COLBERT), along with other crew habitability hardware. Three spacewalks totaling approximately 19.5 hours involved a wide variety of repair, replacement, and experiments-tending tasks outside of the ISS. In addition, STS-127 was the last ISS crew rotation scheduled for the Space Shuttle, with Flight Engineer Nicole Stott replacing Expedition 20 crewmember Tim Kopra.

On September 10, 2009, JAXA launched its first H-II Transfer Vehicle (HTV) carrying about six tons of supplies and equipment to the ISS. About a week later, the transfer vehicle was captured by the ISS robotic arm and berthed to ISS Node 2, Harmony. This was the first free-flight capture by the ISS robotic arm. Among the cargo were two experiments transported in the HTV unpressurized pallet. The experiments were removed and transferred to the Kibo External Facility by the coordinated use of the ISS robotic arm and the Japanese robotic arm on Kibo. Additional cargo resupply was provided in FY 09 by four Russian Progress flights.

In FY 09, progress continued to be made toward establishing a National Laboratory on the ISS. A Space Act Agreement was signed in December 2008, with Ad Astra Rocket Company to study the demonstration of their Variable Specific Impulse Magneto-plasma Rocket (VASIMR) on the ISS. A workshop was conducted in February 2009 under the Memorandum of Understanding (MOU) with the U.S. Department of Agriculture's Agricultural Research Service (ARS) to identify the top ten areas for ARS scientific investigation. Initial plant and animal genesis experiments were flown in fall 2008. The National Institutes of Health issued a call for ISS-based research proposals in March 2009, with a workshop held in June 2009. Astrogenetix made further progress in vaccine development with a salmonella target vaccine undergoing application for Food and Drug Administration classification as an investigational new drug. Additional Astrogenetix National Laboratory Pathfinder experiments on STS-119, -125, -128, and -129 surveyed four candidate bacterial pathogens for vaccine development,

including Methicillin-resistant Staphylococcus Aureus (MRSA). NASA also released an Announcement of Opportunity (AO) in August 2009 for use of ISS National Laboratory facilities by private-sector U.S. companies, as well as academic and research institutions. The AO will be continuously open through 2014.

FY 09 was also an important year for Space Shuttle transition and retirement activities. NASA's first priority continued to be a focus on maintaining the capabilities needed to safely complete the Shuttle manifest. The last Space Shuttle Main Engine (SSME) scheduled for flight, SSME-2061, was tested at the Stennis Space Center and delivered to the Kennedy Space Center on August 6, 2009. Production on the last five Space Shuttle External Tanks (ET), including the last ET-138, continued at the Michoud Assembly Facility (MAF) in Mississippi. As NASA prepares to retire the Space Shuttle, the Agency also continues to transition workforce, technology, facilities, and operational experience from this remarkable vehicle to a new generation of safer, even more capable systems. Preparations progressed throughout FY 09 for the Ares I-X test flight, which utilized the former Apollo and Space Shuttle Launch Pad LC-39B, as well as Space Shuttle personnel and processing facilities. In addition, NASA continued to focus on the critical role played by its highly skilled contractor and civil service workforce. Efforts included sharing a skilled workforce among the Space Shuttle, Constellation, and ISS programs; working with the Space Shuttle prime contractors on retention issues; and performing regular surveys of the Space Shuttle civil servant workforce and line management to identify and address emerging workforce issues.

SCaN

In FY 09, NASA's Space Communications and Navigation (SCaN) Program Office continued to provide the highly reliable space communication capability that is indispensable to all of NASA's space missions. The three networks SCaN operated and managed—the Near Earth Network, the Space Network (the Tracking and Data Relay Satellite System), and the Deep Space Network (DSN)—met the communications needs, such as Earth monitoring and support of deep space exploration missions, of a wide range of customers, both internal and external to NASA.

SCaN achieved major progress during the fiscal year toward consolidating all NASA space communications assets into a single integrated network by completing an Architecture Definition Document (ADD) for NASA's space communications architecture. This document will drive the integration of SCaN's three networks while providing the flexibility and added capability required for all of NASA's science and exploration missions for the next 20 to 25 years, as directed in the NASA Authorization Act of 2005.

SCaN also implemented a number of efficiency initiatives to reduce the costs of operation and maintenance of the NASA communications networks and to leverage the savings into the buildup of capabilities and the rejuvenation of the aging SCaN infrastructure. These initiatives focused on leveraging technology to migrate the burden of operations to the machine rather than people. This included more reliance on remote operations and better technology to enable operators to handle more than one link at a time. This would allow for fewer people controlling and managing the assets. Additionally, reliance on remote operations enables a reduction in the number of operators required at each site. Instead of three shifts per site, NASA is moving toward three shifts per network, in which an operator at one site can operate and manage the assets at all sites for that particular network at the first phase. During the second phase, and upon completion of networks integration activities, an operator can then operate and manage the assets at all sites for all NASA networks at the same time and from a single location. SCaN has expended great effort to consolidate and harmonize technology across all NASA assets, which will result in fewer people required to maintain the hardware and software, leading to greater cost efficiencies and improved services.

During FY 09, SCaN completed all studies and plans for the rejuvenation of all its assets and has initiated procurement activities to replace the aging DSN 70-meter antennas, as well as the Space Network ground site, which also suffers from outdated and obsolete technology.

NASA initiated a new Disruption Tolerant Networking project, aimed at starting the buildup of an "Interplanetary Internet" by 2015. A first flight test and demonstration of the new Internet-like communications technique was conducted over deep space data links in October 2008, using NASA's Deep Impact spacecraft in orbit around the sun.

SCaN continued its strong interagency cooperation and has been a driving force toward interoperability and compatibility among various national and international space communications systems. This will ensure better international cooperation and cross support among space agencies, as well as better usage of assets nationally.

Launch Services

The Launch Services Program (LSP) successfully managed the launch of five missions on expendable launch vehicles (ELVs) during FY 09. Three of the five missions were launched from the East Coast's Cape Canaveral Air Force Station, Florida, including Kepler on a Delta II on March 6, 2009; the dual-manifested Lunar Reconnaissance Orbiter/Lunar CRater Observation and Sensing Satellite on an Atlas V on June 18, 2009; and the Space Tracking and Surveillance System (STSS) Demonstrators (DEMO) on a Delta II on September 25, 2009. Additionally, two Delta II's were launched from the western range at Vandenberg Air Force Base, California: NOAA-N on February 6, 2009, and STSS Advanced Technology Risk Reduction (ATRR) on May 5, 2009. The STSS missions were launched on behalf of the Missile Defense Agency. On February 25, 2009, the Orbiting Carbon Observatory (OCO) satellite, also launched from the West Coast on a Taurus II, was lost in the southern Pacific near Antarctica. For each mission, NASA competitively procured launch services from domestic commercial companies. To find out more about these and other NASA science missions (except for STSS ATRR), see the Science Mission Directorate section in this report.

Also in FY 09, the ISS Program Commercial Resupply Services (CRS) contract was issued. Contract terms and deliverables are included for the Launch Services Program (LSP) evaluation of the launch vehicles to be used to resupply the space station. The LSP has begun initial technical exchanges with SpaceX under the CRS contract. Furthermore, two SAAs have been established by the LSP: the first is for Taurus II and the second with ATK for its SLV A and B small launch vehicles. Technical exchanges between LSP and ATK have been initiated in FY 09 as a result of this SAA.

In 2009, the Rocket Propulsion Test (RPT) Program continued to maintain the Agency's ability to safely test rocket propulsion systems by evaluating requirements and focusing resources to complete those requirements. To assure the accuracy

of the requirements, the RPT has maintained close coordination with the Space Shuttle Program, the Constellation Program, and the Department of Defense.

Science Mission Directorate

NASA's Science Mission Directorate (SMD) successfully launched five new space and Earth science missions designed to improve our understanding of solar processes, Earth, the universe, and the history of the solar system. The Science Mission Directorate has four divisions: Astrophysics, Planetary, Heliophysics, and Earth Science.

On October 19, 2008, the Interstellar Boundary Explorer (IBEX) mission was successfully launched on a Pegasus rocket. IBEX is detecting, for the first time, the edge of the solar system to study galactic cosmic rays and energetic particles from beyond the solar system that pose health and safety hazards for humans exploring beyond Earth's orbit. As the solar wind from the sun flows out beyond Pluto, it collides with the material between the stars, forming a shock front. IBEX contains two neutral atom imagers that are designed to detect particles from the termination shock at the boundary between the solar system and the interstellar space. IBEX makes these observations from a highly elliptical orbit that takes it beyond the interference of Earth's magnetosphere. IBEX is a Heliophysics Division mission.

On October 22, 2008, India launched its first lunar explorer, Chandrayaan-1, carrying two NASA science instruments. The spacecraft entered lunar orbit on November 8, 2008. NASA's Moon Mineralogy Mapper (M3) surveyed mineral resources of the moon, and the Miniature Synthetic Aperture Radar (Mini-SAR) mapped the moon's polar regions looking for ice deposits in the permanently shadowed craters. Recently, scientists using NASA's Mini-SAR on Chandrayaan-1 were able to look inside two of the moon's coldest, darkest craters, at its north and south poles. The floors of the craters, Seares near the moon's north pole and Haworth crater at the south pole, are not visible from Earth. However, by using the Mini-SAR radar on the Chandrayaan-1 spacecraft, scientists are able to map and search the insides of the craters for water ice. More analysis will assist scientists to determine if buried ice deposits exist in the permanently shadowed craters near the moon's poles. M3 results were featured on the cover of the October 23, 2009, edition of *Science*. M3 is part of the Planetary Division's Discovery Program.

Another noteworthy mission in the Planetary Division's Discovery Program is the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission. The planet Mercury orbits deep within the sun's gravity well. Although the planet can be as close as 51 million miles from Earth, getting the spacecraft into orbit around Mercury depended on an innovative trajectory using the gravity of Earth, Venus, and Mercury itself to slow and shape the spacecraft's descent into the inner solar system. On its 4.9-billion-mile journey to become the first probe to orbit the planet Mercury, MESSENGER has flown by Earth once (in 2005), Venus twice (in 2006 and 2007), and Mercury twice (both times in 2008).

During the two Mercury flybys, MESSENGER's cameras captured more than 1,200 high-resolution and color images of the planet—unveiling another 30 percent of Mercury's surface that had never before been seen by spacecraft and gathering essential data for planning the overall mission after orbit insertion in 2011. The second flyby provided an opportunity for several of the MESSENGER Educator Fellows, master science educators, to share the experience and excitement felt by the scientists and engineers. Besides being there for the closest approach, the Fellows were also able to listen to the discussions of the data from the flyby. With the use of Web 2.0 and social media networking, the Fellows reported, in real time, to their school districts and students about their experiences.

On January 15, 2009, a team of NASA and university scientists using data from the Keck Observatory reported the first definitive detection of methane in the atmosphere of Mars to indicate that the planet is still alive in either a biologic or geologic sense. Methane—four atoms of hydrogen bound to a carbon atom—is the main component of natural gas on Earth. It is of interest to astrobiologists because organisms release much of Earth's methane as they digest nutrients. If microscopic Martian life is producing the methane, it likely resides far below the planet's surface, where it is still warm enough for liquid water to exist. Liquid water, as well as energy sources and a supply of carbon, are necessary for all known forms of life. It will take future missions, like NASA's Mars Science Laboratory, to discover the origin of the Martian methane. One way to tell if life is the source of the gas is by measuring isotope ratios. Isotopes are heavier versions of an element; for example, deuterium is a heavier version of hydrogen. In molecules that contain hydrogen, like water and methane, the rare deuterium occasionally replaces a hydrogen atom.

Since life prefers to use the lighter isotopes, if the methane has less deuterium than the water released with it on Mars, it is a sign that life is producing the methane.

On February 6, 2009, NASA launched the NOAA-N Prime spacecraft for the National Oceanic and Atmospheric Administration (NOAA). NOAA-N Prime is the last in the Television Infrared Observation Satellite (TIROS) series of NOAA satellites that observe Earth's weather and the environment. NOAA-N Prime carried a suite of instruments to provide critical global data for weather and climate predictions. The NOAA-N Prime spacecraft will continue to provide a polar-orbiting platform to support (1) environmental monitoring instruments for imaging and measuring Earth's atmosphere, its surface and cloud cover, including Earth radiation, atmospheric ozone, aerosol distribution, sea surface temperature, and vertical temperature and water profiles in the troposphere and stratosphere; (2) measurement of proton and electron flux at orbit altitude; (3) data collection from remote platforms; and (4) the Search and Rescue Satellite-Aided Tracking system.

Like its predecessors, NOAA-N Prime provided global images of clouds and surface features and vertical profiles of atmospheric temperature and humidity for use in numerical weather and ocean forecast models, as well as data on ozone distribution in the upper part of the atmosphere and near-Earth space environments—information used by marine, aviation, power generation, agriculture, and other communities. NOAA-N Prime was also part of the international satellite-aided search and rescue program.

On February 24, 2009, the Orbiting Carbon Observatory (OCO) satellite mission was lost in a launch failure when the payload fairing of the Taurus launch vehicle failed to separate during ascent. A payload fairing is a clamshell-shaped cover that encloses and protects a payload on the pad and during early flight. Fairings are a standard component of expendable launch vehicles, and they are always jettisoned as soon as possible after a launch vehicle has achieved an altitude where aeroheating is no longer a risk to the satellite. On this OCO flight, the fairing should have been jettisoned shortly after Stage 2 ignition. However, the fairing remained attached for the remainder of the flight. The OCO satellite was separated from the Stage 3 but was contained within the still-attached fairing. Failure to shed the fairing prevented the satellite from reaching its planned orbit, resulting in atmospheric reentry. Aeroheating and reentry loads most likely caused the breakup

and/or burnup of OCO. Any surviving pieces were dispersed in the Pacific Ocean near Antarctica. OCO was an Earth Sciences Division mission.

On March 5, 2009, NASA launched the Kepler Space Telescope. The Kepler spacecraft is the first designed to detect Earth-like planets, potentially capable of hosting life, as they circle distant suns. Kepler is designed to detect planets as they pass in front of their stars, which causes a tiny dip in the stars' light. This is called the "transit method" of finding planets. Transits are only seen when a star's planetary system is nearly perfectly aligned with our line of sight. For a planet in an Earth-size orbit, the chance of it being aligned to produce a transit is less than one percent. However, Kepler will stare at one huge area of the sky in the constellations Cygnus and Lyra over several years. Over the lifetime of the mission, the Kepler spacecraft will simultaneously measure the variations in the brightness of more than 100,000 stars every 30 minutes, searching for the tiny "winks" in light output that happen when a planet passes in front of its star. The effect lasts from about an hour to about half a day, depending on the planet's orbit and the type of star. Kepler is an Astrophysics Division mission.

On May 11, 2009, the NASA Shuttle Atlantis went into space to service and repair the Hubble Space Telescope (HST). The HST Servicing Mission #4 allowed astronomers to release stunning new images from Hubble's operating science instruments. Spacewalking astronauts brought the orbiting observatory to a new apex of scientific performance. Astronauts installed two new instruments, the Wide Field Camera 3 and the Cosmic Origins Spectrograph, and repaired the Advanced Camera for Surveys and Space Telescope Imaging Spectrograph circuit boards. Another instrument, the Near Infrared Camera and Multi-Object Spectrometer, returned to operation during Hubble's three months of calibration and testing. As a result of the astronauts' work, new spectacular images and space science discoveries from the Hubble Space Telescope will help to rewrite science textbooks. Equipped with new eyes and fresh technology, Hubble Space Telescope will work for years to come to answer the profound questions of modern astronomy. Hubble is an Astrophysics Division mission, and its servicing was accomplished via a partnership with NASA's Space Operations Mission Directorate.

On May 14, 2009, Herschel and Planck space observatories were launched into space together from Kourou, French Guiana, aboard an Ariane 5 rocket. Both of these are European Space Agency (ESA) missions with significant U.S. contributions.

The mission of the Herschel Space Observatory, a collaborative project between NASA and ESA, is to discover how the first galaxies formed and how they evolved to give rise to present-day galaxies like our own. Herschel has the largest mirror ever built for a space telescope at 3.5 meters in diameter, designed to collect long-wavelength radiation in the far-infrared and submillimeter portion of the electromagnetic spectrum from some of the coldest and most distant objects in the universe. It will be able to observe dust-obscured and cold objects that are invisible to other telescopes. Additional targets for Herschel include clouds of gas and dust where new stars are being born, disks out of which planets may form, and cometary atmospheres packed with complex organic molecules.

Specifically, the Herschel Space Observatory's principal objectives are to help scientists study and understand (a) how galaxies formed and evolved in the early universe and the nature of enormously powerful galactic energy sources; (b) the formation, evolution, and interrelationship of stars and the interstellar medium in the Milky Way and other galaxies; (c) chemistry in our galaxy; and (d) molecular chemistry in the atmosphere of Mars and our solar system's comets and giant planets, as well as the nature of comet-like objects in the Kuiper belt beyond Neptune.

While Herschel is an ESA-led mission, NASA made significant hardware contributions for the Heterodyne Instrument for the Far Infrared (HIFI) and Spectral and Photometric Imaging Receiver (SPIRE) instruments and developed the NASA Herschel Science Center, which provides Herschel data to all U.S. scientists. For HIFI, NASA provided local oscillators and mixers for bands five and six; and amplifiers, isolators and multiplier diodes for bands one through four. For the SPIRE instruments, NASA provided five Bolometer detector arrays, cold readout electronics, RF filters, and harnesses.

Planck is also a collaborative project between NASA and ESA. The Planck spacecraft orbits a distant point, called the second Lagrange point (L2) of our Earth-sun system, about 1.5 million kilometers (930,000 miles) away. Planck will give us the best view yet of the early moments of cosmic history. Planck will make the most precise measurements to date of tiny variations in the universe's oldest light, called the cosmic microwave background, created more than 13 billion years ago. That is, the Planck mission will measure the cosmic microwave background over a broad range of wavelengths to an unprecedented accuracy. Planck is expected to provide

answers to many fundamental questions about the early history and evolution of the universe. Scientists hope to find data in order to (a) set tight constraints on cosmological parameters, (b) study the ionization history of the universe, (c) probe the dynamics of the inflationary era, and (d) test fundamental physics.

The mission will refine our estimates of the size, mass, age, composition, geometry and fate of the universe—whether it will collapse in on itself or expand forever. NASA played important roles in the mission's development and will provide important contributions to data and science analyses. While Planck is also an ESA-led mission, NASA made significant hardware contributions. NASA provided cryogenic low-noise amplifier technology and radiometer expertise for the Low Frequency Instrument (LFI), spider web and polarization-sensitive bolometers for the High Frequency Instrument (HFI), cryocooler compressors, and a cryocooler cold end.

The Geostationary Operational Environmental Satellite (GOES) program, which began in 1974, is a program of the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. NOAA funds and manages the program and determines the need for satellite replacement. NASA acts as NOAA's acquisition agent to design, develop, and launch GOES satellites. After a satellite is launched and checked out by NASA, the spacecraft is turned over to NOAA for its operation.

On June 27, 2009, NASA launched the GOES-O spacecraft. Forecasting the approach of severe storms for more than 25 years, GOES spacecraft remain an essential cornerstone of weather observation and forecasting. Atmospheric phenomena are tracked, ensuring real-time coverage of events such as severe local storms, tropical hurricanes, and cyclones—meteorological events that directly affect public safety, property, and economic health and development.

The GOES spacecraft operate as a two-satellite constellation in geosynchronous orbit above the equator and observe 60 percent of Earth. They measure Earth's atmosphere, its surface, its cloud cover, and the solar and geosynchronous space environment, and they provide a platform for the Imager, Sounder, Solar X-Ray Imager, and space environment monitoring instruments. The system also supports land- and ocean-based Data Collection Platforms, transmits Imager and Sounder data, relays Low Rate Information Transmission data, relays GOES

variable reformatted Imager and Sounder data (these data will improve knowledge of exactly where severe weather events are located), relays Emergency Managers Weather Information Network broadcasts, and participates in the international Cospas-SARSAT Search and Rescue Satellite-Aided Tracking system.

In September 2009, according to sensors on NASA's Advanced Composition Explorer (ACE) spacecraft, galactic cosmic rays hit a space age high. In 2009, cosmic ray intensities increased 19 percent beyond anything seen in the past 50 years. The cause of the surge is solar minimum, a deep lull in solar activity that began around 2007. Researchers have long known that cosmic rays go up when solar activity goes down. In 2009, solar activity was as weak as it had been in modern times, setting the stage for a perfect storm of cosmic rays.

Galactic cosmic rays come from outside the solar system. They are subatomic particles—mainly protons but also some heavy nuclei—accelerated to almost light speed by distant supernova explosions. The sun's magnetic field is our first line of defense against these highly charged, energetic particles. At times of low solar activity, this natural shielding is weakened, and more cosmic rays are able to reach the inner solar system.

In late September 2009, NASA's IBEX spacecraft made it possible for scientists to construct the first comprehensive sky map of our solar system and its location in the Milky Way galaxy. The new view will change the way researchers view and study the interaction between our galaxy and sun. The sky map was produced with data that two detectors on the spacecraft collected during six months of observations. The detectors measured and counted particles referred to as energetic neutral atoms. The new map revealed the region that separates the nearest reaches of our galaxy, called the local interstellar medium, from our heliosphere—a protective bubble that shields and protects our solar system from most of the dangerous cosmic radiation traveling through space. For the first time, we are looking beyond the sun's atmosphere and beginning to really understand our place in the galaxy.

On October 7, 2009, NASA planned, developed, and carried out a White House–hosted "Star Party" in which President Obama and his family joined astronomers, scientists, NASA senior officials, and 150 elementary and middle school students. Participants learned about crater formation on the moon and viewed Jupiter and its four Galilean moons, as well as distant stars and nebulae in our galaxy. The

White House astronomy event provided live-streamed video, a host of telescopes, and several hands-on activities that could be replicated at museums and science centers across the country.

In fall 2009, NASA funded and launched the first series of flights in a six-year campaign to study changes to Antarctica's sea ice, glaciers, and ice sheets. Using NASA's DC-8 and other aircraft, Operation Ice Bridge will repeatedly study selected key targets that are most prone to change; provide essential data on changes in ice elevation; and help bridge the data gap until NASA's Ice, Cloud, and Land Elevation Satellite-II is launched. The first Operation Ice Bridge airborne campaign over Greenland and the Arctic Ocean occurred earlier this year. Arctic flights will resume in spring 2010.

Aeronautics Research Mission Directorate

Research by NASA's Aeronautics Research Mission Directorate (ARMD) continued to contribute directly to aeronautics breakthroughs for the benefit of the broad aeronautics community and in support of NASA's goals for both human and robotic space exploration. ARMD oversees long-term, cutting-edge fundamental research in traditional and emerging disciplines for the purpose of generating innovative concepts, tools, and technologies that enable revolutionary advances in future aircraft and the airspace in which they will fly. Our world-class capability is built on a tradition of expertise in aeronautical engineering and its core research areas, including aerodynamics, aeroacoustics, materials and structures, propulsion, dynamics and control, sensor and actuator technologies, advanced computational and mathematical techniques, and experimental measurement techniques.

ARMD's robust research portfolio addressed the challenges of transforming our Nation's air transportation system to meet growing capacity needs and also supported the Agency's space exploration vision.

ARMD's research in FY 09 included the following:

- Research that supports the Next Generation Air Transportation System (NextGen).
- Research in key areas related to the development of advanced aircraft technologies and systems, including those related to aircraft safety, environmental compatibility, and fuel efficiency.

- Foundational research across a number of core competencies that supports aeronautics and space exploration activities.

ARMD continued a robust fundamental research program well aligned with the principles, goals, and objectives of the National Aeronautics Research and Development (R&D) Policy and directly supported the development of NextGen. ARMD research focused on improving airspace capacity and mobility and improving aviation safety and aircraft performance while reducing noise, emissions, and fuel burn. Additionally, ARMD focused on five strategic objectives.

(1) Conduct high-quality, cutting-edge research that benefits the constituents of the entire aeronautics community.

(2) Openly disseminate the results of all research to the widest practical and appropriate extent, consistent with national security and foreign policy, through archival publications (such as books, technical papers, technical memoranda, and peer-reviewed journal articles), conference proceedings, and NASA publications.

(3) Pursue a coordinated approach to managing the Nation's research, development, test, and evaluation (RDT&E) infrastructure. For example, ARMD's continued cooperation with the Department of Defense (DOD) through the National Partnership for Aeronautical Testing resulted in the development of guiding principles for determining priorities and consistent pricing.

(4) Foster intellectual partnerships with industry and academia by means of comprehensive acquisition methods including SAAs and the NASA Research Announcement (NRA) that allows full and open competitive research awards. ARMD had 385 total NRA research efforts in FY 09, funded at over $70 million. Of these, nine NRAs were new efforts initiated in FY 09, representing $5.3 million. ARMD has 78 SAAs in place across all programs.

(5) Continue strong partnerships with other Government agencies and organizations, especially the Federal Aviation Administration (FAA), Joint Program and Development Office (JPDO), and DOD.

As a member agency of the JPDO, NASA, along with its partner agencies, continued to plan and coordinate the development of the Next Generation Air Transportation System (NextGen). The NextGen portfolio includes large-scale

investments, research, and operational changes that will profoundly impact the capabilities of the Nation's air transportation system. This includes developments in air traffic control, airspace management, satellite-based navigation, security (both at the airport and in the air), digital communications, net-centric operations, and changes in the way aviation weather information is gathered and disseminated throughout the system. In addition, NextGen offers a new approach to managing the environmental impact of aviation. For example, several air traffic procedures currently in use provide more efficient aircraft trajectories that reduce the amount of fuel aircraft burn during flight. These directly reduce emissions and noise. Over the longer term, gains provided by satellite-based navigation systems will offer more efficient routes that reduce the amount of time aircraft spend in flight. Other research undertaken by NASA included engine systems and aircraft designs that will lead to a substantial reduction in fuel burn and pollutant emissions.

In FY 09, ARMD executed a robust research portfolio that addressed challenges of the future air transportation system, including expanding capacity needs, environmental issues, efficiency, safety, and mobility challenges. As a major highlight illustrating this progress, NASA researchers, in collaboration with San Jose State University, Perot Systems and the FAA, successfully completed a series of human-in-the-loop experiments that explored advanced concepts and technology for separation assurance—safe separation between aircraft, a key research need for NextGen. Such technology is critical to relieving air traffic controller workload, a primary constraint on airspace capacity. By automating fundamental air traffic control functions, such as conflict detection and resolution, researchers believe that automation could manage separation. These experiments, which involved six professional controllers and 20 professional pilots, examined the performance of controllers, pilots, and separation-assurance automation during nominal and dramatically increased (doubled and tripled) traffic demand through a complex airspace sector in the FAA's Indianapolis Air Route Traffic Control Center. Researchers provided varying levels of automation support to the controller and pilot subjects, including automated conflict detection, automated strategic conflict resolution, and automated tactical conflict resolution. The test scenarios included routine operations and off-nominal situations such as data communication failures and aircraft blunders toward proximate traffic.

Initial results showed that even under conditions of heavier-than-normal simulated air traffic, using automated separation-assurance technology resolved more than 99 percent of potential traffic conflicts without substantially increasing controller workloads. While further investigation will validate the underlying technology and procedures, such concepts hold the promise of dramatically increasing the capacity of our air transportation system, thereby facilitating the economic growth that comes with improved mobility of people and goods about the country.

The following sections describe additional technical accomplishments of the ARMD programs during FY 09.

Fundamental Aeronautics Program

The goal of the Fundamental Aeronautics Program is to conduct cutting-edge research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for air vehicles that fly in all speed regimes. The Program focused on achieving technological capabilities necessary to overcome national challenges in air transportation including reduced noise, emissions, and fuel consumption; increased mobility through a faster means of transportation; and the ability to ascend/descend through planetary atmospheres. These technological capabilities will enable design solutions for the performance and environmental challenges of future air vehicles. The Program developed technological capabilities that range from basic knowledge of underlying physical phenomena to the understanding of system-level interactions. The Program also had significant emphasis on the development of tools for advanced multidisciplinary design and analysis capabilities to realize integrated technology advances in future aircraft and to guide its research and technology investments.

The Program structure was organized by flight regime and encompassed research in the four areas of Subsonic Fixed Wing, Subsonic Rotary Wing, Supersonics, and Hypersonics. The Subsonic Fixed Wing project addressed the challenge of making future aircraft quieter and cleaner to meet stringent noise and emissions requirements resulting from the expected growth in the air transportation system (two to three times higher capacity by 2025). These aircraft must also meet challenging performance requirements to provide greater efficiency with reduced fuel burn. The Subsonic Rotary Wing project addressed the technical barriers that constrain

rotorcraft from reaching widespread use in civil aviation. These barriers include improved range, speed, payload capacity, fuel efficiency, and environmental acceptance. The unique ability of rotorcraft to operate independent of a runway could greatly expand access to air travel. The Supersonics project conducted research to address the efficiency, environmental, and performance barriers that prevent practical supersonic cruising over land. The Hypersonics project focused on air-breathing technologies for the first stage of a highly reusable two-stage-to-orbit launch system. It also researched technologies for hypersonic entry and descent of very heavy payloads into planetary atmospheres to enable a high-mass Mars entry system.

The following examples illustrate significant accomplishments of each project. The Subsonic Fixed Wing project, in partnership with several other Government agencies, industry, and academia, completed an alternative fuels experiment in which a 100 percent Fischer-Tropsch synthetic fuel was tested as well as a 50/50 blend of the synthetic fuel and conventional jet fuel. The experiment evaluated the effect of the fuels on aircraft emissions and emissions chemistry. Results indicated that the fuels reduced the particulates and aerosols in the emissions. However, some engine seal leakage occurred with use of the 100 percent synthetic fuel. The project also completed a database of alternative fuels and fuel blends, including their standard properties.

The Subsonic Rotary Wing project, in partnership with the Army and industry, tested an Individual Blade Control (IBC) main rotor to assess the potential improvement in rotor performance and reduction in vibration and noise. The Individual Blade Control dynamic actuators allowed ±3 degrees of blade pitch to be input to each blade at up to 7 per revolution frequency. Preliminary results from the test showed a reduction in power and an increase in lift-to-drag as well as reduced in-plane noise and multi-parameter hub loads. Additionally, the project tested a variable speed transmission and obtained data for comparison with computational modeling of the system. Results indicated that the computational predictions for the operational parameters are within 10 percent of the measured parameters. Such validated computational modeling capabilities will help enable the future design of quieter, more efficient rotorcraft with propulsion/rotor systems capable of optimized rotational speeds for hover and forward flight.

The Supersonics project completed a number of activities that contributed to the development of new capabilities to design and analyze supersonic vehicles that achieve high fuel efficiency with low sonic boom. New adjoint-equation-based fuselage-wing shaping tools were developed from existing computational methods that were validated against wind tunnel data. Knowledge-based design tools for fuselage and engine nacelle shaping to reduce boom or drag levels were either developed or improved. A new computational and experimental study of the effects of engine exhaust plume on sonic boom and efficiency was completed. An initial multi-fidelity design system for the conceptual design of supersonic aircraft incorporating jet plume effects and sonic boom target optimization was made operational. Further data on sonic boom, lift, and nozzle effects were gathered using the F-15 research aircraft and large-wing tunnel facilities. Each of these accomplishments will enable future design and development of supersonic vehicles with high efficiency and low sonic boom.

The Hypersonics project completed the Inflatable Reentry Vehicle Experiment (IRVE-2) for Mach 6 atmospheric reentry. This successful experiment demonstrated flexible thermal protection system technology for support of high-mass planetary atmospheric entry. Additionally, the project completed the development of a secure, Web-based collaborative environment for the carbon matrix composite (CMC) user community. This advanced material is critical for future hypersonic air vehicle designs that are able to withstand 3,000°F. The Web-based collaborative environment, for use by researchers and engineers within NASA, other Government agencies, industry, and academia, fosters an online dissemination of engineering methodologies for fabrication, analysis, and design of ceramic composite materials and components. It also provides access to a material property database for a number of material systems.

Fundamental Aeronautics Program personnel presented their technical plans and research results in numerous forums and technical conferences in FY 09. These forums and conferences included meetings held collaboratively with other Government agencies and technical conferences sponsored by a variety of technical societies, including the American Institute of Aeronautics and Astronautics (AIAA), the American Society of Mechanical Engineers (ASME), and the American Helicopter Society (AHS). Program research teams were recognized for

their contributions to advancing the technology state of the art, including receiving the AHS Howard Hughes Award for outstanding improvement in fundamental helicopter technology. Fundamental Aeronautics researchers were awarded several patents and were selected by their peers to join the ranks of Fellow and Associate Fellow in various technical societies.

Aviation Safety Program

The Aviation Safety Program built upon the unique safety-related research capabilities of NASA to develop innovative algorithms, tools, concepts, and technologies that will improve the intrinsic safety attributes of current and future aircraft and overcome aircraft safety technological barriers that would otherwise constrain the full realization of NextGen.

The Aviation Safety Program consisted of four projects. The Aircraft Aging and Durability (AAD) Project addressed the challenge of improving the operational resiliency of future aircraft structures and advanced materials against aging-related hazards. The Integrated Intelligent Flight Deck (IIFD) Project conducted research to ensure the proper integration of the human operator in a highly automated and complex operational environment. The Integrated Resilient Aircraft Control (IRAC) Project sought to prevent loss-of-control incidents through better modeling of upset flight conditions (from a variety of causes, including icing and structural degradation) and adaptive control methods. The Integrated Vehicle Health Management (IVHM) Project addressed the challenge of using a prognostic approach to vehicle health management, in particular the integration, processing, and effective use of large amounts of data across highly integrated and complex flight-critical systems.

During FY 09, the AAD Project developed a process to increase the capability for superalloy turbine engine disks to run at higher temperatures than previous state-of-the-art designs while maintaining required high stress and cycle life. This process will allow safe, durable operations under the conditions required for future engine designs. The final spin test to validate the performance will be conducted during FY 10.

The IIFD Project assessed multi-modal presentation formats and interaction methods for uncertainty display concepts and virtual visual environments. Simulations demonstrated statistically significant reductions in communication

errors, mental workload, and flight technical error, as well as increases in usability and situation awareness. These factors were measured using multi-modal presentation formats and interaction methods in NextGen terminal area operations as compared to a baseline of current flightdeck systems in current air traffic terminal area operations.

The IRAC Project developed and evaluated concepts for online integrity monitoring for adaptive control systems through simulation tests. Simulation results demonstrated that failure of the adaptive control can be detected at least 99 percent of the time with lower than one percent false positive rate. In developing adaptive control systems, it is critical that safeguards must be put in place to prevent the automation itself from being the cause of new unforeseen failures.

The IVHM Project developed an innovative methodology for on-board estimation of aircraft engine performance parameters. Simulation results demonstrated that this technique provides improved performance estimation results, significantly exceeding the 10 percent estimation accuracy improvement metric. Real-time on-board models such as these can be directly utilized by prognostics and health management applications to improve aircraft safety.

Researchers for the Aviation Safety Program presented nearly 300 conference papers in FY 09 and published over 100 peer-reviewed journal papers and books. In addition, Program researchers filed 14 invention disclosures. As a result of work done under the Program, the Agency signed 34 software licenses and usage agreements.

Airspace Systems Program

The Airspace Systems Program directly addressed air traffic management needs of increasing capacity and efficiency of NextGen. The Program consisted of two projects, NextGen-Airspace and NextGen-Airportal. Each project made major contributions to air traffic needs of the future through the development of concepts and technologies for en route, transitional, terminal, and surface operations. Both projects remain highly integrated through close attention to information management at critical transition interfaces in the national airspace system.

The NextGen-Airspace Project conducted a number of simulations, demonstrations, and analyses to examine concepts and technologies aimed at enhancing air traffic operations in en route and approach airspace. Researchers successfully

completed a study of trajectory analysis for service provider–based (i.e., the FAA is the service provider) automated separation assurance with time-based metering (i.e., separation based on time, not distance, between aircraft). The study was conducted at increased traffic levels without any reduction of baseline metering accuracy or separation violations. The objective was to simultaneously consider conflict resolution algorithms and time-based constraints while providing safe separation. Researchers developed, validated, and implemented algorithms for an integrated solution and conducted initial real-time, high-fidelity evaluations. The results indicated that the integrated separation assurance/time-based metering system outperformed its stand-alone separation assurance predecessor, with integrated success rates of 94.5 percent and 89.4 percent at current traffic and doubled traffic respectively.

An evaluation of traffic flow management capability, developed by an NRA award recipient and in conjunction with the FAA, was shown to reduce arrival delays at San Francisco International Airport through improved scheduling using fog dissipation probabilities and predictions and advanced optimization algorithms. A collaborative field test at the FAA Air Traffic Control System Command Center to assess the benefits at San Francisco International Airport is planned for 2010.

The NextGen-Airportal Project developed and validated algorithms, concepts, and technologies to increase throughput of the runway complex and achieve high efficiency in the use of airport resources, such as gates, taxiways, runways, and final approach airspace. Aircraft movement on the airport surface is highly constrained and subject to high degrees of scheduling uncertainty, which makes planning difficult for controllers. In addition, inefficient taxi operations, such as long departure queues, result in excess fuel burn and adverse environmental impact. During FY 09, the Project developed algorithms to generate robust, optimized solutions for surface traffic planning and control, as well as an environmental planner to consider constraints in the optimization process. The evaluations included scenarios for both nominal and off-nominal conditions under increased airport traffic density and considered environmental constraints and aircraft operator schedule preferences. The results indicated that an optimization process for surface traffic movement can reduce taxi-time and engine-on time relative to current-day operational procedures. Savings of about 19 percent in fuel burn for simulated, optimized taxi operations were realized with increased traffic density of 1.5 times current day levels.

NASA and the FAA also continued to collaborate on the four Research Transition Teams (RTTs) to accelerate concepts and technology to further maturity. These RTTs include Efficient Flow into Congested Airspace (EFICA), Dynamic Airspace Configuration (DAC), Flow-Based Trajectory Management (FBTM), and Integrated Arrivals/Departures/Surface Management (IADS). The goal of the RTTs is to ensure that research and development needed for NextGen implementation are identified, conducted, and effectively transitioned to the implementing agency. In FY 09, each RTT developed a *Plan for Implementing the Common Vision*, identifying distinct Research Transition Products (RTPs), along with descriptions of NASA-provided elements, NASA research milestones, maturity, transition date, and the FAA intended use. In addition to the planning, NASA and the FAA collaborated on a number of development activities as part of the RTTs. For the EFICA RTT, NASA conducted a Human-in-the-Loop (HITL) 3D-Path Arrival Management (3D-PAM) field trial at the Denver Air Route Traffic Control Center. This assessed real-world descent trajectory uncertainty during arrival phase of flight. For the DAC RTT, NASA produced a white paper on the corridors-in-the-sky concept, identified research issues and further studies, and completed a Human-in-the-Loop simulation on Adaptable Airspace. On the FBTM RTT, NASA and the FAA conducted a simulation to examine capabilities, roles and responsibilities; communication and coordination; and information and decision support tool needs for trajectory management. For the Integrated Arrival/Departure/Surface RTT, NASA developed an approach for joint FAA/NASA testbed activities and the integration of NASA North-Texas Research Station (NTX) facility with FAA testbeds.

Researchers for the Airspace Systems Program published over 171 conference papers in FY 09, 35 of which were peer-reviewed and five of which received Best Paper awards at conferences sponsored by the AIAA, the USA/Europe Seminar on Air Traffic Management Research and Development, and Digital Avionics Systems. In addition, researchers published 14 NASA Technical Memorandums/Technical Reports/Contractor Reports.

Aeronautics Test Program

The Aeronautics Test Program (ATP) ensures the continuous availability of a portfolio of NASA-owned ground and flight test capabilities, which are strategically

important to meeting national aerospace program goals and requirements. Within ATP, the Aeronautics Ground Test Facilities Project provides facility operations support to ensure facility and staff availability and user price stability; facility maintenance and upgrades to address known deficiencies in facility safety, reliability, and productivity; facility test technology to develop and implement new and improved test capability, improve productivity and efficiency, and improve data quality; and facility-related research to involve universities with experimental work. The Flight Operations and Test Infrastructure Project provides the Western Aeronautical Test Range, support aircraft, testbed aircraft, and the Simulation and Flight Loads Laboratories, which together provide and support flight testing and are managed to ensure safety, rate stability, reliability, productivity, and improvement.

In its first three years, the ATP was intentionally tactical in nature, and investments were focused on stabilizing aeronautics test facility conditions, charge rates, and workforce competency. In FY 09, the ATP completed the development of a new strategic plan that contained three thrusts: (1) provide the vision and leadership required to meet national goals; (2) provide sustained support for workforce, capability improvements, test technology development, and maintenance; and (3) provide strategic planning, management, and coordination with NASA, Government, and industry stakeholders.

In FY 09, the ATP implemented an investment fund to provide for the recapitalization of flight operations and test infrastructure and to establish a clear pricing structure and charging policy for flight test operations support to assist customers in their test planning.

The ATP strengthened collaborations through the National Partnership for Aeronautical Testing (NPAT) and the Interagency Infrastructure Working Group (IIWG). The ATP, through the NPAT, implemented the National Force Measurement Technology Capability (NFMTC), a multi-year project to address gaps in state-of-the-art strain gage balance capability. In collaboration with the Air Force, the ATP instituted the Hypersonic Propulsion Integrated Test Team to address national hypersonic testing requirements. This group was active in the decision by the Defense Advanced Research Projects Agency (DARPA) to determine which tunnel offered the best capability to conduct turbine-based combined cycle transition testing. In collaboration with the Air Force, the ATP instituted

the Test Technology Collaboration Action Team to address national test technology requirements and to develop a national investment strategy. The ATP also utilized the collaborative power of NPAT to transfer Navy testing from the 30 by 60 Foot Full-Scale Tunnel to the strategically important National Full-Scale Aerodynamics Complex.

In collaboration with the NPAT, the ATP completed an assessment of the Nation's supersonic wind tunnel capabilities. This identified the wind tunnels that are critical to the Nation and will therefore require continued investment. The ATP and NPAT also initiated an assessment of the Nation's hypersonic wind tunnel capabilities.

ATP personnel authored numerous papers. Chief among these was a National Force Measurement Technology Capability–related paper coauthored by personnel from the Air Force and presented at the 2009 American Institute of Aeronautics and Astronautics Conference.

Partnerships with Government and Industry

NASA strives to be in the leadership position for fundamental research required to solve aeronautics challenges. In part, NASA accomplished this goal through close and strong partnerships with industry, academia, and other Government agencies in order to maximize the research capabilities of the Nation.

Because these partnerships are so important, NASA put many mechanisms in place to engage academia and industry, including industry working groups and technical interchange meetings at the program and project levels; SAAs for cooperative partnerships with industry; and the NRA process, which provides full and open competition for the best and most promising research ideas. Cooperative partnerships with industry consortia can result in a significant leveraging of resources for all partners and can provide opportunities to test the value of component-technology advances in full system-level contexts.

Additionally, ARMD continued its strong collaboration with the Department of Defense through NPAT and the ATP. In FY 09, that partnership included a series of tests using a shared model and test team in four national transonic wind tunnels (three NASA tunnels and one Air Force tunnel). The objectives were to compare the results from each facility using a common test matrix and to enable consistent

practices among the national facilities through shared test processes, techniques, and data reduction methods.

The ATP involved the NPAT in quarterly meetings to share information on testing rate structure and content, maintenance and capital investment activities, test facility schedules, and long-range planning. Collaborating through the NPAT enabled the ATP to develop a vision and funding plan that informs and reflects strategic and national testing priorities and direction.

Aeronautics Research Relevance and Benefits to the Public

NASA's aeronautics research is focused on addressing national priorities, with the ultimate goal of enabling the transition of research results into use by Government and private-sector stakeholders. ARMD disseminates its research results to the widest practical and appropriate extent (consistent with foreign policy and national security) through a variety of mechanisms. One mechanism is partnerships with stakeholders on specific research activities that identify and demonstrate potential benefits to users. For example, in FY 09, Southwest Airlines (SWA) evaluated two data-mining software procedures acquired from a NASA open-source Web site. The Web site is maintained by the Aviation Safety Program and has over 300 members. Southwest Airlines used the software to automatically analyze flight data recorder output from 7,200 flights to seek operational improvements. The airlines found improved results compared to the results of their usual analysis methods. As a result, Southwest will incorporate the software tools into daily operations—monitoring 1,600 flights per day on 305 aircraft to improve the quality of their flight operations.

In FY 09, collaborative field tests at the Denver Air Traffic Control Center were conducted with three aircraft types flown by Continental, United Airlines, and the FAA to simulate an improved NASA air traffic controller decision tool. A real-time operational demonstration will be conducted in December of 2010. The improved procedure guides aircraft to a precise location at a precise time to begin fuel-efficient descents to the runway. Due to the inability of current air traffic control procedures to accurately space aircraft at the start of descent, such descents are now possible only under light traffic conditions. NASA studies indicated that full use of fuel-efficient descents will result in fuel burn savings of 200 million gallons each year if fully implemented for all U.S. airports.

ARMD further fostered collaborative research partnerships in FY 09 with the academic and private-sector communities through the use of NRAs. NRAs provided avenues for new and innovative research ideas to be incorporated into NASA research programs while providing significant financial support to universities across the country. This process further encouraged awardees to spend time at NASA Centers in order to enhance the exchange of ideas and expand the learning experience for everyone involved.

In FY 09, ARMD funded several educational activities for primary- and secondary-level students to enhance basic science and math skills and to familiarize students with basic aeronautics concepts. NASA was a partner in the interactive Smart Skies program, a FlyBy Math™ set of distance, rate, and time investigations to engage students in grades five through nine in real-life applications of mathematics and science. Using the FlyBy Math™ curriculum materials, students learned to predict air traffic conflicts using distance, rate, and time relationships.

NASA also funded an adjunct activity to the Smart Skies called Math in Plane View, which is an online linked visualization tool that offers multiple dynamic representations designed to help students understand distance-rate-time relationships in the real-world context of air traffic control. A side-by-side layout enables students to observe and manipulate three views: planes on their routes, the corresponding distances versus time graph, and the equation of each line on the graph.

The Summer Opportunity in Aeronautics for High School Scholars (SOAR) program was a three-week summer aeronautics enrichment program for high school juniors and seniors; it was held at NASA Langley Research Center. SOAR engaged students across the United States in a science, technology, engineering, and mathematics (STEM) program focused on aeronautics to encourage their pursuit of various education disciplines critical to NASA's future missions. The program featured interactive aeronautics activities, aeronautics design projects, flight simulation software, radio-controlled model aircraft demonstrations, model rocketry, scientific ballooning, and wind tunnel testing, among many other activities.

In FY 09, ARMD continued its second year in motivating and inspiring the next-generation workforce through the Aeronautics Scholarship Program, funding 20 new two-year undergraduate and 5 three-year graduate scholarships. Scholarships

included summer internships at NASA research centers to infuse well-trained and motivated students into the research workforce to strengthen their interest in aviation and apply their academic learning to NASA research efforts.

Department of Defense

DOD

In FY 09, the Department of Defense (DOD) was involved in a wide variety of complex and challenging space activities, ranging from support for our Nation's global military operations and national civil space programs to development and fielding of new technologies and approaches to meet the Nation's defense space needs.

DOD space systems supported military operations in Iraq, Afghanistan, and around the world. Numerous space assets provide crucial capabilities leveraged daily by today's warfighter, including communications, navigation, environmental monitoring, and early warning of threats.

Throughout FY 09, DOD pursued improvements to these vital operational capabilities. The Ultra High Frequency Follow-on (UFO) satellite nearly doubled its available communication bandwidth through a modification of its operational mode to activate additional channels. A second Wideband Global SATCOM spacecraft was placed in orbit on April 3, 2009. In the arena of space-based missile warning, a new era began in August 2009 with the operational acceptance of the Space Based Infrared System (SBIRS) Highly Elliptical Orbit (HEO) system, consisting of two hosted payloads and associated ground systems. The SBIRS HEO-1 system was also certified for intelligence production use on August 27, 2009. The launch of the final GPS IIR satellite on August 17, 2009, further enhanced the Global Positioning System (GPS) constellation, providing navigation and timing globally.

Access to space continued to be a DOD priority in FY 09, with DOD systems and infrastructure providing support to military, civil, or commercial launches. The Evolved Expendable Launch Vehicle (EELV) program continued building its impressive track record by successfully placing five satellites in orbit during FY 09. These launches, conducted by the United Launch Alliance (ULA), supported

missions for the DOD, the National Reconnaissance Office (NRO), and the National Aeronautics and Space Administration (NASA). In addition, the United Launch Alliance launched seven Delta II rockets in 2009. These included two civil launches (Kepler and NOAA's N-prime spacecraft), two launches for the Missile Defense Agency's Space Tracking and Surveillance Spacecraft (STSS) program, two GPS satellites, and the commercial launch of Italy's third COSMO-SkyMed synthetic aperture radar (SAR) satellite. The DOD and NASA partnership to support Nation's civil space program was evident as the U.S. Air Force operated space launch ranges that supported 11 NASA missions in FY 09: five Space Shuttle launches and six NASA unmanned spacecraft launches.

In February 2009, the collision of two non-DOD satellites, Iridium 33 and Cosmos 2251, generated over 1,500 pieces of new debris in space and alerted national attention to the fact that space is increasingly congested, contested, and competitive. In response, the DOD placed renewed emphasis on Space Situational Awareness (SSA) and Command and Control (C2) of our space forces in three primary areas. First, today's SSA sensors are challenged by the rapid pace of change in the space domain. Existing sensors are physically unable to track small objects, have difficulty locating unexpected space objects, and are limited in their ability to discern space object activities. To fill this critical void, DOD is investing in new SSA sensors, both on the ground and in space, to include the Space Fence and the Space-Based Space Surveillance programs. Second, significant investment is being made in the Joint Space Operations Center (JSpOC) at Vandenberg Air Force Base, California, to integrate the new SSA sensors and provide the Nation with improved command and control of military space forces. Finally, as good stewards of the space environment, DOD is working with commercial and foreign entities to proactively prevent satellite collisions and enhance collision warning by making SSA data available.

The Department of Defense remained committed to improving the Nation's means to develop, acquire, field, and employ space capabilities in shortened time-frames and in more affordable ways. In FY 09, the Operationally Responsive Space (ORS) program continued to develop capabilities for rapid deployment of systems to support operational needs, with a focus on developing enabling technology and

prototypes for mission capabilities. The ORS-l spacecraft is scheduled to launch at the end of calendar year 2010.

In conclusion, DOD remained committed to the National Security Space mission. FY 09 efforts ensured 24/7/365 support to warfighters around the world. Numerous military, civil, and commercial programs leveraged DOD launch facilities and range support to deliver new satellite capabilities into orbit. FY 09 saw renewed focus to improve today's operational capabilities, from SSA to ORS, to ensure that the U.S. continues to enjoy the unique advantages of space. Sharing DOD capabilities, from the GPS signal utilized at no cost by millions around the world to enhanced SSA data sharing, demonstrated the continued commitment to maximize the military, civil, and commercial utility of the National Security Space mission. As always, the DOD remains fully committed to ensuring the United States remains the world's premier spacefaring Nation.

Federal Aviation Administration

FAA

In 2009, the Federal Aviation Administration continued to lay the groundwork for the Next Generation Air Transportation System known as NextGen. NextGen is a wide-ranging transformation of the entire National Airspace System (NAS) to meet future demand and support the economic viability of the system while reducing delays, improving safety, and protecting the environment. It is a complex, multilayered, evolutionary process of developing and implementing new aviation technologies and procedures. NextGen is not a single piece of equipment or a program or a system that will instantaneously transform the NAS. It is an evolutionary process, and existing systems must be sustained in the transition. NextGen builds on legacy systems to increase capability in today's airspace system, adds new performance-based procedures and routes, and, ultimately, delivers programs that will transform the NAS.

The FAA's development activities on the Aviation Environmental Design Tool (AEDT) continued in a more integrated fashion toward accurately quantifying the interdependent aspects of aircraft fuel burn, noise, and emissions. In early 2009, a first alpha version of AEDT was produced for NASA's analyses; this version not only was an important development milestone for AEDT but also provided seamless integration with NASA's Airspace Conflict Evaluation Simulator (ACES) tool and the FAA's airspace and airport simulation tool (SIMMOD). Both are cornerstone planning tools for NextGen. A prototype version of the FAA's Terminal Area Route Generation, Evaluation, and Traffic Simulation (TARGETS) integrated with AEDT environmental capabilities was successfully developed as a proof of concept.

This critical integration will allow for new navigational procedures to be designed while taking into consideration the effects of noise, fuel burn, and emissions.

In 2009, FAA researchers at the William J. Hughes Technical Center made advances on the Future En Route Workstation (FEWS) interface to support controller management of increased traffic levels. In FEWS III, researchers made additional modifications to the workstation simulation to support the use of Area Navigation (RNAV), self-spacing, and aircraft grouping procedures. The simulation assumed Automatic Dependent Surveillance-Broadcast (ADS-B) capabilities and used three-mile lateral separation standards in all conditions. Scenarios included very high (two to three times current) traffic levels in which 70 percent of the aircraft were equipped with Data Communications. Weather was also a factor in some conditions. Eleven controllers from five en route facilities participated in the simulation. They used two systems to evaluate the concepts: a baseline system simulating the En Route Automation Modernization (ERAM) system and the FEWS system. Results showed that controllers managed more aircraft and reported lower workload when using the FEWS system than when using the baseline system.

Laptop computers and other battery-powered electronic devices can pose a significant fire hazard when carried aboard passenger aircraft. In 2009, the FAA, in conjunction with the airline industry, embarked on a series of tests to determine the optimum procedure for fighting a laptop computer fire on board an aircraft. Halon 1211, the typical fire extinguisher installed in passenger aircraft, was effective in extinguishing the burning electrolyte but did not prevent adjacent cells from going into thermal runaway and catching on fire. It was determined that water was the most effective agent in cooling the remaining cells and stopping the chain reaction. A training video, developed by the Fire Safety Team, illustrated effective and practical methods to extinguish a cabin fire involving lithium batteries in a laptop computer. The video, "Extinguishing In-Flight Laptop Computer Fires," may be viewed at the Fire Safety Team Web site: *http://www.fire.tc.faa.gov/2007Conference/session_details.asp?sessionID=26*.

NextGen will use Cockpit Display of Traffic Information (CDTI), ADS-B, and other new technologies and procedures to enable the delegation of some traditional air traffic control (ATC) tasks to the cockpit. But to take advantage of these advances, aircraft must first be appropriately equipped, and no single design

supports the broad array of envisioned delegations. In 2009, researchers for the Center for Advanced Aviation System Development (CAASD) completed the development of a prototype multipurpose CDTI. The prototype development process included both the necessary algorithmic processing and the user interface and allowed CAASD researchers to conclude that multipurpose CDTI is feasible. Pilots were asked to use the CDTI in a number of scenarios that involved air-to-air ADS-B applications in most operating domains. Pilots received minimal training on the features of the display and yet were able to operate it effectively. Further research will be conducted in 2010.

In September 2009, the international standards organization ASTM International approved D7566, specification for synthetic aviation fuel, allowing the use of a semi-synthetic aviation fuel produced from the Fischer-Tropsch (FT) processes in commercial airliners. These fuels are referred to as FT fuels. The Commercial Aviation Alternative Fuel Initiative (CAAFI), a coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants, and U.S. Government agencies, played a key leadership role in achieving this major milestone to introduce alternative aviation fuels. Under CAAFI's coordination, aviation fuel industry stakeholders worked at an unprecedented pace to achieve the consensus necessary to publish this groundbreaking specification. CAAFI stakeholders also took key steps to advance the acceptance and understanding of alternative aviation fuels produced from biomass by conducting three flight demonstrations on commercial airliners between December 2008 and January 2009. The demonstration flights exemplified the technological readiness of renewable bio-jet fuels and contributed greatly to the public acceptance of these fuels for use in aviation. Important technical data were also generated to be used for the eventual industry qualification of these types of fuels. Other new types of alternative fuels, such as fuels produced from algae or cellulosic material, will be added to D7566 as they are qualified by the industry working group. For more information, visit *http://www.caafi.org.*

The FAA's Office of Commercial Space Transportation (AST) licenses and regulates U.S. commercial space launch and reentry activities and the operation of non-Federal launch and reentry sites to protect public health and safety, safety of property, and national security and foreign policy interests of the United States. In

addition, AST encourages, facilitates, and promotes U.S. commercial space transportation by the private sector.

In 2009, AST licensed 4 orbital commercial space launches, conducted 24 safety inspections, and issued 5 experimental permit launches. Continuing the safety record of past years, FY 09 saw no injury to the public or damage to public property from any commercial launch.

The four orbital commercial space launches the FAA licensed in 2009 were a Delta II launch from Vandenberg Air Force Base (AFB) in California; a Delta IV launch from Cape Canaveral Air Force Station in Florida; the first Falcon 1 launch to carry a commercial payload, by Space Exploration Technologies Corporation (SpaceX) from the Ronald Reagan Ballistic Missile Test Site at Kwajalein Atoll in the Marshall Islands; and a Zenit 3SL launched by the Sea Launch multinational partnership from a mobile platform in the Pacific Ocean.

The five launches covered by experimental permits included three flights by the MOD-1 vehicle operated by Armadillo Aerospace, one flight of the Armadillo QUAD vehicle, and one by the Ignignokt vehicle operated by TrueZer0. These permit flights were part of the Northrop Grumman Lunar Lander Challenge competition in Las Cruces, New Mexico.

AST conducted 24 safety inspections on over 14 different types of licensed and permitted activities. The goal of every AST safety inspection is to ensure public safety by verifying FAA licensee and permittee compliance with FAA regulations and license/permit terms and conditions. Inspectors traveled to various locations including Cape Canaveral, Florida; Vandenberg Air Force Base, California; Mojave, California; Kodiak, Alaska; Wallops Flight Facility, Virginia; the Republic of the Marshall Islands; and the equator in the Pacific Ocean for sea launch operations.

As part of its licensing responsibilities, AST developed and issued the Final Environmental Impact Statement and Record of Decision for the Spaceport America Commercial Launch Site in Sierra County, New Mexico, and the Final Environmental Assessment and Finding of No Significant Impact for Jacksonville Aviation Authority Launch Site Operator License at Cecil Field, Florida. AST issued a launch license renewal for Orbital Sciences Corporation's Pegasus air-launched vehicle operating from the Reagan Test Site at Kwajalein. A launch site operator license renewal was issued to East Kern Airport District for the operation

of Mojave Airport as a launch site in California, and a new launch site operator license was issued to the New Mexico Spaceport Authority to operate a launch site at Spaceport America in New Mexico.

Several research and development projects were completed in FY 09, including a high-altitude wind prediction and measurement technology assessment, a study of the impact on suborbital rocket trajectories by temporal winds at three inland launch sites, and a study of potential impacts from reusable launch vehicle operations in the NAS. The last study was conducted in the interest of the FAA's NextGen program.

AST continued to provide real-time support to NASA during Shuttle reentries, using its Shuttle Hazard Area to Aircraft Calculator (SHAAC) tool. This tool predicts and identifies the extent of the airspace that could contain falling debris hazardous to aircraft in the event of a Space Shuttle orbiter failure on reentry, such as the failure of Columbia in 2003.

In partnership with NASA, AST continued its support of the selection process of Commercial Resupply Services missions to supply cargo launch and return services for the International Space Station (ISS). This resulted in NASA awarding ISS CRS contracts to both SpaceX and Orbital Sciences Corporation. These commercial space launches will be licensed by the FAA. AST participated in the NASA ISS CRS initial contracts meetings with both contractors and in the Vehicle Baseline Review with SpaceX. AST supported the selection process for the Commercial Crew Development (CCDev) competition that was initiated and led by NASA to develop system concepts and capabilities that could ultimately lead to the availability of commercial human spaceflight services. AST continued to support the NASA review meetings for the Commercial Orbital Transportation Services (COTS) Demonstrations missions. AST also participated in activities on the NASA-led Commercial Crew Implementation Team and Human Rating Requirements Team.

Several informative reports of interest to the public, the space industry, and the U.S. Government were released by AST. An *Analysis of Human Spaceflight Safety* was completed in response to Congressional request. Other reports included *State Support for Commercial Space Activities, Space Weather Biological and System Effects for Suborbital Flights*, and *Support Services for Commercial Space Transportation*. Two

detailed technical reports were published: *Hazard Analysis of Complex Systems: A New Method for Hazard Analysis of Rocket Vehicles* and *Graphical Cockpit-Based Depictions of Space Vehicle Operations Based upon Use of Aeronautical Information Data Link Services*.

AST continued to issue annual revisions of several reports, including *Research and Development Accomplishments, 2009; U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports;* Quarterly Launch Reports; *Commercial Space Transportation: 2008 Year in Review;* and the *2009 Commercial Space Transportation Forecasts*. The forecasts, prepared by the industry-led Commercial Space Transportation Advisory Committee and the FAA, projected an average worldwide demand of about 16 launches per year to geosynchronous orbit and 11 launches per year to non-geosynchronous orbits between 2009 and 2018.

Information about the Office of Commercial Space Transportation, regulations, reports, and other documents can be found at *http://ast.faa.gov*.

Department of Commerce

DOC

In FY 09, the Department of Commerce (DOC) continued to play a key role on the National Executive Committee for Space-Based Positioning, Navigation, and Timing (PNT)—the senior body that advises and coordinates Federal departments and agencies on matters concerning the Global Positioning System (GPS) and related systems. The Department hosted the meetings of the National Executive Committee and its Executive Steering Group. The Department provided resources and personnel in support of the committee's secretariat, the National Coordination Office for Space-Based PNT. The Department also assisted the National Coordination Office in organizing outreach events and efforts to educate the public about GPS. These included various conferences and speaking engagements, funding for a new science exhibit called "GPS Adventures Arkansas," two new trade show booths, a new newsletter, and upgrades to the PNT.gov Web site.

DOC's Office of Space Commercialization (OSC) participated in government-to-government consultations with Europe and Japan concerning cooperation in the area of satellite navigation. OSC continued to serve as the U.S. cochair of the U.S.-European working group on trade issues related to GPS and Europe's Galileo system. OSC also assisted the Office of the U.S. Trade Representative (USTR) in completing a report to Congress regarding U.S. equipment industry access to Galileo markets and Europe's compliance with the trade provisions in the GPS-Galileo Agreement of 2004.

OSC coordinated the successful implementation of a 2008 Memorandum of Agreement between the National Oceanic and Atmospheric Administration (NOAA) and the Japan Aerospace Exploration Agency (JAXA), allowing JAXA to install a ground station for Japan's Quasi-Zenith Satellite System (QZSS) at

a NOAA facility in Guam. JAXA and NOAA held a ribbon-cutting ceremony for the completed ground station in FY 09. The Quasi-Zenith Satellite System is designed to be highly compatible and interoperable with GPS for enhanced coverage over Japan.

National Oceanic and Atmospheric Administration

Within NOAA, space-related activities occurred across the entire organization. During the 2009 Atlantic hurricane season, NOAA's GOES system provided a continuous flow of imagery that contributed significantly to the development of storm forecasts. These forecasts helped minimize the loss of life in the United States. GOES satellites provided space weather monitoring for the NOAA Space Weather Prediction Center to issue forecasts and warnings that protected spacecraft and power grids.

NOAA's GOES and Polar-orbiting Operational Environmental Satellite (POES) system continued to provide an uninterrupted flow of global environmental information to support weather, ocean, and space environmental modeling, as well as tropical storm analysis and forecasting, local weather forecasting, and ecosystem and climate monitoring. NOAA's weather and climate prediction numerical models used the global data from these satellites extensively.

NOAA provided forecast support for NASA Space Shuttle missions before launching, during flight, and during landing.

NOAA-N Prime successfully launched on Friday, February 6, 2009, from the Vandenberg Air Force Base in California aboard a Delta-II rocket. This new NOAA polar-orbiting operational environmental satellite circles the globe every 102 minutes, taking images and measurements to support NOAA's efforts to forecast and monitor the environment. NOAA-N Prime, renamed NOAA-19 after reaching orbit, joined Metop-A, a European satellite, as the operational satellites in polar orbit that NOAA used in its forecasts. Data from NOAA-19 supported several NOAA programs, including weather analysis and forecasting, climate research and prediction, global sea surface temperature measurements, atmospheric soundings of temperature and humidity, ocean dynamics research, volcanic eruption monitoring, forest fire detection, global vegetation analysis, and search and rescue

operations. NOAA-19 data helped NOAA monitor conditions in the atmosphere and oceans and keep tabs on long-term climate trends. These data are increasingly important in polar regions, given the potential effects of climate change on the polar ice cap and sea ice extent. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) worked closely with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) to ensure seamless polar-orbiting satellite coverage. Under an agreement, two of NOAA's polar-orbiting satellites—NOAA-18 and NOAA-19, both in afternoon orbits—carried a EUMETSAT instrument. In return, EUMETSAT carried key NOAA instruments on board its first of three Metop satellites, Metop-A, which launched into a morning orbit.

The GOES-O spacecraft successfully launched and reached orbit on Saturday, June 27, 2009, from the Kennedy Space Center. GOES-O, now renamed GOES-14, joined three other GOES spacecraft that helped NOAA forecasters track life-threatening weather and solar storms by providing reliable satellite coverage to see severe weather as it develops. With more than a thousand tornadoes touching down in the United States each year and the serious risk posed by hurricanes to residents along the Gulf and eastern coastlines, GOES-14 was critical. GOES-14 is the second spacecraft in the GOES-N/O/P series and carries instruments that capture high-resolution images of weather patterns and atmospheric measurements. The imagery and data from GOES spacecraft were key to NOAA's ability to continuously monitor and forecast weather in the tropics. Continued improvements in the type and quality of GOES data improved tropical cyclone forecasts. GOES-14 also provided expanded measurements for the space and solar environment using a Solar X-Ray Imager. These data allowed improved forecasts and warnings for solar disturbances, which protected billions of dollars of commercial and Government assets in space and on the ground and lessened the effect of power surges for satellite-based electronics and the communications industry.

In December 2008, NOAA and NASA officials announced that the Lockheed Martin Space Systems Company of Denver, Colorado, was selected to build two spacecraft for NOAA's next generation GOES series, GOES-R. On May 27, 2009, NOAA announced that the Harris Corporation Government Communications Systems Division of Melbourne, Florida, was selected to develop the GOES-R

ground system. This system will capture, process, and distribute GOES imagery and other information to users around the world.

The GOES-R ground system will be installed and operated at the NOAA Satellite Operations Facility in Suitland, Maryland, and at the Wallops Command and Data Acquisition Station in Wallops, Virginia. The advanced spacecraft and instrument technology used on the GOES-R series will result in more timely and accurate weather forecasts. It will improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and, ultimately, economic health and development. The first launch of the GOES-R series satellite is scheduled for 2015.

The Jason-2 satellite launched successfully on June 20, 2008. On October 29, 2008, after four months of tests and qualification of the segment, command and control operations for the Jason-2 ocean altimetry satellite were handed over to NOAA from the French Space Agency, Centre National d'Études Spatiales (CNES). The handover was a major step in Jason-2 operations. NOAA now carries out routine operations on the satellite and processes the operational data received by its ground stations and interface with users. It also archived and distributed all scientific products. Jason-2 provides satellite-based ocean altimetry measurements, which measure sea level height. This extraordinarily precise measurement reveals upper level ocean heat content and patterns and indicates changes in the volume of water. With this information, scientists can predict El Niño and La Niña cycles—cycles vitally important to short-term climate prediction—and detect currents, such as the Gulf Stream. The current information provided by ocean altimetry is detailed enough to show the location, width, and temperature differences in adjacent waters and detect and predict current eddies, temporary ocean features that can be of critical interest to ocean users such as drilling operators in the Gulf of Mexico.

NESDIS researchers made significant progress in FY 09 advancing the development of the NOAA end-to-end satellite ocean color radiometry system. This system is key for supporting multiple NOAA line office and goal team/program activities. Several important milestones were met during FY 09. For example, Medium Resolution Imaging Spectrometer (MERIS) chlorophyll-a ocean color radiometry products were declared operational in January 2009 and are now routinely posted on the CoastWatch Web site. (Chlorophyll-a is a proxy for phytoplankton biomass.)

In addition, Moderate Resolution Imaging Spectroradiometer (MODIS) regional chlorophyll-a products for the Chesapeake Bay region were declared operational in February 2009 and are on the CoastWatch Web site. CoastWatch made standardized MODIS ocean color data available for the Gulf of Mexico region; additional regions will be online shortly. Collectively, these efforts helped to facilitate continuity and accessibility of quality ocean color data and derived products in support of NOAA and external users and their operational and climate applications, particularly in the areas of integrated ecosystem assessments, harmful algal bloom forecasts, and water quality monitoring in the Chesapeake Bay and other important coastal regions.

In FY 09, NOAA satellites were key factors in the rescues of 184 people throughout the United States and its surrounding waters, thanks to the Search and Rescue Satellite-Aided Tracking (SARSAT) Program. In each incident, NOAA satellites detected and located a distress signal from an emergency beacon and relayed the information to first responders on the ground. NOAA's polar-orbiting and geostationary satellites, along with Russia's COSPAS spacecraft, are part of the international Search and Rescue Satellite-Aided Tracking system, called COSPAS-SARSAT. This system uses a network of satellites to quickly detect and locate distress signals from emergency beacons on board aircraft and boats and from handheld personal locator beacons. When a satellite finds the location of a distress signal within the United States or its surrounding waters, the information is relayed to the SARSAT Mission Control Center at NOAA's Satellite Operations Facility in Suitland, Maryland. From there, it is sent to a Rescue Coordination Center, operated by either the U.S. Air Force, for land rescues, or the U.S. Coast Guard, for water rescues. Now in its 27th year, COSPAS-SARSAT has been credited with supporting more than 25,000 rescues worldwide, including 6,134 in the United States and its surrounding waters.

2009 SARSAT rescue highlights:

- Six people were rescued from a fishing vessel off the coast of Freeport, Texas, when their boat became disabled.
- One person was rescued near Barrow, Alaska, after his snowmobile broke through the ice when crossing the Chip River.
- One person was rescued from a crashed helicopter 18 miles north-northeast of Santa Fe, New Mexico.

To increase our severe weather forecasting ability, NESDIS developed a new use for GOES-12 sounder data. NOAA can now forecast the onset of severe weather, such as thunderstorms and tornadoes, up to six hours in advance. NESDIS collaborated with scientists at the Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin, to develop and test this model. Using hourly multilevel water vapor observations from the GOES-12 sounder, scientists can track regions where upper level drying is occurring over low-level moistening. A rapid change in these measurements is often a precursor to severe weather development.

In March 2009, NOAA's National Geophysical Data Center (NGDC) supported safe navigation by developing a new, much higher resolution model of Earth's magnetic field. This new model captures not only the field generated from the interior of Earth's core, but also the anomalous field in the crust, a major source of error when navigating by magnetic compass. Magnetic anomaly maps enable improved navigation and are widely used in the geological sciences, in resource exploration, and in science education to illustrate various aspects of Earth evolution such as plate tectonics and seafloor spreading. All maps, compasses, GPS units, and even iPhones rely on magnetic models to provide the orientation difference between true, geographic, and magnetic north. The new and improved model, designated EMAG2, will lead to more accurate navigational capability for ships and aircraft.

In July 2009, NCDC released the International Best Track Archive for Climate Stewardship (IBTrACS) global tropical cyclone dataset. IBTrACS is a new dataset based on the best track data from numerous sources by consolidating and unifying data to one location. This dataset is the culmination of tropical cyclone best track data from many available sources, including the World Meteorological Organization's officially recognized Regional Specialized Meteorological Centres and Tropical Cyclone Warning Centres. NCDC personnel collected, combined, and quality controlled the data; vetted the process through the scientific community; and publicly distributed the dataset. Tropical cyclone best track data are used to monitor the positions and intensities of tropical cyclones. They include the position of maximum sustained winds and minimum central pressure of tropical cyclones at six-hour intervals. IBTrACS facilitates an improved understanding of global tropical cyclone distribution, frequency, and intensity.

Despite the significant impact of tropical cyclones on society and natural systems, there was no central repository for global best track data prior to the development of IBTrACS. A comprehensive archive of global tropical cyclone best track data was sorely needed, since such a database is utilized for a wide variety of projects, including climate change research, the determination of appropriate building codes for coastal zones, risk assessments for emergency managers, and analyses of potential losses for insurance and business interests.

The Fairbanks Command and Data Acquisition Station (FCDAS) met an outstanding performance goal of 99.8 percent for data recovery during FY 09. FCDAS took in excess of 56,000 spacecraft communications during calendar year 2009, a new station metric achievement, matching the metric the entire NASA Ground Network will achieve during 2009. This metric is significant, as it approached a 200 percent increase in spacecraft operations since January 1, 2003, and it was accomplished without an increase in staff or support contract modifications.

Sensors aboard environmental satellites collected massive amounts of data on the atmospheric, oceanic, and terrestrial conditions throughout the world. The data were stored on-board the spacecraft for a portion of an orbit and then transmitted down to FCDAS when the satellites passed over the station. FCDAS sends radio signals to the satellites to direct operation of their propulsion and sensor systems.

Space-based navigation, weather, communications, reconnaissance, and imagery data were valuable to many national and international operations. FCDAS contains antennas, electronic equipment, and support facilities designed to provide radio communications with satellites observing Earth. Due to its location at high latitude, FCDAS is well-positioned to achieve line of sight with polar-orbiting satellites as they converge on the north polar region.

In order to safeguard the vast amount of critical data and information provided through the NOAA Satellite Operations Facility (NSOF) in Suitland, Maryland, NESDIS created a remote backup system at our Wallops Island, Virginia, facility. In the event of a disaster at NSOF, this remote backup system will continue to process and distribute critical environmental satellite products. NESDIS personnel not only resolved the network and infrastructure issues in order to create this backup facility but also ensured that the computing infrastructure was continuously synchronized with the primary facility at NSOF to minimize the potential loss of

service and product degradation resulting from a switchover to the backup facility. This system ensures that if a disaster occurs that disables NSOF, NESDIS will be able to continue to provide all critical products to the National Weather Service, Department of Defense, and other users with minimal interruption of service. This ensures the availability of continuous and timely environmental information to the Nation.

During FY 09, the NGDC space weather team focused on developing tools, techniques, and models to help decision makers and the public understand the impacts of space weather on their systems. These new tools included improved measurements of the ionosphere (part of Earth's atmosphere) and a model of global radio wave absorption in the ionosphere. Improved modeling and forecasting of space weather phenomena promotes increased safety for transportation, along with improved reliability in critical products to the National Weather Service, Department of Defense, and other users with minimal interruption of service. This ensures the availability of continuous and timely environmental information to the Nation.

NESDIS uncovered a source of solar drawings from the Wendelstein Observatory in Austria for the period from 1946 to 1987. These drawings were largely forgotten but represent a key source of information regarding solar features (sunspots, solar flares, etc.) during the transition from ground-based solar observations to space-based. Through an arrangement with the University of Munich, NESDIS temporarily acquired the original drawings and digitally preserved them through the NOAA Climate Data Modernization Program. These data are now available to space scientists, climate researchers, and the public through the NOAA Data Centers.

NOAA's NCDC collected over 20 years of remotely sensed data from multiple satellite-based instruments from national and international partners. With these data, NCDC produced a global high-resolution sea surface wind product and distributed it worldwide to a variety of users, including the offshore energy sector, climate modelers, and the coastal ecosystem community. SeaWinds measurements provide information for several sectors of the public and research communities. SeaWinds provides wind climatologies for the Offshore Wind Energy community; is used by NOAA Coral Reef Watch to predict coral bleaching events; and

provides wind stress estimates for the ocean and climate modeling communities, including the coastal ecosystem community, to aid in the production of coastal upwelling estimates.

NGS submitted positioning products—from 2000 to the present—to the International Global Navigation Satellite System Service (IGS) for inclusion with comparable products to create a new International Terrestrial Reference Frame released in 2009. Model upgrades and strategy changes made over the years have significantly improved estimates of satellite and station positions to the centimeter level; however, they have also made the full position history inconsistent. NGS reanalyzed the GPS data collected from 1994 through 2007, resulting in a consistent position history and new position products. Data collected from the network were used for a variety of purposes, including precise GPS satellite positions, precise position of the tracking stations, and precise position of Earth's axis of rotation.

In November 2008, NGS performed preliminary terrestrial gravity observations in Puerto Rico and the Virgin Islands with the establishment of one absolute gravity station in Puerto Rico and another on the Island of St. Thomas in the U.S. Virgin Islands. These new absolute gravity stations were used as control points for scheduled airborne gravity observations to support the creation of a vertical datum. The work in Puerto Rico and the Virgin Islands tested procedures and methodologies for conducting nationwide gravity collection, as defined in the Gravity for the Redefinition of the American Vertical Datum plan. Without a comprehensive, cohesive, and accurate gravity-based vertical datum, geographic positioning systems cannot be used to accurately determine elevations.

NGS completed an aerial gravity survey along parts of the Gulf Coast to enhance Vertical Datum (VDatum) in partnership with the U.S. Army Corps of Engineers. Coastal gravity data were collected along the Gulf Coast from the Alabama/Georgia state line to the border with Mexico. Applications that use VDatum include inundation modeling, ecosystem modeling, coastal management, hydrographic survey depths, and shoreline extracting from LIght Detection And Ranging (LIDAR) data. VDatum is a free software tool developed jointly by NGS, the Office of Coast Survey, and the Center for Operational Oceanographic Products and Services.

VDatum is a revolutionary vertical datum transformation tool that translates geospatial data between vertical reference systems and removes the most serious

impediments to data sharing. VDatum provides NOAA and other mapping agencies with the ability to seamlessly integrate geospatial data for numerous critical applications, allowing for easy and accurate transformation of elevation data from one vertical datum to another. In 2009, the Office of Coast Survey, NGS, and the Center for Operational Oceanographic Products and Services were instrumental in releasing the VDatum tool in New Orleans, Louisiana, and the Pacific Northwest (San Francisco Bay to Strait of Juan de Fuca).

NGS developed software for processing Global Navigation Satellite System (GLONASS) satellite data to support differential positioning between GLONASS receivers. This software is in the process of being embedded into the Online Positioning User Service (OPUS) so that users can submit U.S. GPS or GLONASS data for precise positioning coordinates of where observations were collected. NGS will also develop software to compute the path of the GLONASS satellites as they orbit Earth for a wide variety of satellite-based precise positioning activities. Incorporating GLONASS satellites into traditional GPS solutions enhances their accuracy and reliability because of the availability of more satellites to process a solution. For GPS receivers to provide accurate information, the precise location of positioning satellites as they orbit Earth must first be determined.

NGS developed draft versions of two real-time positioning guidelines—*User Guidelines for Classical Global Navigation Satellite Systems GNSS (Global Navigation Satellite Systems) Real-Time Positioning* and *Guidelines for Operating a Real-Time GNSS Network*. In addition to NGS outreach efforts at more than 15 workshops across the country to market these products, the publications gained the attention of trade magazines. *GPS World* highlighted NGS in their February 2009 Survey and Construction newsletter and included a link to the NGS Web site where the draft user guidelines can be found. NGS is working toward developing national guidelines for Real-Time Networks (RTNs) to ensure the consistency, accuracy, and alignment of RTNs operated by a wide variety of entities across the Nation.

The Mongolia Office of the Millennium Challenge Account invited NOAA to provide geodetic expertise to assist with further developing the office's geospatial infrastructure in support of the privatization and capitalization of land assets held by Mongolians. NGS scientists traveled to Mongolia in February 2009 to improve the country's geospatial capabilities. Over a two-week period, NGS

met and interviewed Mongolian government officials from the Agency for Land Administration; Geodesy and Cartography personnel; and the Minister for the Ministry of Roads, Transportation, Construction, and Urban Development on the status of Mongolia's existing geospatial capabilities. These meetings focused on the Mongolian geodetic infrastructure and how modern remote-sensing methodologies could contribute to performing accurate land parcel mapping for private land ownership initiatives.

NOAA's Office of Response and Restoration and the University of New Hampshire's Coastal Response Research Center developed a data platform that seamlessly aggregates diverse spatial datasets into an Internet-based mapping format. The Environmental Response Management Application (ERMA™) integrates real-time data such as weather, currents, and Automated Information System data, as well as static datasets, with maps, resulting in high-resolution visualization on the Internet. An ERMA™ for Portsmouth, New Hampshire, recently debuted during an industry-led National Preparedness for Response Exercise Program. NOAA will provide ERMA for New England by expanding and enhancing the Portsmouth pilot project, to be used during the Spill of National Significance exercise in March 2010.

The platform allows users to collect, manipulate, analyze, and display spatially referenced data for solving complex resource issues. The Web delivery of the platform provides a common operational picture for all individuals involved in an incident, improves communication and coordination among responders and stakeholders, and provides resource managers with the information necessary to make faster and better informed decisions. Each version of ERMA™ is specific to a single geographic region. ERMA™ sites are currently being developed for the Caribbean, the Pacific Northwest, and the Pacific Islands. There is also interest for development in New York and the Arctic, and funds are available for development in the Great Lakes in FY 11.

Across the Pacific, derelict fishing gear (DFG) is recognized as a major environmental threat to coastal and near-shore areas. In FY 09, a summit was held for NOAA, NASA, and other Federal agency, academic, and private-sector experts in marine debris, oceanography, and remote-sensing technology. Objectives of the summit were to identify and synthesize existing information on the behavior

and movement of DFG in the North Pacific; the use of satellite data in modeling likely areas of DFG accumulation; appropriate sensor, unmanned aerial systems, and anomaly detection technologies; and completed activities that were used to detect and track DFG. The partnerships have continued, and a special issue was in development for publication in the journal *Marine Pollution Bulletin* that will highlight current knowledge, activities, and needs to effectively detect DFG at sea.

In 2009, the NOAA Integrated Ocean Observing System (IOOS®) Program collaborated with NESDIS's CoastWatch Program to make satellite-derived ocean color products of the Gulf of Mexico available via standardized Web services used by IOOS. The data products support the NOAA operational Harmful Algal Bloom (HAB) analysis for the Gulf of Mexico. These new capabilities provide satellite data using community-derived standards, which support not only the operational Harmful Algal Bloom system but a multitude of other user needs.

OSC collaborated with the FAA on the release of a joint publication titled *Introduction to U.S. Export Controls for the Commercial Space Industry* in October 2008. The intent of the guidebook was to help entrepreneurial space businesses understand the processes associated with the International Traffic in Arms Regulations (ITAR).

In collaboration with NASA, NOAA's Office of Oceanic and Atmospheric Research (OAR) developed a new ocean surface wind product, which provides a long-term (from 1987 to 2008), uniform record of global ocean surface winds. It was created through the use of an enhanced analysis method of data from two space-based, remote-sensing tools—QuikSCAT and ADEOS-2—combined with wind data from ships and buoys. Wind data from future satellite missions will be added to the dataset as they become available in order to extend the data record and keep it current.

For the first time, OAR scientists demonstrated that tsunamis in the open ocean can change sea surface texture in a way that can be measured by satellite-borne radars. The finding could one day help save lives through improved detection and forecasting of tsunami intensity and direction at the ocean surface. According to the study, large tsunamis crossing the open ocean stir up and darken the surface waters along the leading edge of the wave. The rougher water forms a long, shadow-like strip parallel to the wave and proportional to the strength of the tsunami.

That shadow can be measured by orbiting radars and may one day help scientists improve early warning systems. This constitutes a new way to detect tsunamis. The research project was led by NOAA's Earth System Research Laboratory and the Cooperative Institute for Research in Environmental Sciences, in Boulder, Colorado. An article on this project was published in July 2009 in the journal *Natural Hazards and Earth System Sciences*.

From the icebreaker *Oden*, stationed near the North Pole, and a NASA DC-8 research airplane, scientists collected data from the sea-ice interface through the cloud-topped atmospheric boundary layer and into the free troposphere above. These measurements will allow scientists to better understand the atmospheric processes leading to Arctic cloud formation and how clouds influence the annual freeze-up of Earth's polar ice cap. The measurements will also help improve the accuracy of NASA satellite images of Arctic sea-ice coverage using the long-range mapping capabilities of the DC-8. NOAA contributed a suite of remote sensors to measurement arrays on and near the *Oden*, while the University of Colorado deployed instruments on both the *Oden* and the DC-8.

In 2009, NOAA researchers used a variety of research aircraft, including NOAA's own aircraft fleet as well as NASA and National Science Foundation research aircraft, to conduct research on climate change and air quality. The effective deployment of these aircraft required detailed information on the state of the atmosphere often thousands of miles from the base of operations. NOAA mission planning for these very capable research platforms relied heavily on satellite retrievals for atmospheric meteorology, cloud data, and atmospheric composition.

On September 20, 2009, NOAA hurricane researchers from the Atlantic Oceanographic and Meteorological Laboratory (AOML), in partnership with staff from BAE Systems and the Navy, completed the first test flight of an unmanned aircraft system from aboard a manned aircraft operated by NOAA's Aircraft Operations Center. The Coyote, a mini-unmanned aircraft, was launched from NOAA's P-3 hurricane reconnaissance aircraft over the Gulf of Mexico at an altitude of 10,000 feet via a free-fall parachute. After Coyote completed its launch sequence as programmed, it navigated along a predetermined flight pattern at 1,000 feet. During its 49-minute flight, the Coyote successfully completed a loss of communications demonstration, communication range tests at three altitudes,

spiral maneuvers, and flight at altitudes as low as 64 feet above the ocean surface. The P-3 aircraft circled above the unmanned aircraft at 10,000 feet and launched four dropsondes for post-flight comparisons with the meteorological data obtained from the Coyote autopilot and dropsondes. All objectives for the test flight and demonstration were met. BAE is developing the Coyote for use by the Navy. It is also being adapted for hurricane research data collection efforts. Unmanned aircraft have the potential for gathering critical observations from the lower levels of the hurricane environment, where the winds are strongest, areas too dangerous for manned aircraft.

In May 2009, NOAA renewed its affiliation with the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University in Fort Collins, Colorado. Chosen through a competitive process, the institute will investigate satellite applications for improving regional and global-scale weather forecasts and water resource forecasts and provide integrated weather information to meet future aviation and surface transportation needs. The NOAA/CIRA partnership provides professors and students of the university with an exciting and challenging opportunity to collaborate with NOAA scientists on cutting-edge research.

CIRA will focus on ways to improve the development of satellite-based algorithms for weather forecasting; improve weather and climate models; develop techniques to integrate satellite, terrestrial, oceanic, and biological observations; increase understanding of environmental changes on weather and climate; and develop effective and efficient methods to quickly distribute and display large sets of environmental and model data using various data networks.

National Institute of Standards and Technology

In FY 09, the National Institute of Standards and Technology (NIST) provided Federal agencies and the aerospace industry with the research, standards, products, and services needed to advance the President's space agenda. These wide-ranging outputs fall into four main categories: (1) validation, measurement, and calibration; (2) manufacturing technology; (3) observation and sensing; and (4) spacecraft and living environments. NIST supported accurate and compatible measurements made by the aerospace industry by providing Standard Reference Materials (SRM)

and calibration services. Customers used these materials and services to ensure the accuracy of their own instrument calibrations and the validity of their measurement methods. In 2009, aerospace companies purchased 106 units of Standard Reference Materials, including ferrous and nonferrous metals certified for chemical composition and for hardness, and artifacts certified for nanoscale dimensional properties. In addition, these companies submitted over 240 instruments or artifacts to NIST for calibration. NIST performed over 1,500 separate tests on these items, spanning dimensional, force, vibration, and electrical measurements, which provided the companies with a source of metrological traceability for their primary measurement standards.

NIST administers the National Voluntary Laboratory Accreditation Program (NVLAP), which accredited two aerospace and aeronautic facilities in 2009. NVLAP accreditation ensures that the laboratories are following best practices for quality in testing and measurements as established by standards organizations such as the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).

Ensuring the security of communications and data remains crucial to aerospace applications. NIST helped NASA Langley Research Center with information technology security through the NIST Cryptographic Module Validation Program and the Cryptographic Algorithm Validation Program, ensuring proper use of Federal Information Processing Standards. NASA works with many vendors and other government space agencies such as JAXA, which must comply with Federal Information Processing Standards.

Carbon nanotubes are lightweight materials with potentially great strength and unique electrical properties, plus other attributes that make them very interesting for potential aerospace applications. NIST collaborated with the NASA Johnson Space Center to promote the standardization of test techniques for single-wall carbon nanotubes. Following a third workshop that brought together over 70 leading experts, NIST and NASA developed a recommended practice guide, *Measurement Issues in Carbon Nanotubes*, which was published by NIST in 2008 (*http://www.nist.gov/mml/mmsd/nanotube_041508.cfm*). In 2009, this practice guide formed the basis for accepted U.S. proposals to ISO's Technical Committee on Nanotechnology for the standardization of single-wall carbon nanotube measurement practices. Several

technical standards are expected to gain final approval by ISO in coming months. In addition, NIST demonstrated a new way to separate NASA's laser-produced single-wall nanotubes, which will remove a major technological barrier to many space-based applications of nanotubes.

NIST's Synchrotron Ultraviolet Radiation Facility SURF III was used as a source of soft x-rays and vacuum ultraviolet light to calibrate mirrors, detectors, and spectrometers used in NASA spacecraft. These include the Extreme Ultraviolet Variability Experiment (EVE), which will be launched on the Solar Dynamics Observatory (SDO), and the calibration rocket experiment for the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite. Both of these satellites are designed to study extreme ultraviolet (EUV) solar irradiance and its variability over minutes (flares) to years (11-year solar cycle). These measurements are important to the National Space Weather Program (NSWP), which tracks solar storms that impact space-based communications and navigation technologies. In addition, SURF III provides the calibration standard for experimental determination of atomic radiation intensities that are required for interpretation of data from HST experiments. NIST has initiated work on the calibration of ultraviolet instrumentation for satellites in the NOAA GOES program.

NIST provided spectroscopic data for astronomers who are analyzing observations from NASA's land- and space-based missions, including the Hubble Space Telescope, the Chandra X-ray Observatory, the Far Ultraviolet Spectroscopic Explorer, and the Spitzer Infrared Observatory. In 2009, NIST provided critical compiled data for titanium, nickel, argon, chlorine, hydrogen, helium, lithium, beryllium, boron, fluorine, neon, barium, strontium, and other elements of particularly strong current interest. For each dataset, NIST distilled a single, self-consistent set of best values from the frequently inconsistent, incomplete, and heterogeneous-quality data scattered across the open literature. NIST published these critically compiled datasets in peer-reviewed scientific journals and disseminated them publicly through NIST's online Atomic Spectra Database (*http://www.nist.gov/physlab/data/asd.cfm*). These efforts provided standardized, best quality data across the astronomical community and eliminated the need for astronomers to separately invest time in performing the same task. This work was partially funded by NASA.

NIST used its unique spectroscopic instruments to measure atomic data values needed by astronomers but not available in the literature. The measurements support the analysis of results from NASA's x-ray, ultraviolet, and infrared space-based observatories. NIST measured data and provided analysis for several ions of iron. This work was partially funded by NASA.

NIST collaborated with the Harvard-Smithsonian Center for Astrophysics (CfA) to create and observe exotic states of matter similar to those observed from space by orbiting observatories. This work improved the analysis of data from the multi-billion-dollar Chandra X-ray Observatory, operated in orbit for NASA by CfA. Spectra from highly charged states of iron, which are among the most prevalent and brightest observed from space, are produced under known and well-controlled conditions and studied using a combination of instruments from NIST and Harvard. Analysis is underway to try to resolve discrepancies that have persisted for years between experiments from various groups as well as between theory and experiments. This work was partially funded by NASA.

NIST participated in a high-level discussion with the NASA Langley Research Center in order to prioritize collaborative activities in support of the Tier-1 Decadal Survey Mission, Climate Absolute Radiance and Refractivity Observatory (CLARREO). This mission is designed to help establish a benchmark climate data record. Leading up to this high-level meeting, NIST was actively engaged in the CLARREO Science Study Team discussions and meetings. NIST also participated in three instrumentation incubator projects closely coupled to CLARREO, examining detector linearity in the reflected solar region (400 to 2,500 nanometers), characterizing the far infrared optical properties of candidate materials for satellite optical systems, and calibrating the performance of prototype systems for on-board calibration blackbody sources designed for the CLARREO mission.

NIST scientists demonstrated hyperspectral scene projection from a stored hyperspectral data cube image of a coral reef off the coast of Puerto Rico. This work, carried out in the context of global remote sensing of interest to NASA and DOD, is a critical step on the path toward having a more realistic calibration system for future satellites.

In collaboration with NASA and NOAA, NIST directed the development of the prototype marine optical system (MOS) for the next-generation Marine Optical

Buoy (MOBY-C) that can be used to help calibrate satellites. NIST also has continued its calibration/validation support of the present MOBY that is situated off the shore of Lanai, Hawaii, that is used for in situ vicarious calibration of several active environmental satellites.

In support of the U.S. Geological Survey (USGS) Landsat Data Continuity Mission (LDCM) Operational Land Imager (OLI) sensor, NIST calibrated several transfer radiometers and conducted stray-light characterization for several spectrometers to be used in prelaunch calibration of the spacecraft instruments. NIST also helped develop a calibration plan for spacecraft system-level testing of the optical system.

In support of the NPOESS Preparatory Project (NPP), NIST developed and built a flat-plate illuminator that was used in a thermo-vacuum environment testing of the Visible Infrared Imager Radiometer Suite (VIIRS) instrument at the Goddard Space Flight Center in preparation for spacecraft system-level tests to be done at the Ball Aerospace Technology Corporation in Boulder, Colorado. NIST also began a new project that will use an interferometer-based strategy to study the spectral response of the VIIRS infrared bands. NIST also prepared for tests of the VIIRS sensor spectral response in end-to-end testing in the solar reflected region.

NIST participated in meetings of NASA's Aerosol-Cloud-Environment (ACE) Decadal Survey Mission science team and helped develop the calibration plan. NIST also participated in a meeting of the Hyperspectral Infrared Imager (HyspIRI) Decadal Survey Mission science team.

NIST completed its analysis of the calibration of the Total Solar Irradiance Radiometer Facility at the Laboratory for Atmospheric and Space Physics in Boulder, Colorado. NIST also participated on the GLORY science team to develop a remote-sensing, Earth-orbiting instrument to collect data on aerosols and total solar irradiance.

NIST participated in an international intercomparison of the calibration of radiometric equipment using its Earth Observing System (EOS) thermal transfer radiometer and a water-bath blackbody in Miami, Florida. This intercomparison was conducted as an activity of the Committee on Earth Observing Satellites (CEOS).

NIST helped calibrate the spectral response of the Jet Propulsion Laboratory/Caltech Cosmic Infrared Background Experiment (CIBER) sensor that flew in June 2009.

NIST collaborated with the Utah State University Space Dynamics Laboratory to advance the development and calibration of optical sensors. The collaboration emphasizes the calibration and characterization of satellite imagers and sensors that are important for defense and climate-change research.

NIST used its Low Background Infrared facility to provide calibrations of infrared sources and test chambers for quality assurance for the Missile Defense Agency's testing of Exoatmospheric Kill Vehicle (EKV) units prior to deployment. The Low Background Infrared facility also supported calibrations of the antiballistic missile-defense hardware-in-the-loop simulation test chamber, 10V, being developed by the Missile Defense Agency at the Arnold Engineering Development Center in Tennessee. The 10V chamber will simulate real engagement scenarios in the testing of Exoatmospheric Kill Vehicle missile units.

NIST supported the testing of calibrators for the near infrared spectrograph (NIRSpec) being built by the European Space Agency and its contractors for the James Webb Space Telescope (JWST). NIRSpec will enable scientists to better understand the formation of stars, stellar clusters, and galaxies.

With NASA funding, NIST developed a prototype circuit for critical signal processing applications on future space-based observatories. The demanding specifications for these circuits were met by using superconducting electronics operated at ultralow temperature.

The NIST Manufacturing Extension Partnership (MEP) program maintains a network of 59 centers, with at least one in every state and Puerto Rico. MEP centers offer business and technical assistance services to the Nation's small and medium-sized manufacturers. In FY 09, MEP centers implemented 241 business improvement projects with 151 individual manufacturing companies in the aerospace and defense industry. In addition, the MEP program worked with several prime aerospace companies, including Boeing, Rockwell-Collins, Lockheed Martin, and Honeywell, to most effectively utilize and develop their supply bases. Working with these prime companies and partner agencies, MEP centers have reduced supplier lead times; improved quality; and developed a stronger, more reliable aerospace supply base.

As important parts of their state and local economic development communities, several MEP centers (including the Colorado Association for Manufacturing

Technology, the Texas Manufacturing Assistance Center, the Alabama Technology Network, and the Ohio Manufacturing Extension Partnership) are also actively involved in their state aerospace industry initiatives.

NIST is working with industry to test and advance MTConnect, a low-cost, open machine tool integration standard sponsored by the Association for Manufacturing Technology, General Electric, TechSolve, and other partners. MTConnect fosters greater interoperability between controls, devices, and software applications by publishing data over networks using the Internet Protocol. NIST researchers are part of MTConnect's Technical Advisory Group, and they led the performance evaluation tests. Encouraged by initial demonstrations at the 2008 International Manufacturing Technology Show, factory managers at the Boeing plant in Auburn, Washington, sought to collaborate with NIST to further explore the potential of this technology. In May 2009, NIST and Boeing worked together to test a machine-monitoring "dashboard" application that collected actual production figures for analysis and archiving. This allowed easy monitoring of progress and delays in plant production for different original equipment manufacturer machine tools. Tests were conducted on 60 machine tools from two different vendors.

NIST and members of the STEP Manufacturing Team (including The Boeing Company) met in May 2009 at Boeing's Renton, Washington, facility to demonstrate and discuss advanced uses of the STEP-NC AP238 (also known as ISO 10303-238) standard. STEP-NC is an extension to the international standard—STandard for Exchange of Product model data, a comprehensive ISO standard that describes how to represent and exchange digital product information. STEP-NC extends the STEP standard to parts created by computer numerical control. STEP-NC will enable manufacturers to design a three-dimensional part electronically and then send the part geometry, along with tolerance, feature, and high-level process information, directly to a machine tool without taking the extra step to define all of the machine-specific motion codes needed to make the part. The May 2009 international implementation and testing event demonstrated and tested the integration of tolerance information from design with machining and inspection using the STEP-NC standard. Technicians machined several parts using a complex mold part as the basis for data exchange at the Connecticut Center for Advanced Technology, KTH/Sweden, and NIST and then brought them to

Mitutoyo/Kirkland for inspection. The association between measured surfaces and the tools and operations that created them made it easy to see how tooling choices impacted quality. NIST's evaluation of the results determined that deviation from the desired part geometry occurred in some cases due to tooling compromises.

NIST researchers collaborated with NASA on measurement methods for x-ray telescopes that require hundreds of extremely thin mirrors nested like the layers of an onion. Researchers completed the design and theoretical analysis of a new measurement technique that uses two computer-generated holograms to address the challenge of measuring mandrels for the fabrication of these x-ray telescope mirrors.

In 2009, NIST performed the first official NIST laser tracker calibration per the ASME B89.4.19 standard and the first official NIST articulated arm coordinate measuring machines (CMM) calibration per ASME B89.4.22. Major aerospace manufacturers such as Boeing and Pratt & Whitney increasingly rely on measurements of complex surfaces by frameless measurement systems such as laser trackers and articulating arm coordinate measuring machines. Calibrations of these types of systems allow manufacturers to use cost-effective, flexible, and reconfigurable measurement equipment in their manufacturing environment.

Many of NASA's next-generation satellite observatories require new detectors with improved sensitivity and scalability. With funding from NASA, NIST developed new detectors based on the voltage-biased superconducting transition-edge sensor (TES). The TES offers new capabilities for the detection of electromagnetic signals from millimeter waves through x-rays. Following on their successful development at NIST, the TES has become the reference technology and a leading candidate for future NASA satellite missions at x-ray (International X-ray Observatory), millimeter (CMB Polarimeter Satellite), and submillimeter (Submillimeter and Far-InfraRed Experiment, or SAFIRE) wavelengths, as well as for many NASA-funded suborbital instruments including balloon-borne instruments and instruments intended for the Stratospheric Observatory for Infrared Astronomy (SOFIA).

With NASA funding, NIST began the development of Superconducting Quantum Interference Devices (SQUIDs) and SQUID-based multiplexers to read out large arrays of TES detectors in a manageable number of output channels. NIST has already provided SQUID systems to many researchers at NASA Centers

(Goddard Space Flight Center and the Jet Propulsion Laboratory) and to those in academia working on NASA-funded projects (including the California Institute of Technology, Stanford, the Massachusetts Institute of Technology, the University of California at Berkeley, Princeton University, Harvard University, and the University of Chicago). SQUIDs and SQUID multiplexers developed at NIST will be used in most of NASA's future TES instruments.

Over the past several years, NIST developed noise mitigation features that made it possible to demonstrate TES x-ray calorimeters with improved energy resolution. The performance goal for the International X-ray Observatory satellite mission of 2 eV at 6 keV has been reached by a collaboration of the NASA/Goddard Space Flight Center and NIST, which will make it possible to better probe general relativity in the strong gravitational limit by studying the x-ray emissions of iron falling into black holes.

NIST is now deploying SQUID multiplexers with two orders of magnitude better immunity to stray fields from the environment. This immunity will be critical for systematic error control in high-precision systems to study the cosmic microwave background (CMB). NIST SQUIDs will be used in two NASA-funded balloon-borne CMB experiments (SPIDER and EBEX).

In response to this report, in 2007, NIST established a significant effort through the Innovations in Measurement Science program to develop CMB polarimeters with the necessary level of sensitivity. A NIST team worked with collaborators at NASA Centers and in universities to develop large arrays of CMB polarimeters to make this challenging measurement.

Over the last several years, with funding from NASA, NIST has taken several critical steps towards fielding even larger detector arrays (greater than 10,000 pixels) in NASA missions. These include the development of dissipation-less microwave SQUID multiplexers and code-division multiplexers. In combination, these will make it possible to read out many thousands of detector channels in a single coaxial cable. NIST has fully demonstrated these devices and worked to disseminate this technology to its collaborators at NASA Centers and universities.

NIST continued work on new concepts to achieve on-chip electrical cooling of cryogenic detectors. These on-chip coolers, based on superconducting tunnel junctions, could greatly simplify spacecraft cryogenic requirements by providing

a final on-chip stage of cooling from 0.3 to 0.1 Kelvin. Researchers at NIST have developed large-area coolers fabricated using standard microelectronic processes. These devices have demonstrated cooling from 260 to 115 millikelvin with cooling power 100 to 1,000 times greater than in previous demonstrations. NIST worked with the NASA John H. Glenn Research Center to complete the characterization of the large vacuum chamber located near Sandusky, Ohio, for use as a reverberation chamber. The goal is to use the vacuum chamber for radiated immunity tests to ensure that space vehicles will not be interfered with by incidental electromagnetic fields from radar, communications, and other sources. The chamber was well suited to such tests with acceptable uniformity and a lack of hot spots that might overstress electronics during high-power tests. A detailed report was delivered to NASA.

NIST continued to provide support for high-performance satellite and radar systems through its antenna parameter calibration services. Recent customers include Northrop Grumman and Harris Corporation.

In FY 09, NIST worked with the U.S. Air Force, industry, and NASA in fuels research geared towards developing alternative fuels and generating an understanding upon which to base innovative designs for jet and rocket propulsion systems. Two of the major foci of the work involved chemical characterization and thermophysical properties. In particular, NIST evaluated properties of synthetic Fischer-Tropsch fuels (including several renewable bio-based fluids) and rocket/jet fuels.

NIST supported collaborators working in industry, academia, and national laboratories to improve the stability of thermal barrier coatings that are used to extend the high-temperature behavior of nickel-based superalloy turbine blades and, thus, enhance turbine engine efficiency. In 2009, NIST generated and disseminated multicomponent diffusion data to advance the modeling of the critical strengthening mechanism, the gamma-prime precipitation process; demonstrated how to model interdiffusion reactions occurring between the thermal barrier coating and the nickel-based superalloy; and continued to refine diffusion databases needed to model, validate, and predict the microstructural evolution of third-generation nickel-based disk superalloys during manufacturing and service.

The worldwide electronics industry transition to lead-free solder and surface finishes is well under way. However, high-reliability aerospace microelectronic

products are faced with an extreme reliability issue due to the phenomenon of "tin whisker" formation in systems employing lead-free solders and surface finishes. These whiskers can cause shorts in electronic panels, which could lead to aircraft failure. The NIST Tin Whisker Project worked to identify the fundamental cause of whisker growth to assist U.S. industry, including aerospace firms, in mitigating this problem. In 2009, NIST experts in tin-whisker mitigation were central participants on a team of 16 nationally recognized expert scientists and engineers on Phases 1 and 2 of the Lead Free Electronics Manhattan Project. The project, sponsored by the Office of Naval Research and the Joint Defense Manufacturing Technology Panel, was formed to address the serious reliability threat from lead-free solders and surface finishes that are infiltrating critical aerospace and defense systems. In April 2009, Phase 1 of the Project identified gaps in current industry best practices for the use of lead-free solders and surface finishes in the high-reliability aerospace and defense programs. In August 2009, Phase 2 produced a three-year roadmap that addressed the reliability and sustainment risks identified in Phase 1. The third phase of this project, renamed the Lead-free Electronics Risk Reduction Program, has articulated eighty R&D tasks needed to address the lead-free technology knowledge gaps.

NIST is currently working with NASA's Glenn Research Center on spacecraft fire-detection research. Due to the lack of experimental data for spacecraft fires, scientists designed ISS and Shuttle smoke detectors based upon Earth gravity test data and experience. The absence of or reduction in gravity has a significant impact on the smoke properties from a spacecraft fire. NASA and NIST developed the Smoke Aerosol Measurement Experiment (SAME) to characterize smoke properties from overheated spacecraft materials using a suite of aerosol measurement instruments and smoke-collection devices. Additional experiments are prepared for the re-flight of SAME (SAME-R).

NIST worked with the Air Force Office of Scientific Research to formulate and manufacture a variety of biopolymer nanocomposites through synthesis of the polymer and in-situ intercalation/dispersion of treated nanoparticles in an attempt to improve the flammability characteristics of the materials. The structure and properties of the materials will be examined, including the network microstructure, rheology, processing, electrical, and mechanical properties.

NIST worked with The Boeing Company to provide fundamental understanding of observed combustion promotion by halogenated fire suppressants during the FAA aerosol can fire suppression test. NIST worked on developing an understanding of the likely cause of the unwanted enhanced burning using detailed numerical simulations of reacting systems and reduced-scale surrogate experiments. Alternative agents and approaches for overcoming the unwanted enhanced burning were considered.

International Trade Administration

Industry and Trade Policy

The Office of Transportation and Machinery (OTM) within the Department of Commerce's International Trade Administration (ITA) participated in the development of Administration policies on aeronautical R&D through the National Science and Technology Council's (NSTC) Subcommittee on Aeronautics Science and Technology (ASTS). In FY 09, the ASTS completed the first biennial update to the National Aeronautics Research and Development Plan, which establishes research goals and objectives for Federal aeronautics R&D investments in priority areas. In FY 10, the ASTS will update the National Plan for Aeronautics R&D and Related Infrastructure, which establishes aeronautics R&D goals, objectives, and guidance outlining the path forward for developing an aeronautics R&D, test, and evaluation infrastructure plan. The ASTS will also update the associated Technical Appendix to the R&D Plan, which identifies research investments by Federal departments and agencies related to the national goals and objectives and includes a preliminary assessment of Federal R&D activities to identify areas of opportunity for potential increased emphasis.

OTM participated in the planning and implementation process for NextGen through the interagency JPDO, which oversees the initiative. OTM staff continued to represent the Department of Commerce on both the Global Harmonization Working Group (GHWG) and the Aviation Security Working Group. As part of the GHWG, OTM staff participated in the drafting of the NextGen International Strategy, which assembled participating agency priorities. Also, OTM staff

supported the GHWG Executive Committee and cochaired the Liaison Standing Committee (charged with collaborating with the other working groups on technological and procedural developments with global implications). Further, OTM staff coordinated a review of various JPDO documents, including the Global Harmonization Roadmap and the Safety Culture Improvement Resource Guide, as well as documents from industry partners (such as the RTCA, Inc., NextGen Mid-Term Implementation Plan).

OTM participated in a meeting and workshop for the Commercial Aviation Alternative Fuels Initiative (CAAFI). CAAFI is a public/private group sponsored by the FAA, the Air Transport Association of America, the Aerospace Industries Association, and Airports Council International-North America. The purpose of the meeting was to review developments in aviation alternative fuels; set roadmaps for current and future research, development, and deployment; and facilitate communications, relationship-building, and partnerships across sectors. In addition, OTM staff worked with Kallman Worldwide to highlight the 2009 Paris Air Show as an opportunity for alternative fuels producers to showcase their products and scope the potential market.

OTM continued its participation in aviation security activities, including work on the JPDO Aviation Security Working Group. OTM staff took part in various security technology demonstrations and presentations to determine viability and provide perspective on the state of aviation security technology. OTM staff worked to ensure cooperation between the GHWG and the Aviation Security Working Group with regard to specific projects, such as the Flight Data Initiative (advanced flight data recorder technology), the Emergency Management Operational Control System (a portable air traffic management system for use in disaster-stricken areas), and the Security Integrated Tool Suite (for assessing the threat level of various flight objects). OTM updated market and policy assessments for civil-use Unmanned Aerial Systems (UAS). OTM continued public outreach on UAS issues through meetings with major UAS manufacturers at the 2009 Paris Air Show. In addition, OTM staff participated in the 2009 Association for Unmanned Vehicle Systems International (AUVSI) conference in Paris. A number of outcomes of the conference were incorporated into the ongoing market and policy assessments.

ITA supported the U.S. Trade Representative on issues relating to the enforcement of U.S. rights under the World Trade Organization and in free trade agreement negotiations. In particular, OTM provided support for the ongoing U.S./EU trade dispute over Large Civil Aircraft by providing industry expertise in areas relating to changes in the market, actions of the major stakeholders, and political analysis of the countries impacted. With the impending release of a final determination in the U.S. case against Airbus subsidies and an interim ruling in the EU case against Boeing, EU officials have called for a negotiated settlement regarding aircraft subsidies. If these talks materialize, OTM will be a key source of industry and trade policy expertise for the U.S. negotiators.

ITA's OTM and Office of Financial Services Industries participated in the Group on the Sector Understanding on Export Credits for Civil Aircraft (the "Aircraft Sector Understanding") at the Organization for Economic Cooperation and Development (OECD). The governments of almost all countries with major aircraft manufacturers are signatories to the Aircraft Sector Understanding, an annex to the OECD Arrangement on Officially Supported Export Credits, which establishes rules for export credit agencies. The OECD rules aim to ensure that government-provided export financing is not a competitive factor in civil aircraft sales competitions. After several years of negotiations, a new Aircraft Sector Understanding was reached in 2007. As a member of the U.S. delegation, ITA supported the United States' efforts to ensure the successful implementation of the new agreement. In addition, OTM and the Office of Financial Services Industries supported interagency efforts to engage the Canadian government on expanding the so-called Home Markets Understanding to the C-Series, a new Canadian aircraft that will compete with Boeing's 737. Under this understanding, the producers of large civil aircraft have agreed not to provide official financing into each other's market in order to preserve a level playing field.

ITA and NOAA continued their active participation in the implementation of the Bush Administration's National Space Policies as well as the new review of Federal space policy directed by President Obama. In order to ensure that commercial interests continue to be adequately addressed, OTM and NOAA worked to ensure that current policies' implementation actions and the new policies' language

both create an environment that will improve U.S. industry's competitiveness, stimulate the American economy, and create U.S. jobs.

OTM represented commercial remote-sensing satellite industry interests within the Remote Sensing Interagency Working Group (RSIWG), led by the State Department. The RSIWG coordinates policy for the export of commercial remote sensing satellite systems and negotiates government-to-government agreements that address the safeguarding of those systems' technology. The RSIWG consulted with several foreign countries on satellite cooperation and met with industry to understand the impact on industry.

ITA played an important role in promoting U.S. aerospace trade interests as the industry faced mounting competition from abroad. ITA participated in and organized trade events and provided advocacy to support U.S. companies in international aerospace competitions, including commercial sales for aircraft, helicopters, airport construction, communications, and remote sensing satellites; commercial projects; and air traffic management projects.

In June 2009, ITA organized and supported the Commerce Department's participation in the Paris Air Show and arranged senior-level meetings for the Acting Assistant Secretary for Manufacturing and Services with foreign government and industry officials as well as U.S. industry executives. ITA/OTM met with numerous U.S. and foreign government and industry officials to discuss ongoing policy issues impacting the competitiveness of U.S. industry. OTM staff also provided similar services during the Moscow International Aviation and Space Salon and toured the Moscow Design Center to discuss ongoing aerospace business interests in Russia.

OTM continued to monitor the progress of the Indian Air Force's Medium Multi-Role Combat Aircraft (MMRCA) acquisition program for 126 aircraft worth over $10 billion. OTM staff updated policy assessments for the MMRCA as the competition progressed through technical and field evaluations as well as policy assessments on the Indian FY 07 rollback of tariff exemptions for importation of general aviation aircraft into India. The net impact of the tariff placed an effective 25 percent duty on fixed wing general aviation imports and an 18.5 percent duty on general aviation helicopter imports. Although the tariff exemption remained in effect in FY 09, OTM continued to work within Commerce and on an interagency

basis to advocate for reinstatement of the tariff exemption in the next Indian budget, scheduled for release in February 2010.

Industry and Trade Promotion

ITA's U.S. and Foreign Commercial Service Aerospace Team recorded 148 export successes in FY 09 valued at over $2 billion. An export success is an activity in which Department of Commerce personnel effectively assist a U.S. company with identifying new international sales channels or resolving an issue that is hindering an export sale. Commercial Service (CS) personnel impacted deals with small- and medium-sized companies, as well as larger corporations such as Boeing, Lockheed Martin, Raytheon, and Northrop Grumman.

The CS Aerospace Team held over 500 counseling sessions with U.S. aerospace companies, helping them to resolve international trade issues, identify new export markets, and develop strategies for entering those markets.

The CS Aerospace Team participated in 30 domestic and international aerospace trade events at which CS Aerospace Team members supported U.S. industry with one-on-one counseling sessions, arranged individualized business-to-business meetings with international business partners, and provided additional export counseling services. ITA also sponsored Aerospace Products Literature Centers (APLC) at several air shows, which offered low-cost, efficient venues for U.S. small- to medium-sized aerospace companies to explore international and niche aerospace markets. ITA trade show support generated hundreds of trade leads for participating companies, allowing them to enter or expand their exports to international markets. These international trade events included the Paris Air Show and Asian Aerospace, among others.

Bureau of Industry and Security

DOC's Bureau of Industry and Security (BIS) participates in seminars specific to the civil aircraft industry to address ongoing export control issues. For example, BIS participated in the Paris Air Show in June 2009, providing a one-day seminar on export controls and conducting one-on-one meetings with industry representatives.

Department of the Interior

DOI

During FY 09, agencies within the Department of the Interior (DOI) greatly expanded their use of remotely sensed data to assist them in their responsibilities. Traditional aerial photography, federally managed, commercially available, and foreign satellite data, as well as advanced radar data, were essential sources of data.

Additionally, many agencies within the Department drew on the expertise of sister agencies to more fully understand and apply remotely sensed data.

The National Park Service (NPS) has a long history and standing investment in remote sensing and GPS technologies. A wide range of its projects and programs have business requirements that utilize aerial and spaceborne platforms ranging from acquisition to applications and the use of imagery in reports and related products.

The Inventory and Monitoring (I&M) Program conducted 12 baseline inventories of over 270 parks spanning over 30 million acres of public lands. Geology, Soils, Vegetation, and Base Cartography are four surveys that provided important baseline inventories for the support of land management decisions. Every level of resolution of spacebased remote sensing is used by these efforts. For more information, see the I&M program brief at *http://science.nature.nps.gov/im/assets/docs/IM_Program_Brief.pdf.*

In 2009, the NPScapes project packaged data from Landsat Thematic Mapper (TM), National Land Cover Data, GAP Land Cover, and Landscape Fire and Resource Management Planning Tools Project (LANDFIRE), as well as various metrics from these data, for all of the NPS units in order to allow parks to start monitoring landscape dynamics in and around their units. This will be expanded in the future to include Land Cover data for all of North America derived from MODIS imagery and NOAA's Coastal Change Analysis Program (C-CAP) data.

The Northeast Coastal and Barrier Network (NCBN) of the NPS I&M Program collaborated with the U.S. Geological Survey (USGS) Florida Integrated Science Center to collect LIDAR data and aerial photography at Fire Island National Seashore and Gateway National Recreation Area to support the network's coastal geomorphological monitoring program. These data are used to generate highly accurate elevation models of beach, dune, and other coastal features and are used by park natural resource managers to assess rates of erosion and deposition. Ongoing monitoring of the NCBN coastal parks using LIDAR will also assist managers in assessing the effects of climate change (such as sea-level rise) on these coastal systems.

Many park vegetation maps utilized remote sensing, with 9 million acres mapped, 8.2 million acres underway, and 12 million remaining. The use of the U.S. Department of Agriculture's (USDA) National Agriculture Imagery Program (NAIP) resources, sometimes coupled with Landsat TM and a variety of commercial SPOT, QuickBird, and IKONOS products, are used to support these mapping inventories. (For more information, see the Vegetation Inventory Brief at *http://science.nature.nps.gov/im/inventory/veg/index.cfm*.) GPS is also a critical tool in checking field data, accuracy assessments, and project mapping. The use of Continuous Operating Referenced Stations (CORS) data and the National Differential GPS system maintained by the U.S. Coast Guard are critical tools in resource assessments.

U.S. Fish and Wildlife Service staff will be collocating with the NPS I&M program in Colorado to stand up a set of I&M parallel efforts for Wildlife Refuges. Sharing of resources, techniques, and space-based data will be a critical tool for this new joint effort. This data sharing and teamwork will demonstrate agency collaboration and leverage data collection and analysis efforts as part of the new, changing climate-based initiative.

The NPS's I&M Program, Southwest Alaska Network, used a combination of high-resolution IKONOS imagery, Landsat data, and historical aerial photographs to quantify decadal changes in glacier ice cover (1973–2002) and to document land cover change (1955–2005) in three national park units. In addition, MODIS data assisted in documenting seasonal variation in lake ice and in calculating growing season metrics across the study region.

Using Landsat data, the Southwest Alaska Network, in cooperation with NASA, quantified current glacial extent and changes in ice cover over a roughly 30-year

period in Kenai Fjords, Katmai, and Lake Clark National Park and Preserve. Scientists used automated classification techniques and manual interpretation to delineate ice boundaries. In addition, the NPS and USGS developed baseline Digital Elevation Models for the Bear and Exit Glaciers using LIDAR data acquired through a partnership grant.

Under an Interagency Agreement with the U.S. Forest Service's (USFS) Pacific Northwest Research Station, the Southwest Alaska Network developed methods for using Landsat data to detect changes in land cover in Lake Clark National Park and Preserve (1987–2005), including loss of tree cover due to fire or insect outbreaks, shrub establishment on glacial outwash and/or abandoned river channels, and pond drying. The new analytical approach resulted in more stable and thematically consistent labels for changes occurring on the landscape and better integration of information from existing land cover maps. Additional funding from NASA supported the analysis of scenes from Katmai National Park and Preserve.

Evaluating approximately 423,952 acres of parklands, researchers generated wildland fire burn severity products from Landsat data for 18 fires that occurred between 2005 and 2007 within Alaska national parks. Resulting data products included burn severity datasets and detailed fire perimeters, which NPS distributed to park staff and public users.

A University of Colorado research team, in coordination with the Alaska Arctic Inventory and Monitoring Network, assessed rates of coastal erosion and accretion along the shores of Bering Land Bridge National Preserve and Cape Krusenstern National Monument. The team used repeat aerial photography with time series from the 1950s, 1980s, and 2003, as well as IKONOS satellite imagery, to determine coastline changes. Comparisons of the imagery showed significant changes to the 450 kilometers of coastline along the park shorelines. These changes affect animal habitat, water, soil, permafrost, and other aspects of coastal ecosystems, cultural resources, and local communities. The project will assist NPS in developing protocols to continue acquiring aerial photographs and satellite imagery for long-term monitoring of the coastline.

NPS Yellowstone National Park staff used a temporal series of high-resolution (1-meter resolution or less) commercial imagery and Landsat-derived Normalized Burn Ratio products to delineate stand-replacing fire effects from 1988 to the

present in Yellowstone National Park. The park purchased 1,600 square kilometers of QuickBird 2-foot-resolution imagery along road corridors and developed areas. This imagery will be used for multiple park projects, including updating buildings, roads, utilities, vegetation, and trails in GIS data layers. Since high-resolution imagery became the de facto background base map for park operations maps, the QuickBird imagery will also be used as background imagery for cartographic products.

Starting in 2005, the NPS became the Interior sponsoring agency for the Monitoring Trends in Burn Severity (MTBS) project as a joint venture between DOI and USFS with the USGS and the USFS Remote Sensing Application Center (RSAC) responsible for the project. The project will map all wildland and prescribed fires greater than 1,000 acres in the west and 500 acres in the east from the present back to the early 1980s.

Yellowstone Park staff worked with researchers at Idaho State University to quantify high-alpine vegetation change over time using current and historic remotely sensed imagery. Historical aerial photo negatives of Yellowstone National Park and the surrounding high alpine areas, from USGS Earth Resources Observation and Science (EROS) Center, were scanned to digital format. Landsat, IKONOS, QuickBird, and WorldView satellite imagery was also pulled from archive, and new satellite tasking was ordered for the study areas.

Natural Resource staff used Landsat-derived products to run models developed by the Yellowstone Ecological Research Center and the NASA Ames Research Center. The models were designed to predict the amount of forage available at the end of the growing season, which may affect the movement of ungulate species such as bison, elk, deer, and pronghorn. Archival Landsat imagery and GPS collar locations of bison were used to test the model for 1990 through the present.

Envisat Advanced Along-Track Scanning Radiometer (ASAR) image data (radar) collected during Hurricane Ike provided the first satellite view of surge flooding in southwest Louisiana. (Extensive cloud cover prevented useable optical satellite image collections.) The ASAR images were used by the Federal Emergency Management Agency (FEMA) to support search and rescue planning and efforts.

Staff members from the USGS Biological Resources Discipline participated in the USGS initiative to build a civil-operational radar remote sensing system to

provide national strategic mapping of land deformation and water issues. If successful, the USGS program will build on established satellite optical and radar abilities to map risks and resource sustainability related to (1) land deformation related to subsurface extractions and injections, (2) deformations related to volcanic activities and crustal movements, and (3) changing surface and canopy subsurface water inundation extents and depths.

The U.S. Fish and Wildlife Service (FWS) used a diverse set of remotely sensed data, from traditional aerial images to satellite radar imagery, for a wide variety of habitat and land management activities as varied as habitat, wetland and vegetation mapping; monitoring fish and wildlife populations; refuge management; trend analysis and modeling; climate change mapping; and strategic habitat conservation planning.

Despite a relatively small budget allocation for direct funding of remote sensing programs, the FWS contributed toward the Multi-Resolution Land Characteristics (MRLC) program, which used Landsat datasets to create the National Land Cover Dataset (NLCD) and NAIP.

Starting with North Carolina in the FWS's Southeast Region, multiple return LIDAR data from the North Carolina Floodplain Mapping Program were processed using free, open source, geospatial software to complete a forest canopy height model for all of North Carolina. This canopy height model was then compared to known nesting locations of different bird species to derive species preference models for canopy heights. A simulated 1-meter sea level rise was also applied using the North Carolina Floodplain Mapping 20-foot elevation grid. The resulting mask was used to approximate the impact of sea level rise on different canopy height classes along the North Carolina coast.

Bare earth digital elevation model (DEM) data generated from LIDAR data were used for a variety of purposes:

- to determine the wildlife-friendly lighting ordinance zone boundary along the coastline of Walton County, Florida;
- to determine the lands of the Perdido Key beach mouse range that potentially would be available to the mouse if there were a 100-year flood event within the area; and
- as part of a predictive distribution model for the Godfrey's butterwort (Pinguicula ionantha).

The Gulf Coast Joint Venture (GCJV) used a combination of aerial photography and satellite imagery to develop habitat models for priority bird species along the western Gulf Coast. The GCJV used both USGS digital orthophotographs and USDA NAIP orthophotographs for estimating the amount of available foraging habitat for wintering waterfowl in emergent coastal marshes. Landsat imagery was used to model pond use by redhead ducks for protection and enhancement of ponds based on available shallow shoal grass, distance to freshwater basins from foraging sites, and degree of isolation and permanence. The GCJV also used Landsat imagery to develop estimates of seasonal surface water on agricultural landscapes for wintering waterfowl and fall migrating shorebirds.

In the FWS Division of Bird Habitat Conservation, joint ventures rely on remotely sensed data to provide information on habitat restoration, inventory, and management. Most joint ventures use National Wetland Inventory and NLCD datasets and, in some years, acquire aerial photographs to assess habitat conditions and report progress in wetland restoration. In central Nebraska, the Rainwater Basin Joint Venture (RWBJV) collected the final season of 2-foot resolution color infrared (CIR) aerial photography as part of a five-year project (2004–2009) to document spring wetland conditions. RWBJV also acquired LIDAR data to delineate wetlands and create hydrologic models to prioritize wetland restoration efforts. The Atlantic Coast Joint Venture (ACJV) used land-cover data derived from Landsat imagery in a variety of analyses to support the conservation of bird habitat from Florida to Maine. In the Southeast Region, ACJV used the data from USGS's Southeast ReGAP project to determine the capacity of the existing landscape to support populations of priority species. One research project used these data to predict future land cover to evaluate the likelihood of alternative management scenarios for maintaining bird populations (e.g., to the year 2100). Also, landscape metrics such as percent cover, amount of edge, and contagion were computed for use in modeling species' response to vegetative characteristics.

Other uses of remotely sensed land cover data included the development of energetic (i.e., kilocalorie) surfaces that were input into the development of a migration model and general land cover summary statistics assessment of net landscape changes in the ACJV administrative boundary. During 2009, the ACJV initiated a project in collaboration with USGS that used LIDAR data to assess the impact

of sea level rise on populations of priority bird species in salt marshes in the mid-Atlantic and New England portion of the joint venture. The ACJV also used DEMs to calculate landscape metrics (e.g., slope, aspect, or surface roughness) that were useful in modeling species response to landscape features. The ACJV supported a project that used NEXRAD data to map bird migration hot spots. These data were useful in determining areas that are important in maintaining populations of migratory species but are not commonly considered when developing focus areas for conservation actions.

The 2008 Intergovernmental Panel on Climate Change (IPCC) "Climate Change and Water Technical Paper" described wetlands as the most vulnerable habitat on Earth. As a result, the need to map and monitor wetland habitats substantially increased, not only for habitat and landscape planning, but also for assessing climate change impacts on fish, wildlife, and human resources. User surveys confirmed the need to provide updated current wetland maps on a five-year cycle. Currently, the National Wetland Inventory is at a 100-year update schedule.

The FWS is the lead Federal agency for a publication produced by the Office of Management and Budget (OMB) through the National Wetland Inventory program, Circular A-16: "National Spatial Data Infrastructure (NSDI) Wetland Data Theme." In 2009, the National Wetland Inventory became the endorsed Federal Geographic Data Committee standard. The National Wetland Inventory began over 30 years ago by mapping wetland types using USGS spring, leaf-off, high-altitude, black-and-white/color infrared aerial photographs using the Cowardin classification system. Today, due to the lack of a national program for spring imagery, the National Wetland Inventory uses a variety of state or local government–acquired spring, leaf-off, CIR aerial digital imagery to inventory and update wetland maps. The USDA's NAIP imagery is sometimes used when current spring, leaf-off imagery is not available.

Dissolved organic material (DOM) exported from land complicates the remote sensing of water quality in coastal waters by NASA satellites. However, the variability of DOM chemistry is a useful indicator of watershed processes. As such, it can be used to monitor climate effects on carbon cycling by identifying trends in land-to-sea carbon transport as a function of changing precipitation patterns. USGS scientists in the Water Resources Discipline (National Research Program,

Boulder, Colorado, and Maine Water Science Center), in association with oceanographers at the Bigelow Laboratory for Ocean Sciences, conducted a project designed to study DOM in the Penobscot River, its influences on the DOM in the Gulf of Maine, and the complications posed by its presence on remote sensing of water quality in the Gulf of Maine by NASA satellites. Results showed that high rates of river discharge during fall storms export the greatest amount of DOM per unit area of the watershed. In addition, large variations in exported DOM were observed throughout the year. These large interannual variations were related to strong upward trends in the absorption properties of DOM and detritus over the entire Gulf of Maine. They were incorporated into algorithms designed to utilize satellite-derived absorption data (MODIS) to determine DOM concentrations in the Gulf of Maine.

The Bureau of Land Management (BLM) used an array of remote sensing technologies to inventory, monitor, and address concerns about resource conditions and energy and mineral resource extraction on public lands. The technologies ranged from simple digital cameras to global-monitoring satellites (e.g., MODIS, Landsat). The BLM recognizes two intrinsic values that are uniquely provided by remote sensing: providing data that can be used at multiple scales (from plot level to Western U.S.) and providing consistent/quantifiable data over time. Both these values provide the foundation to support BLM's long-term resource management and monitoring goals.

In FY 09, BLM made its largest single-year acquisition ever of the USDA NAIP orthoimagery. NAIP full-state imagery was acquired for nine western states—California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Washington, and Wyoming. Due to the massive landscapes covered by the NAIP program, this imagery dataset proved to be the de facto base orthoimagery dataset for the BLM. It can be used for change detection studies and surface disturbance delineation; road development updates and route inventory creation crucial to planning efforts; characterization of land exchanges, mining, reclamation and recreation facilities; monitoring the health of rangelands and oil and gas development impacts; and vegetation treatments, fire planning, and trespass studies.

Traditionally, and for 2009, the widest use of remote sensing data was for fire-related activities. Most of the activities centered on interpretation of active fires,

post-fire perimeter delineation, and vegetation classification for fire/fuel risk modeling and disturbance mapping. However, the utility of remote sensing data goes far beyond the fire world. BLM, with its partners, conducted a large range of natural resource management projects that leveraged remote sensing data and analyses to support the BLM mission.

BLM Oregon partnered with multiple agencies to capture LIDAR data in 2007. These data were processed in 2009 to provide updated forest stand inventory at an estimated cost savings of greater than 60 percent. The inventory also proved to be more accurate than traditional methods because the data were derived from measurements throughout the area rather than interpreted from sample sites.

The BLM in Utah supported the national Forest Vegetation Information System forest inventory program by mapping 1.2 million acres of vegetation cover types including forest stands, woodlands, shrubs, grasses, agriculture, and urban areas. Both aerial photography and Landsat data were used in the model, as well as several indices depicting vegetation, slope, aspect, elevation, and other statistical representatives.

In 2008, the Billings, Montana, Field Office began work on a new resource management plan (RMP). From the planning development standpoint, resource specialists needed a baseline description of vegetation within the planning area to support monitoring management effectiveness over time. To fill this baseline need, BLM contracted USGS EROS Center to apply their continuous field mapping techniques to develop local and regional scale models of vegetation covering 90 percent of the field office boundary. Eight model components were generated for this project: continuous field estimates (from 1 to 100 percent) of percentage of bare ground, herbaceous plants (grass and forb), shrub, litter, sagebrush, big sagebrush, Wyoming sagebrush, and vegetation height. USGS successfully completed this mapping work and, in 2009, integrated these continuous field data to produce a variety of derived habitat mapping products for resource management planning activities.

Change detection and surface disturbance analysis studies were completed in the BLM Wyoming Buffalo Field Office. The Powder River Basin Oil and Gas Project Environmental Impact Statement was approved in 2003. The Environmental Impact Statement included limits for surface disturbance due to oil and gas

development and required monitoring of this disturbance for development planning. The study evaluated the level of disturbance by computing the areas and acreage of disturbance.

Both true color and color infrared aerial 2006 NAIP photographs were used to delineate potential habitat for the Pine Nut Mountains Ivesia, a rare endemic species known to occur only within the higher elevations of the Pine Nut Mountains in western Nevada. Remote sensing greatly improved the efficiency and effectiveness of locating likely habitat based on vegetative reflectance and ground texture.

BLM continued to be a leader in the field of photogrammetry, having pioneered the use of close-range and traditional photogrammetry for a host of applications, such as cultural resource preservation and quantifying erosion impacts due to off-highway vehicle activity, hazardous waste management, engineering projects, and boundary dispute litigation.

The Astrogeology Science Center of the USGS continued to be involved heavily in the Mars Exploration Rovers (MER) mission, whose twin rovers, Spirit and Opportunity, both surpassed 2,100 sols (Martian days) of surface operations in FY 09. Since the rovers' landings in January 2004, USGS Astrogeology Science Center members led efforts to plan, acquire, archive, and interpret data from the rover cameras, principally the Microscopic Imager on the instrument arm. They also analyzed color Panoramic Camera data of rocks, soils, and active processes on the surface of Mars. The USGS also contributed leadership to the Science Operations Working Group to plan each day of rover operations, working alongside science team members throughout the world and engineers at the Jet Propulsion Laboratory.

USGS scientists mapped minerals on Mars with the NASA Mars Reconnaissance Orbiter. Using the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) and High Resolution Imaging Science Experiment (HiRISE) imager, USGS scientists, working with other scientists, discovered an ancient acid-saline lake deposit consisting of layered clay and sulfate minerals in the bottom of Cross Crater, located in the southern highlands of Mars. This discovery added another piece to the emerging picture of early Mars and provided insights that may help future rover missions focus on the trail of water in their search for evidence of ancient life. A new, unnamed mineral was recognized spectrally from orbit above

Mars at this site and others. Known by its simple chemical formula $Fe(OH)SO_4$, it is manufactured here on Earth for its desirable pigment properties. USGS implemented efforts to find a natural terrestrial occurrence so this mineral can be formally named.

The USGS Astrogeology Science Center directly supported the testing, calibration, operation, and analysis of images acquired by the HiRISE camera aboard the Mars Reconnaissance Orbiter (MRO). This camera provided the highest resolution images of Mars from orbit (equivalency of 30 centimeters/pixel) and will be used to certify future spacecraft landing sites for the 2011 Mars Science Laboratory rover and support numerous Mars science investigations.

USGS scientists from the Astrogeology and Crustal Imaging and Characterization Centers participated as science team members on the NASA Cassini-Huygens Mission to Saturn and its moon Titan. Their work included (1) searching for seasonal changes in the lakes and larger seas of hydrocarbon around Titan's north pole, detecting a mirror-like reflection from the northern seas at infrared wavelengths, and investigating lakes near the south pole with radar for the first time; (2) monitoring Titan's rotation, which suggests that the body may have an internal ocean, by comparing the latest radar images with older ones of the same area; (3) generating digital elevation models of Titan from stereo pairs of radar images, including a complete map of the north polar region, to provide quantitative information about liquid transport, ice volcanism, dune activity, and other processes; (4) producing a set of high-level Titan map products containing all prime-mission radar observations, including image mosaics, topographic models, and maps of microwave emission and scattering properties relevant to understanding surface composition; (5) producing a complete set of maps of Titan with multiple color images from the Visual-Infrared Mapping Spectrometer; (6) mapping the composition of Saturn's rings and satellites; (7) representing science teams for planning future observations; and (8) calibrating returned imaging spectroscopy data. USGS scientists led or contributed to authoring several chapters in the book *Titan from Cassini-Huygens*, which is likely to remain the key reference for several decades.

USGS Crustal Imaging and Characterization Center scientists participated in the NASA/Indian Chandrayaan-1 mission, Moon Mineralogy Mapper. USGS

imaging spectroscopy scientists made a major discovery of water and hydroxyl on the sunlit areas of the lunar surface, where many predicted it was impossible for it to exist. USGS scientists found water with two spacecraft: the Chandrayaan-1 and Cassini.

Two scientists from the USGS Astrogeology Science Center were science instrument team members, and three were involved as participating scientists in the NASA LRO mission. This spacecraft is the first robotic precursor for the return of U.S. astronauts to the moon. LRO launched in June 2009 and has provided a wealth of data and images of the lunar surface useful for future planning. Astrogeology team members worked on exploration and identification of water ice at the lunar poles with LRO radar and radiometer data, studied unusual volcanic and impact crater deposits with camera data, and developed image mosaics and topographic maps of the surface to support future robotic and human in-situ lunar exploration. The Astrogeology Science Center also supported software development for the LRO radar and camera systems to produce image mosaics and topographic maps of the lunar surface and contributed to the development of standards for such mapping.

Computer scientists and cartographers from the USGS Astrogeology Science Center played key roles in making a global image mosaic of Mercury. Using images obtained by the MESSENGER spacecraft during its third flyby of Mercury (in 2009), USGS team members assembled images from the previous two flybys and images from the Mariner 10 mission (1973) to assemble a large mosaic that will be vital to planning future observations of the planet when MESSENGER goes into an elliptical orbit around Mercury in 2011.

The Landsat Program is a joint effort of the USGS and NASA to gather Earth resource data using a series of land observing satellites. Whereas NASA's role is the development and launch of Earth observing instruments and spacecraft, the USGS is responsible for flight operations, maintenance, and management of all ground data reception, processing, archiving, product generation, and distribution. A primary objective of the Landsat Program is to ensure a collection of consistently calibrated Earth imagery.

The Landsat Project at USGS manages two active satellites, Landsat 5 and Landsat 7, and the entire historical archive of data collected since 1972—more

than 2.4 million images. In 2009, a change in data policy (no-charge, Web-enabled data) transformed the distribution of Landsat data for scientists and operational users worldwide. As a result, more than 1.1 million Landsat images were delivered to customers! In 2009, the Landsat Project also reached milestones with both satellites. Landsat 5 celebrated 25 years in orbit, and Landsat 7 reached 10 years in orbit. With respective design lives of three years and five years, both of these satellites continued to provide essential data well beyond their expected lifespans. The Landsat team worked to extend the longevity of the satellites in orbit; enhance Landsat data quality; and improve the systems used to archive, process, and access Landsat data; it also led the design and development of the ground system for the upcoming Landsat Data Continuity Mission.

The USGS and NASA collaborated on the creation of several global land datasets derived from Landsat images: one from the 1970s and one each from circa 1990 and 2000. Each global dataset was created from the primary Landsat sensor in use at the time: Multispectral Scanner (MSS) in the 1970s, TM in 1990, and Enhanced Thematic Mapper Plus (ETM+) in 2000.

To extend this multi-decadal Landsat data collection, NASA and the USGS again partnered to develop the Global Land Survey 2005 (GLS 2005), a new global land dataset with core acquisition dates from 2005 to 2006. The data consist of Landsat TM, ETM+, and Earth Observing-1 (EO-1) data, making GLS 2005 the first-ever global dataset derived from multiple sensors. The entire dataset neared completion in 2009 with more than 95 percent available for free download. Plans to collaborate on a GLS 2010 dataset were in the works and expected to begin in late 2009.

The Landsat Data Continuity Mission (LDCM) was the development phase for the next Landsat mission (Landsat 8). In 2009, the LDCM project responded to the challenges of new and evolving mission requirements. The original launch date of July 2011 was moved to December 2012 to satisfy NASA's criteria for a 70 percent probability of meeting schedule and staying within budget.

Using images from the Landsat data archive, the USGS, in collaboration with the USFS, generated and provided access to burn severity assessments for thousands of fires from 1984 to 2007. In FY 09, all large historical fires were assessed for the southeastern United States as well as those that occurred in 2007 across all

50 United States. Additionally, the USGS provided support to the LANDFIRE refresh effort where burn severity assessments for smaller fires are provided directly to the LANDFIRE project to support data product updates. Burn severity data are used to monitor vegetation recovery and analyze long-term fire effects. They facilitate the assessment of ecological or socioeconomic factors that are affected by wildland fire. These data are used to study the effectiveness of management practices implemented in response to the National Fire Plan and the Healthy Forest Restoration Act.

Climate change effects are being seen in high northern latitudes more dramatically than in other parts of the globe. Understanding how climate change will impact permafrost, carbon dynamics, and watershed hydrology will help scientists predict future ecosystem responses. Cooperation with the Canada Centre for Remote Sensing (CCRS) allowed the USGS to secure Canadian imagery and examine the entire Yukon River Basin. Models and maps of vegetation change during the boreal forest growing season, a surrogate for ecosystem productivity, were produced from interpolated weather and site potential using MODIS data at a resolution of 250 meters (CCRS MODIS and eMODIS products). Projected productivity maps were then compared to actual productivity maps to identify anomalous areas, those that are more or less productive than expected during any given year's weather conditions. This approach accounted for inter-annual variations associated with weather to reveal effects caused by insect infestation, fires, changed drainage patterns, and permafrost degradation, all of which are of increasing concern as warming continues. Anomalous areas that are persistent over multiple years are mapped and can be used by modelers to account for disturbances in boreal forests of the Yukon River Basin.

In 2009, USGS scientists and their counterparts in West African countries completed a major effort to use Landsat imagery to map land use and land cover of much of West Africa for 1975 and 2000. This was the culmination of a project carried out collaboratively with the Agricultural-Hydrological-Meteorological (AGRHYMET) Regional Center in Niger and partners from 12 participating countries, with support from the U.S. Agency for International Development. Environmental scientists from each country were trained in the analysis, mapping, and monitoring of trends in land resources using a wealth of Landsat imagery

spanning nearly 30 years. The mapping was done on a national level. To map this vast region efficiently and quickly, the USGS scientists developed a special tool called the Rapid Land Cover Mapper. It is a vector-raster hybrid approach that lends itself to time-series land use and land cover mapping. The new results provided West African land managers with a better understanding of the land use/land cover patterns and trends in each country. The information is used by the Inter-Governmental Authority on Combating Drought in the Sahel (CILSS), particularly in their food security and natural resource management programs.

Remote sensing project activities in the Office of Surface Mining (OSM) included the continuation of a two-year pilot project working with USGS and the National Geospatial-Intelligence Agency. The project determined the best methods for the acquisition and delivery of image data, products, and services for the OSM regulatory program and determined which remote image data products and services support virtual inspection. The state of West Virginia used high-resolution satellite imagery for determining approximate original contours in support of the state's regulatory program and realized cost savings over the use of GPS field devices on the ground.

OSM staff used high-resolution satellite imagery along with other geospatial tools to inventory abandoned mine sites in Virginia. This resulted in the identification of acid mine drainage sites, dangerous high walls, apple cores, gob piles, and spoil piles.

Remote sensing education outreach is an integral part of the program. OSM staff conducted a "Basics of Remote Sensing" course at the 2009 American Society for Mining and Reclamation Conference. The use of remotely sensed imagery to support on-the-ground Surface Mining Control and Reclamation Act activities will continue in FY 11.

In FY 09, USGS worked with universities, local agencies, and the Plate Boundary Observatory (PBO) component of the National Science Foundation's EarthScope program to conduct geodetic investigations using GPS, LIDAR, Interferometric Synthetic Aperture Radar (InSAR), creepmeters, and sensitive long baseline and borehole strainmeters. To address the problem of earthquake hazards in the urban Los Angeles region, the USGS operated approximately 100 continuous GPS stations along the San Andreas Fault and in the densely populated urban area and

processed data from state-of-the-art, continuously operating GPS stations operated by the Scripps Institution of Oceanography and the Plate Boundary Observatory. In addition, the USGS worked with partners to use LIDAR and InSAR data to quickly and accurately produce large aerial maps of pre- and post-earthquake land deformation.

High-resolution LIDAR data identified active faults in Oregon and Washington that have the potential to generate damaging earthquakes. The USGS used funds from the multi-hazards initiative to collect and analyze LIDAR data in four at-risk areas in Oregon and Washington. In the Portland area, LIDAR studies identified sites for field studies for clarifying whether the Gales Creek fault had slipped in the recent geologic past and thus remains a hazard. Near Mount Hood, LIDAR revealed a set of faults, each with about two meters of surface displacement, which may be part of the southern extension of the Saint Helens seismic zone. This will be the subject of further investigations by the USGS and the Oregon Department of Geology and Mineral Industries (DOGAMI). In eastern Washington, LIDAR studies identified a major north-south fault that is approximately perpendicular to faults previously mapped in the Yakima fold and thrust belt in the Columbia Plateau. Finally, LIDAR was used to analyze the potential interaction of faults in the Cascade Range and the Yakima fold and thrust belt in central Washington, where a massive landslide occurred on October 14, 2009.

Satellite InSAR and GPS are essential elements of the USGS's volcano hazards mitigation strategy. The USGS used InSAR and GPS data to track minute surface motion due to volcanic processes in Hawaii; the Cascade Range of Washington, Oregon, and California; Yellowstone, Wyoming; Long Valley, California; and the Aleutian volcanoes of Alaska. USGS scientists used these data to model the subsurface flow of water and molten rock, including the depth and volume of new magma under a volcano.

A team of scientists from Washington State University, the Jet Propulsion Laboratory, and the USGS's Cascade Volcano Observatory developed a prototype rapid-deployment hazard monitoring instrumentation network and applied it to volcano monitoring. The Optimized Autonomous Space In-Situ Sensor-web (OASIS) has two-way communication capability between ground and satellites, uses ground and space data for optimal allocation of power and bandwidth resources to send

data to the observatory, and can autonomously request the re-tasking of satellites if monitoring data suggest a significant change in monitoring parameters. The sensor-web can also reconfigure itself for the best data pathway, for example, if ash in the air from explosive eruptions blocks monitoring signals or if a station in the web is destroyed. Helicopters can rapidly deploy the sensor-web without landing, thereby minimizing risk to scientists. The team successfully tested the system on Mount St. Helens. Future applications include response to unrest at unmonitored volcanoes in foreign countries, response to natural and human-caused disasters where conditions on the ground are hazardous, and planetary exploration.

USGS scientists from the Geologic Hazards Team and the USGS EROS Center, in collaboration with the China Geological Survey and funded in part by the U.S. Agency for International Development (USAID) Office of Foreign Disaster Assistance (OFDA), began assessing the distribution and influence of geologic, topographic, and ground-shaking conditions on the hundreds of thousands of landslides triggered by the 2008 Wenchuan earthquake in the Himalayan foothills in Sichuan, China. For this work, they relied on data from the Shuttle Radar Topography Mission and ASTER topography from the Terra mission, along with imagery from the QuickBird, IKONOS, and WorldView-1 sensors.

The Bureau of Reclamation continued its use of Landsat TM satellite imagery, digital aerial imagery and LIDAR data in its water resource management mission. Reclamation used digital aerial multispectral and thermal imagery to map riparian and in-stream habitat to support salmon recovery activities in the Columbia and San Joaquin River Basins. Reclamation also used LIDAR data supplemented with GPS and ground survey data to produce digital representations of river channel and floodplain topography. These elevation data were input to hydraulic models, which predicted river flow velocities and depths at a number of river discharge scenarios. Model results helped characterize riverine habitat for fish species at specific river discharges and estimate potential loss of life and economic damage arising from hypothetical dam failure scenarios.

Reclamation also used remotely sensed data to estimate consumptive water use from agricultural crops, riparian vegetation, and open water in the Central Valley of California; in the Newlands Irrigation Project, Nevada; and at several locations within the Colorado River Basin. Consumptive water use data are required in the

monitoring of water use compacts and in the verification of compliance with fallowing programs associated with water conservation programs. Evapotranspiration was estimated using both energy balance models and models based on land cover maps. Energy balance models use estimates of net radiation, soil heat flux, and sensible heat flux derived from a time series of image and surface-measured data to produce spatially varying maps of evapotranspiration. The land cover approach applies theoretical water use curves to vegetation class acreages obtained from maps generated from remotely sensed imagery.

The Gulf of Mexico Regional Office's Minerals Management Service's (MMS) and ESA's World Fire Atlas Data group began a fully collaborative effort to improve detection of natural gas flaring events from Gulf of Mexico Federal waters. ESA used the Advanced Along-Track Scanning Radiometer (AATSR) sensor onboard Envisat to collect world-wide fire event and hot spot data. ESA's World Fire Atlas Data have been collected since late 1995. Unique to ESA's data collection is the ability to record fire events from offshore oil and natural gas production operations. Gulf of Mexico natural gas flaring is an MMS-regulated production activity. The ESA group developed a new proprietary processing algorithm with improved detection sensitivity. ESA provided flare event data to MMS using the new algorithm; MMS provided in-situ data of detected flares to enhance satellite calibration operations.

Approximately 135 production platforms were destroyed by Hurricanes Ivan in 2004, Katrina and Rita in 2005, and Gustav and Ike in 2008. To assist in future post-storm infrastructure assessment, MMS, in collaboration with NOAA, collected baseline synthetic aperture radar (SAR) imagery of production infrastructure in the Gulf. The baseline data will be compared to SAR imagery collected post-hurricane to identify infrastructure destruction, damage, and oil spills. Approximately 20 to 25 percent of the domestic production of natural gas and crude oil comes from the Gulf. In 2009, there were over 3,500 fixed oil and gas production platforms in the Federal waters of the Gulf. These structures are connected by thousands of miles of seafloor pipelines that ultimately tie into onshore production and processing facilities. Post-storm SAR imagery will allow MMS to rapidly assess destruction and damage to infrastructure, identify oil spills, document navigation hazards, assess the impact to human health and safety, and respond to potential environmental damage.

The USGS conducted a national-scale assessment of the potential for ecosystem carbon sequestration under various climate, policy, and land use change scenarios, as required by Section 712 of the Energy Independence Security Act of 2007. The disturbance modeling team, composed of interdisciplinary scientists, produced a series of statistical and process-based models that predict future disturbances, including wildfires and insect outbreaks. These models rely heavily on datasets derived from remotely sensed imagery, especially from the Landsat and MODIS sensors. The USGS is leading the development of the disturbance modeling effort with the objective of producing disturbance models for the southern Mississippi River Valley, the prototype assessment area.

USGS scientists used NAIP imagery to identify and inventory the environmental impacts of wind-energy infrastructure development. The features mapped include individual turbines, roads, and power lines. The mapping was done on a subset of wind generation facilities across the nation, specifically chosen to vary in turbine capacity, overall facility size (number of turbines), topography (flat plains, ridgelines, and hilly regions), and land use (farmland, brown fields, and natural habitat). The new maps provide baseline data for understanding how aspects of wind production (turbine spacing, energy output, capacity factor, and levels of disturbed land) change with the aforementioned variables. To date, the majority of studies projecting wind energy market penetration estimate land surface requirements of wind power with theoretical relationships that relate the power in wind at a known wind speed and blade height to the area of land required to capture this wind. The mapping and modeling done by USGS scientists will allow empirical estimates to replace theoretical relationships and more fully specify the effects of geographic location, topography, and land use effects on wind energy production. This will improve future projections and optimize the placement of wind generation facilities within the U.S.

Rapid Assessment of Values at Risk (RAVAR) is a modeling effort that provides dollar estimates of values (structures, infrastructure, etc.) as well as assessments of nonmonetary values such as critical habitats that are threatened by a wildfire. When county-level parcel data are not available, the USFS requests that the USGS conduct an analysis of remotely sensed imagery to identify structures located within the area of concern. The NAIP photography has served as the primary

source of imagery. On average, the USGS has provided the locations of over 11,000 structures for fifty 1:24,000 scale, 7.5-minute quadrangles to the USFS for analysis and use by the fire science and incident support communities. Response time from request to data provisioning is normally around five hours.

USGS scientists developed indicators for use in long-term monitoring programs in the Wyoming Land Conservation Initiative (WLCI). In order to identify and prioritize indicators for monitoring, scientists used conceptual models of how major ecosystems in the WLCI respond to anthropogenic stressors. The conceptual models were used by local planning teams for more effective land use decisions. Efforts are underway to develop dynamic land change modeling scenarios to simulate the multiplicative effects of energy development and climate change on native vegetation and a suite of exotic plant species.

The USGS is conducting multi-year monitoring and analysis of land use and land cover change for the Nation and its ecological regions using the extensive Landsat data archive and other information. The project, conducted in conjunction with NASA and the Environmental Protection Agency, completed the development of the Great Plains land cover change database, a synthesis report of results, and conducted preliminary analyses of the implications of contemporary land transformation. The analyses provided valuable information about the rates, causes, and consequences of land use change in the Great Plains region since 1973. Additionally, an analysis of land cover trends in the ecoregions of the East, using a land cover change database completed in prior years, was completed. The study showed that recent land use pressures from timber-cutting cycles, urbanization, and other land use demands caused a significant decline in eastern U.S. forest cover, which triggered an important transition from gain of regional forest cover to loss of forest cover. Information from the Great Plains and eastern U.S. studies were used to develop estimates of the land use impact on ecological processes including carbon sequestration, to understand future scenarios of change, and to develop future forecasting capabilities. Subsequent years will focus on the West and Midwest, as well as a national synthesis of land use and land cover trends.

The USGS made declassified images from the Global Fiducials Library (GFL) available to the public. To support researchers and policy makers in identifying and understanding long-term environmental trends and processes, the GFL maintains a

long-term archive of images from U.S. National Imagery Systems for selected environmentally sensitive and scientifically important sites. These images are released to the public through the Global Fiducials Library Web site: *http://gfl.usgs.gov.*

The outbreak of mountain pine beetle (MPB), Dendroctonus ponderosae, that killed millions of lodgepole pine trees west of the Continental Divide started to spread across the eastern slopes of the Rocky Mountains in Colorado. This epidemic represents a major potential disturbance to ecosystems and communities in Colorado's Front Range, where many of the state's residents and visitors draw on ecosystem services such as clean water and diverse recreation opportunities. USGS scientists investigated the possible ecological and social impacts of the MPB epidemic in a field study that collected extensive data on forest health, insect activity, management history, fire fuels, etc., at 40 sites along the Front Range. To assess conifer health in Grand County, Colorado, the USGS developed methodology for the use of moderate-resolution remotely sensed imagery. Landsat and ASTER multispectral sensors were employed for this effort because their spatial resolution is discrete enough to characterize health conditions at forest landscape level, they cover a suitably large geographic mapping area, and they are cost-effective.

The USGS Unmanned Aircraft Systems (UAS) Project Office led the implementation of an exciting new technology originally developed by the U.S. Army. This technology is used to monitor environmental conditions, analyze the impacts of climate change, respond to natural hazards, understand landscape change rates and consequences, conduct wildlife inventories, and support related land management missions. USGS teamed with the DOI's Aviation Management Directorate (AMD) to lead the safe and cost-effective adoption of UAS technology by the DOI bureaus and USGS scientists. An important milestone was reached during 2009, when the USGS sponsored the first UAS training for DOI employees.

The Navajo Regional Office requested that the Bureau of Indian Affairs (BIA) provide time series mosaics of different compositions such as burn scar detection, vegetation, and true color composites. The BIA processed 15 Landsat 7 ETM+ scenes per mosaic for each composition and pan-merged them. The time series covered the years from 1999 through 2003.

Federal Communications Commission

FCC

The Federal Communications Commission (FCC) formulates rules to facilitate the provision of commercial satellite services in the United States. It also issues licenses for the launch and operation of all nongovernmental U.S. satellites. Internationally, the FCC coordinates satellite radio-frequency usage with other countries. The FCC's accomplishments for FY 09 related primarily to commercial communications satellites and Earth observation satellites.

The FCC took two significant actions in rule-making proceedings in FY 09. In one proceeding, the FCC adopted rules concerning vehicle-mounted earth stations. The rules include technical and licensing requirements for the use of Ku-band frequencies. The new rules were adopted in order to increase the potential that broadband communications capabilities will be made available for various emergency preparedness and commercial purposes where high-bandwidth, advanced mobile communications capabilities are beneficial. In a second proceeding, the FCC modified technical and licensing requirements for Earth Stations on Vessels (ESVs) operating in C- and Ku-band frequencies. ESVs are mobile transmitters that facilitate communications services, including broadband services and Internet access, to cruise ships, merchant ships, ferries, yachts, U.S. Navy vessels, and other maritime vessels that carry a stabilized satellite dish. The modified technical rules are designed to provide ESVs with greater operational flexibility while continuing to ensure that the other services are protected from harmful interference.

The FCC authorized a number of commercial communication satellite launches and operations. The authorizations are as follows:

- January 9, 2009: to Intelsat for a geostationary satellite planned for the longitude 32.8° east orbit location.
- February 23, 2009: to Northrop Grumman to construct, launch, and operate four geostationary satellites planned for the longitude 125° west, 73° west, 68.5° east, and 116.5° east orbit locations and to construct three non-geostationary satellites. The satellites were planned to operate in the Ka- and V-bands. Northrop Grumman relinquished this authorization at the deadline for submitting a required performance bond.
- May 29, 2009: to Intelsat for a geostationary satellite planned for the longitude 58.1° west orbit location.
- August 31, 2009: to XM Radio for a geostationary satellite planned for the longitude 85.2° west orbit location.

The FCC also began to authorize satellites for operations in the recently available 17-gigahertz (GHz) downlink band, as follows:

- December 17, 2008: to Pegasus for a geostationary satellite planned for the longitude 115° west orbit location.
- March 13, 2009: to EchoStar for a geostationary satellite planned for the longitude 62.15° west orbit location.
- March 18, 2009: to EchoStar for a geostationary satellite planned for the longitude 75° west orbit location.
- April 20, 2009: to EchoStar for a geostationary satellite planned for the longitude 79° west orbit location.
- May 26, 2009: to Intelsat for a geostationary satellite planned for the longitude 95.15° west orbit location. Intelsat relinquished the authorization at the deadline for submitting a required performance bond.
- June 15, 2009: to Intelsat for a geostationary satellite planned for the longitude 122.9° west orbit location. Intelsat relinquished the authorization at the deadline for submitting a required performance bond.
- July 28, 2009: to Intelsat for geostationary satellites planned for the longitude 90.9° west and 99.1° west orbit locations. Intelsat relinquished these authorizations at the deadline for submitting a required performance bond.
- July 28, 2009: to DirecTV for geostationary satellites planned for the longitude 99.175° west, 102.825° west, 107° west, and 110.9° west orbit

locations. DirecTV relinquished the authorization for the 107° west orbit location at the deadline for submitting a required performance bond.

- July 28, 2009: to EchoStar for geostationary satellites planned for the longitude 110.4° west and 107° west orbit locations.
- July 28, 2009: to Pegasus for geostationary satellites planned for the longitude 107° west and 91° west orbit locations. Pegasus relinquished these authorizations at the deadline for submitting a required performance bond.

The FCC added one non-U.S.-licensed space station to the Commission's permitted space station list in order to allow the space station to provide domestic and international satellite service to U.S. earth stations that have routine technical parameters. Specifically, on February 10, 2009, the FCC added the Netherlands' NSS-9 space station to its permitted list for C-band frequencies.

On October 21, 2008, the FCC created a new list of satellites, the "I-Sat List," in order to simplify the licensing of earth stations communicating using the Inmarsat satellite system. The FCC updated and modified that list on December 24, 2008; April 10, 2009; and September 8, 2009.

The FCC also granted a number of requests for non-US.-licensed space stations to provide service in the United States on a non-routine basis as listed below.

- January 30, 2009: EchoStar received authorization to deploy terminals to receive direct-to-home service from the Ciel 2 satellite, licensed by Canada to operate at the longitude 129° west orbit location.
- August 18, 2009: ViaSat reserved Ka-band spectrum for use with a satellite licensed by the Isle of Man, to be operated at the 115° west orbit location.

The FCC also remained active in international satellite coordination. In the first quarter of FY 09, the FCC reached a total of three Administration-to-Administration Coordination Agreements for U.S. networks with Sweden. In the second quarter of FY 09, the FCC reached a total of 343 Administration-to-Administration Coordination Agreements for U.S. networks with Canada, the Russian Federation, Japan, and Mexico. In the third quarter of FY 09, the FCC reached a total of 38 Administration-to-Administration Coordination Agreements for U.S. networks with Canada, Japan, and Spain. In the fourth quarter of FY 09, the FCC reached a total of 27 Administration-to-Administration Coordination Agreements for U.S. networks with Canada, Pakistan, and the Russian Federation.

U.S. Department of Agriculture

USDA

The mission of the U.S. Department of Agriculture (USDA) is to provide leadership on food, agriculture, natural resources, and related issues, based on sound public policy, the best available science, and efficient management. Select departmental responsibilities include increasing the competitiveness and sustainability of rural and farm economies, improving the protection and safety of the Nation's agriculture and food supply, and protecting and enhancing the Nation's natural resource base and environment. Through a diverse range of research and operational applications, multiple USDA agencies demonstrated the value of remote sensing data and related technologies to support departmental activities. Although each agency had different responsibilities, several of these agencies shared data and technologies to ensure the most efficient and cost-effective use of USDA resources.

As the primary research agency for the USDA, the Agricultural Research Service (ARS) conducted research to solve problems relating to global food security, agricultural air quality, ecosystem health, biofuels, and climate change. ARS collaborated with NASA and other USDA agencies to develop technologies that would help each agency accomplish its mission. Partnerships with additional Federal agencies, universities, industry, and state governments were also integral to ARS research.

Water quality and quantity management was the largest area of emphasis for ARS remote sensing activities. Remote sensing research on soil moisture continued with the development of algorithms for soil moisture estimation from aircraft and satellites. ARS scientists also contributed to the development of the next generation of satellite remote sensing systems through the Soil Moisture Active-Passive

(SMAP) mission, with three scientists serving on the Science Definition Team. Researchers demonstrated that thermal infrared (TIR) data could be used to map evapotranspiration and plant moisture stress on spatial scales ranging from within-field to continental. ARS scientists also showed that thermal infrared and multispectral visible, near-infrared, and shortwave infrared data could be used to schedule irrigation, perform spatially variable irrigation, map drought, and estimate soil moisture and vegetation canopy water content. Additional research into more efficient fertilizer application using remote sensing of crop nitrogen status demonstrated reduced excess fertilizer losses to the environment, thus leading to improved water quality and better economic returns to farmers.

ARS developed a data assimilation system for merging land surface information from models and remote sensing into a single enhanced estimate of land surface variables including root-zone soil moisture, stream flow, and evapotranspiration. This data assimilation technique enhanced the value of remote sensing retrievals for monitoring key environmental variables as well as improved precipitation estimates from numerical weather-prediction models.

Scientists used remotely sensed information in the management of soil and nutrient resources via projects to map crop tillage practices, crop residue cover, and soil carbon. These applications proved important for conserving soil and water, sustaining soil quality, and sequestering carbon. Specific research on how winter cover crops reduced nitrogen runoff to sensitive ecosystems, like the Chesapeake Bay, used remote sensing to map and quantify the contributing landscapes. Similarly, radar remote sensing was developed as a tool to better understand and manage the fate of agrochemicals and sediment in coastal watersheds. In addition, ARS continued its collaboration with the National Agricultural Statistics Service (NASS) to develop soybean and corn production estimates from satellites, resulting in improved crop yield estimates at a significant cost savings.

ARS also used remote sensing to develop procedures to monitor the proliferation of invasive species in order to manage rangeland and to understand the impacts of climate change on managed and natural ecosystems. ARS researchers developed a rangeland decision support tool for public land management, incorporating remote sensing access via the Internet. Additionally, pest-management research was enhanced with airborne and satellite imagery. Both cattle fever tick and

screwworm flies were the focus of eradication and containment research, where remote sensing was used to map infestations and favorable habitats.

The National Institute of Food and Agriculture (NIFA) is the extramural research arm of the USDA. The NIFA primarily provided financial assistance in the form of grants to conduct high-priority agricultural research and education. The NIFA awarded many grants that used NASA data products to solve complex, environmentally related problems on topics such as land use, water and nutrient management, resource conservation, and pest management in forest and crop lands. A few examples of NIFA-supported research include the following:

- characterizing uncertainty in land use/cover maps across the Upper Great Lake states region;
- using remote sensing to examine nutrient and water use in deciduous perennial crops to provide growers with the ability to manage water and nitrogen with more efficiency;
- developing and using remote sensing–based tools to evaluate the impacts of USDA conservation practices on environmental quality;
- developing and testing remote sensing methods for automated and repeatable quantification of insect disturbance to Wisconsin forests; and
- developing outbreak prediction models for the improvement of aphid pest-management strategies for Russian wheat.

The NIFA also funded long-term studies in Mississippi, Kentucky, Alabama, and Wisconsin that utilized remote sensing and geospatial technologies to develop precision management techniques for various agricultural production strategies and to evaluate land use practices. The NIFA and the Science Mission Directorate of NASA jointly funded several geospatial extension programs at land-grant, sea-grant, and space-grant institutions. After NIFA/NASA funding terminated, these geospatial outreach programs continued to help train local and regional technologists in the use of NASA data products and geospatial technologies. By leveraging the ongoing coordination in these state geospatial programs in the realm of geospatial technologies (e.g., interoperability, standards, metadata, architecture), the geospatial extension specialists helped ensure that the vast quantity of data and information being collected by NASA and other Federal agencies was utilized effectively and shared more broadly with the public.

The United States Forest Service (USFS), in collaboration with NASA Goddard Space Flight Center (GSFC) and the University of Maryland, continued to process data from the NASA Terra and Aqua satellites as part of the MODIS Active Fire Mapping Program. The USFS Remote Sensing Applications Center (RSAC) in Salt Lake City, Utah, collected real-time MODIS imagery and derived fire-detection data for the western United States. Separately, the MODIS Active Fire Mapping Program also obtained real-time MODIS fire-detection data for Alaska, western Canada, and the eastern United States. These data combined enabled the USFS to produce active wildland fire-mapping products daily for the Contiguous United States (CONUS), Alaska, and Canada.

The USFS disseminated MODIS fire products to national fire managers and the general public via the Internet (*http://activefiremaps.fs.fed.us*). These products provided the interagency fire community with a synoptic view of the wildland fire situation, aiding in the strategic allocation of firefighting resources and assets throughout the country. In addition, MODIS Active Fire Mapping Program data and products were integrated into several interagency fire support programs and applications. Major media entities routinely used the maps and fire-detection data as well. Such customers included the *Washington Post*, the *New York Times*, the Cable News Network (CNN), the Associated Press (AP), and the *Los Angeles Times*. In total, nearly three million users accessed the MODIS Active Fire Mapping Web site during 2009.

The USFS also worked with the NASA Ames Research Center on a number of fire-related remote sensing technologies. Work with Ames included advanced sensor design and image processing from airborne platforms, utilization of satellite communication data links, mission profiling for tactical wildland fire mapping, and unmanned aerial system development. More specifically, the USFS and ARC collaborated on the use of UAS for fire mapping and forest health missions. Because of the light fire season, efforts in 2009 focused primarily on further testing and development with the *Ikhana* aircraft and the Autonomous Modular Scanner sensor. Due to the success of this partnership, the USFS incorporated many of the technologies demonstrated on board the *Ikhana* aircraft. In early 2009, two Aircell systems were installed in the USFS fire-mapping aircraft to facilitate the immediate downlink and dissemination of imagery acquired over wildfires.

The Farm Service Agency (FSA) administered and managed farm commodity, credit, conservation, disaster, and loan programs as laid out by Congress through a network of Federal, state, and county offices. Geospatial data played a fundamental role in the management of FSA's programs. The agency maintained a nationally consistent geospatial dataset representing farm and field boundaries known as Common Land Units (CLUs). FSA used CLUs, digital soil surveys, 1-meter imagery, satellite imagery, and other datasets for program implementation, management, and monitoring, as well as for response and recovery efforts during natural disasters. FSA also utilized NASS remotely sensed data for the analysis of commodity and conservation programs.

In the spring of 2009, FSA used remotely sensed data to respond to and help mitigate impacts of flooding in the Red River Valley of North Dakota and Minnesota. MODIS, Advanced Wide Field Sensor (AWiFS), and locally collected high-resolution aerial imagery were used in conjunction with National Weather Service and other USDA and FSA geospatial datasets to immediately respond to and coordinate efforts with other Federal, state, and local agencies. These data were also used during the recovery period to assist those producers impacted and to support FSA administration of the Emergency Loan, Emergency Conservation, and Livestock Indemnity Programs. The same type of remotely sensed data was used in the tsunami response and damage mitigation effort in American Samoa in October.

As the primary source of aerial imagery for the USDA, FSA administered the NAIP, leveraging partnership funds from other Federal, state, and local entities to acquire imagery during the growing season over the CONUS. In 2009, FSA collected imagery over 32 states. NAIP, as well as a large imagery archive, was accessible to the public through the USDA Geospatial Data Gateway.

During FY 09, the National Agricultural Statistics Service (NASS) used remote sensing data to construct and sample area frames for statistical surveys, estimate crop area and yield, and create crop-specific land cover data layers as inputs for GIS. NASS used remote sensing data and techniques to improve the accuracy of its statistics. For example, NASS used Landsat imagery, digital NAIP orthophoto quadrangles, and other remotely sensed inputs for the CONUS and Puerto Rico to select the yearly area-based samples for the June Agricultural Survey. In addition, NASS constructed a new area-based sampling frame for Florida.

The remote sensing acreage estimation project used Resourcesat-1's AWiFS and Landsat imagery to produce crop acreage estimates for the 2009 crop year for crops at the state and county levels for 27 states, up from 19 states the previous year. Acreage estimates were created for 15 different crops, up from 5 the previous year, covering all market-sensitive crops and states. With the expanded coverage and timeliness, the NASS Agricultural Statistics Board was able to fully utilize the remote sensing acreage estimates when preparing official estimates for Monthly Crop Production Reports.

NASS researchers derived remote sensing-based acreage estimates from a crop-specific land cover categorization called the Cropland Data Layer (CDL). The ground truth for building the CDL came from the FSA CLU program over the agricultural domain, while the U.S. Geological Survey's National Land Cover Dataset circa 2001 provided the nonagricultural ground truth. In addition, NASS distributed the CDL on DVD and via the USDA Geospatial Data Gateway portal for 35 states to users for the previous 2008 crop season.

NASS also continued its partnership with ARS to conduct research and implement the use of MODIS sensor vegetative index and surface temperature data for setting state and county corn and soybean yield estimates. Two states, Kansas and Ohio, were added to the remote sensing yield program for the 2009 crop year. These additions brought the total number of states to seven. The technology transfer from ARS to NASS was successfully completed, and NASS processed the yields for five states. The Agricultural Statistics Board utilized estimates from this algorithm when setting the official September, October, and November yield estimates for these states.

The Foreign Agricultural Service (FAS) had primary responsibility for the Department's international activities, including market development, trade agreements and negotiations, and the collection and analysis of statistics and market information. This latter responsibility was tasked to the FAS Office of Global Analysis (OGA), which was the focal point within FAS for assessing the global agricultural production outlook and conditions that affect world food security. Satellite-derived information provided an objective and repeatable source of information for early warnings of unusual crop conditions and potential disruptions in global food supply. This information, when used in the context of the convergence

of evidence methodology, enabled more rapid and precise determinations of global food supply conditions. The FAS satellite remote sensing program remained a critical element in the USDA analysis of global agricultural production and crop conditions by providing timely, accurate, and unbiased estimates of global area, yield, and production. The FAS partnered with DOD in assessing food supply conditions for stabilization and reconstruction operations in Iraq, Afghanistan, and the surrounding region. The FAS provided an early warning of drought-related food supply disruptions in Iraq, which enabled the U.S. Government to position emergency food supplies.

The FAS exploited many global imagery datasets, including vegetation health products from the University of Maryland and NASA, while continuing to purchase most of its satellite data commercially. The FAS also supported other Federal agencies, sharing satellite imagery and products with U.S. Government space agencies and DOD. The FAS continued to manage the USDA Satellite Imagery Archive (SIA). The SIA saved the USDA millions of dollars by employing a centralized data acquisition, archival, and dissemination strategy to eliminate redundant satellite purchases and hence decreased departmental expenditures. The FAS and NASA also cooperated on many projects to exploit space technologies, including near-real-time satellite data acquisition and global reservoir monitoring. This Global Agriculture Monitoring (GLAM) partnership continued to expand to multiple universities, commercial companies, and international organizations. Information on the FAS remote sensing program can be found at *http://www.pecad.fas.usda.gov/cropexplorer.*

The Natural Resources Conservation Service (NRCS) remained the primary Federal agency working with private landowners to help protect and conserve the Nation's natural resources. For over 50 years, NRCS has used remote sensing products to carry out conservation programs. Digital orthoimagery, derived from aerial and satellite data, was the primary remote sensing product used by NRCS to inventory, monitor, manage, and assess our natural resources in GIS nationwide. By partnering with other Federal and state agencies, NRCS acquired statewide 1-meter or better resolution orthoimagery for 32 states and parts of Alaska, Hawaii, the Pacific Basin, and Puerto Rico. NRCS was an active member of several geospatial coordination groups, including the National Digital Orthophoto Program (NDOP),

which assisted in orthoimagery coordination efforts. All orthoimagery purchased by NRCS was made available to internal users and the general public via the USDA Geospatial Data Gateway Web site. NRCS contracted for high-resolution aerial photography (four-inch ground resolving distance) over 70,000 confidential statistical sites to collect natural resources data for the annual National Resources Inventory (NRI) program. NRCS also contracted for high-resolution aerial photography over 7,245 Wetland Reserve Program (WRP) easements to be used to monitor compliance and ecological succession. The use of remote sensing techniques has replaced making expensive on-site visits to collect the same data. High-resolution satellite imagery was acquired for conducting the NRI and soil survey in Alaska, Hawaii, and the Pacific Basin. NRCS also used commercial high-resolution satellite imagery from the National Geospatial-Intelligence Agency's (NGA) Web-based Access and Retrieval Portal (WARP) to fill in gaps in aerial film coverage. NRCS continued using Landsat and AWiFS scenes from the USDA SIA and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data from the Land Processes Distributed Active Archive Center for statewide natural resource analysis, change detection, and soil survey premapping. NRCS upgraded most satellite orthoimagery licenses in Hawaii and the Pacific Basin to allow more open distribution of orthoimagery data to government, universities, not-for-profit organizations, and the general public.

NRCS also funded high-resolution digital elevation data in selective areas of many states. High-resolution digital elevation data were used in a variety of NRCS agency programs such as Soil Survey, Engineering, Watershed Assessments, Water Resources, and Conservation Planning. NRCS was a member agency of the National Digital Elevation Program (NDEP), a multi-agency Federal partnership chaired by USGS to expedite the collection and availability of digital elevation data. NRCS funded Interferometric Synthetic Aperture Radar (IfSAR)-based digital elevation data in North Dakota and South Dakota. NRCS funded LIDAR-based digital elevation data in coordination with USGS/NDEP in Alabama, Arkansas, Illinois, Kansas, Oregon, Tennessee, and Kentucky.

National Science Foundation

NSF

The National Science Foundation (NSF) continued to serve as the lead Federal agency for the support of ground-based astronomy and space science. Through the Divisions of Astronomical Sciences, Atmospheric Sciences, and Physics, as well as the Office of Polar Programs, the NSF sponsored a broad base of observational, theoretical, and laboratory research aimed at understanding the states of matter and physical processes in the universe. Areas of research ranged from the most distant reaches of the universe and the earliest moments of its existence to nearby stars and planets, including our own sun and planetary system, as well as Earth's atmosphere and space environment.

Division of Astronomical Sciences

In addition to providing core support for the optical and radio observatories whose state-of-the-art instrumentation and observing capabilities are accessible to the community on the basis of scientific merit, the Division of Astronomical Sciences (AST) supported the development of advanced technologies and instrumentation for astronomical sciences. The NSF's national astronomical facilities included the National Radio Astronomy Observatory (NRAO), the National Astronomy and Ionosphere Center (NAIC), the National Optical Astronomy Observatory (NOAO), and the National Solar Observatory (NSO). The NSF also served as the executive agency for the Gemini Observatory—an international

partnership operating optical/infrared telescopes in both the Northern and Southern Hemispheres—providing the United States' share of support for the program.

In partnership with Europe, Canada, Japan, and Taiwan, construction continued on the Atacama Large Millimeter/submillimeter Array (ALMA), an interferometer located near San Pedro de Atacama, Chile. FY 09 saw formal acceptance of the first North American and Japanese antennas and continued delivery of North American antennas at a rate of one every two months. Signals from the two accepted antennas were combined and the first interferometric measurements made from the ALMA mid-level site. The number of antennas at various stages of integration and testing in Chile now totals 17—12 from the United States, 4 from Japan, and 1 from Europe. The third and fourth cryogenic receiver systems were delivered to Chile and installed in antennas.

AST continued support for the development of the Advanced Technology Solar Telescope (ATST), the next-generation U.S. ground-based solar telescope. The ATST, a collaboration of scientists from 22 institutions representing a broad segment of the U.S. solar physics community, previously earned the strong recommendation of the National Research Council of the National Academy of Sciences. In FY 09, the ATST passed a comprehensive final design review and was subsequently approved by the National Science Board for construction funding. Funding for construction of the $298 million ATST will be issued in early calendar year 2010.

In FY 09, AST continued to fund a four-year technology development and design effort for the Large Synoptic Survey Telescope (LSST). The LSST will be a 6.5-meter effective aperture telescope with a field of view exceeding 3 degrees. In addition, the LSST will use a 3-gigapixel camera to image the entire accessible sky repeatedly, producing approximately 20 terabytes of data nightly. The science goals of the LSST project are extremely broad, spanning the fields of cosmology, galactic structure, and solar system astronomy. The LSST will undertake both a census of distant (trans-Neptunian) solar system objects and surveys of near-Earth and potentially hazardous asteroids. Over a 10-year lifetime, the LSST should provide a 90 percent–complete sample of potentially hazardous objects with diameters greater than 250 meters and an 80 percent–complete sample of those with diameters down to 140 meters. The University of Arizona's Steward Observatory Mirror Lab is fabricating the 8.4-meter-diameter primary/tertiary mirror using

funds donated from private sources. The decision to fund the construction of LSST is pending the outcome of the 2010 Astronomy and Astrophysics decadal survey. If funded, the LSST will be a joint project of the National Science Foundation and the Department of Energy.

The Atacama Cosmology Telescope (ACT) is a new 6-meter-diameter millimeter-wave telescope located at 5,200 meters (17,000 feet) on Cerro Toco in the Atacama Desert of northern Chile, near the ALMA site. It is designed to measure minute variations in intensity of the cosmic microwave background (the radiation at microwave wavelengths that is a remnant of the Big Bang) to study how the universe began, what it is made of, and how it evolved to its current state. ACT is a dedicated special-purpose telescope, equipped with a state-of-the-art customized camera with over 2,500 detectors cooled to a third of a degree above absolute zero. During FY 09, the telescope commenced full science operations, obtaining measurements that span size scales on the sky two to three times finer than in any previous experiment.

In FY 09, ACT discovered 13 new clusters of galaxies. The most distant cluster is at z=0.82, over nine billion light-years away. The clusters were revealed through the Sunyaev-Zeldovich effect, an interaction of the electrons in the clusters with the cosmic microwave background radiation. Once found, the clusters were confirmed optically by team members.

Also in FY 09, ACT measured the spectrum of fluctuations in the cosmic microwave background. For the first time, the team mapped out the transition from the regime described by the "standard model of cosmology" to the finer resolution regime of the recent epoch, where distinct gravitationally bound objects (such as galaxies and clusters of galaxies) fill the cosmos.

Division of Atmospheric and Geospace Sciences

In 2009, the NSF's Division of Atmospheric Sciences (ATM) formally changed its name to the Division of Atmospheric and Geospace Sciences (AGS) to more accurately reflect the Division's contributions to space science.

The Division of Atmospheric and Geospace Sciences' high-altitude aircraft, the High-performance Instrumented Airborne Platform for Environmental Research (HIAPER), is a highly modified and instrumented Gulfstream V (GV) midsize

jet. It is FAA-certified to operate at 51,000 feet. Its ability to fly for a long duration (over 12 hours), its range (over 6,000 kilometers), and its scientific payload capacity (6,000 pounds) enabled scientific research previously not possible with existing platforms. HIAPER is the most advanced airborne research platform in the U.S. civilian fleet. The German Aerospace Center (DLR) recently completed modifications, including advanced instrumentation, to a Gulfstream 550 that can collaborate with the NSF's GV aircraft in scientific campaigns. In FY 09, the GV continued to conduct several long-duration flights for the HIAPER Pole to Pole Observations (HIPPO) deployment to study the carbon cycle and greenhouse gases. In FY 09, the GV conducted research flights from Colorado, Alaska, Tahiti, Fiji, Easter Island, New Zealand, and Costa Rica.

The Research Aircraft Facility at the National Center for Atmospheric Research (NCAR), a Federally Funded Research and Development Center (FFRDC) of the NSF, continues to operate and maintain HIAPER. The GV's expected lifetime is 10 to 25 years, during which new instrumentation innovations will be continually integrated onto the airframe as appropriate. NCAR also operates and maintains NSF's heavy-lift C-130Q research aircraft. The C-130Q recently completed a major inspection, and the aircraft is in excellent condition.

The Division of Atmospheric and Geospace Sciences' Upper Atmospheric Research Section (UARS) supported a wide variety of research programs in space science in FY 09. These included the funding of advanced radar systems to study the ionosphere and magnetosphere, ground-based optical equipment to study the aurora and airglow, partial support to ground-based solar telescopes and instruments, and a wide-ranging portfolio of basic research in space physics. Major UARS-funded activities included the Upper Atmospheric Facilities (UAF); the National Space Weather Program (NSWP); the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program; the Geospace Environment Modeling (GEM) program; and the Solar, Heliosphere, and INterplanetary Environment (SHINE) program.

In addition, during FY 09 a formal NSF Science and Technology Center called the Center for Integrated Space Weather Modeling (CISM) continued to develop and test an end-to-end computer simulation for space physics research and applications. CISM's coupled models simulated the processes by which energy from the

sun and solar wind propagates to Earth, as well as the resulting effects on Earth's magnetosphere, ionosphere, and thermosphere. CISM researchers integrated these results with education and outreach activities. An effective knowledge transfer program also ensured that CISM shared the models for use in operational space weather forecasting centers of the United States Air Force and NOAA.

Throughout FY 09, the Community Coordinated Modeling Center (CCMC) for space weather research, co-sponsored by NSF and NASA and located at NASA's Goddard Space Flight Center, continued to provide the research community with access to state-of-the-art space weather models and conducted important model validation activities necessary for the transition of research models to operational use.

In FY 09, the AGS Division continued to support the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC). The University Corporation for Atmospheric Research (UCAR) and its collaborator, Taiwan's National Space Organization (NSPO), designed and built the COSMIC six-satellite constellation, which was launched on April 14, 2006, with support and assistance by the United States Air Force Space Test Program (STP). Shortly thereafter, data became available from the three payloads—the special space-based GPS radio occultation (RO) receivers, Tiny Ionosphere Photometers, and Tri-Band Beacons—and were provided freely to the world scientific community.

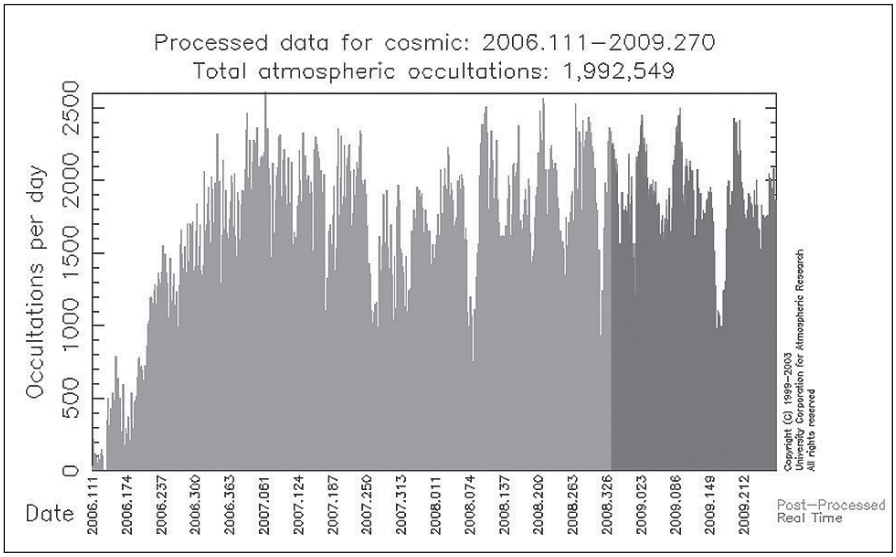
These data have been shown to be of extremely high quality and very useful for studies of the ionosphere, stratosphere, and troposphere. The RO data are being assimilated operationally now at many of the operational weather prediction centers, including the U.S. National Centers for Environmental Prediction, the European Centre for Medium-Range Weather Forecasts (ECMWF), Météo France, the U.K. Met Office, the Meteorological Service of Canada, Taiwan's Central Weather Bureau, and others. All of the centers have reported that RO data are having a significant positive impact on numerical weather forecasts. For example, recent studies by NOAA's National Centers for Environmental Prediction (NCEP) and by the European Centre for Medium-Range Weather Forecasts show that RO is a leading observational system in reducing forecast error, in spite of the low cost of RO and the small number of soundings compared to other satellite observing systems. Similar positive results are being found at other weather centers. In addition, the RO data are having a positive impact on the operational assimilation of

data from infrared and microwave sounding systems and aircraft observations by reducing their biases, thus complementing these sounding systems and enhancing the positive effect of RO data beyond their direct impact.

In ionospheric studies, COSMIC RO data are accelerating the development of physical models for space weather prediction by providing dense, accurate, and global electron density measurements. These are used for model testing and initialization, including the response of the global ionosphere to the impact of solar storms as their effects propagate around the globe.

During FY 09, all six satellites were operating and providing data. On average, COSMIC produced from 1,500 to 2,000 GPS RO soundings per day. Ninety percent of these were processed and delivered to operational centers within 3 hours. COSMIC is now supporting more than 1,100 registered users from 52 countries. In collaboration with the UCAR's UNIDATA, COSMIC soundings are now provided in a real-time data stream to support the university community. COSMIC will continue to receive funding from U.S. agencies and Taiwan to continue its operation through April 2011.

In FY 09, research facilities remained the key component of UARS efforts. The Upper Atmospheric Facilities program continued to promote basic research on the structure and dynamics of Earth's upper atmosphere. In particular, the CEDAR and GEM programs conducted research efforts utilizing these facilities. Observations made by the Advanced Modular Incoherent-Scatter Radar (AMISR) at Poker Flat,



Alaska, throughout FY 09 demonstrated the unique capabilities of this new instrument, including the ability to image the ionospheric effects of auroral particle precipitation in three dimensions. These observations provided a wealth of data particularly useful to modelers interested in validating space weather models. A second AMISR system began operation at Resolute Bay in Arctic Canada. This radar is ideally situated to observe the properties of the ionosphere in the polar cap, a region that is characterized by high ionospheric variability that often causes disruption of important navigation and communication systems.

UARS also continued to support the study of magnetospheric physics within the international Super Dual Auroral Radar Network (SuperDARN) consortium by contributing a new radar installation in southern Virginia to a chain of midlatitude SuperDARN radars designed to study geomagnetic storm electric fields. Another midlatitude SuperDARN radar began operating at Fort Hays State University in Kansas to extend the longitudinal coverage of the instrument chain.

In FY 09, UARS continued to support its new program for CubeSat-based small satellite science missions for atmospheric and space weather research. The program had a very active and exciting year in 2009. Two projects that started as a result of the 2008 competition, Radar Aurora Explorer (RAX) and FIREFLY, have both progressed very well. Under the American Recovery and Reinvestment Act of 2009, two additional CubeSat projects were awarded in September 2009. These were also selected from the proposals submitted in response to the first CubeSat solicitation in 2008. Both are truly excellent science projects within their area and, in addition, stand out by being double spacecraft missions. This makes them perfect pathfinders for the ultimate goal of CubeSat constellation missions. For the second CubeSat solicitation with a deadline in May 2009, UARS received proposals for a total of 26 new missions. As was the case for the first solicitation, the quality of the proposals in terms of scientific creativity and technological innovation was exceptional.

UARS supported the satellite-based Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) in FY 09. AMPERE utilized the 66 networked satellites of the existing Iridium constellation to create a new facility for collecting geomagnetic field data. The AMPERE facility yields the first-ever real-time observations of the electric currents that link Earth's magnetosphere and ionosphere and provides the first-ever continuous global observations for tracking

geomagnetic storm-time dynamics. Geomagnetic storms occur when charged particles emitted by solar flares interact with Earth's magnetosphere. Such storms can cause major disruptions of power and communications systems on the ground.

The UARS community also continued to benefit from the Division of Astronomical Sciences' efforts in FY 09 to develop and manage the Advanced Technology Solar Telescope. In addition, UARS funding supported the continuing design and development of the Frequency Agile Solar Radiotelescope (FASR), as well as NSF Astronomy's efforts to construct a radiotelescope test bed in Western Australia known as the Murchison Widefield Array (MWA). With funding from the American Recovery and Reinvestment Act of 2009, UARS was able to support much-needed upgrades at three solar observatories: the Big Bear Solar Observatory and the Owens Valley Radio Observatory in California and the Mees Solar Observatory in Hawaii.

The National Space Weather Program is a multi-agency Federal program aimed at mitigating the adverse effects of space weather on the Nation's technological infrastructure by providing timely, accurate, and reliable space environment observations, specifications, and forecasts. The NSWP Strategic Plan and Implementation Plan contain further information about the NSWP. The plans are available online through the Office of the Federal Coordinator for Meteorology (OFCM). In FY 09, UARS contributed to an OFCM-led study of mitigation strategies to address the removal of space science sensors on the National Polar-orbiting Operational Environment Satellite System (NPOESS) satellite system.

Office of Polar Programs

For FY 09, the primary activities of the Office of Polar Programs (OPP) in ground-based space science and astronomy included continued full-scale observations with the 10-meter off-axis radio telescope at the U.S. Amundsen-Scott South Pole Station to survey deep space galaxy clusters and the continued construction of the IceCube Neutrino Observatory.

Following the initial discovery of three new galaxy clusters via the Sunyaev-Zeldovich Effect, the South Pole Telescope successfully completed its third winter survey-observing period (northern summer 2009) with the mapping of over 200 new Sunyaev-Zeldovich Effect galaxy clusters. (The Sunyaev-Zeldovich Effect is a

decrement in the strength of the Cosmic Microwave Background Radiation as it is scattered by electrons in galaxy clusters.) Using the power of this new method of distant galaxy cluster mass detection for mapping enables the reconstruction of the universe's evolution.

The South Pole IceCube Neutrino Observatory deployed 19 new strings of optical photodetectors in deep ice under the South Pole Station in Antarctica, making two-thirds of the total detector volume available for science observations. The observatory expects the completion of all 80 strings (plus 6 additional Deep Core Array strings for low-energy neutrino detection) in the beginning of 2011. Data collection continued with the advance filtering and reconstruction of neutrino events. Scientific topics under study included searches for weakly interacting massive particles, neutrino point sources, and magnetic monopoles.

Department of State

DOS

The Department of State (DOS) carries out diplomatic efforts to support U.S. space policies and programs internationally. State supports U.S. civil space activities through the negotiation of bilateral and multilateral agreements with partner countries and leads U.S. participation in numerous international space and technological venues and international organizations. State also maintains outreach programs to advance U.S. space and foreign policy objectives.

DOS continued to represent the U.S. on the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and its Legal and Scientific and Technical Subcommittees. With so many countries now engaged in space activities, the DOS considers promoting the safe and responsible use of space by all current and future spacefaring nations a vital goal. At UNCOPUOS, the DOS led U.S. efforts on the problem of orbital space debris, meteorology, astronomy and astrophysics, space transportation, nuclear power sources in space, and legal issues related to international liability and responsibility of launching nations. Still building on the results of the International Heliophysical Year to improve international cooperation in understanding the impact of space weather on satellites and the Earth environment in general, DOS continued to promote space weather as an important foreign policy tool worldwide. The Department of State continued vigorous international efforts to implement the National Space-Based Positioning, Navigation, and Timing (PNT) Policy in FY 09. In October 2008, the first Plenary meeting under the U.S.-EU GPS-Galileo Cooperation Agreement of 2004 met at the U.S. Naval Observatory in Washington, D.C. The four working groups established under the Agreement were given directions for future work. During FY 09, Working Group C worked on characterizing a combined GPS-Galileo

receiver that demonstrated the commitment of both parties to the interoperability of their systems.

The U.S. and Japan concluded agreements for Japan to install monitoring stations for its Quasi-Zenith Satellite System (QZSS) at Guam and Hawaii. The monitoring station at Guam, operated in cooperation with a NOAA weather station, was finished and opened in August 2009. The Hawaii monitoring station at NASA's Kokee Park facility will be finished in early 2010. Both monitoring stations provide for the sharing of all data. In Tokyo in November 2008, the U.S. and Japan held their yearly consultation under the U.S.-Japan Joint Statement on GPS Cooperation. Technical information was exchanged on Japan's planned QZSS system, and Japan also clarified its new Basic Space Law and its implications for greater U.S.-Japan cooperation in the space arena.

Russia- and State-led delegations held several working group meetings on radio-frequency compatibility and interoperability between GPS and Russia's GLONASS as well as on search and rescue issues related to new GLONASS equipment.

State organized and led, with significant administrative and logistical support from NASA's Jet Propulsion Laboratory, the third full meeting of the International Committee on Global Navigation Satellite Systems (ICG-3) in Pasadena, California, in December 2008. Significant progress was made in this meeting on the ICG work plan and in solidifying support for common definitions of compatibility and interoperability. In September 2009, Russia hosted the fourth general meeting of the ICG in St. Petersburg, Russia. State vigorously pushed for the eventual adoption of a new principle on transparency that states: "Every provider should publish documentation that describes signal and system information, policies of provision and minimum levels of performance for its open services." Compliance with this principle will enable greater utilization of available signals in combined system receivers, which will improve service for civil users worldwide. During FY 09, the U.S. provided significant funding to the United Nations Office of Outer Space Affairs to support meetings of the ICG as well as workshops in developing countries to promote awareness of GNSS (Global Navigation Satellite System) applications for infrastructure, sustainable growth, transportation efficiency and safety, and environmental management.

During FY 09, State supported a wide, international public diplomacy campaign on the reliability and accuracy of GPS. State speakers supported this campaign

with PowerPoint presentations at many international conferences, including the European Navigation Conference, the Moscow International GNSS Conference, the Korean International GNSS symposium, the Berlin GNSS symposium sponsored by the European Position Determination System (EUPOS), meetings of the international section of the Civil GPS Service Interface Committee, and the Institute of Navigation annual conference.

The State Department sponsored a two-week Satellite Navigation Science and Technology for Africa workshop at the Abdus Salam International Centre for Theoretical Physics in Trieste, Italy, in late March 2009. From over 200 applicants, nearly 50 students from 7 African countries participated in the workshop to develop and use science and technology for socioeconomic transformation and full integration into the world economy. GPS applications to increase food security; manage natural resources; provide efficient emergency location services; improve surveying and mapping; and provide greater precision and safety in land, water, and air navigation systems were discussed in a tutorial format.

In 2009, the Department of State promoted several partnerships in the area of geospatial technologies, the synergy of Earth observation, GIS, GPS, and Web-based mapping tools with non-traditional space partners in Muslim-majority countries, including Saudi Arabia, Egypt, and the United Arab Emirates.

The State Department's Office of Space and Advanced Technology (OES/SAT) hosted the first working group meeting under the U.S.-Saudi Arabia Science and Technology Cooperation Agreement that was signed in December 2008. At the meeting, held in Washington, D.C., on December 4–5, 2009, the group developed a work plan of cooperation related to space, aerospace, and remote sensing. After the working group meeting, officials from King Abdulaziz City for Science and Technology (KACST) and NASA signed an agreement to facilitate collaboration on lunar and near-Earth object research. Thanks to this Memorandum of Understanding, KACST became an affiliate partner of NASA's Lunar Science Institute at NASA Ames Research Center in Moffett Field, California.

Using the U.S.-Egypt Science and Technology Fund for Science and Technology Cooperation, OES/SAT is organizing a workshop on space applications, to be held in Cairo on June 14–17, 2010, with Egypt's National Authority for Remote Sensing and Space Sciences (NARSS). The agenda for this meeting will focus on multiple

remote sensing applications including management of water resources, agriculture, land-use and land-cover change, natural disasters, and urban planning.

Finally, the Department continued to work with the Abu Dhabi Environment Agency (EAD) on developing activities to promote the use of geospatial tools and access to environmental information in the Middle East North Africa (MENA) region. U.S. Government agencies and private stakeholders will be contributing to the upcoming Abu Dhabi Global Environmental Data Initiative (AGEDI) Summit to be hosted by the United Arab Emirates in the second half of 2010.

Department of Energy

DOE

During FY 09, the Department of Energy's (DOE) Office of Science (SC) cooperated with NASA on a wide variety of activities, such as developing techniques to conduct fundamental physics experiments in outer space, using plasma science to devise new propulsion systems, engaging in joint efforts to understand atmospheric and environmental phenomena, and entering into a working partnership in advanced computing research. These activities occurred under an Memorandum of Understanding (MOU) between NASA and DOE, signed by the NASA Administrator and the DOE Secretary in 1992. DOE's Office of Nuclear Energy plans to continue to support NASA's space science and exploration programs by pursuing the development of space radioisotope and reactor power system technologies for future space missions and by maintaining the necessary nuclear facility infrastructure.

SC continued to work on the Alpha Magnetic Spectrometer (AMS) instrument, designed and built to be carried aboard a Space Shuttle for installation on the International Space Station (ISS). With much greater sensitivity than previously possible, the AMS, an international scientific collaboration, will use the unique environment of space to study the origin and structure of the universe, search for antimatter and dark matter, and collect information from cosmic sources emanating from stars and galaxies millions of light-years beyond the Milky Way. The SC provided funding in FY 09 to support the research group at the Massachusetts Institute of Technology (MIT) that leads the AMS program. In FY 09, work focused on the integration of the instrument at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland, and then testing and space-qualifying the detector. It is scheduled to be shipped to the Kennedy Space Center in 2010.

SC and NASA's Science Mission Directorate (SMD), along with international partners, have collaborated since FY 00 on the design and fabrication of the Large Area Telescope (LAT), the primary instrument for NASA's Fermi Gamma-ray Space Telescope (FGST). Previously called the Gamma-ray Large Area Space Telescope (GLAST), FGST was renamed after launch in June 2008. The LAT instrument, using the techniques of experimental particle physics research, detects and studies gamma rays emitted by the most energetic objects and phenomena in the universe. In FY 09, the Stanford Linear Accelerator Center (SLAC) National Accelerator Laboratory continued running the LAT Instrument Science Operations Center (ISOC), which processes data during operations. SLAC and SC-funded university groups continued participation in data-taking and scientific studies. The first year of data was released to the community, and over 35 science results were published in peer-reviewed journals.

Determining the nature of dark energy and how it may cause the acceleration of the expansion of the universe remains a high-priority science objective for both SC and NASA. A study, released in September 2007 by the Beyond Einstein Program Advisory Committee (BEPAC) of the National Academies of Science, recommended that SC and NASA proceed together on a Joint Dark Energy Mission (JDEM).

In FY 09, SC provided funding to the Lawrence Berkeley National Laboratory (LBNL) and other labs and universities for JDEM R&D activities. In FY 09, the NASA project office at Goddard Space Flight Center and the DOE project office at LBNL worked on the development of a suite of mission concepts that would deliver results on dark energy using a variety of experimental techniques. Also in FY 09, NASA and DOE formed an Interim Science Working Group to provide scientific assistance during the mission concept study period.

The Office of Nuclear Physics within the SC continued to make available the Alternating Gradient Synchrotron (AGS), an essential component of the Relativistic Heavy Ion Collider (RHIC) complex at Brookhaven National Laboratory (BNL). The AGS is the only accelerator in the United States capable of providing heavy ion beams at energies (up to 1 GeV/nucleon) of interest to the space radiobiology community. The AGS allows for NASA-funded radiobiology experiments to be performed with silicon, iron, and gold beams. The NASA Space

Radiation Laboratory (NSRL) also operates at BNL and is an efficient and effective radiation simulation facility for human space exploration. SC and NASA continued to develop mutually beneficial technical resources for experimentation and data analysis at BNL. For example, DOE and NASA supported the design and fabrication of the Electron Beam Ion Source (EBIS) at BNL in FY 09; the project is on track for completion in FY 10. NASA contributed approximately 25 percent of project costs to accelerate project completion. This joint DOE-NASA project will enhance the range and intensities of heavy ion beams available to the Relativistic Heavy Ion Collider complex, including the NASA Space Radiation Laboratory.

In FY 09, the Office of Nuclear Physics continued to support astrophysicists who used approximately 972,000 XT4-equivalent processor hours at the National Energy Research Scientific-computing Center (NERSC), which is funded by DOE's Office of Advanced Scientific Computing Research (ASCR). Most of this time was used to study the formation, evolution, and observational properties of Type Ia supernovae originating from binary white dwarfs, the origin of the stellar mass scale in star formation.

Other space-related aspects of the Nuclear Physics Program contain relevance to NASA, other Federal agencies (e.g., the National Reconnaissance Office and the U.S. Air Force) and the private sector. To facilitate the testing of electronic components used in high-radiation space environments, Nuclear Physics Program accelerator facilities (the BNL Tandem, the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory, and the Texas A&M Superconducting Cyclotron) regularly provided beam time to NASA, DOE applied laboratories, European and Japanese space agencies, and private companies.

In FY 09, the SC Office of Fusion Energy Sciences (OFES) continued research in fusion and plasma sciences, some of which has potential application for fusion and plasma propulsion, which could be relevant to future NASA missions for human and robotic exploration of space. NASA expressed interest in the application of the spherical torus and the plasma-jet-driven magnetic-inertial fusion (PJMIF) concepts for advanced fusion space propulsion. Fusion Energy Sciences is continuing to research the spherical torus configuration at the National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL). In FY 09, through the results of an open competition, Fusion Energy Sciences took the first

significant step in the experimental exploration of the PJMIF concept by initiating the Plasma Liner Experiment (PLX) at Los Alamos National Laboratory. The NASA Marshall Space Flight Center is assisting with this experiment by loaning a spherical vacuum vessel to Los Alamos National Laboratory for the purpose of the experiment through an Interagency Agreement. The two fusion concepts hold the potential for reducing travel times to the planets in our solar system by more than a factor of 10. In addition, the plasma jet research may provide a very high-thrust electric propulsion system, which could be powered by a fission reactor, solar panels, or, eventually, a fusion reactor.

In response to the FY 07 report of the interagency Task Force on High Energy Density Physics, prepared under the guidance of the National Science and Technology Council, the Office of Fusion Energy Sciences and the National Nuclear Security Administration (NNSA) issued a Joint Solicitation in FY 08. This solicitation resulted in the receipt of proposals in the field of laboratory astrophysics, i.e., the physical simulations of astrophysical phenomena in the laboratory. As a result, three awards were made in FY 09 in the area of laboratory measurement of opacities of elements relevant to developing the appropriate model for the internal structure of the sun. Another award was given for a laboratory investigation of relativistic electron-positron plasmas that might be relevant to a number of energetic astrophysical phenomena including gamma ray bursts.

SC and NASA worked together to calculate the daily primary productivity of terrestrial ecosystems at diverse sites in northern and central states. SC's AmeriFlux program continued to provide real-time meteorological, solar radiation, and CO_2 flux data, which scientists combined with NASA/MODIS data to calculate annual net and gross primary productivity. This joint work investigated continental-scale seasonal and geographic patterns of carbon-cycle processes related to the North American carbon program. The AmeriFlux program produced unique ground-based measurements of net ecosystem production and atmospheric CO_2 concentration from approximately 30 locations across the United States. Radiometric instrumentation upgrades occurred at select AmeriFlux sites to provide improved calibration information for Terra platform observations. Collectively, the ground-surface observations from AmeriFlux sites provide critical baseline data to calibrate existing and planned NASA satellite data streams.

SC's Atmospheric Radiation Measurement (ARM) provided ground-validation support for NASA's Atmospheric Infrared Sounder (AIRS) instrument. The AIRS is a high-spectral-resolution infrared sounder on the Earth Observing System (EOS) Aqua platform. Additional measurements were conducted to coincide with overpasses of the Aqua satellite carrying the AIRS sensor at the Tropical Western Pacific (TWP) and North Slope of Alaska sites. The ARM data have been used to improve the water vapor and temperature profiles retrieved from the AIRS sensor. Information on water vapor and temperature provides important parameters for the development and validation of climate models. During FY 08, the ARM continued support of NASA's solar-viewing Bruker 125 HR Fourier Transform Spectrometer (FTS) at the Tropical Western Pacific facility, which validates space-based column CO_2 retrievals and ensures the accuracy of CO_2 source and sink information. During the winter of 2008, NASA participated in the SC's Indirect and Semi-Direct Aerosol Campaign (ISDAC). The focus of this cross-disciplinary interagency research effort was to advance the understanding of how aerosols impact climate in the Arctic.

NASA, NOAA, and DOE agreed to renew their MOU addressing the use of Uninhabited Aerial Systems (UAS) for weather and climate change research. The MOU, signed in November 2006, facilitated a collaborative, cost-sharing partnership between NASA's SMD, NOAA's Office of Marine and Aviation Operations (OMAO), and DOE's SC in utilizing Uninhabited Aerial Systems.

One of their goals was to define how these systems may extend climate and weather-related measurements over regions of Earth that are currently undersampled. The three agencies met in May 2009 in Stresa, Italy, during the International Symposium on Remote Sensing of Environment (ISRSE) and decided to proceed with arrangements to renew the MOU, which expires in 2011.

In FY 09, SC's Scientific Discovery through Advanced Computing (SciDAC) program, jointly with National Nuclear Security Administration, supported researchers at NASA's Ames Research Center in the development of numerical methods and computational tools to investigate turbulent flows with strong shocks and density variations. The research studied models of turbulence and computational algorithms and made improvements in the ability to predict these flow phenomena. NASA researchers in this collaboration investigated aspects of

computational algorithms, including stable and accurate treatment of interface boundaries, grid refinement, and accurate solvers for a wide spectrum of flow types. This collaboration ended at the close of FY 09.

The Office of Science Low Dose Radiation Research Program continued to interact with the Space Radiation Project within NASA's Human Research Program. DOE's Low Dose Radiation Research Program focuses on doses of radiation measured at or below current workplace exposure limits. NASA's Space Radiation Project seeks to understand the biological effects of space radiation so that radiation risks may be accurately assessed. Both research programs recognize the importance of delineating mechanisms of action for biological responses induced in the low-dose region. In FY 01, NASA and DOE developed a Memorandum of Agreement (MOA) to better coordinate their efforts to understand and predict the health risks associated with exposure to low-dose radiation. In FY 09, there were 11 jointly funded projects, including two NASA Specialized Center of Research (NSCOR) program projects. A new program research solicitation offered in FY 08 is expected to yield an additional number of joint DOE-NASA–supported projects.

DOE's Office of Nuclear Energy continued to support NASA's space science and exploration programs by pursuing the development of specific heating and power technologies for future space missions in coordination with NASA and other relevant stakeholders and by maintaining the necessary program and nuclear facility infrastructure capabilities to provide radioisotope power systems and heater units. In FY 09, DOE continued the development and testing of a Multi-Mission Radioisotope Thermoelectric Generator for first use on the Mars Science Laboratory mission, which is to be launched in 2011, and the development of the Advanced Stirling Radioisotope Generator now under consideration for Discovery, or Scout-class, missions in the 2014 timeframe. Designed for use in multiple mission environments, including planetary surfaces and deep space, these new radioisotope power systems, which convert the decay heat of plutonium-238 into electricity, will each provide greater than 100 watts of electricity for more than 14 years.

Maintaining a reliable supply of plutonium-238 for future missions that rely on these unique power systems has been a key challenge since domestic production of plutonium-238 ceased in 1988. The Office of Nuclear Energy augments the Nation's limited inventory of plutonium-238 through purchases from Russia. However, in

2009, Russia suspended its agreement to sell plutonium-238 to DOE, and a new agreement could delay future deliveries by three to five years. The Office of Nuclear Energy is continuing its efforts to resolve these supply issues.

The Office of Nuclear Energy and DOE national laboratories also supported technology development that could lead to a fission surface power system for deployment by NASA on the moon around the year 2020. During FY 09, DOE supported test component and reactor design, as well as lander integration concepts, for a candidate fission surface power system. As part of maintaining the required infrastructure capabilities, DOE continued the maintenance and operation of equipment and facilities at Oak Ridge National Laboratory, Idaho National Laboratory, and Los Alamos National Laboratory.

Smithsonian Institution

The Smithsonian Institution continued to contribute to national aerospace goals through the activities of the Smithsonian Astrophysical Observatory (SAO), which, together with the Harvard College Observatory in Cambridge, Massachusetts, forms the Harvard-Smithsonian Center for Astrophysics. Through this organization, more than 300 scientists engaged in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education. The Smithsonian National Air and Space Museum (NASM) in Washington, DC, also contributed to national aerospace goals through its research and education activities.

FY 09 marked the sixth year of operations for NASA's Spitzer Space Telescope—operated by the Jet Propulsion Laboratory—whose Infrared Array Camera (IRAC) was developed at SAO and constructed at the NASA Goddard Space Flight Center. Spitzer studies the universe at infrared wavelengths of light, enabling it to peer into nearby dust-obscured regions to study stellar birth and evolution; observe the atmospheres of exoplanets; and spot distant, highly redshifted galaxies.

On May 15, 2009, more than five and a half years after launch, Spitzer ended its cryogenic mission phase when it ran out of liquid helium coolant. However, Spitzer is still cold enough (–406°F) that two of IRAC's four detectors can continue to operate.

The Spitzer Warm Mission began its observational phase using IRAC on July 28, 2009, with an anticipated lifetime of five years. IRAC team members at SAO are leading or participating in five Spitzer Warm Mission Exploration Science Programs. As of August 31, 2009, IRAC had logged a total of over 15,700 hours of operation in flight.

In FY 09, Smithsonian astronomers using Spitzer announced the discovery that the nearby star Epsilon Eridani has two rocky asteroid belts and an outer icy ring, making it a triple-ring system. The inner asteroid belt is a virtual twin of the belt in our solar system, while the outer asteroid belt holds 20 times more material.

A new IRAC image from the Spitzer Space Telescope offered a rare view of imminent collision between the cores of two merging galaxies, each powered by a black hole with millions of times the mass of the sun. The spectacular image of NGC 6240, which consists of a single tangled galaxy containing the two cores, combined visible light from the Hubble Space Telescope and infrared light from Spitzer. The image caught the galaxies during a rare, short-lived phase of the evolution, when both cores of the interacting galaxies are closing in on each other very rapidly.

A sample of other FY 09 findings made by the Spitzer Space Telescope with IRAC team member participation includes

- evidence that Jupiter-sized planets must gain weight quickly during their infancy, since the gaseous disks from which they form disappear within just a few million years;
- the measurement of thermal emission from the distant "hot Jupiter" called XO-1b;

- the detection of streams of young stars flowing from their natal cocoons in distant galaxies;
- a comprehensive survey of young star clusters within 3,000 light-years of the sun;
- the in-depth characterization of stars, dust, and gas in two of our closest neighboring galaxies, the Large and Small Magellanic Clouds;
- the examination of star-forming galaxies 10 billion light-years away; and
- the measurement of clustering of red galaxies around a quasar nine billion light-years from Earth.

As the Chandra X-ray Observatory entered its second decade of operation in FY 09, it continued to play an increasingly important role in the exploration of the universe. With its unrivaled ability to create high-resolution x-ray images, Chandra has enabled astronomers to investigate phenomena as diverse as comets, black holes, dark matter, and dark energy. The Smithsonian Astrophysical Observatory, located in Cambridge, Massachusetts, controls science and flight operations from the Chandra X-ray Center.

In December 2008, astronomers announced that, using Chandra, they had clearly seen the effects of "dark energy" on the most massive collapsed objects in

the universe. These x-ray results provide a crucial independent test of dark energy, long sought by scientists, which depends on how gravity competes with accelerated expansion in the growth of cosmic structures. Scientists think dark energy is a form of repulsive force—gravity that repels rather than attracts—that now dominates the universe, although they have no clear picture of what it actually is. Understanding the nature of dark energy is one of the biggest problems in science.

Scientists using Chandra made other discoveries on some of the largest scales across the universe. For example, they found the most crowded collision of galaxy clusters in a system known as MACSJ0717.5+3745. By combining information from Chandra and two other telescopes, scientists can use this system to learn what happens when some of the largest objects in the universe smack together.

Chandra also was used to look back into the early universe to pinpoint the "coming of age" of galaxies and black holes. This discovery made by Chandra and other telescopes helped resolve the true nature of gigantic blobs of gas observed around very young galaxies.

The end of FY 09 brought an opportunity for Chandra to celebrate its incredibly successful first decade of science. The Chandra X-ray Center held a symposium in September 2009, where key project personnel; hundreds of scientists; and the astronauts from STS-93, who helped launch Chandra in 1999, were in attendance. Everyone involved in the Chandra mission is looking forward to the next decade of discovery with this remarkable observatory.

FY 09 marked the third full year of operation of the Hinode satellite, which provides continuous viewing of the sun from space. SAO's X-Ray Telescope (XRT) on board Hinode is the highest resolution telescope of its type ever flown for solar studies. The XRT observes x-rays from the solar corona—the sun's million-degree hot outer atmosphere. The XRT is providing groundbreaking new observations of both the large-scale global configurations responsible for solar activity and the small-scale processes that initiate instabilities and eruptions. The Science Operations Center at SAO serves as the focal point from which both satellite operations and scientific studies are coordinated.

Results from Hinode have been reported at three dedicated international conferences to date in Europe, the U.S., and Tokyo, Japan. XRT has demonstrated the ways in which magnetic disturbances travel through the corona, and it has

identified the ways in which magnetic energy is stored in S-shaped "sigmoids" that subsequently erupt into huge mass ejections. Far smaller jet-like events in the corona have been found to be so numerous that they may be a major source of energy and particles for the solar wind, which travels outward from the sun at nearly 1,000,000 miles per hour and blows past Earth. The ability of XRT to resolve the coronal structures is leading to a deeper understanding of the energy storage and release in coronal regions. The XRT has proven to be a highly versatile instrument, appearing in the majority of refereed publications using Hinode results.

SAO's Ultraviolet Coronagraph Spectrometer (UVCS) team made significant progress in understanding the properties and evolution of different types of solar winds from the sun. Two of the highlights from the research published in FY 09 are described below.

The sun produces a nearly continuous supersonic flow of charged particles, primarily protons and electrons, called the solar wind. Since the solar wind influences Earth's magnetosphere, generating aurorae but also causing satellite drag and geomagnetic storms, understanding the solar wind will help us to learn about our immediate cosmic environment. Previous analyses of UVCS spectroscopic observations strongly suggested that the solar wind is energized and heated by magnetic waves from the sun, but exactly how is not fully understood. Theoretical work by UVCS researchers showed that solar wind protons receive about 60 percent of the plasma heating by the time the wind reaches Earth's orbit; this fraction increases to 80 percent by the time the wind reaches the orbit of Jupiter. The remainder of the energy goes into heating the electrons. These empirical measurements for separate proton and electron temperatures helped create an improved and more complete model of the solar wind.

In a separate study, UVCS researchers determined the cooling rate of hot plasma inside a Coronal Mass Ejection (CME). CMEs are explosive events on the sun that are capable of injecting up to a billion tons of matter into interplanetary space. When the largest CMEs impact Earth, they can sometimes wreak havoc on satellites and electrical power grids. For this study, the UVCS researchers measured the ultraviolet emissions from a CME that erupted in December 2001 and determined that a significant fraction of the total CME energy goes into heating dense knots of hydrogen/helium gas. In fact, the heat energy contained in the CME knots can exceed the kinetic energy that propels the CME forward.

The Smithsonian Astrophysical Observatory's Submillimeter Array (SMA) continued to be the instrument of choice for star formation studies, high-resolution imaging, and the initial follow-up studies of distant galaxies in the submillimeter. During FY 09, the SMA was used to conduct forefront research on a wide variety of topics ranging from planetary science to the study of the most distant galaxies.

One of the most intriguing discoveries made by the SMA in FY 09 was a planet-forming disk orbiting twin suns. High-resolution images clearly revealed the presence of a rotating molecular disk orbiting the young binary star system V4046 Sagittarii. The SMA images provided an unusually vivid snapshot of the process of formation of giant planets, comets, and Pluto-like bodies. The results also confirmed that such objects might just as easily form around double stars as around single stars like our sun.

The SMA completed its 345-gigahertz (GHz)–band spectral line survey of the carbon star CW Leo, which is the brightest infrared object in the northern sky but is barely visible at optical wavelengths. CW Leo is expelling much of its mass back into the interstellar medium, much as our sun will do a few billion years from now. The dusty wind from CW Leo has an exceptionally rich molecular chemistry, containing salts, organic molecules, and silicates. Stars like CW Leo are believed

to be the main source of dust—as well as carbon, oxygen, and nitrogen-bearing molecules—in the interstellar medium.

The SMA survey of CW Leo was the first such project done with an interferometer, which, thanks to its fine angular resolution, provides spatial distribution information unavailable in earlier single-dish surveys of this source. At submillimeter wavelengths, the SMA survey is particularly sensitive to spectral signatures of molecules from hotter regions close to the star, which were missed by previous surveys. More than 400 spectral lines have been detected in the SMA survey, including more than 100 new detections of which 70 have not yet been assigned to any known molecular transitions.

The SMA enabled a new level of precision in the study of circumstellar disks, leading to a deeper understanding of how planets form. In fewer than ten million years, the material in the circumstellar disk around a young star will be accreted onto the star, dispersed into the interstellar medium, or converted into planets or smaller solid bodies. While the star's gravity tends to pull all of the disk material onto the star, small orbiting clumps of coagulated dust grains in the disk grow into larger bodies that disrupt that infall process. The solid bodies often sculpt gaps, or cavities, in the disk and accrete more material as some grow into planets. Eventually winds from the star will sweep away the remaining disk material. Each of these processes is influenced by many factors that astronomers are working hard to understand, but their efforts have so far been hampered by a lack of precise spatial information about the distribution of the material in the disk.

SAO astronomers used the SMA to probe nine relatively massive proto-planetary disks, down to sizes approximately that of our solar system. They used newly improved models to measure the distribution of mass in the disk, including rings suggestive of gaps carved out by planets, and to estimate other key parameters such as turbulence in the material. The scientists concluded that not only does giant planet formation seem possible in all of these nine disks; it might already have begun within three of them. The absence of giant planets in the remaining six highlights the importance of other parameters, such as age. This work combined the high-precision submillimeter imaging capability of the SMA with sophisticated modeling to probe the early stages in the development of new planetary systems.

SAO astronomers produced a number of other significant findings in FY 09. In October 2008, SAO announced an impending asteroid impact with Earth 10 hours

in advance. The boulder-sized object exploded high in the atmosphere, showering the ground below with fragments. Months later, searchers retrieved some of those fragments from the Sudanese desert.

SAO researchers showed that our Milky Way galaxy is larger and heftier than previously thought. Specifically, the Milky Way is 15 percent larger in size and contains 50 percent more mass. That is the cosmic equivalent of a five-foot-five, 140-pound man suddenly bulking up to the size of a six-foot-three, 210-pound NFL linebacker. *The Colbert Report*, a popular Comedy Central program, commented on the finding in one of its episodes in 2009.

Other significant discoveries included stars forming just beyond a black hole's grasp at the galactic center, evidence that a cosmic dance helps galaxies lose weight, and hints that magnetic fields play a larger role in star formation than previously thought.

In public outreach, SAO hosted a landmark three-day conference titled "Crossroads: The Future of Human Life in the Universe," co-sponsored by the Harvard Origins of Life Initiative. Notable scientists who lectured included geneticist J. Craig Venter, physicist Freeman Dyson, futurist Juan Enriquez, and planet hunter David Charbonneau.

SAO continued to offer its popular monthly Observatory Night lectures and telescope observing sessions, with a special effort to feature topics relevant to the 2009 International Year of Astronomy, which commemorated the 400th anniversary of Galileo's first astronomical use of the telescope. Topical lectures included "Galileo Opens the Door" and "The Day We Found the Universe." SAO also participated in an International Year of Astronomy Webcast called "Around the World in 80 Telescopes." SAO provided occasional Author's Night programs, as well as Sci-fi Movie Nights that explored the theme "Everything I learned about science, I learned at the movies."

A new museum exhibit developed by SAO educators and scientists debuted at the Boston Museum of Science. Titled "Black Holes: Space Warps & Time Twists," the 2,500-square-foot traveling exhibition pulled visitors into the modern search for real black holes—the most mysterious and powerful objects in the universe. The exhibit toured the New England region.

In FY 09, NASM continued to educate and inspire the public through exhibits and education programs, including discovery stations, lecture series, family

educational events, and intern programs. The Museum commemorated the 40th anniversary of the Apollo 11 lunar landing with astronaut appearances, educational programming related to lunar science and the history of lunar exploration, and the opening of the exhibit "Alan Bean: Painting Apollo, First Artist on Another World." In conjunction with the International Year of Astronomy, NASM opened a public observatory that provides visitors with the opportunity to view the sun, moon, stars, and planets with a 16-inch telescope on loan from the Harvard College Observatory. Programming commemorating the Centennial of Military Aviation was offered throughout the year, leading up to a public symposium.

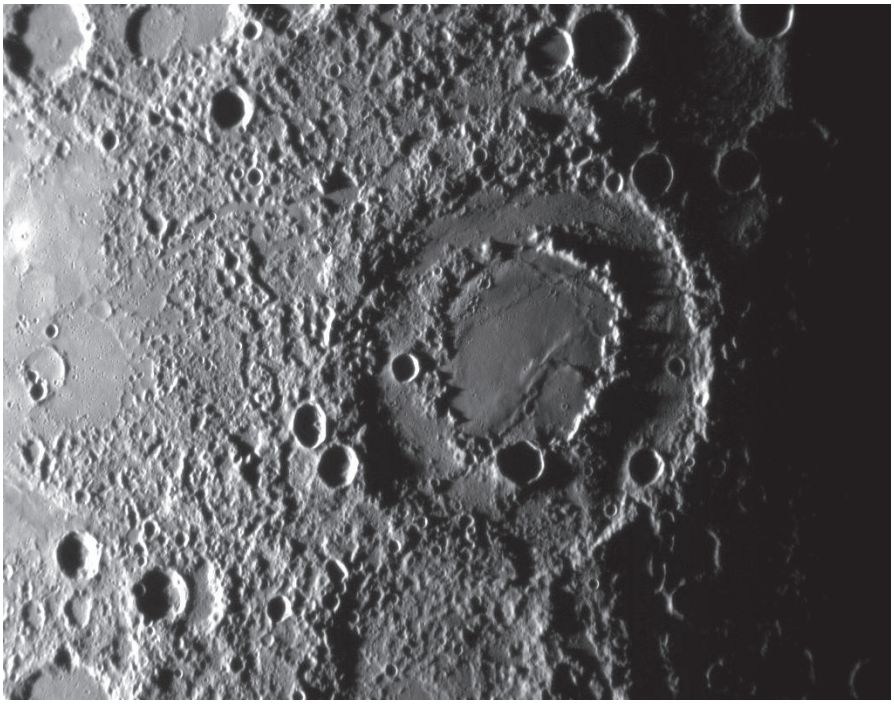
At the Museum's Steven F. Udvar-Hazy Center, which celebrated its fifth anniversary in 2009, plans continued for Phase Two, which will accommodate the Museum's archives and the facilities for restoration and preservation of the Nation's collection of air and space artifacts.

Staff members in NASM's Center for Earth and Planetary Studies (CEPS) continued to participate on the science teams of several spacecraft missions. Dr. John Grant was a Participating Scientist for the Mars Exploration Rover (MER) mission operating on Mars. Also, as chair of the MER Science Operations Working

Group, he directed the science team to consensus on targets and operations for the long-lived rovers. He conducted real-time mission planning from a control station installed on site at CEPS. Dr. Grant was also co-chair of the Mars Science Laboratory (MSL) Landing Site Steering Committee, which worked to identify landing sites for the new Mars rover.

CEPS staff were on the science teams for the Mars Advanced Radar for Subsurface and Ionosphere Sounding instrument on Mars Express, the High Resolution Imaging Science Experiment and the Shallow Subsurface Radar instruments on the Mars Reconnaissance Orbiter, the Lunar Reconnaissance Orbiter, and the MESSENGER mission to Mercury, which this year revealed a never-before-seen impact basin. CEPS scientist Dr. Tom Watters led the team that studied this newly discovered feature.

CEPS continued its active research program in planetary and terrestrial geology and geophysics using remote-sensing data from Earth-orbiting satellites, as well as piloted and unpiloted space missions. The scope of research activities included work on the moon, Mars, Earth, and Mercury, resulting in 41 peer-reviewed publications. Research topics included studies of Martian aeolian and volcanic features, terrestrial lava flows, lunar radar studies, Mercury data, and comparative



planetology. In addition, CEPS scientists used new capabilities in Earth-based radar imaging to study the surface and deep deposits of the moon at resolutions comparable to those of photos taken from lunar orbit. This work revealed unexpected variations in the roughness of lava flows that form the vast lunar plains, suggesting changes in the style or rate of volcanic activity over time.

As a NASA Regional Planetary Image Facility (RPIF), CEPS housed a collection of over 300,000 images of the planets and their satellites that is a reference library for science researchers and the public, serving the mid-Atlantic and southeastern U.S. The CEPS RPIF holds the most complete collection of lunar images of any RPIF in the world.

APPENDICES

Appendix A-1

U.S. Government Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

	Earth Orbit[a]		Earth Escape[b]	
Calendar Year	**Success**	**Failure**	**Success**	**Failure**
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32[c]	0	0	0
1992	26[c]	0	1	0
1993	28[c]	1	1	0
1994	31[c]	1	1	0
1995	24[c,d]	2	1	0
1996	30	1	3	0
1997	22[e]	0	1	0
1998	23	0	2	0
1999	35	4	2	0
2000	31[f]	0	0	0
2001	23	0	3	0
2002	18	0	0	1[b]
2003	28[c,f]	0	2	0
2004	8[c]	0	1	0
2005	10	0	2	0
2006	20[d]	0	2	0
2007	16	2	2	0
2008	22[f]	0	0	0
2009	24[f]	1	0	0
TOTAL	**1,646**	**156**	**106**	**16**

a. The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from Earth.
b. This Earth-escape failure did attain Earth orbit and, therefore, is included in the Earth-orbit success totals.
c. This excludes commercial satellites. It counts separately spacecraft launched by the same launch vehicle.
d. This counts various sets of microsatellites as a single payload.
e. This includes the Small Spacecraft Technology Initiative (SSTI) Lewis spacecraft that began spinning out of control shortly after it achieved Earth orbit.
f. This includes American spacecraft not launched in the U.S.

Appendix A-2

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)[a]

Calendar Year	United States[b]	USSR/ CIS	France[c]	Italy[c]	Japan	People's Republic of China	Australia	United Kingdom[c]	European Space Agency	India	Israel	Iran
1957		2										
1958	5	1										
1959	10	3										
1960	16	3										
1961	29	6										
1962	52	20										
1963	38	17										
1964	57	30										
1965	63	48	1									
1966	73	44	1									
1967	57	66	2	1			1					
1968	45	74										
1969	40	70										
1970	28	81	2	1	1	1						
1971	30	83	1	2	2	1		1				
1972	30	74		1	1							
1973	23	86										
1974	22	81		2	1							
1975	27	89	3	1	2	3						
1976	26	99			1	2						
1977	24	98			2							
1978	32	88			3	1						
1979	16	87			2				1			
1980	13	89			2					1		
1981	18	98			3	1			2	1		
1982	18	101			1	1						
1983	22	98			3	1			2	1		
1984	22	97			3	3			4			
1985	17	98			2	1			3			
1986	6	91			2	2			2			
1987	8	95			3	2			2			
1988	12	90			2	4			7			
1989	17	74			2				7		1	
1990	27	75			3	5			5		1	
1991	20	62			2	1			9	1		
1992	31	55			2	3			7	2		
1993	24	45			1	1			7			
1994	26	49			2	5			6	2		
1995	27	33			1	2			12		1	
1996	32	25			1	3			10	1		
1997	37	28			2	6			12	1		
1998	34	24			2	6			11			
1999	32	26				4			10	1		
2000	30	34				5			12			
2001	23	23			1	1			8	2		
2002	18	23			3	4			11	1	1	
2003	26	21			2	6			4	2		
2004	19	22				8			3	1		
2005	16	26			2	5			5	1		
2006	15	16			5	3			5			
2007	25	33			3	13			8	3	1	
2008	19	26			1	11			7	3		
2009*	18	22			2	1			5	4		1
*(through September 30, 2009)												
TOTAL	**1,395**	**2,849**	**10**	**8**	**73**	**116**	**1**	**1**	**187**	**28**	**5**	**1**

a. This includes commercial expendable launches and launches of the Space Shuttle as well as launches to useless orbit.
b. Launches from U.S.-Russia joint platform included in U.S. totals.
c. Since 1979, all launches for ESA member countries have been joint and are listed under ESA.

Appendix B
SUCCESSFUL LAUNCHES TO ORBIT ON U.S. VEHICLES

October 1, 2008–September 30, 2009

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
October 19, 2008 Star 27/IBEX 2008-051A Pegasus-XL/L-1011 cargo plane	Space physics	320,000 7,000 8 days 11	Interstellar Boundary Explorer, designed to make observations beyond the solar system's termination shock
October 25, 2008 Cosmo/SkyMed 3 2008-054A	Military surveillance	623 622 97.2 97.9	Italian Earth observation and military surveillance radar satellite
November 15, 2008 STS-126/Endeavour 2008-059A Shuttle	International Space Station	352 344 91.5 51.6	Resupply and installation of the Leonardo module Repair of a broken Solar Array Rotary Joint
January 18, 2009 USA 202 (NROL 26) 2009-001A Delta IV Heavy	Geostationary intelligence	38,077 35,943 1,440 3	National Reconnaissance Office
February 6, 2009 NOAA 19 2009-005A Delta 2	Weather	867 845 102.10 98.8	NOAA-N PRIME Part of the Polar Orbiting Environmental Satellites (POES)
March 7, 2009 2009-011A Kepler Delta 2	Astrophysics		Search for terrestrial planets near the habitable zone of their stars and the possibility of life
March 15, 2009 STS-119/Discovery 2009-012A Shuttle	International Space Station	353 335 91.40 51.6	Delivered and installed the fourth starboard truss segment (ITS S6), as well as additional solar arrays and batteries
March 24, 2009 Navstar 63 (USA 203) 2009-014A Delta 2	Navigational	20,272 20,093 718 55.1	GPS 2R-20 replaced GPS 2A-27 in the navigation network
April 4, 2009 WGS F2 (USA 204) 2009-017A Atlas 5	Military communications	35,452 35,397 1,417.60 .1000	Wideband Global Satcom Part of a military mission to serve U.S. forces deployed in Iraq and Afghanistan
April 20, 2009 SICRAL 1B 2009-020A Sea Launch Zenit 3SL	Military communications	35,787 35,785 1,436 0	Italian military communications satellite
May 5, 2009 STSS ATRR (USA 205) 2009-023A Delta 2	Military	Unknown	Space Tracking and Surveillance System Advanced Technology Risk Reduction satellite Operated by the U.S. Missile Defense Agency

Appendix B

(Continued)

SUCCESSFUL LAUNCHES TO ORBIT ON U.S. VEHICLES

October 1, 2008–September 30, 2009

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), period (min), Inclination to Equator (°)	Remarks
May 11, 2009 STS-125/Atlantis 2009-025A Shuttle	Hubble Space Telescope	566 302 93.30 28.5	Hubble Servicing Mission SM-4 for repairs and upgrades
May 19, 2009 TacSat 3 2009-028A Minotaur 1	CubeSats and TacSat	463–465 427–433 93.50–93.60 40.5	Tacsat 3 contained the Advanced Responsive Tactically Effective Military Imaging Spectrometer hyperspectral imager, the Office of Naval Research's Satellite Communications Package, and the Air Force Research Laboratory's Space Avionics Experiment Secondary payloads included the Pharmasat experiment (2009-028B) and three cubesats: Hawksat 1 (2009-028C), CP6 (2009-028D), Aerocube 3 (2009-028E)
June 18, 2009 LRO/LCROSS 2009-031A Atlas 5	Astrophysics		Lunar Reconnaissance Orbiter, designed to map the lunar surface and characterize landing sites for future missions Carried Lunar CRater Observation and Sensing Satellite (LCROSS) (2009-031B), a lunar impact probe for detecting water ice in the lunar polar regions
June 27, 2009 GOES 14 (GOES O) 2009-033A Delta 4	Geostationary Earth observation	35,788 35,786 1,436.10 .5000	Geostationary Operational Environmental Satellite
July 14, 2009 RazakSat 2009-037A Falcon 1	Imaging	690 665 98.30 9	Malaysian imaging satellite, formerly known as MACSat First flight of a commercial payload aboard a Falcon rocket
July 15, 2009 STS-127/Endeavour 2009-038A	International Space Station	336 328 91.20 51.6	Delivered and installed the Kibo Japanese Experiment Module Exposed Facility (JEM EF), Kibo Japanese Experiment Logistics Module–Exposed Section (ELM-ES), and Spacelab Pallet-Deployable 2 (SLP-D2) Carried DRAGONSat (2009-038B), ANDE Pollux Sphere (2009-038E), ANDE Castor Sphere (2009-038F)

Appendix B

(Continued)

SUCCESSFUL LAUNCHES TO ORBIT ON U.S. VEHICLES

October 1, 2008–September 30, 2009

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
August 17, 2009 Navstar 64 2009-043A Delta 2	Navigation	20,228 20,138 718 54.9	Also known as USA 206 and as GPS 2R-21(M)
August 29, 2009 STS-128/Discovery 2009-045A Shuttle	International Space Station	352 310 91.2 51.6	Delivered and installed the Multi-Purpose Logistics Module (MPLM); the Lightweight Multi-Purpose Experiment Support Structure Carrier (LMC); three-crew quarters, galley, and second treadmill (TVIS2); and the Crew Health Care System 2 (CHeCS 2)
September 8, 2009 USA 207/PAN 2009-047A Atlas 5	Geostationary communications	Unknown	Classified communications satellite
September 25, 2009 STSS DEMO 1 (USA 208) 2009-052A Delta 2	Military	Unknown	Also included STSS DEMO 2 (USA 209) (2009-052B) Space Tracking and Surveillance System for missile launch and flight monitoring using infrared sensors U.S. Missile Defense Agency

* U.N. Committee on Space Research

Appendix C
HUMAN SPACEFLIGHTS

October 1, 2008–September 30, 2009

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TMA-13 (Expedition 18)	October 12, 2008	E. Michael Fincke Yuri V. Lonchakov Gregory E. Chamitoff Sandra H. Magnus Koichi Wakata Richard Garriott	177:19:49	Richard Garriott as American tourist
Space Shuttle Endeavour (STS-126)	November 15, 2008	Christopher J. Ferguson Eric A. Boe Stephen G. Bowen Robert S. "Shane" Kimbrough Heidemarie M. Stefanyshyn-Piper Donald R. Pettit Sandra H. Magnus Gregory E. Chamitoff	15:20:29	Primary payload: Multi-Purpose Logistics Module (MPLM) Magnus remained on the Station, replacing Expedition 17/18 Flight Engineer Gregory E. Chamitoff
Space Shuttle Discovery (STS-119)	March 15, 2009	Lee J. Archambault Dominic A. "Tony" Antonelli Joseph M. Acaba John L. Phillips Steven R. Swanson Richard R. Arnold Koichi Wakata Sandra H. Magnus	12:19:29	Primary payload: S6 truss segment Wakata remained on the Station, replacing Expedition 18 Flight Engineer Sandra Magnus
Soyuz TMA-14 (Expedition 19)	March 26, 2009	Gennady I. Padalka Michael R. Barratt Koichi Wakata Charles Simonyi	199:01:48	Charles Simonyi as American tourist
Space Shuttle Atlantis (STS-125)	May 11, 2009	Scott D. Altman Gregory C. Johnson Andrew J. Feustel Michael T. Good John M. Grunsfeld Michael J. Massimino K. Megan McArthur	12:21:37	Hubble Space Telescope Servicing Mission 4
Soyuz TMA-15 (Expedition 20)	May 27, 2009	Roman Romanenko Robert Thirsk Frank De Winne	188:05:46	First six-person crew on board the Station
Space Shuttle Endeavour (STS-127)	July 15, 2009	Mark L. Polansky Douglas G. Hurley David A. Wolf Christopher J. Cassidy Julie Payette Thomas H. Marshburn Timothy L. Kopra Koichi Wakata	15:16:45	Primary payload: Kibo Japanese Experiment Module Exposed Facility (JEM EF), Kibo Japanese Experiment Logistics Module–Exposed Section (ELM-ES) Kopra remained on the Station, replacing Japanese astronaut Koichi Wakata
Space Shuttle Discovery (STS-128)	August 29, 2009	Frederick W. "Rick" Sturckow Kevin A. Ford Patrick G. Forrester José M. Hernández Christer Fuglesang John D. "Danny" Olivas Nicole P. Stott Timothy L. Kopra	13:20:54	Primary payload: Leonardo Multi-Purpose Logistics Module, Lightweight Multi-Purpose Experiment Support Structure Carrier Stott remained on the Station, replacing Flight Engineer Timothy Kopra
Soyuz TMA-16 (Expedition 21)	September 30, 2009	Maksim Suraev Jeffrey Williams Guy Laliberté	168:23:44	Guy Laliberté as tourist

Appendix D-1A

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of real-year dollars)

FY	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	331	261	490	34	34						785
1960	524	462	561	43	43						1,066
1961	964	926	814	68	68						1,808
1962	1,825	1,797	1,298	199	148	51					3,294
1963	3,673	3,626	1,550	257	214	43					5,433
1964	5,100	5,016	1,599	213	210	3					6,828
1965	5,250	5,138	1,574	241	229	12					6,953
1966	5,175	5,065	1,689	214	187	27					6,968
1967	4,966	4,830	1,664	213	184	29					6,707
1968	4,587	4,430	1,922	174	145	28	0.2	1			6,526
1969	3,991	3,822	2,013	170	118	20	0.2	1	31		6,005
1970	3,746	3,547	1,678	141	103	8	1	1	28		5,366
1971	3,311	3,101	1,512	162	95	27	2	1	37		4,775
1972	3,307	3,071	1,407	133	55	31	6	2	39		4,611
1973	3,406	3,093	1,623	147	54	40	10	2	41		4,863
1974	3,037	2,759	1,766	158	42	60	9	3	44		4,683
1975	3,229	2,915	1,892	158	30	64	8	2	54		4,965
1976	3,550	3,225	1,983	168	23	72	10	4	59		5,376
TQ*	932	849	460	43	5	22	3	1	12		1,352
1977	3,818	3,440	2,412	194	22	91	10	6	65		6,046
1978	4,060	3,623	2,738	226	34	103	10	8	71		6,587
1979	4,596	4,030	3,036	248	59	98	10	8	73		7,314
1980	5,240	4,680	3,848	231	40	93	12	14	72		8,759
1981	5,518	4,992	4,828	234	41	87	12	16	78		10,054
1982	6,044	5,528	6,679	313	61	145	12	15	80		12,520
1983	6,875	6,328	9,019	327	39	178	5	20	85		15,674
1984	7,458	6,858	10,195	395	34	236	3	19	103		17,448
1985	7,573	6,925	12,768	584	34	423	2	15	110		20,277
1986	7,807	7,165	14,126	477	35	309	2	23	108		21,768
1987	10,923	9,809	16,287	466	48	278	8	19	112	1	26,562
1988	9,062	8,322	17,679	741	241	352	14	18	115	1	26,742
1989	10,969	10,097	17,906	560	97	301	17	21	121	3	28,563
1990	12,324	11,460	15,616	506	79	243	31	25	124	4	27,582
1991	14,016	13,046	14,181	772	251	251	29	26	211	4	27,999
1992	14,317	13,199	15,023	798	223	327	34	29	181	4	29,020
1993	14,310	13,064	14,106	731	165	324	33	25	180	4	27,901
1994	14,570	13,022	13,166	632	74	312	31	31	179	5	26,820
1995	13,854	12,543	10,644	759	60	352	31	32	278	6	23,946
1996	13,884	12,569	11,514	828	46	472	36	37	231	6	24,911
1997	13,709	12,457	11,727	789	35	448	42	39	219	6	24,973
1998	13,648	12,321	12,359	839	103	435	43	39	213	6	25,519
1999	13,653	12,459	13,203	982	105	575	59	37	200	6	26,644
2000	13,601	12,521	12,941	1,056	164	575	60	44	207	6	26,518
2001	14,230	13,304	14,326	1,062	145	577	60	36	232	12	28,692
2002	14,868	13,871	15,740	1,180	166	644	64	28	266	12	30,791
2003	15,364	14,360	19,388	1,305	191	649	74	42	337	12	35,053
2004	15,379	14,322	19,115	1,464	209	745	71	61	366	12	34,901
2005	16,198	15,234	19,690	1,551	229	807	70	73	360	12	36,475
2006	16,623	15,765	22,114	1,647	245	860	82	84	364	12	39,526
2007	16,285	15,568	22,418	1,680	200	912	87	65	404	12	39,666
2008	17,117	16,502	24,795	1,698	195	862	90	59	479	13	42,995
2009	17,775	17,275	26,528	1,868	200	1,078	64	27	485	14	45,671

a. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as in space. For the years 1989–1997, this Other column also includes small figures for the Environmental Protection Agency (EPA). Also includes $2.1 billion for replacement of Space Shuttle Challenger in 1987.

b. The DOE has recalculated its space expenditures since 1998

c. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

* Transition Quarter

Appendix D-1B

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 09 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	5.999	1,986	1,566	2,940	204	204						4,709
1960	5.907	3,095	2,729	3,314	254	254						6,296
1961	5.836	5,626	5,404	4,751	397	397						10,552
1962	5.754	10,501	10,340	7,469	1,145	852	293					18,954
1963	5.690	20,899	20,632	8,819	1,462	1,218	245					30,913
1964	5.619	28,659	28,187	8,985	1,197	1,180	17					38,370
1965	5.553	29,155	28,533	8,741	1,338	1,272	67					38,612
1966	5.459	28,252	27,651	9,221	1,168	1,021	147					38,040
1967	5.345	26,543	25,816	8,894	1,138	983	155					35,849
1968	5.178	23,751	22,938	9,952	902	751	145	1	5			33,792
1969	5.000	19,957	19,112	10,066	852	590	100	1	5	156		30,029
1970	4.782	17,913	16,961	8,024	674	493	38	5	5	134		25,660
1971	4.534	15,013	14,061	6,856	734	431	122	9	5	167		21,651
1972	4.319	14,281	13,262	6,076	576	238	134	26	9	170		19,914
1973	4.124	14,046	12,755	6,693	608	223	165	41	8	171		20,056
1974	3.950	11,995	10,897	6,975	624	166	237	36	12	174		18,497
1975	3.684	11,895	10,738	6,970	581	111	236	29	7	198		18,289
1976	3.337	11,846	10,761	6,617	562	77	240	33	13	198		17,940
TQ*	3.112	2,901	2,642	1,432	134	16	68	9	3	37		4,208
1977	3.016	11,517	10,377	7,276	584	66	275	30	18	195		18,236
1978	2.895	11,755	10,490	7,927	654	98	298	29	23	206		19,072
1979	2.713	12,468	10,932	8,236	673	160	266	27	22	198		19,841
1980	2.510	13,155	11,749	9,660	580	100	233	30	35	181		21,989
1981	2.308	12,736	11,522	11,143	541	95	201	28	37	181		23,206
1982	2.102	12,706	11,621	14,041	657	128	305	25	32	168		26,319
1983	1.968	13,527	12,451	17,746	643	77	350	10	39	167		30,840
1984	1.884	14,054	12,923	19,211	744	64	445	6	36	194		32,878
1985	1.817	13,763	12,585	23,204	1,061	62	769	4	27	199		36,849
1986	1.760	13,742	12,612	24,864	839	62	544	4	40	190		38,315
1987	1.720	18,789	16,873	28,016	801	83	478	14	33	192	2	45,690
1988	1.676	15,191	13,951	29,637	1,242	404	590	23	30	193	2	44,830
1989	1.625	17,827	16,410	29,102	910	158	489	28	34	197	5	46,422
1990	1.564	19,280	17,929	24,431	791	124	380	48	39	194	6	43,151
1991	1.508	21,142	19,679	21,391	1,165	379	379	44	39	319	6	42,235
1992	1.454	20,815	19,189	21,841	1,160	324	475	49	42	263	6	42,190
1993	1.418	20,294	18,527	20,005	1,036	234	459	47	35	255	6	39,569
1994	1.387	20,205	18,058	18,258	877	103	433	43	43	249	7	37,193
1995	1.358	18,808	17,028	14,450	1,030	81	478	42	43	377	8	32,508
1996	1.330	18,460	16,711	15,309	1,101	61	628	48	49	307	8	33,121
1997	1.305	17,884	16,250	15,298	1,030	46	584	55	51	286	8	32,578
1998	1.282	17,499	15,797	15,846	1,076	132	558	55	50	274	8	32,720
1999	1.267	17,295	15,783	16,725	1,244	133	728	75	47	253	8	33,752
2000	1.250	17,006	15,656	16,181	1,320	205	719	75	55	258	8	33,157
2001	1.226	17,440	16,305	17,558	1,302	178	707	74	44	284	15	35,165
2002	1.197	17,802	16,608	18,846	1,413	199	771	77	34	318	14	36,867
2003	1.175	18,050	16,871	22,778	1,533	224	762	87	49	396	14	41,182
2004	1.152	17,710	16,493	22,012	1,686	241	858	82	70	421	14	40,190
2005	1.122	18,180	17,098	22,099	1,741	257	906	79	82	404	13	40,938
2006	1.087	18,077	17,144	24,049	1,791	266	935	89	91	396	13	42,984
2007	1.052	17,129	16,375	23,580	1,767	210	959	92	68	425	13	41,722
2008	1.024	17,525	16,895	25,385	1,738	200	883	92	60	490	13	44,019
2009	1.000	17,775	17,275	26,528	1,868	200	1,078	64	27	485	14	45,671

a. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as in space. For the years 1989–1997, this Other column also includes small figures for the Environmental Protection Agency (EPA). Also includes $2.1 billion for replacement of Space Shuttle Challenger in 1987.

b. The DOE has recalculated its space expenditures since 1998.

c. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

* Transition Quarter

Appendix D-2

FEDERAL SPACE ACTIVITIES BUDGET

(in millions of dollars by fiscal year)

	Budget Authority						Budget Outlays		
Federal Agencies	**2008 actual**	**2009 actual**	**Recovery enacted**	**2010 actual**	**2010 ARRA**	**2011 est.**	**2008 actual**	**2009 actual**	**2010 actual**
NASA[1, 2]	16,502	17,275	852	18,228			17,231	18,389	18,362
DOD	25,949	26,528		26,463			24,080	24,273	24,142
DOE[3]	195	200	1	203		217	192	193	204
DOC	862	1,078	75	1,261			603	991	1,221
DOI	64	64	0	67			64	64	67
USDA	26.8	26.3		26.6			22.6	21.6	21.6
DOT	13	14	0	15		15	12	14	15
NSF[4, 5]	464	485	142	484	146		361	310	515

(1) The 2008 Consolidated Appropriations Act rescinded $192.5 million in NASA prior-year unobligated balances, effectively reducing NASA's total FY 08 budget authority by this amount.

(2) Beginning in 2009, NASA program budgets reflect only direct program costs. Indirect costs are budgeted within the Cross-Agency Support Programs account (captured within the Federal Space Activities Budget table).

(3) Beginning in 2007, Department of Energy budget figures do not include any physics research and operations funding for ground-based experiments managed in the High Energy Physics program.

(4) The 2008 Actuals that NSF reported in June 2009 were $479 million in authority and $361 million in outlays.

(5) $146 million in FY 10 American Recovery and Reinvestment Act (ARRA) authority is carried over from FY 09 ARRA authority.

Appendix D-3

FEDERAL AERONAUTICS ACTIVITIES BUDGET

(in millions of dollars by fiscal year)

	Budget Authority					Budget Outlays		
Federal Agencies	**2008 actual**	**2009 actual**	**Recovery enacted**	**2010 actual**	**2011 est.**	**2008 actual**	**2009 actual**	**2010 actual**
NASA[1, 2]	615	500	150	497		603	778	542
USDA	33.2	48.9		55.4		30.1	47.5	52.6
DOD	10,873	13,248	49	14,166		10,994	12,252	13,573
DOI	26	22	15	30		26	22	30
DOT	2,646	2,897	200	3,104	2,886	2,562	2,587	2,742

(1) The 2008 Consolidated Appropriations Act rescinded $192.5 million in NASA prior-year unobligated balances, effectively reducing NASA's total FY 08 budget authority by this amount.

(2) Beginning in 2009, NASA program budgets reflect only direct program costs. Indirect costs are budgeted within the Cross-Agency Support Programs account (captured within the Federal Space Activities Budget table).

Acronyms

3D-PAM	3D-Path Arrival Management

A

AAD	Aircraft Aging and Durability
AATSR	Advanced Along-Track Scanning Radiometer
ABI	Advanced Baseline Imager
ACD	Advanced Capabilities Division
ACE	Advanced Composition Explorer; Aerosol-Cloud-Environment
ACES	Airspace Conflict Evaluation Simulator
ACJV	Atlantic Coast Joint Venture
ACT	Atacama Cosmology Telescope
ADD	Architecture Definition Document
ADS-B	Automatic Dependent Surveillance-Broadcast
AEDT	Aviation Environmental Design Tool
AGEDI	Abu Dhabi Global Environmental Data Initiative
AGRHYMET	Agricultural-Hydrological-Meteorological
AGS	Alternating Gradient Synchrotron
AGS	Division of Atmospheric and Geospace Sciences
AHS	American Helicopter Society
AIAA	American Institute of Aeronautics and Astronautics
AIRS	Atmospheric Infrared Sounder
ALMA	Atacama Large Millimeter/submillimeter Array
AMD	Aviation Management Directorate
AMISA	Arctic Mechanisms of Interaction between Surface and Atmosphere
AMISR	Advanced Modular Incoherent-Scatter Radar
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMS	Alpha Magnetic Spectrometer
AO	Announcement of Opportunity
AOML	Atlantic Oceanographic and Meteorological Laboratory
AP	Associated Press
APLC	Aerospace Products Literature Centers
ARM	Atmospheric Radiation Measurement
ARMD	Aeronautics Research Mission Directorate
ARRA	American Recovery and Reinvestment Act
ARS	Agricultural Research Service
ASAR	Along-Track Scanning Radiometer
ASCOS	Arctic Summer Cloud Ocean Study
ASCR	Office of Advanced Scientific Computing Research
ASME	American Society of Mechanical Engineers
AST	Office of Commercial Space Transportation; Division of Astronomical Sciences
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTS	Aeronautics Science and Technology
ATM	Division of Atmospheric Sciences
ATP	Aeronautics Test Program
ATRR	Advanced Technology Risk Reduction
ATST	Advanced Technology Solar Telescope
AWiFS	Advanced Wide Field Sensor

B

BIA	Bureau of Indian Affairs
BIS	Bureau of Industry and Security
BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory

C

C-CAP	Coastal Change Analysis Program
C2	Command and Control
CAAFI	Commercial Aviation Alternative Fuel Initiative
CAASD	Center for Advanced Aviation System Development
CCDev	Commercial Crew Development
CCMC	Community Coordinated Modeling Center
CCRS	Canada Centre for Remote Sensing
CDL	Cropland Data Layer
CDTI	Cockpit Display of Traffic Information
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEOS	Committee on Earth Observing Satellites
CEPS	Center for Earth and Planetary Studies
CERN	European Organization for Nuclear Research
CfA	Center for Astrophysics
CFC	chlorofluorocarbons
CIBER	Cosmic Infrared Background Experiment
CILSS	Inter-Governmental Authority on Combating Drought in the Sahel
CIR	Combustion Integrated Rack; color infrared
CIRA	Cooperative Institute for Research in the Atmosphere
CISM	Center for Integrated Space Weather Modeling
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLU	Common Land Units
CMB	cosmic microwave background
CMC	carbon matrix composite
CME	coronal mass ejection
CMM	coordinate measuring machines
CNES	Centre National d'Études Spatiales
CNN	Cable News Network
COLBERT	Combined Operational Load Bearing External Resistance Treadmill
CONUS	Contiguous United States
CORS	Continuously Operating Reference Station
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COTS	Commercial Orbital Transportation Services
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
CRM	Coastal Relief Model
CRS	Commercial Resupply Services
CS	Commercial Service
CxP	Constellation Program

D

DAC	Dynamic Airspace Configuration
DARPA	Defense Advanced Research Projects Agency
DEM	digital elevation model
DEMO	Space Tracking and Surveillance System Demonstrators
DFG	derelict fishing gear

DLR	German Aerospace Center
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOGAMI	Department of Geology and Mineral Industries
DOI	Department of the Interior
DOM	dissolved organic material
DOS	Department of State
DSN	Deep Space Network

E

EAD	Abu Dhabi Environment Agency
EBIS	Electron Beam Ion Source
ECMWF	European Centre for Medium-Range Weather Forecasts
EELV	Evolved Expendable Launch Vehicle
EFICA	Efficient Flow into Congested Airspace
EKV	Exoatmospheric Kill Vehicle
ELV	expendable launch vehicles
EOS	Earth Observing System
ERAM	En Route Automation Modernization
ERMA™	Environmental Response Management Application
EROS	Earth Resources Observation and Science Center
ESA	European Space Agency
ESMD	Exploration Systems Mission Directorate
ESPC	Environmental Satellite Processing Center
ESV	Earth station on vessel
ET	external tank
ETDP	Exploration Technology Development Program
ETM+	Enhanced Thematic Mapper Plus
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUPOS	European Position Determination System
EUV	extreme ultraviolet
EVA	Extravehicular Activity
EVE	Extreme Ultraviolet Variability Experiment

F

FAA	Federal Aviation Administration
FAS	Foreign Agricultural Service
FASR	Frequency Agile Solar Radiotelescope
FBTM	Flow-Based Trajectory Management
FCC	Federal Communications Commission
FCDAS	Fairbanks Command and Data Acquisition Station
FCF	Fluids and Combustion Facility
FEMA	Federal Emergency Management Agency
FEWS	Future En Route Workstation
FFRDC	Federally Funded Research and Development Center
FGST	Fermi Gamma-ray Space Telescope
FIR	Fluids Integrated Rack
FSA	Farm Service Agency
FT	Fischer-Tropsch
FTS	Fourier Transform Spectrometer
FWS	U.S. Fish and Wildlife Service
FY	fiscal year

G

GCJV	Gulf Coast Joint Venture
GDP	Gross Domestic Product
GEM	Geospace Environment Modeling
GFL	Global Fiducials Library
GHWG	Global Harmonization Working Group
GHz	gigahertz
GIS	Geographic Information System
GLAM	Global Agriculture Monitoring
GLAST	Gamma-ray Large Area Space Telescope
GLONASS	Global Navigation Satellite System
GLS	Global Land Survey
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRAV-D	Gravity for the Re-definition of the American Vertical Datum
GSFC	Goddard Space Flight Center
GV	Gulfstream V

H

HAB	Harmful Algal Bloom
HEO	Highly Elliptical Orbit
HFI	High Frequency Instrument
HIAPER	High-performance Instrumented Airborne Platform for Environmental Research
HIFI	Heterodyne Instrument for the Far Infrared
HIPPO	HIAPER Pole to Pole Observations
HiRISE	High Resolution Imaging Science Experiment
HITL	Human-in-the-Loop
HRP	Human Research Program
HST	Hubble Space Telescope
HTV	H-II Transfer Vehicle
HyspIRI	Hyperspectral Infrared Imager

I

I&M	Inventory and Monitoring Program
IADS	Integrated Arrival/Departure/Surface
IBC	Individual Blade Control
IBEX	Interstellar Boundary Explorer
IBTrACS	International Best Track Archive for Climate Stewardship
ICG-3	International Committee on Global Navigation Satellite Systems
IEC	International Electrotechnical Commission
IfSAR or InSAR	Interferometric Synthetic Aperture Radar
IGS	International Global Navigation Satellite System Service
IIFD	Integrated Intelligent Flight Deck
IIWG	Interagency Infrastructure Working Group
IOOS®	Integrated Ocean Observing System
IP	International Partner
IPCC	Intergovernmental Panel on Climate Change
IRAC	Integrated Resilient Aircraft Control Project
IRVE-2	Inflatable Reentry Vehicle Experiment
ISDAC	Indirect and Semi-Direct Aerosol Campaign
ISO	International Organization for Standardization

ISOC	Instrument Science Operations Center
ISRSE	International Symposium on Remote Sensing of Environment
ISS	International Space Station
ITA	International Trade Administration
ITAR	International Traffic in Arms Regulations
IVHM	Integrated Vehicle Health Management

J

JAXA	Japan Aerospace Exploration Agency
JDEM	Joint Dark Energy Mission
JPDO	Joint Planning and Development Office
JSpOC	Joint Space Operations Center

K

KACST	King Abdulaziz City for Science and Technology

L

LANDFIRE	Landscape Fire and Resource Management Planning Tools
LAT	Large Area Telescope
LBNL	Lawrence Berkeley National Laboratory
LCROSS	Lunar CRater Observation and Sensing Satellite
LDCM	Landsat Data Continuity Mission
LEO	Low-Earth Orbit
LER	Lunar Electric Rover
LFI	Low Frequency Instrument
LIDAR	LIght Detection And Ranging
LMMP	Lunar Mapping and Modeling Project
LPRP	Lunar Precursor Robotic Program
LRO	Lunar Reconnaissance Orbiter
LSP	Launch Services Program
LSST	Large Synoptic Survey Telescope

M

M3	Moon Mineralogy Mapper
MAF	Michoud Assembly Facility
MENA	Middle East North Africa
MEP	Manufacturing Extension Partnership
MER	Mars Exploration Rover
MERIS	Medium Resolution Imaging Spectrometer
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
Mini-SAR	Miniature Synthetic Aperture Radar
MIT	Massachusetts Institute of Technology
MLAS	Max Launch Abort System
MMC	Multipurpose Marine Cadastre
MMRCA	Medium Multi-Role Combat Aircraft
MMS	Minerals Management Service
MOA	Memorandum of Agreement
MOBY	Marine Optical Buoy
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
MPB	mountain pine beetle

MRLC	Multi-Resolution Land Characteristics
MRO	Mars Reconnaissance Orbiter
MRSA	Methicillin-resistant Staphylococcus Aureus
MSL	Mars Science Laboratory
MSS	Multispectral Scanner
MTBS	Monitoring Trends in Burn Severity
MTS	Marine Transportation System
MWA	Murchison Widefield Array

N

NAIC	National Astronomy and Ionosphere Center
NAIP	National Agriculture Imagery Program
NARSS	National Authority for Remote Sensing and Space Sciences
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service
NCAR	National Center for Atmospheric Research
NCBN	Northeast Coastal and Barrier Network
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NDEP	National Digital Elevation Program
NDOP	National Digital Orthophoto Program
NERSC	National Energy Research Scientific-computing Center
NESC	NASA Engineering Safety Center
NESDIS	National Environmental Satellite, Data, and Information Service
NextGen	Next Generation Air Transportation System
NFMTC	National Force Measurement Technology Capability
NGA	National Geospatial-Intelligence Agency
NGDC	National Geophysical Data Center
NGS	National Geodetic Survey
NIFA	National Institute of Food and Agriculture
NIRSpec	near infrared spectrograph
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Dataset
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NODC	National Oceanographic Data Center
NOS	National Ocean Service
NPAT	National Partnership for Aeronautical Testing
NPOESS	National Polar-orbiting Operational Environment Satellite System
NPP	NPOESS Preparatory Project
NPS	National Park Service
NRA	NASA Research Announcement
NRAO	National Radio Astronomy Observatory
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NRO	National Reconnaissance Office
NSBRI	National Space Biomedical Research Institute
NSCOR	NASA Specialized Center of Research
NSDI	National Spatial Data Infrastructure
NSF	National Science Foundation
NSO	National Solar Observatory

NSOF	NOAA Satellite Operations Facility
NSPO	National Space Organization
NSRL	NASA Space Radiation Laboratory
NSRS	National Spatial Reference System
NSTC	National Science and Technology Council
NSTX	National Spherical Torus Experiment
NSWP	National Space Weather Program
NTX	North-Texas Research Station
NVLAP	National Voluntary Laboratory Accreditation Program
NWS	National Weather Service

O

OAR	Office of Oceanic and Atmospheric Research
OASIS	Optimized Autonomous Space In-Situ Sensor-web
OCO	Orbiting Carbon Observatory
OECD	Organization for Economic Cooperation and Development
OES/SAT	Office of Space and Advanced Technology
OFCM	Office of the Federal Coordinator for Meteorology
OFDA	Office of Foreign Disaster Assistance
OFES	Office of Fusion Energy Sciences
OGA	Office of Global Analysis
OGDR	Operational Geophysical Data Record
OLI	Operational Land Imager
OMAO	Office of Marine and Aviation Operations
OMB	Office of Management and Budget
OMI	Ozone Monitoring Instrument
OPP	Office of Polar Programs
OPUS	Online Positioning User Service
ORS	Operationally Responsive Space
OSC	Office of Space Commercialization
OSM	Office of Surface Mining
OTM	Office of Transportation and Machinery

P

PBO	Plate Boundary Observatory
PJMIF	plasma-jet-driven magnetic-inertial fusion
PLX	Plasma Liner Experiment
PNT	Positioning, Navigation, and Timing
POES	Polar-orbiting Operational Environmental Satellite
PPPL	Princeton Plasma Physics Laboratory

Q

QZSS	Quasi-Zenith Satellite System

R

R&D	research and development
RATS	Research and Technology Studies
RAVAR	Rapid Assessment of Values at Risk
RAX	Radar Aurora Explorer
RDT&E	research, development, test, and evaluation
RHIC	Relativistic Heavy Ion Collider

RMP	resource management plan
RNAV	Area Navigation
RO	radio occultation
RPIF	Regional Planetary Image Facility
RPT	Rocket Propulsion Test
RSAC	Remote Sensing Applications Center
RSIWG	Remote Sensing Interagency Working Group
RTN	Real-Time Networks
RTP	Research Transition Product
RTT	Research Transition Team
RWBJV	Rainwater Basin Joint Venture

S

SAA	Space Act Agreement
SAFIRE	Submillimeter and Far-InfraRed Experiment
SAME	Smoke Aerosol Measurement Experiment
SAO	Smithsonian Astrophysical Observatory
SAR	synthetic aperture radar
SARJ	Solar Alpha Rotary Joint
SARSAT	Search and Rescue Satellite-Aided Tracking
SBIRS	Space Based Infrared System
SC	Office of Science
SCaN	Space Communications and Navigation Program
SciDAC	Scientific Discovery through Advanced Computing
SDO	Solar Dynamics Observatory
SHAAC	Shuttle Hazard Area to Aircraft Calculator
SHINE	Solar, Heliospheric, and INterplanetary Environment
SIA	Satellite Imagery Archive
SLACNAL	Stanford Linear Accelerator Center National Accelerator Laboratory
SMA	Submillimeter Array
SMAP	Soil Moisture Active-Passive
SMD	Science Mission Directorate
SOAR	Summer Opportunity in Aeronautics for High School Scholars
SOCC	Satellite Operations Control Center
SOFIA	Stratospheric Observatory for Infrared Astronomy
SpaceX	Space Exploration Technologies
SPIRE	Spectral and Photometric Imaging Receiver
SQUID	Superconducting Quantum Interference Device
SRM	Standard Reference Materials
SSA	Space Situational Awareness
SSME	Space Shuttle Main Engine
STEM	science, technology, engineering and mathematics
STP	Space Test Program
STSS	Space Tracking and Surveillance System
SuperDARN	Super Dual Auroral Radar Network
SXI	Solar X-Ray Imager

T

TARGETS	Terminal Area Route Generation, Evaluation, and Traffic Simulation
TES	transition-edge sensor
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIR	thermal infrared
TIROS	Television Infrared Observation Satellite

TM	Thematic Mapper
TPW	Total Precipitable Water
TWP	Tropical Western Pacific

U

UAF	Upper Atmospheric Facilities
UARS	Upper Atmospheric Research Section
UAS	Unmanned Aerial System; Unmanned Aircraft System; Uninhabited Aerial Systems
UCAR	University Corporation for Atmospheric Research
UFO	Ultra High Frequency Follow-on
ULA	United Launch Alliance
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USTR	U.S. Trade Representative
UVCS	Ultraviolet Coronagraph Spectrometer

V

VASIMR	Variable Specific Impulse Magneto-plasma Rocket
VDatum	Vertical Datum
VIIRS	Visible Infrared Imager Radiometer Suite

W

WARP	Web-based Access and Retrieval Portal
WLCI	Wyoming Land Conservation Initiative
WRP	Wetland Reserve Program

X

XRT	X-Ray Telescope

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