Aeronautics and Space Report of the President

Fiscal Year 2013 Activities

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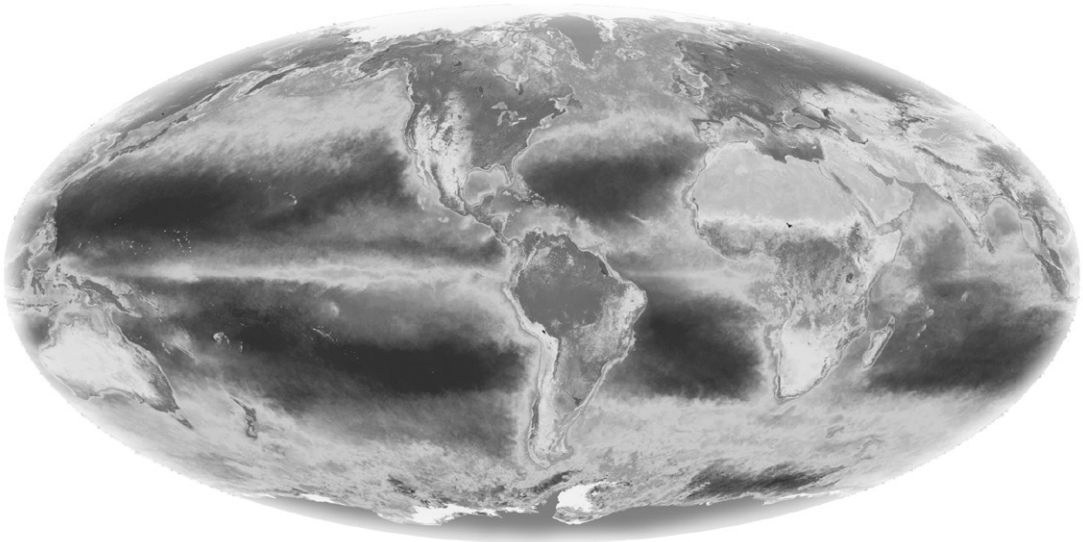

Fiscal Year 2013 Activities

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, 2012, through September 30, 2013. Please note that these activities reflect the Federal policies of that time and do not include subsequent events or changes in policy.

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National Aeronautics and Space Administration

NASA

Human Exploration and Operations Mission Directorate

International Space Station

The International Space Station (ISS) continued its focus on research and technology development in FY 2013, including a major communications systems upgrade to enhance research capabilities. A second new U.S. commercial cargo vehicle, provided by Orbital Sciences Corporation, conducted its demonstration flight to the ISS during FY 2013.

The ISS began FY 2013 with Expedition 33 ISS Commander Suni Williams (NASA), Yuri Malenchenko (Roscosmos), and Aki Hoshide (Japanese Aerospace Exploration Agency [JAXA]) living on board. On October 10, 2012, the SpaceX Dragon vehicle (SpX-1), carrying almost 900 pounds of supplies, was berthed to the Node 2 nadir port, where it remained until October 28, when it departed the ISS and splashed down in the Pacific Ocean off the coast of Baja California. This was the first operational flight of the SpaceX Dragon under the Commercial Resupply Services (CRS) contract, following its successful demonstration flight in May 2012. Since the retirement of the Space Shuttle, the Dragon spacecraft is the only vehicle capable of returning large amounts of cargo, including frozen science samples, from the ISS to Earth. The onboard crew was joined on October 25, 2012, by Kevin Ford (NASA), Oleg Novitskiy (Russia), and Evgeny Tarelkin (Russia), who launched on a Russian Soyuz rocket from the Baikonur Cosmodrome in Kazakhstan. A Russian Progress cargo vehicle carrying several tons of supplies docked to the ISS on

October 31, 2012. Williams and Hoshide conducted a U.S. Extravehicular Mobility Unit (EMU) spacewalk on November 1, 2012, to mitigate an ammonia leak in the cooling system for one of the eight ISS power channels. On November 18, 2012, Williams, Malenchenko, and Hoshide undocked their Soyuz vehicle from the ISS and landed in Kazakhstan, ending Expedition 33.

Expedition 34 began on November 18, 2012. Astronaut and ISS Commander Ford and cosmonauts Novitskiy and Tarelkin remained on board and were joined on December 21, 2012, by Chris Hadfield (Canadian Space Agency [CSA]), Roman Romanenko (Russia), and Tom Marshburn (NASA) when their Russian Soyuz vehicle docked to the ISS. A Russian Progress cargo vehicle carrying several tons of supplies docked to the ISS on February 11, 2013. On March 3, 2013, the SpaceX Dragon vehicle (SpX-2), carrying almost 1,300 pounds of supplies, was berthed to the Node 2 nadir port. Expedition 34 ended on March 15, 2013, when Ford, Novitskiy, and Tarelkin undocked their Soyuz vehicle from the ISS and landed in Kazakhstan.

Expedition 35 began on March 15, 2013. ISS Commander Hadfield, Romanenko, and Marshburn remained on board and were joined on March 29, 2013, by Pavel Vinogradov (Russia), Aleksandr Misurkin (Russia), and Chris Cassidy (NASA) when their Russian Soyuz vehicle docked to the ISS. On March 25, 2013, the SpaceX Dragon (SpX-2) unberthed from the ISS and returned almost 2,700 pounds of equipment and experiments to Earth, splashing down in the Pacific Ocean off the coast of Baja California. Vinogradov and Romanenko conducted a Russian Orlan spacewalk on April 19, 2013, to install the Obstanovka experiment and replace an Automated Transfer Vehicle (ATV) laser radio reflector. They also retrieved a Biorisk experiment container. A Russian Progress cargo vehicle carrying several tons of supplies docked to the ISS on April 26, 2013. Marshburn and Cassidy conducted a U.S. EMU spacewalk on May 11, 2013, to replace a pump package unit suspected of leaking ammonia coolant. Expedition 35 ended on May 13, 2013, when Hadfield, Romanenko, and Marshburn undocked their Soyuz vehicle from the ISS and landed in Kazakhstan.

Expedition 36 began on May 13, 2013. ISS Commander Vinogradov, Misurkin, and Cassidy remained on board and were joined on May 29, 2013, by Fyodor Yurchikhin (Russia), Karen Nyberg (NASA), and Luca Parmitano (European

Space Agency [ESA]) when their Russian Soyuz vehicle docked to the ISS. An ESA Automated Transfer Vehicle (ATV4) named Albert Einstein docked to the Service Module aft port on June 15, 2013, carrying more than seven tons of supplies to the ISS. Misurkin and Yurchikhin conducted a Russian Orlan spacewalk on June 24, 2013, to configure connectors to allow the ground to test the Service Module Kurs automated docking system equipment, perform maintenance on the Functional Cargo Block (FGB) module, and install and retrieve experiments. Parmitano and Cassidy conducted a U.S. EMU spacewalk on July 9, 2013, to perform various systems and experiment support tasks. Parmitano and Cassidy also conducted a U.S. EMU spacewalk on July 16, 2013, completing several tasks before the extravehicular activity (EVA) was ended early due to excessive water in Parmitano's EMU helmet. A Russian Progress cargo vehicle carrying several tons of supplies docked to the ISS on July 28, 2013. On August 9, 2013, JAXA's H-II Transfer Vehicle (HTV4), carrying several tons of supplies, was berthed to the Node 2 nadir port. Misurkin and Yurchikhin conducted a Russian Orlan spacewalk on August 16, 2013, to perform system tasks in support of the future arrival of the Russian Multipurpose Laboratory Module, install the Vinoslivost experiment, and install gap spanners. Misurkin and Yurchikhin also conducted a spacewalk on August 22, 2013, to remove the external onboard laser communications terminal, install a portable workstation, collect particulate samples on the Mini Research Module 2, and inspect antennas. They also unfurled a Russian flag in honor of Russian Flag Day. Expedition 36 ended on September 11, 2013, when Vinogradov, Misurkin, and Cassidy undocked their Soyuz vehicle from the ISS and landed in Kazakhstan.

Expedition 37 began on September 11, 2013. ISS Commander Fyodor Yurchikhin, Nyberg, and Parmitano remained on board and were joined on September 26, 2013, by Oleg Kotov (Russia), Sergey Ryazanskiy (Russia), and Mike Hopkins (NASA). On September 29, 2013, the second U.S. commercial cargo vehicle developed under the Commercial Orbital Transportation Services (COTS) program arrived at the ISS during the vehicle's demonstration flight. Developed by Orbital Sciences Corporation, the Cygnus spacecraft was launched on an Antares rocket from Virginia on September 18, 2013, and completed a series of demonstration objectives prior to its arrival at the ISS. The Cygnus vehicle was captured with the ISS

robotic arm and berthed to the ISS at the Node 2 nadir port. The Cygnus vehicle carried 1,300 pounds of cargo to the ISS.

Research and technology development continued to be the primary focus of operations on board the ISS throughout FY 2013. For the first time, ISS crewmembers achieved an average of at least 35 hours per week for payload investigations on the ISS. In early April, the crew performed a major upgrade to the onboard communications system, significantly increasing uplink bandwidth (from 3 to 25 megabits per second) and downlink bandwidth (from 150 to 300 megabits per second). Downlink video channels increased from four to six, and space-to-ground audio channels increased from two to four. These upgrades enhanced ISS research capabilities and improved the operability of the ISS data systems.

On October 4, 2012, five CubeSat satellites were deployed from the ISS using a multipurpose experiment platform on the Japanese Experiment Module robotic arm, the first-ever satellite deployments from the ISS. Robotic Refueling Mission operations, to successfully demonstrate capabilities for robotic satellite servicing, continued in FY 2013 with the first-ever demonstrations of fluids transfer. The Alpha Magnetic Spectrometer particle physics detector continued to search for antimatter, dark matter, and cosmic rays to better understand the universe. And, for the first time, the standard ISS orientation was modified for an extended period to support full-sun-rotation viewing for the ESA SOLAR experiment.

ISS crewmembers commissioned the JAXA aquatic habitat for first use with the Medaka fish and conducted multiple NanoRacks investigations designed and led by students. Crewmembers initiated investigations on the effects of space radiation on mammalian reproduction systems and embryonic mouse stem cells while also initiating the Ocular Health study to characterize the risk of microgravity-induced visual impairment/intracranial pressure for long-duration ISS inhabitants. The crew also performed the first test of the Microflow cytometer on the ISS, focusing on body fluids and blood. In addition, the crew continued to study the long-term effects of microgravity on ISS crewmembers, including cardiac function, bone loss, immune function, nutrition, and brain function. The new vegetable production system for growing edible plants in microgravity and the NanoRacks Astrium small centrifuge for molecular and cellular investigations on plant and animal tissue in artificial gravity were delivered to the ISS.

In July 2013, the ISS program cohosted the 2nd Annual ISS Research and Development Conference, including awards for top discoveries in microgravity; top applications in materials science, Earth science, education, and medical advancements; and exploration-related technology-development initiatives.

Space Life and Physical Sciences Research and Applications

Human Research Program

In 2013, the Human Research Program (HRP) transitioned to a new NASA Research Announcement (NRA) format in order to be more responsive and flexible and to enable solicitations throughout the year. Historically, one research announcement was issued in July, resulting in the selection of proposals in April of the following year. The Human Exploration Research Opportunities (HERO) NRA is a new solicitation that will remain open year-round, with new research opportunities, or appendices, being issued as needed. In July, the HERO NRA announced four research opportunities, including a Twin Astronaut Studies special topic, "Differential Effects on Homozygous Twin Astronauts Associated with Differences in Exposure to Spaceflight Factors." This opportunity emerged from NASA's decision to fly veteran astronaut Scott Kelly aboard the ISS for a period of one year beginning in March 2015, while his identical twin brother, retired astronaut Mark Kelly, remains on Earth.

A team of seven scientists from the Space Radiation Element and the Universities Space Research Association (USRA) developed a new NASA Space Cancer Risk (NSCR) projection model, which was released in December 2012. The tool evaluates the cancer risks, including the level of uncertainty, for astronauts from exposure to solar particle events and galactic cosmic rays. The NSCR model originated from recommendations of the National Council on Radiation Protection and Measurements, with revisions from the latest analysis of human radio-epidemiology data. The model was independently reviewed by the National Research Council in 2012. The NSCR model was the recipient of the 2013 Johnson Space Center (JSC) Software of the Year Award and is located online at *http://spaceradiation.usra.edu/irModels*.

Long-duration spaceflight is associated with physiologic changes in the body similar to those of disuse or detraining. One of these changes is a decline in aerobic fitness or conditioning. A proven measure of such fitness is maximum oxygen uptake (VO2max), also known as aerobic capacity. While on the ISS, astronauts exercise for about one hour per day in an attempt to maintain their aerobic capacity. For the first time, HRP researchers directly measured VO2max during long-duration spaceflight in 14 astronauts. Each astronaut's VO2max was measured before flight, once a month during flight, and after flight using specially designed hardware. Subjects rode on a cycle ergometer using a protocol that started with a warm-up, followed by incremental increases in workload that ended in a maximal effort. During the test, astronauts wore a nose clip and breathed through a mouthpiece so that all of the expired air was analyzed for oxygen and carbon dioxide, from which VO2max is measured. The study findings lead to several recommendations: exercise sooner, increase intensity, and improve testing. Aerobic exercise countermeasures should start as soon as possible after a crewmember arrives on the ISS, preferably in the first few days. Also, the intensity of the existing exercise countermeasures should be increased. Importantly, the testing strategy should be modified because changes in VO2max could not accurately be detected using the standard test based on heart rate during submaximal exercise.

Lunar geologists and inhalation toxicologists developed a two-tiered approach to investigate the inherent toxicity of lunar dust. A parent sample returned by Apollo 14 was used to isolate native dust of respirable size. Respirable native dust constitutes only a few percent by mass of lunar soil, and it is of great concern because it can be inhaled deeply into the lungs. In addition, a small portion of the parent sample was ground into respirable size to simulate activation of the surface of the dust, as might occur on the lunar surface. The results of the studies led to a recommended safe exposure estimate of 0.5 milligrams per meter (mg/m) as a safe concentration of dust in a habitable environment for periodic exposures of up to six months. The original 300-fold gap in uncertainty was reduced to essentially no uncertainty. However, the recommended exposure is likely a conservative value and should not be applied to dust from unusual locations on the moon. In FY 2013, this research was published in a series of three papers in volume 25 of the journal *Inhalation Toxicology*, which can be accessed online at *http://informahealthcare.com/journal/iht*.

ISS Research—Space Biology and Physical Sciences

The organization selected by NASA to manage non-NASA utilization of the ISS National Laboratory, the Center for the Advancement of Science in Space (CASIS), established a new Board of Directors composed of national leaders in research and technology development. The board is chaired by France Cordova, former president of Purdue University and former NASA Chief Scientist. Other members include Dr. Leroy Hood, president of the Institute for Systems Biology and a recipient of the National Medal of Science for his contributions to DNA sequencing technology, among other accomplishments.

Efforts to define open-source approaches to ISS research that will make experimental data available to an expanded community of researchers progressed in 2013, with a workshop jointly sponsored by NASA and CASIS to discuss applications of high-throughput analytics, often referred to as "Omics," to ISS research in biology and medicine. The results from the workshop were used to build working relationships between NASA and CASIS for the eventual implementation of open-source research on the ISS.

Exploration Systems Development

An Integrated Exploration Mission

The President's Fiscal Year 2014 budget request continued to implement the bipartisan strategy for space exploration approved by Congress in 2010, a plan that advances U.S. preeminence in science and technology, improves life on Earth, and protects our home planet, all while helping create jobs and strengthening the American economy. This budget reflected current fiscal realities by aligning and leveraging relevant portions of NASA's science, space technology, and human exploration capabilities to achieve the President's challenge of sending astronauts to an asteroid by 2025. Within the Human Exploration and Operations (HEO) Mission Directorate (HEOMD), Exploration Systems Development (ESD) is continuing NASA's exploration efforts, which include the Orion spacecraft, Space Launch System (SLS) heavy-lift launch vehicle, and Exploration Ground Systems (EGS) infrastructure required to conduct crewed missions of exploration into deep space, including a proposed mission to send astronauts to a redirected asteroid

that would be inserted into a stable orbit around the moon. Orion and SLS fit well within a broader U.S. Government–managed launch strategy of procuring commercial launches of crew and cargo to the ISS while concentrating NASA's development efforts on exploration missions beyond Earth orbit. SLS and Orion are fundamental building blocks in a capability-based architecture designed for long-term human exploration of our solar system, particularly the goal of landing humans on Mars. Both Orion and SLS are being designed to support multiple missions and destinations rather than being optimized for one particular mission or architecture. The capabilities being developed will open a broad range of exciting destinations for human exploration in the solar system. NASA's approach to expanding the human presence into the solar system includes sending humans to an asteroid in the next decade and ultimately sending humans to Mars.

As part of the Agency's overall asteroid strategy, NASA announced in April 2013 a first-ever mission to identify, capture, and redirect an asteroid into orbit around the moon. The overall mission is composed of three separate and independently compelling elements: the detection and characterization of candidate near-Earth asteroids; the robotic rendezvous, capture, and redirection of a target asteroid to the Earth-Moon system; and the crewed mission to explore and sample the captured asteroid using the Space Launch System and the Orion crew capsule. This mission represents an unprecedented technological challenge—raising the bar for human exploration and discovery while helping protect our home planet and bringing us closer to a human mission to Mars in the 2030s. NASA is currently working to align ongoing activities across the Agency to affordably achieve the objectives while we plan this mission. Continued progress will depend on feasibility, affordability, and congressional support. The President's budget request augments existing activities in space technology, science, and human exploration and operations to enhance our near-Earth asteroid detection and characterization assets; accelerate advanced solar-electric-propulsion development; and design and test capabilities to capture a small, yet slowly tumbling asteroid in space.

Exploration Systems Development: NASA is continuing to meet its milestones in the development of the Space Launch System, a rocket system ultimately capable of bringing an unprecedented 130 metric tons of payload to Earth orbit, and the Orion Multi-Purpose Crew Vehicle (MPCV) program, which continues

on schedule for an uncrewed test flight in 2014. This test flight, Exploration Flight Test-1 (EFT-1), will see Orion conduct two orbits of Earth and re-enter the atmosphere at a high speed characteristic of a returning deep space exploration mission. The test will provide valuable data about the spacecraft's systems, including, most importantly, its heat shield. The flight test article for this mission is already in place at the Kennedy Space Center (KSC) and being readied for this test in the fall of 2014. NASA's budget supports progress toward a first uncrewed test of Orion and the SLS together, known as Exploration Mission-1 (EM-1) in 2017, with the first crewed mission of the two vehicles slated for 2021. These two missions will test and demonstrate these systems. Together, the SLS and Orion represent a critical step on the path to human deep space exploration. Because our commercial space partners continue to make rapid and cost-effective progress toward meeting the Agency's requirements for access to the ISS and to low-Earth orbit, NASA is able to focus its human Orion spacecraft on deep space exploration.

Orion: In December 2012, NASA and the European Space Agency (ESA) signed a Memorandum of Understanding under which ESA will provide a service module for the Orion EM-1 mission, currently scheduled to launch in 2017. Also, during FY 2013, NASA completed a major space technology development milestone by successfully testing a pressurized, large cryogenic propellant tank made of out-of-autoclave composite materials. Switching to composite construction could lead to rocket propellant tanks that are 30 percent lighter and cost 25 percent less than state-of-the-art metal tanks. Such a weight reduction would dramatically increase the performance capabilities of future space systems, such as an upgrade to the upper stage of the SLS heavy lift rocket. Other recent accomplishments include the following: the Heat Shield structure was completed and shipped to KSC to await installation on EFT-1; the Launch Abort System was completed; the Service Module and Spacecraft Adaptor were mated; and the Spacecraft Adaptor Jettison Fairing Separation Test took place. Between 2011 and 2013, nine successful parachute tests were conducted. During August 2013, the first Orion stationary recovery test in Norfolk, Virginia, occurred. In November, Orion powered on for the first time at KSC. Orion continues to work with ESA on completing the Service Module Structural Test Article. In designing for challenging deep space missions, the Orion team will perform rigorous human-rating tests and critical certification

milestones required for safe, successful human spaceflight. With a proven launch abort system and its inherent design to provide the highest level of safety for the crew during long-duration missions, the Orion MPCV is poised to take on increasingly challenging missions that will take human space exploration beyond Earth orbit and out into the solar system.

SLS: During 2013, the A-1 Test Stand at Stennis Space Center (SSC) began its conversion to support testing of the RS-25 rocket engine, which will begin in spring 2014. All foundation work for the Core Stage Vertical Assembly Center (VAC) tool at Michoud Assembly Facility (MAF) in Louisiana has been completed. The VAC tools were shipped from Sweden in three sequential shipments, concluding in December. Also during 2013, Boeing continued to make progress on core stage engineering, with over 220 drawings released each month, including drawings for 70 percent of the total core stage mass that have been released. Painting of the Orion Stage Adapter was completed on schedule to support the EFT-1 launch. SLS has also installed the Core Stage Flight Computers in the Integrated Avionics Test Facility, and testing will begin in spring 2014. Weld tools that are now operational include the Segmented Ring Tool, Vertical Weld Center, and Enhanced Robotic Weld Tool. The program continues to progress toward its Critical Design Review (CDR), which is scheduled for March 2015.

Exploration Ground Systems: In FY 2013, Ground Systems continued to develop launch site infrastructure to prepare, assemble, test, launch, and recover the SLS and Orion flight systems. The program conducted a Preliminary Design Review (PDR) Readiness Assessment on December 17, with the PDR kickoff planned for January 2014. NASA performed crawlerway upgrades to repair the degradation of base material and surface rocks to eliminate risks associated with transportation of launch vehicles to Pads A and B for multiple users. The demolition of the Shuttle-era flame trench at Pad B is also under way and on schedule. During 2013, NASA continued to establish and develop 21st Century Space Launch Complex (CSLC) partnerships aimed at understanding Government and commercial ground processing, launch, and range infrastructure requirements while implementing the modifications identified during studies conducted in FY 2011 and FY 2012. NASA has also pursued opportunities to partner or leverage investments for modernization activities to support safer and more efficient launch operations,

enhance payload-processing capabilities, facilitate appropriate private-sector activities, engage in operations environmental remediation, and support the modernization of launch-range capabilities. Area communication and security systems were upgraded to bring them up to date with current technology, such as digital imaging, by utilizing newly installed connectivity. NASA has also been executing temperature and lighting upgrades in heritage facilities to reduce utility costs, constructing waste facilities for oily wastewater and other hazardous materials, and performing studies and tests to develop effective, environmentally friendly coatings for launch equipment and chemical treatments to neutralize hypergolic fuels to an inert state.

Commercial Crew Development

The Commercial Crew Program facilitates U.S. commercial industry development of safe, reliable, and cost-effective human space transportation to and from low-Earth orbit and the International Space Station. During 2013, our commercial partners continued to make progress maturing their respective commercial crew transportation systems.

CPC contractors include the following: The Boeing Company, Houston, Texas; Sierra Nevada Corporation Space Systems, Louisville, Colorado; and Space Exploration Technologies Corp. (SpaceX), Hawthorne, California. Our three partners are successfully completing technical, programmatic, and financial milestones as they mature their respective commercial crew transportation systems.

- Boeing completed its production design review, phase 1 safety review board, landing and recovery ground systems design review, launch vehicle adapter Preliminary Design Review, integrated vehicle analysis and wind tunnel testing, upper-stage liquid-oxygen-duct development testing, and orbital-maneuvering engine-development testing. Additionally, Boeing released the second major revision to its integrated software.
- Sierra Nevada completed its integrated baseline review and the integrated system safety analysis review #1.
- SpaceX completed its integrated system requirements review, ground systems and ascent Preliminary Design Review, pad-abort test review,

human-certification-plan review, on-orbit and entry Preliminary Design Review, and the inflight-abort-test review.

Also in FY 2013, NASA awarded the first phase of commercial transportation Certification Products Contracts (CPC). Under these contracts, our partners will work with NASA to develop products required to implement the Agency's flight safety and performance requirements. This includes implementation across all aspects of the space system, including the spacecraft, launch vehicle, and ground and mission operations.

Launch Services

During FY 2013, the Launch Services Program (LSP) successfully launched three major payloads: the Tracking and Data Relay Satellite (TDRS)-K, the Landsat Data and Continuity Mission (LDCM), and the Interface Region Imaging Spectrograph (IRIS). The TDRS-K and LDCM missions presented a particular challenge for LSP, as they were launched less than 12 days apart from opposite coasts. TDRS-K launched aboard an Atlas V from Cape Canaveral Air Force Station in Florida on January 31, 2013, and LDCM lifted off from Vandenberg Air Force Base (VAFB) in California, also aboard an Atlas V, on February 11. Supporting both launches tested LSP's scheduling and resource management capabilities, and the program responded with two resounding successes that further vital science and technology. The LSP also continued to provide launch-related systems engineering, launch integration, and mission design and analysis support to approximately 35 NASA-sponsored missions in various phases of development. To find out more about these and other NASA science missions, see the Science Mission Directorate (SMD) section in this report.

The LSP continued its efforts to expand the selection of launch vehicles, working across the launch-vehicle industry to support the continued growth of the U.S. commercial space sector by providing competitive opportunities to U.S. commercial launch providers. In FY 2013, the program acquired launch services for two future science missions: the Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx) and the Ice, Cloud, and land Elevation Satellite (ICESat-2). Both will be launched by United Launch

Services: OSIRIS-REx aboard an Atlas V from Cape Canaveral Air Force Station in Florida, and ICESat-2 aboard a Delta II from Vandenberg Air Force Base in California. NASA and LSP are also partnering with several universities to launch small research satellites through the Educational Launch of Nanosatellites project and the CubeSat Launch Initiative, which provides opportunities for small satellite payloads to fly as secondary payloads on upcoming launches. These payloads provide educational opportunities for students in science, technology, engineering, and mathematics disciplines. CubeSats have been selected from 25 states across the United States, with 29 launched and 11 manifested on NASA, National Reconnaissance Office, and U.S. Air Force missions. To provide additional launch options for small civil-sector payloads and to promote the continued evolution of the U.S. commercial space launch market, LSP released a solicitation for a CubeSat-class, firm-fixed-price launch service. NASA awarded a contract to Generation Orbit Launch Services, Inc., for three CubeSats in 2016. This contract is a pathfinder for acquiring future launch services for low-cost and/or high-risk-tolerant payloads. The LSP is also continuing to lead the certification effort of SpaceX's Falcon 9 v1.1-configuration launch vehicle for flight readiness in support of the Science Mission Directorate's Jason-3 mission in 2015.

Human Spaceflight Capabilities

By the end of FY 2013, the Rocket Propulsion Testing (RPT) program had safely performed over 349 tests. This was a 300 percent increase over 2012. The test time totaled over 270,000 seconds of testing and over 13,000 seconds of hot-fire testing at various levels of thrust.

The J-2X engine (a new upper-stage rocket) completed its testing series on the A-1 test stand at Stennis Space Center, culminating with a 330-second test in early September 2013. The first human-rated liquid-oxygen/liquid-hydrogen rocket engine to be developed in 40 years, the J-2X upper stage engine is a candidate for the heavy-lift Space Launch System. This capability is critical to NASA's deep space exploration program development.

The Orbital Sciences Corporation and Aerojet Rocketdyne conducted test firings of the AJ-26 engine at Stennis Space Center. This engine was used on

the Orbital Antares rocket that successfully launched in September 2013 from NASA's Wallops Flight Facility (WFF) and supports the Commercial Orbital Transportation Services project.

Marshall Space Flight Center (MSFC) tested the F-1 gas generator for the SLS Advanced Booster Engineering Demonstration Risk Reduction Program. This program is designed to lead to an affordable advanced booster that meets the evolved capabilities of the heavy lift SLS.

Boeing conducted testing of its orbital maneuvering and reaction control system thruster at the White Sands Test Facility in support of NASA's Commercial Crew Program. White Sands Test Facility engineers conducted several tests to support the Department of Defense (DOD) Missile Defense Agency engine and thruster test program, the Peacekeeper Safing Project, and the Minuteman hot-fire test and decontamination efforts for the Minuteman Life Extension Program.

NASA completed limited facility repairs and modifications to the Plum Brook Station B-2 facility at Glenn Research Center (GRC) to enable NASA's only thermal vacuum facility capable of testing articles containing cryogenic oxygen and hydrogen. In addition, Stennis Space Center continues major refurbishment activities for the B-2 test stand critical to SLS core stage testing. Stennis Space Center began the first phase of refurbishing the High Pressure Industrial Water (HPIW) system, which provides cooling, deluge, and acoustic dampening for test articles. The HPIW has the capability to provide 300,000 gallons per minute at nearly 300 pounds per square inch.

Space Communications and Navigation

In FY 2013, the Space Communications and Navigation (SCaN) Program Office focused on the critical sustainability and development of the ground and space components of the networks that provide space communications for NASA's missions. The three networks—the Near Earth Network (NEN), the Space Network (SN) Tracking and Data Relay Satellite System (TDRSS), and the Deep Space Network (DSN)—continued to meet the space communications needs, such as Earth monitoring and support of deep space science missions, of a wide range of customers, both internal and external to NASA.

In FY 2013, SCaN maintained at least 99 percent proficiency of all of its networks, providing communication and navigation services to approximately 35 spacecraft using the Deep Space Network, approximately 30 spacecraft using the Space Network, and approximately 30 spacecraft using the Near Earth Network. The Near Earth Network also provided communication and navigation services to approximately 25 launches during launch and early orbit phases.

The Deep Space Network is an international network of antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The network also supports selected Earth-orbiting missions. The Space Network consists of a space segment, composed of the Tracking and Data Relay Satellite System, and a ground segment, which includes the White Sands Test Facility in New Mexico and the Guam Remote Ground Terminal. Data from the satellites and the International Space Station are downlinked to the ground segment. The Near Earth Network provides tracking, telemetry, and communications services, using antenna assets located around the world, for orbital missions and occasionally suborbital missions.

SCaN completed some key milestones during FY 2013:

- SCaN Program System Engineering decided upon the requirements for integrating the three networks, which will be incrementally accomplished during the rest of the decade.
- The TDRS-K spacecraft successfully launched and achieved its initial operating capability, and the TDRS-L spacecraft successfully completed its Pre-Ship review.
- TDRS-M successfully held its Critical Design and Production Readiness Reviews.
- The Space Network Ground Segment Sustainment project successfully completed its technical Critical Design Review.
- The Near Earth Network project successfully passed its K-Band Mission Concept Review.
- The Deep Space Network Aperture Enhancement Project successfully completed its system-level Critical Design Review.
- The Lunar Laser Communication Demonstration payload was successfully launched on the Lunar Atmosphere and Dust Environment Explorer

(LADEE) and completed its technical objective of transmitting over 600 million bits per second from the moon.

- The Laser Communications Relay Demonstration project successfully held its Mission Concept Review.
- The SCaN Test Bed achieved operational capability and began testing ways to change the functionality of radios during spaceflight.
- The Spectrum Management Program continued to work with the White House, Congress, national regulators, and interagency partners in implementing the President's Broadband Initiative. NASA led the Executive Branch's efforts in several technical compatibility studies, the most critical of which focused on the compatibility of introducing new commercial broadband systems in S-band spectrum occupied by TDRSS.
- The Consultative Committee for Space Data Systems (CCSDS) is a major international organization that develops internationally agreed and interoperable space communications standards that enable joint international missions and reduce cost and risk to space missions. In 2013, SCaN engineers led CCSDS working groups in completing many new standards, including the Conjunction Data Message (CDM) international standard that prevents satellite collisions and the resulting space debris.

Advanced Exploration Systems

The Advanced Exploration Systems (AES) Program is pioneering new approaches for high-priority capabilities needed for human exploration through rapidly developing prototype systems, demonstrating key capabilities in flight, and validating operational concepts.

In FY 2013, AES continued the successful execution of 27 projects with 64 program-level milestones spread across nearly all the NASA Centers. The team accomplished 46 milestones on schedule and within the available resources in AES. This was accomplished despite an extremely challenging sequestration budget environment that included a reduction of over 20 percent in budget authority and final budget impacts remaining unknown until the last two months of the execution year.

These milestones included the following:

- AES awarded a fixed-price cost-sharing contract to conduct an expandable habitat demonstration on the ISS with Bigelow Aerospace. This represented the first cost-sharing technology demonstration contract awarded by the Agency to provide valuable in-orbit performance data to NASA and industry. In addition, AES awarded a fixed-price contract for the passive common berthing mechanism to enable berthing of the Bigelow module to the ISS, the first contract of this type awarded by NASA. Since the awarding, the effort has completed four burst tests, demonstrating a factor of safety that is more than double the required levels and finishing the Phase 1 Safety Review for the ISS.
- AES awarded the Z-2 Suit garment contract to continue the development and risk reduction for future exploration spacesuits. This effort under AES's leadership also accomplished the design, development, and assembly of the first portable life-support system to be completed by NASA in 30 years, a significant leap forward in the development of the life-support systems required for EVA. Underwater tests of a modified Advanced Crew Escape Suit were conducted to develop short-duration EVA capabilities for asteroid exploration.
- AES's Spacecraft Fire Safety flight demonstration effort completed the Mission Concept Review, Requirements Review, Project Technical Review-1, and final material testing confirmation. Flight demonstrations remain on schedule aboard three Cygnus vehicle cargo flights to the ISS.
- The Radiation Protection efforts completed delivery and began operations of five flight sensors to the ISS that characterize the radiation exposure information of the crew. In addition, the Critical Design Review and flight hardware assembly were completed for the Radiation Environmental Monitor on EFT-1.
- The Morpheus/Autonomous Landing and Hazard Avoidance Technology (ALHAT) efforts recovered from a test failure in August of 2012 by rebuilding a completely new test vehicle with over 70 upgrades and purchasing the required elements for a third vehicle. The result was a successful tethered test campaign of the new vehicle, with free-flight tests

planned to begin in early FY 2014. The ALHAT system's hazard identification and avoidance capabilities were demonstrated in a helicopter flight test.

- AES Resource Prospector Mission planning progressed significantly this year with the completion of a Mission Concept Review in September 2013. This included significant studies with potential international partners and continued development of the NASA elements of the mission. To support these efforts, AES released a request for information in July for potential NASA-industry partnerships to develop an industry-led robotic lunar lander.
- As part of our ongoing Joint Robotic Precursor Activities, AES strengthened our coordination with the Science Mission Directorate by providing a HEO instrument-selection team to support the Mars 2020 mission formulation. This led to the Mars 2020 Science Definition Team accepting the proposed HEO instrument contribution to demonstrate oxygen production from the Martian atmosphere. This capability is needed for future human missions to produce the propellants for the trip back to Earth.
- In response to the Strategic Implementation Planning efforts for the ISS, AES conducted an inclusive review of all demonstrations, which resulted in increasing support to efforts that are fundamental in advancing exploration capabilities through demonstrations on the ISS. An example is an additive manufacturing demonstration on the ISS that began development in 2013.
- AES led the Agency's efforts to define the Strategic Knowledge Gaps for the moon, asteroids, and Mars by enlisting the expertise of external assessment groups and the international community through the International Space Exploration Coordination Group (ISECG).
- AES is supporting NASA's Asteroid Redirect Mission (ARM) by leading studies and preliminary efforts to develop the asteroid capture system and crew interaction systems for asteroid exploration. This included providing the core leadership for the Asteroid Initiative Request for Information released on June 18 that gathered ideas from a broad community on ARM system concepts, augmenting Near Earth Asteroid observation

capabilities and partnering approaches for planetary defense. Over 400 responses were received.

- AES released the 14-nation ISECG Global Exploration Roadmap, second edition, and created synergy with International Space Station partnership planning with a set of common goals, a unified path for future international human exploration initiatives, identification of near-term collaboration opportunities, and two global outreach events.
- AES led the creation of the international white paper on the benefits of space exploration, for use by international space agencies to assist with communication within their home countries and inform political and budgetary processes.

Other notable AES accomplishments include leading a partnership between NASA and the private sector to define common goals and industry objectives that could enable future human exploration. Twenty-four more CubeSats were selected under the CubeSat Launch Initiative, with 20 satellites preparing for launch in 2013. Three CubeSat payloads were selected for flight on the EM-1 mission in 2017.

The deep space habitat project continued university engagement through the eXploration Habitat (X-Hab) Academic Innovation Challenge. Additional ongoing efforts include the Goldstone Radar imaging campaign of near-Earth asteroids and the continued operation of the Radiation Assessment Detector (over one year) on the Mars Science Laboratory (MSL) mission, which resulted in two papers published in the journal *Science*.

Science Mission Directorate

NASA's Science Mission Directorate (SMD) conducts scientific exploration enabled by the use of space observatories and space probes that view Earth from space, observe and visit other bodies in the solar system, and peer out into our galaxy and beyond. From space, in space, and about space, NASA's science vision encompasses questions as practical as hurricane formation, as enticing as the prospect of lunar resources, and as profound as the origin of the universe. SMD seeks answers to significant questions that touch us all: How and why are Earth's climate and environment changing? How and why does the sun vary and affect Earth and

the rest of the solar system? What are the impacts on humanity? How do planets and life originate? What are the characteristics of planetary systems orbiting other stars, and do they harbor life? Are we alone?

SMD has five program divisions: Earth Science, Heliophysics, Planetary Science, Astrophysics, and the Joint Agency Satellite Division (JASD). SMD also has a James Webb Space Telescope (JWST) program office. In FY 2013, SMD successfully launched three new space and Earth science missions designed to improve our understanding of solar processes, Earth system change, the nature of the universe, and the history of the solar system. SMD lays the intellectual foundation for the robotic and human expeditions of the future while meeting today's needs for scientific information to address national issues such as climate change, space weather, and education.

Earth Science Division

Earth is a complex, dynamic system we do not yet fully understand. The Earth system, like the human body, comprises diverse components that interact in complex ways. We need to understand the Earth's atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere as a single connected system. The purpose of NASA's Earth Science program is to develop a scientific understanding of Earth's system and its response to natural or human-induced changes, in addition to improving the prediction of climate, weather, and natural hazards.

In November 2012, an international team of experts supported by NASA and ESA combined data from multiple satellites and aircraft to produce the most comprehensive and accurate assessment of current ice sheet losses in Greenland and Antarctica and their contributions to sea-level rise. The combined rate of melting for the ice sheets covering Greenland and Antarctica increased greatly during the last 20 years. Together, these ice sheets are losing more than three times as much ice each year as they were in the 1990s. About two-thirds of the loss is coming from Greenland, with the rest from Antarctica. The study was produced by an international collaboration—the Ice Sheet Mass Balance Intercomparison Exercise—that combined observations from 10 satellite missions to develop the first consistent measurement of polar ice-sheet changes. Satellite

data from NASA's Ice, Cloud, and land Elevation Satellite (ICESat) and the NASA–German Aerospace Center's Gravity Recovery and Climate Experiment (GRACE) missions were included in the study. This activity was a major challenge involving cutting-edge research to produce the most detailed estimates of ice loss from Greenland and Antarctica to date.

On January 17, 2013, an international research team led by an investigator from NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, analyzed more than a decade of satellite microwave radar data collected between 2000 and 2009 over Amazonia. The observations included measurements of rainfall from NASA's Tropical Rainfall Measuring Mission (TRMM) and measurements of the moisture content and structure of the forest canopy (top layer) from the SeaWinds scatterometer on NASA's Quick Scatterometer (QuikSCAT) spacecraft. An area of the Amazon rainforest twice the size of California continued to suffer from the effects of a mega-drought that began in 2005. These results, together with observed recurrences of droughts every few years and associated damage to the forests in southern and western Amazonia in the past decade, suggest that the rainforests might be showing the first signs of potential large-scale degradation due to climate change. The scientists found that during the summer of 2005, more than 270,000 square miles (700,000 square kilometers, or 70 million hectares) of pristine, old-growth forest in southwestern Amazonia experienced an extensive, severe drought. This mega-drought caused widespread changes to the forest canopy that were detectable by satellite.

In partnership with the U.S. Geological Survey (USGS), NASA launched the Landsat Data Continuity Mission (LDCM) on February 11, 2013, adding a new chapter to an enduring program to monitor land change over time. LDCM (later renamed to Landsat 8) provides images of our ever-changing planet in unparalleled clarity. The Landsat data series, begun in 1972, has provided the longest continuous record of changes in Earth's surface as seen from space and is the only satellite system to repeatedly observe the global land surface at moderate resolution. Landsat data provide a consistent and reliable foundation for research on land-use change, forest health, and carbon inventories, as well as changes to our environment, climate, and natural resources. Additionally, the free and open access to Landsat data enables the measurements to be used routinely by decision makers

both inside and outside the Government for a wide range of natural resource issues, including water resource management, wildfire response, agricultural productivity, rangeland management, and the effects of climate change. For example, Landsat 8 contributed to finding the coldest place on Earth—a high ridge in Antarctica on the East Antarctic Plateau where temperatures in several hollows can dip below –133.6 degrees Fahrenheit (–92 degrees Celsius) on a clear winter night. Scientists made the discovery while analyzing the most detailed global surface temperature maps to date developed with data from remote sensing observations from Landsat 8. Researchers analyzed 32 years' worth of data from several satellite instruments, including those on Landsat 8, and found that temperatures plummeted to record lows dozens of times in clusters of pockets near a high ridge between Dome Argus and Dome Fuji, two summits on the ice sheet known as the East Antarctic Plateau.

In June 2013, a new dataset called Bedmap2 was released, giving a clearer picture of Antarctica from the ice surface to the bedrock below. This dataset is critical to improving knowledge of the contribution of Antarctica to sea-level change. Researchers used data from satellites, aircraft, and surfaced-based surveys to build a data product with higher resolution, greater coverage, and improved precision of surface elevation, ice thickness, and bedrock topography. Major contributions came from ICESat (surface elevation measurements) and the Operation IceBridge aircraft mission (ice-thickness data). The Bedmap2 project involved an international consortium led by the British Antarctic Survey and involving many NASA-supported scientists.

Heliophysics Division

NASA's Heliophysics program seeks to understand the sun, heliosphere, and planetary environments as a single connected system. We live in the extended atmosphere of an active star; while sunlight enables and sustains life, the sun's variability produces streams of high-energy particles and radiation that can harm life or alter its evolution. In addition to solar processes, the Heliophysics domain of study includes the interaction of solar plasma and radiation with Earth, the other planets, and the galaxy. By analyzing the connections between the sun, solar wind, planetary space environments, and our place in the galaxy, we are uncovering the

fundamental physical processes that occur throughout the universe. Understanding the connections between the sun and its planets will allow us to predict the impacts of solar variability on humans, technological systems, and the presence of life itself.

During January 2013, scientists released 20 balloons in Antarctica, each eight stories tall, to help answer an enduring space weather question: When the giant radiation belts surrounding Earth lose material, where do the particles actually go? The NASA-funded mission was called BARREL, or Balloon Array for Radiation-belt Relativistic Electron Loss. During this month of bright, sunny days, the BARREL team launched a balloon every one or two days into the circumpolar winds. Each balloon floated for anywhere from 3 to 40 days, measuring x-rays produced by fast-moving electrons high up in the atmosphere. BARREL worked hand in hand with NASA's Van Allen Probes, which travel directly through the Van Allen radiation belts during their orbit of Earth. As the Van Allen Probes were observing an increase in waves and a decrease in the number of electrons in the belts, BARREL tracked electrons that precipitated out of the belts and hurtled down Earth's magnetic field lines toward the poles. These measurements from the different vantage points of the balloons in the atmosphere and satellites in space help us understand the ultimate fate of these energetic particles that can damage space assets in their path.

A coronal mass ejection (CME) impacted Earth's magnetosphere for several hours on January 17, 2013. As the CME encountered the boundary of the magnetosphere, its magnetic fields and those around Earth realigned in a process called magnetic reconnection, which allows energy and solar particles to enter into the magnetosphere. Three of NASA's THEMIS (Time History of Events and Macroscale Interactions during Substorms) spacecraft were flying through the magnetosphere's boundary approximately 45 minutes apart and caught this interaction. THEMIS showed that an arm of cold, dense plasmasphere material stretched all the way up to the magnetic reconnection point where the CME had made contact with Earth's magnetopause. The three sets of THEMIS observations demonstrated that the plume had a dramatic impact on the characteristics of the magnetic reconnection, effectively slowing down the transfer of energy and particles into the magnetosphere. Understanding how the near-Earth space responds to the dynamic

conditions on the sun and in the solar wind is key to understanding how to protect our orbiting spacecraft from the effects of space weather.

On May 13, 2013, NASA's Aeronomy of Ice in the Mesosphere (AIM) satellite detected polar mesospheric clouds (PMCs) at latitude 70° north, a week or more sooner than they appeared in the previous six years as observed by AIM. PMCs, Earth's highest clouds, are a summer phenomenon, occurring at polar latitudes when temperatures become cold enough for ice to form near the mesopause (~84 kilometers altitude). There are two ways that clouds could have occurred so early. First, the air could have been unusually moist. However, AIM measures the water vapor content simultaneously with the ice layers and saw nothing unusual. It is more likely that temperature is the culprit. The AIM observations show that temperatures associated with the PMCs were as much as 10 degrees Celsius lower than the average for that day near 83 kilometers altitude. In addition, the NASA Aura Earth science spacecraft's Microwave Limb Sounder instrument has been measuring global temperatures at mesopause altitudes since 2005, and these data show that 2013 was much colder than all the previous years since AIM was launched. This early start was puzzling because it occurred when the output of the sun is at the maximum of its 11-year solar cycle. The unexpected behavior of the clouds could be a response to changes in the global circulation highlighting how connections between different layers of the atmosphere operate over great distances. The ability to study these connections is likely to lead to a new understanding of how our atmosphere works.

The Interface Region Imaging Spectrograph (IRIS) launched into space on June 27, 2013, to begin a two-year quest to probe some of the sun's biggest mysteries. After a 60-day checkout period in orbit, IRIS revealed that the region located between the surface of the sun and its atmosphere is a more turbulent place then previously understood. IRIS made it possible to study the explosive phenomena in the sun's interface region in sufficient detail to determine the phenomena's role in heating the outer solar atmosphere. The mission's observations also opened a new window into the dynamics of the low solar atmosphere that play a pivotal role in accelerating the solar wind and driving solar-eruptive events.

On July 10, 2013, NASA reported what had long been suspected: our heliosphere, the area of the sun's influence created by the solar wind, has a tail like a

comet. A comet moving through the inner solar system leaves particles to form streams trailing off behind it. But, the tail of our heliosphere has never actually been observed until now. NASA's Interstellar Boundary Explorer, or IBEX, mapped the boundaries of the tail of the heliosphere in the "light" of neutral atoms, something that had never before been possible. Scientists described this tail, called the heliotail, in detail in a paper published on July 10, 2013, in *The Astrophysical Journal*. By combining observations from the first three years of IBEX imagery, the team mapped out a tail that shows a combination of fast- and slow-moving particles. There are two lobes of slower particles on the sides and faster particles above and below, with the entire structure twisted as it experiences the pushing and pulling of magnetic fields outside the heliosphere. Based on the map of the heliotail they have now provided, an observer looking straight down the tail sees a shape a little like a four-leaf clover. This shape makes sense, given the fact that the sun has been sending out mostly fast solar wind near its poles and slower wind near its equator for the last few years—a common pattern in the most recent phase of the sun's 11-year activity cycle.

NASA's Van Allen Probes discovered a particle accelerator in the heart of Earth's radiation belts on July 25, 2013. The discovery that the particles are accelerated by a local energy source is akin to the discovery that hurricanes grow from a local energy source, such as a region of warm ocean water. The Van Allen Probes were designed to distinguish between two broad possibilities on what processes accelerate the particles to such amazing speeds: local acceleration or radial acceleration. In radial acceleration, particles are transported perpendicular to the magnetic fields that surround Earth, from areas of low magnetic strength far from Earth to areas of high magnetic strength near Earth, picking up speed much the way a rock rolling downhill gathers speed simply due to gravity. This discovery of local acceleration was one of the most highly anticipated and exciting results from the Van Allen Probes. This discovery also brings us closer to being able to predict space weather conditions and its effects.

On September 12, 2013, NASA announced that the Voyager 1 spacecraft had officially become the first humanmade object to venture into interstellar space. New and expected data indicated Voyager 1 had traveled for about one year through plasma, or ionized gas, present in the space between stars, suggesting

that the spacecraft had crossed into interstellar space in the summer of 2012. Voyager is in a transitional region immediately outside the heliosphere, where some effects from our sun are still evident. Voyager 1 first detected an increased pressure of interstellar space on the heliosphere in 2004. Scientists then ramped up their quest for evidence of the spacecraft's interstellar arrival, knowing the data analysis and interpretation could take months or years. Voyager 1 does not have a working plasma sensor, so scientists needed a different way to measure the spacecraft's plasma environment to make a definitive determination of its source. A coronal mass ejection, or a massive burst of solar wind and magnetic fields, that erupted from the sun in March 2012 provided scientists with the data they needed. When this infrequent gift from the sun eventually arrived at Voyager 1's location 13 months later, in April 2013, the plasma around the spacecraft began to vibrate like a violin string. On April 9, 2013, Voyager 1's plasma-wave instrument detected these waves. The pitch of the oscillations helped scientists determine the density of the plasma. The particular oscillations meant that the spacecraft was bathed in plasma more than 40 times denser than what it had encountered in the outer layer of the heliosphere, suggesting that Voyager is now embedded in cold, dense interstellar plasma rather than hotter, more tenuous solar-wind plasma.

Planetary Science Division

The observation and discovery of our solar system's planetary objects is one of the oldest of scientific pursuits. With an exploration strategy based on progressing from flybys, to orbiting, to landing, to roving, and finally to returning samples from planetary bodies, NASA's planetary science program advances the scientific understanding of the solar system in extraordinary ways while pushing the limits of spacecraft and robotic engineering design and operations. Since the 1960s, NASA has broadened its reach with increasingly sophisticated missions launched to a host of nearby planets, moons, comets, and asteroids.

On November 29, 2012, NASA's MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission provided support for the long-held hypothesis that Mercury harbors abundant water ice and other frozen volatile materials within its permanently shadowed polar craters. For the first time,

scientists saw a chapter in the story of how the inner planets, including Earth, acquired water and some of the chemical building blocks of life. Spacecraft instruments completed the first measurements of excess hydrogen at Mercury's north pole, made the first measurements of the reflectivity of Mercury's polar deposits at near-infrared wavelengths, and enabled the first detailed models of the surface and near-surface temperatures of Mercury's northern polar regions. Scientists suggested decades ago there might be water ice and other frozen volatiles trapped at Mercury's poles. The idea received a boost in 1991 when the Arecibo radio telescope in Puerto Rico detected radar-bright patches at Mercury's poles. Images from MESSENGER taken in 2011 and early 2012 confirmed that all radar-bright features at Mercury's north and south poles lie within shadowed regions on the planet's surface. These findings were consistent with the water-ice hypothesis.

On December 3, 2012, NASA's Mars Curiosity used its full array of instruments to analyze Martian soil for the first time and found a complex chemistry within the Martian soil. Water, sulfur, and chlorine-containing substances, among other ingredients, showed up in samples that Curiosity's arm delivered to an analytical laboratory inside the rover. Detection of the substances during this early phase of the mission demonstrated the laboratory's capability to analyze diverse soil and rock samples over the next two years of its prime mission. Scientists also verified the capabilities of the rover's instruments. The specific soil sample came from a site of windblown dust and sand named "Rocknest." The site lies in a relatively flat part of Gale Crater, still miles away from the rover's main destination on the slope of a mountain called Mount Sharp. The rover's laboratory includes the Sample Analysis at Mars (SAM) suite and the Chemistry and Mineralogy (CheMin) instrument. All instruments worked, including during the first run of the two analytical instruments. SAM used three methods to analyze gases given off from the dusty sand when it was heated in its oven. Curiosity's team selected Rocknest as the first scooping site because it has fine sand particles suited for scrubbing interior surfaces of the arm's sample-handling chambers. Sand was vibrated inside the chambers to remove residue from Earth. Curiosity's Mars Hand Lens Imager (MAHLI) produced close-up images of Rocknest that showed a dust-coated crust one or two sand-grains thick, covering dark, finer sand. The composition and mineralogy findings of the

largely basaltic sand/dust have been published, refining our understanding of material that covers much of Mars.

On December 4, 2012, NASA announced plans for a reformulated Mars Exploration Program, including a new robotic science rover (based on the Curiosity design) that is set to launch in 2020. The planned portfolio includes the currently operating Curiosity and Opportunity rovers and the Mars Reconnaissance Orbiter, Odyssey, and joint ESA-NASA Mars Express orbiters at Mars. The portfolio also includes the Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter that launched in 2013 to study the Martian upper atmosphere, as well as participation in the European Space Agency's ExoMars program. NASA participation in the 2016 and 2018 ExoMars missions includes providing the "Electra" telecommunication radios to ESA's 2016 Trace Gas Orbiter and a critical element of the premier astrobiology instrument on the 2018 ExoMars rover. With the Discovery Program's Insight mission, scheduled to launch in 2016, NASA will have a total of six missions exploring our Earth-like neighbor this decade and will be a partner in three ESA missions. The first NASA Mars mission of the next decade—the 2020 rover—will address high-priority Agency science goals by carrying payloads to conduct in situ science and prepare for future Mars science and human exploration.

On December 17, 2012, NASA named the site where the twin Gravity Recovery and Interior Laboratory (GRAIL) spacecraft impacted the moon in honor of the late astronaut Sally Ride, who was America's first woman in space and a member of the GRAIL mission team. On December 14, 2012, the twin spacecraft were commanded to descend into a lower orbit that resulted in an impact on a mountain near the moon's north pole. The formation-flying dual spacecraft impacted the lunar surface as planned at a speed of 3,760 miles per hour (1.7 kilometers per second). The impact marked a successful end to the GRAIL mission, which was NASA's first planetary mission to carry cameras fully dedicated to education and public outreach. Sally Ride, who died in July 2012 after a 17-month battle with cancer, led GRAIL's MoonKam (Moon Knowledge Acquired by Middle School Students) program through her company, Sally Ride Science, in San Diego, California. Along with its primary science instrument, each GRAIL spacecraft carried a MoonKam camera that took more than 115,000 total images of the lunar surface. Imaging targets were proposed by middle school students from across the country and the resulting images returned

for them to study. The names of the spacecraft, Ebb and Flow, were selected by Sally Ride and the mission team from student submissions in a nationwide contest.

NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) successfully launched to the moon on September 6, 2013. This was the first payload to launch on a U.S. Air Force Minotaur V rocket integrated by Orbital Sciences Corp., and it was the first planetary mission launched from Goddard Space Flight Center's (GSFC) Wallops Flight Facility in Virginia. LADEE also carried the Lunar Laser Communication Demonstration (LLCD), which successfully demonstrated deep space optical communications at rates of 622 megabits per second (Mbps), a paradigm shift in space communication technology. LADEE's science objectives were to measure the moon's tenuous atmosphere, characterizing its composition and variability, and to study the orbital dust environment. The Lunar Dust EXperiment (LDEX), the first dedicated dust instrument to orbit the moon, discovered a tenuous veil of tiny 1/1,000-millimeter-sized particles created by the continual rain of micrometeoroids on the lunar surface. LDEX measurements also ruled out electrically levitated dust as the cause of the pre-sunrise glow reported by some Apollo astronauts. The Neutral Mass Spectrometer (NMS) discovered and systematically mapped three noble gases in the moon's atmosphere: argon, neon, and helium. The Ultraviolet/Visible Spectrometer (UVS) systematically studied sodium and potassium, exotic species that exhibit odd variations with the lunar phase. UVS and NMS detected several other atmospheric gases, including magnesium and possibly volatile species. On April 17, 2014, as its remaining fuel was exhausted, LADEE made a planned impact on the moon. During its mission, LADEE gathered detailed information about the structure and composition of the thin lunar atmosphere, which scientists hope to use to develop a thorough understanding of the characteristics of our nearest celestial neighbor. In turn, this will help researchers understand other bodies in the solar system, such as large asteroids, Mercury, and the moons of outer planets.

Astrophysics Division

The Astrophysics Division seeks to understand the universe and our place in it by investigating the very moment of its creation; continuing to learn the full

history of stars and galaxies; discovering how planetary systems form and how environments hospitable for life develop; and searching for the signature of life on other worlds, perhaps to learn that we are not alone.

In 2013, scientists using NASA's Kepler Space Telescope announced the discovery of exoplanets that are almost as small as Earth and in orbits large enough to put the exoplanets near the habitable zone. Several of the exoplanets discovered in 2013 are smaller than Mercury, and at least three of the newly discovered exoplanets are less than twice the size of Earth. Finding such small planets, particularly in the habitable zones, is a significant achievement. Using publicly available Kepler data, astronomers announced on February 6, 2013, that 6 percent of red dwarf stars have habitable, Earth-sized planets. Since red dwarfs are the most common stars in our galaxy, this implies that the closest Earth-like planet could be just 13 light-years away and that there could be more than a billion such planets in our Milky Way Galaxy. The question of whether or not this high frequency holds for sun-like stars will be answered by further analysis of the full Kepler dataset.

Astronomers using NASA's Spitzer Space Telescope and Hubble Space Telescope (HST) announced on January 8, 2013, that they were able to probe the stormy atmosphere of a brown dwarf, creating the most detailed "weather map" yet for this class of cool, star-like orbs. The forecast shows wind-driven, planet-sized clouds enshrouding these strange worlds. Brown dwarfs form out of condensing gas, as stars do, but lack the mass to fuse hydrogen atoms and produce energy. Instead, these objects, which some call failed stars, are more similar to gas planets with their complex, varied atmospheres. The new research is a stepping stone toward a better understanding not only of brown dwarfs, but also of the atmospheres of planets beyond our solar system.

On February 27, 2013, NASA's newest astrophysics mission, the Nuclear Spectroscopic Telescope Array, or NuSTAR, and the European Space Agency's X-ray Multi-Mirror (XMM)-Newton mission teamed up to measure definitively, for the first time, the spin rate of a black hole with a mass two million times that of our sun. The supermassive black hole lies at the dust- and gas-filled heart of a galaxy called NGC 1365 and spins almost as fast as Einstein's theory of gravity will allow. The new data demonstrate that x-rays are being warped by the tremendous gravity of the black hole.

Astronomers using NASA's Hubble Space Telescope announced on August 6, 2013, that they had solved a 40-year mystery on the origin of the stream of gas connecting our Milky Way Galaxy to our neighbor Magellanic Cloud galaxies. New observations reveal that a combination of gravity and gas pressure stripped the gas from the Small Magellanic Cloud about two billion years ago and a second region of the stream originated more recently from the Large Magellanic Cloud. These streams give birth to new stars in galaxies throughout the universe, but only in the nearby Magellanic Clouds can we uncover the exact way this happens.

On August 28, 2013, astronomers using NASA's Chandra X-ray Observatory discovered why material around the giant black hole at the center of the Milky Way Galaxy is extraordinarily faint in x-rays. In one of the longest Chandra-observing campaigns, new Chandra images of the black hole Sagittarius A* show that less than 1 percent of the gas initially within Sagittarius A*'s gravitational grasp ever reaches the event horizon. Instead, much of the gas is ejected before it gets near the event horizon and has a chance to brighten, leading to feeble x-ray emissions. The ejection of this gas tells astronomers about its origin and helps them understand why some supermassive black holes are so much fainter than others, both in the local universe and in the distant early universe.

James Webb Space Telescope

The James Webb Space Telescope (JWST) is a large infrared-optimized telescope designed to study and answer fundamental astrophysical questions that range from the formation and structure of the universe to the origin of planetary systems and the origins of life. A scientific successor to the Hubble Space Telescope and the Spitzer Space Telescope, the JWST observatory will be used by international teams of astronomers to conduct imaging and spectroscopic observations in the 0.6–27 micron (μm) wavelength range. The mission of the JWST program/project is to develop, launch, and operate a state-of-the-art observatory for use by the international astronomy community to advance our understanding of the origin and destiny of the universe; the creation and evolution of the first stars and galaxies to form after the Big Bang; the formation of stars and planetary systems within the Milky Way Galaxy; and the characteristics of planetary systems, including our own.

The Near-Infrared Spectrograph (NIRSpec), the last of three James Webb Space Telescope flight science instruments, arrived at Goddard Space Flight Center from Germany on September 20, 2013. NIRSpec joined other instruments at GSFC for integration into the science instrument module for subsequent testing in 2014. JWST is a collaborative effort between NASA, ESA, and the Canadian Space Agency to develop a large, near- and mid-infrared-optimized space telescope to be launched in October 2018. JWST will observe fainter and more distant targets than previous telescopes such as the Hubble Space Telescope, thereby enabling new scientific discoveries and providing answers to questions as old as human imagination: How did planets, stars, and galaxies come into existence, and are we alone in the universe?

Joint Agency Satellite Division

The Joint Agency Satellite Division (JASD) efficiently manages NASA's fully reimbursable satellite and instrument development program, which includes NOAA-funded missions. JASD offers the Federal agencies a single interface for planning, development, and management of their satellite projects.

Since its inception in 2010, JASD has consistently delivered to NASA's partner agencies and to the science community. For example, regarding Jason-3, the project successfully passed Key Decision Point-C (KDP-C) and was confirmed for implementation on January 17, 2013. On May 8, 2013, the project successfully passed KDP-D, and all three instruments developed by the Jet Propulsion Laboratory (JPL) were delivered to Centre National d'Études Spatiales (CNES) for the start of spacecraft integration. The JPL-developed instruments were the Advanced Microwave Radiometer (AMR), the Global Positioning System Payload (GPSP), and the Laser Retroreflector Array (LRA).

On August 27, 2013, the Deep Space Climate Observatory (DSCOVR) project, another JASD mission, successfully completed KDP-C and was confirmed for implementation. Prior to KDP-C, the DSCOVR project resolved a major information technology security classification issue with the ground system: NOAA required a "High Impact" rating for all its operational assets, and DSCOVR was built as a "Moderate Impact" asset. Through several working-group meetings, the

issue was resolved and codified in an IT Security Implementation memo signed by NASA and NOAA.

Aeronautics Research Mission Directorate (ARMD)

Aviation is the transportation mode that connects nations, cities, businesses, and people to support a growing and vital global economy. Within the United States, aviation is essential to economic well-being. Since our establishment, NASA has continually advanced America's aviation system in order to improve our quality of life and productivity on Earth. NASA contributes unique innovations to aviation through our research activities. These innovations serve as key enablers for the vital role of U.S. commercial aviation in driving American commerce and supporting safe, environmentally sustainable mobility. Our role is to explore early-stage concepts and ideas; develop new technologies and operational procedures through foundational research; and demonstrate the potential of promising new vehicles, operations, and safety technology in relevant environments. We are focused on the most appropriate cutting-edge research and technologies to overcome a wide range of aeronautics technical challenges for the Nation's and the globe's current and future air-transportation system.

Aviation Safety Program

During FY 2013, NASA calibrated and validated a computational tool used to assess the risk of engine ice crystal icing. NASA anticipates that this tool will be available to the engine manufacturers to use during the design process to mitigate the impact of ice crystal icing. This form of icing has been reported to cause engine power loss events under certain atmospheric conditions generally attributed to high-altitude thunderstorms. Researchers hypothesize that solid ice crystals partially melt when entering the warmer engine environment and then may refreeze on parts of the engine compressor, leading to a loss of engine power. NASA conducted calibration tests using a jet engine known to be susceptible to ice crystal icing. The tests were the first to be conducted in the Propulsion Systems Laboratory

(PSL) at Glenn Research Center. The testing confirmed the conditions that the computational tool had predicted would lead to engine power loss events.

NASA also completed the second major test in a series intended to evaluate the capabilities of new engine sensors and diagnostic systems. The first test was conducted during 2012. NASA worked with multiple industry and Government partners to conduct the ground-based tests on a C-17 aircraft engine, and the knowledge gained thus far has been communicated to the aviation community. During the test series, NASA and its partners successfully demonstrated the capability of NASA-developed health management technologies to detect and diagnose incipient engine faults before they cause a safety problem. The tests have given NASA a first opportunity to evaluate the capabilities under the high temperature and vibration environment associated with an operating aircraft engine.

NASA and its partners established the technical feasibility of a vehicle-level prognostic reasoning system. This system would offer an onboard capability to provide additional warning about potential aircraft system failures that could degrade safety. The information could allow pilots or maintenance personnel to take necessary steps to ensure continued safe operation. The prognostic reasoning system combines onboard system measurements with a data-mining capability to detect out-of-the ordinary or anomalous conditions. Using this approach, the reasoning system compares onboard conditions with historical data linked to actual failures. Pilots and maintenance personnel would be notified when the system detected an anomaly. Designers used subject-matter experts during the development of this system to improve the system's ability to detect potential problems correctly while limiting the number of false detections. During the multi-year activity that completed in 2013, NASA and its partners used a prototype reasoning system to correctly predict three safety incidents from a set of regional airline flight data. The system also correctly detected and provided advance warning of four faults that were injected into an aircraft navigation system. To improve opportunities for technology transfer, NASA and its partners tested the reasoning system using existing aircraft hardware, software, and communication protocols.

Airspace Systems Program

NASA officially presented the prototype software for its Precision Departure Release Capability (PDRC) to the Federal Aviation Administration (FAA) in August 2013. With PDRC, controllers will be able to improve the overall efficiency of air traffic management by reducing missed or delayed departures and allowing more aircraft to depart within a given timeframe. Tests of the software conducted during the past few years show that PDRC could help improve compliance with the departure time by up to 80 percent, thereby improving the use of slots in the overhead stream of air traffic that can go empty due to timing issues on the ground. Testing and evaluation of the PDRC software was done during two series of exercises conducted at NASA's North Texas Research Station near the Dallas/Fort Worth International Airport beginning in May 2012 and concluding earlier in 2013. During the evaluation, FAA controllers used the prototype PDRC system to schedule departure times for real, operational airline flights. The PDRC software tool is the latest example in a long history of NASA's technical contributions to the aviation community.

NASA conducted a field trial with American Airlines for NASA's Dynamic Weather Routing (DWR), a tool that continually analyzes flight trajectories and weather conditions and then suggests course corrections to avoid the trouble. Field trials like these are the final step required before NASA delivers the DWR tool to carriers and system developers for improved flight efficiencies and cost savings.

NASA conducted the most recent testing for the Spot and Runway Departure Advisor (SARDA) during summer 2013. SARDA is a decision support tool that helps to improve the efficiency of departure operations on taxiways and runways. While previous simulations included participation by controllers, this simulation was the first time that pilots were also included. Using over 120 current and future operational scenarios, controllers used SARDA to plan and issue gate release and departure clearances to the pilots for execution. Early simulation results suggest that sharing the controller's SARDA information with the pilots enabled improved coordination and allowed the aircrews to meet the controller's SARDA plans more accurately.

Fundamental Aeronautics Program

Aircraft noise is of great concern in the current air transportation system, especially in airport communities. Aircraft noise greatly limits the ability to increase air traffic throughput in order to meet projected increased demand for air travel. NASA has been at the forefront of developing and providing tools to industry that characterize the community impact of aircraft noise, especially through its comprehensive Aircraft Noise Prediction Program (ANOPP) code, which predicts the noise created by the entire aircraft and the noise impact on the ground. NASA recently developed the next generation of ANOPP (ANOPP2) and, in FY 2013, validated it with wind tunnel data. ANOPP2's new capabilities include the prediction of noise created by advanced aircraft configurations, which are very different from the conventional tube-and-wing aircraft in use today, and the effects of atmosphere and local terrain in noise propagation. ANOPP2 will allow for more accurate predictions of community noise impacts for current-generation aircraft and will enable accurate noise impact assessments of future aircraft designs.

NASA is exploring advances to make air travel even more flexible and convenient by seeking ways to increase the use of helicopters in the air transportation system. The goal is to make modern helicopters quieter and more fuel efficient so that they can safely carry more people and cargo and be more effective in conducting current missions and new missions such as increased delivery and transportation. To support these improved capabilities, NASA made significant advances in rotary wing propulsion systems in FY 2013 that included new types of engine compressors and turbines and new transmissions. Also, to make rotorcraft quieter, NASA measured and studied the noise of helicopters doing complicated turns and landings. NASA's concern for air traffic safety created new efforts to examine helicopters operating in bad weather. In August 2013, NASA crashed a helicopter fuselage in its ongoing effort to improve helicopter safety. Using the drop test facility at Langley Research Center, NASA dropped the fuselage 30 feet, simulating a severe but survivable crash. Crash-test dummies served as passengers in the test. The goal of the drop was to test improved seat belts and seats, to collect crashworthiness data, and to check out some new test methods. The drop also provided data that will serve as a baseline for another test scheduled for late 2014. NASA worked to

reduce problems caused by ice forming on the rotor blades through a wind tunnel test in the Icing Research Tunnel at Glenn Research Center in August–September 2013. NASA also sought to understand how pilots can control helicopters at night and in bad weather through a simulation test at the Vertical Motion Simulator at Ames Research Center in June 2013.

Faster vehicles are another way to make air travel more convenient for the flying public. NASA is helping to achieve faster air travel by working on technology that would enable high performance supersonic transports to fly commercially with virtually no noise impact on the ground from sonic booms. NASA completed extensive ground testing in spring 2013 to validate its high-fidelity computational tools that predict sonic boom and aircraft drag. Good to excellent comparisons were achieved between test data and the predictions for both sonic boom and aircraft performance, thereby providing confidence in the accuracy of NASA's most advanced computational tools. These tools may eventually be used to help design new types of aircraft.

To help reduce the impact of air travel on the environment, NASA successfully completed in-flight and ground-based tests to characterize the emissions from aircraft engines burning an alternative biofuel. Preliminary results indicate that the biofuel blends tested may substantially reduce the emission of black carbon, sulfates, and organics. Future efforts will assess contrail formation using these biofuel blends to further ensure that there are no adverse effects on the environment.

Integrated Systems Research Program

During FY 2013, NASA continued to make progress towards reducing or eliminating technical barriers to safe and routine access of unmanned aircraft systems (UAS) into the National Airspace System for civil use. Based on the results of earlier analysis and testing, NASA, in close partnership with the FAA and other regulatory bodies, planned for future technology development focusing on the most critical needs for safe UAS integration and meeting the most immediate requirements of the regulatory bodies. This research will be validated through future flight testing over the next few years.

In September 2013, NASA completed a series of characterization tests of a unique flight test environment for UAS research called the Live Virtual Constructive–Distributed Environment (LVC-DE) in order to establish a baseline of the system's capabilities. During the tests, LVC-DE allowed live unmanned and manned aircraft operators to interact with virtual unmanned and manned aircraft operators, supported by actual and simulated air traffic data from air traffic control facilities and ground control stations. The result was safe but realistic testing of UAS integration concepts and flight characteristics.

NASA also explored technologies and procedures that can guarantee seamless communication between UAS, air traffic controllers, and other pilots. In February 2013, NASA began working with industry to develop a specially designed radio for use by UAS that would enable secure command-and-control communications between the ground and the aircraft. Over the course of seven flights, engineers characterized the frequencies that would be used and investigated how they interact with various topographical and climatological conditions around the United States to ensure uninterruptable two-way transmission.

NASA successfully completed testing in the Langley Research Center's (LaRC) 14×22-Foot Subsonic Wind Tunnel to demonstrate the noise reduction potential of the Hybrid Wing Body (HWB) aircraft configuration. This testing investigated the combined airframe and jet engine noise using an HWB model and a compact jet engine noise simulator. It also characterized the ability of the HWB airframe to "shield" emitted noise. Acoustic analysis of the HWB configuration indicates that it will meet the goal of 42 decibel noise reduction from existing noise standards. To enable the testing, NASA made numerous upgrades to the wind tunnel, further augmenting this critical national asset for future research needs.

NASA also used the 14×22-Foot Subsonic Wind Tunnel in support of research investigating the potential for noise reduction in aircraft flaps and landing gear (which are major components of structural noise generation in aircraft) while minimizing weight and integration penalties. NASA performed detailed evaluations of six selected flap noise reduction concepts on a semi-span model of a Gulfstream G550 aircraft. The testing was performed both alone and with landing gear noise reduction concepts. Data from these test runs were used to down select the most

promising flap and gear noise reduction technologies, which will be subjected to further computational analysis.

NASA conducted significant planning for a new Advanced Composites project during FY 2013. NASA's objective in this five-year project is to significantly accelerate the timeline to bring innovative aerospace composite materials and structures to market, which today can exceed 20 years or more, through the development of next-generation, physics-based tools and streamlined processes. In August 2013, NASA, in conjunction with the Aeronautics Research and Technology Roundtable of the National Research Council, met to discuss and validate the project's goals, objectives, and approach.

Aeronautics Test Program

During FY 2013, NASA continued to make targeted investments in its capabilities so that the Nation's aeronautics community has the tools to deliver the technology innovations and breakthroughs necessary to address the increasingly complex research and development challenges associated with safe and effective real-world flight.

In March 2013, NASA first tested and then validated Glenn Research Center's recently modified Propulsion Systems Laboratory. The new engine icing capability provides a unique high-altitude, ice-crystal-generation capability to test a fully operating turbofan engine at the temperatures, pressures, and air speeds representative of those encountered in flight. Spray bars emit a cloud of moisture so that researchers can safely observe what happens inside a full-scale jet engine.

NASA also modified a test facility at Langley Research Center by installing test section acoustic insulation improvements, a new compact jet engine simulator and fuel system, and microphone array and array traversing system at the 14×22-Foot Subsonic Wind Tunnel. This new and unique acoustic measurement capability provides combined airframe and engine acoustic testing to enable research in advanced aircraft configurations, as well as validation of current and new noise prediction methods. The first test of this new capability successfully demonstrated the noise reduction potential of the Hybrid Wing Body aircraft configuration.

NASA also used the capability to research the potential for noise reduction in aircraft flaps and landing gear on a semi-span model of a Gulfstream G550 aircraft.

To aid in the understanding of the current condition and reliability of the Aeronautics test assets and their ability to meet current and future (five-year horizon) test requirements, NASA established a formal process of conducting periodic assessments. In FY 2013, NASA conducted the first of these assessments on the Flight Loads Laboratory, Western Aeronautical Test Range, and Flight Simulation Lab and obtained valuable knowledge of the ground-based assets that support critical flight testing. The assessment will inform strategic investment decisions to ensure that relevant flight testing capabilities continue to be available to support the research, development, test, and engineering milestones of NASA and Department of Defense programs.

Space Technology Mission Directorate

NASA's Space Technology Mission Directorate (STMD) made major strides in 2013, pioneering new technologies and capabilities that added breadth to NASA's toolkit, aiding current and future missions. The Directorate is engaged in nine major technology development programs that are under way at each of NASA's 10 Field Centers located across the United States.

Four PhoneSat CubeSats were placed in Earth orbit in 2013, demonstrating that off-the-shelf, commercial smartphone technology can serve as a spacecraft's operating system, enabling the transmission of images and scientific information. Through STMD's Flight Opportunities Program, the Agency solicited, selected, and launched cutting-edge space technology payloads on commercial reusable launch vehicles, balloons, and commercial parabolic aircraft. The flights permitted participants to demonstrate their technologies at the edge of Earth's atmosphere—and then return that hardware back to terra firma—before committing them to the ruthless and unforgiving conditions of orbital spaceflight.

In a major "game changing" development in 2013, NASA completed testing on a Boeing-led 2.4-meter-diameter prototype composite cryogenic propellant tank. This tank, designed to contain super-cold-temperature hydrogen, was fabricated using out-of-autoclave techniques. The result: a composite cryogenic tank made

with a 25 percent reduction in production cost and a 30 percent reduction in weight that allows for increased payload capacity. A larger tank is now in the works for testing in 2014, eyed for compatibility with the cryogenic upper stage needed for NASA's new big booster, the Space Launch System.

As an innovative manufacturing project, NASA and Aerojet Rocketdyne successfully hot-fire-tested a 3D-printed rocket engine injector, marking one of the first steps in using additive manufacturing for space travel. The liquid-oxygen and gaseous-hydrogen rocket injector assembly was made using selective laser melting manufacturing—a method to shorten production times and lower unit prices of the past.

The NASA Innovative Advanced Concepts (NIAC) program nurtured visionary ideas that could transform future NASA missions with the creation of breakthroughs. In 2013, the NIAC backed conceptual looks at radical concepts in propulsion and power, aircraft design, orbital debris removal, and near-Earth-object threat mitigation, as well as novel ideas on robotics and interplanetary probes, imaging, and communications.

STMD engaged in more than 400 activities with 75 accredited U.S. universities to enable future missions and maintain our continued leadership in space. For the third consecutive year, the Space Technology Research Grants program awarded competitive technology fellowships for graduate research on the Agency's most difficult space technology challenges. Sixty-five new fellowships were awarded this year, bringing the total number of funded graduate student space technology development efforts to 193. Several fellowship graduates are already making an impact in the Nation's aerospace and innovation workforce.

In 2013, hundreds of NASA Small Business Innovation Research and Small Business Technology Transfer programs were funded. More than 400 proposals were selected from U.S. small businesses for development, demonstrating the potential of private-sector innovation to meet NASA's needs.

Department of Defense

DOD

Aeronautics Activities

Fixed-Wing Vehicles

In July 2013, the U.S. Air Force's (USAF) Surfing Aircraft Vortices for Energy ($AVE) program demonstrated a 10 percent fuel savings during a flight of two C-17As. An instrumented trail aircraft flew in the wake of the lead aircraft on a training mission from Edwards Air Force Base to Hawaii and back. By flying in the wake of the lead aircraft, the trail aircraft experienced significantly lower dynamic pressure and gained partial lift from turbulence in the lead aircraft's wake.

The Air Force Research Laboratory (AFRL) conducted wind tunnel tests of a C-5M scale model to validate the fuel-savings of winglets. The tests confirmed a 4 percent fuel savings. AFRL also evaluated overwing nacelle configurations to improve economy of operations, threat response, noise reduction, and agility. Results indicate a potential 5 percent improvement in efficiency compared to underwing nacelle configurations.

The Marine Corps F35B short-takeoff/vertical-landing aircraft completed the second phase of its developmental testing in sea trials aboard the USS Wasp. The aircraft reached a milestone on August 14, 2013, by completing its first night landing at sea aboard the USS Wasp. Also, Rolls-Royce delivered the 50th three-bearing swivel module and 40th LiftFan for the F-35B to the Department of Defense.

The Air Force Research Laboratory completed low-speed and transonic wind tunnel validation testing for two concept vehicles under the Speed Agile

Configuration Demonstrator program. Two hybrid powered-lift systems for a future short takeoff and landing "speed agile" airlifter were tested. The airlifter is intended to carry payloads of up to 65,000 pounds and cruise at Mach 0.8. Boeing's design features an upper-surface blowing system inboard and circulation control and internally blown flaps on the outboard wind section. Lockheed Martin's system uses circulation control and internally blown flaps on the outboard wing sections and a novel ejecting-reversing-nozzle inboard.

The Department of Defense completed the initial flight of the first production Beechcraft AT-6 aircraft. The AT-6 is an attack version of the single-engine turboprop T-6 trainer. The AT-6 was upgraded to a 1,600-horsepower PT6A-68D engine and has structural modification over the T-6 trainer. The AT-6 also uses the A-10C precision engagement modification capabilities.

In 2013, the USAF added additional crews and flight hours to the requirements for the KC-46A Next-Generation Aerial Refueler in response to a review that showed that current plans did not take full advantage of the KC-46A's cargo and aeromedical evacuation capabilities. In August 2013, Boeing and the Air Force completed a Critical Design Review for the KC-46A, one month ahead of schedule. Boeing began assembling the wing for the first aircraft in June 2013.

In March 2013, the Speed Agile Powered-Lift System Concept Demonstration Team was honored as the recipient of the 2013 Aviation Week Laureate Award in the Aeronautics and Propulsion category. The Speed Agile Powered-Lift Demonstration program is a joint effort of the Air Force Research Laboratory, NASA, Boeing, and Lockheed Martin. The program collaboratively developed a revolutionary approach to airlifter design that combines short-takeoff-and-landing utility with airliner-class cruise efficiency. The Speed-Agile Concept Demonstration program culminated with wind tunnel testing in 2012.

Rotorcraft

The Naval Air Warfare Center developed a semi-active seat for the MH-60 Seahawk to mitigate cockpit vibrations. Tests showed that the seat mitigated 90 percent of the dominant rotor-induced vertical vibration. The modified seat design is a direct retrofit to the current MH-60 crew seat.

Balloon Flight Systems

In July 2013, the Army successfully demonstrated the aerostat-based Joint Land Attack Cruise Missile Defense Elevated Network Sensor (JLENS) system as it tracked an anti-ship cruise missile. JLENS is hosted on two TCOM-built, 243-foot-long aerostats.

In May 2013, the Navy demonstrated its MZ-3A airship, the A170, in the Caribbean area for intelligence and surveillance to support counter-narcotics trafficking operations. The airship carried surface optics and full-motion spectral imagers to detect submerged targets.

The Army directed Northrup Grumman to cease work on the Long Endurance Multi-Intelligence Vehicle (LEMV). The 303-foot-long hybrid had made only one flight, in 2012. The program was cancelled due to its inability to meet performance goals and a shortage of funds to continue research and development.

Hypersonics

In May 2013, an X-51A WaveRider set a record for the longest air-breathing powered hypersonic flight when it flew for 3.5 minutes at Mach 5. WaveRider, built by the Boeing Company, is a scramjet-powered demonstrator and is launched from a B-52H. Upon engine ignition, the aircraft accelerated to Mach 5.1 and provided 370 seconds of valuable flight data. The WaveRider uses the shock waves it creates to generate lift. This event was the fourth flight for WaveRider.

The Large-Scale Scramjet Engine Testing Techniques (LSETT) program, a joint project of the Air Force Research Laboratory, NASA, and ATK, completed ground tests of a fuel-cooled, dual-mode scramjet engine at both NASA's Langley Research Center, in Virginia, and ATK-General Applied Science Laboratory, in Ronkonkoma, New York. The test was conducted using a missile-scale, fuel-cooled ATK combustor and flight-representative inlet/isolator tested in free-jet, semi-free-jet, and direct-connect configurations.

Unmanned Aircraft Systems (UAS)

In August 2013, the Air Force Research Laboratory flew the X-56A for the first time at NASA's Dryden Flight Research Center (now named Armstrong Flight Research Center) in California. The X-56A Multi-utility Aeroelastic Demonstration (MAD) is a modular, unmanned research aircraft capable of demonstrating a variety of adaptive structures and wing and tail configurations for active flutter suppression techniques and gust load alleviation. These technologies are vital for future transports as well as for intelligence, surveillance, and reconnaissance unmanned aerial systems. The X-56A was transferred to NASA during 2013 for active flutter suppression developmental testing and experimentation.

In July 2013, the X-47B Unmanned Combat Air System (UCAS) Aircraft Carrier Demonstration (UCAS-D) completed two arrested landings on the USS George H. W. Bush. This is the first instance of a tailless, unmanned autonomous aircraft landing on a modern aircraft carrier. This event also included multiple precision approaches, nine touch-and-go landings, and three catapult launches.

The MQ-4C Triton unmanned aircraft completed its first flight in May 2013. Triton is an upgraded version of the Global Hawk. Triton has an operational altitude of 53,000 feet and a range of 11,500 miles. Triton is built by Northrup Grumman for the Navy. Its mission is wide-area, long-duration intelligence, surveillance, and reconnaissance.

In May 2013, the Naval Research Laboratory's Ion Tiger hydrogen-fuel-cell-powered unmanned plane flew for more than 48 hours, eclipsing its previous record of 26 hours and 2 minutes set in 2009. The new fuel system uses high-pressure liquid hydrogen stored in lightweight tanks, which allows for a threefold increase in fuel density.

In September 2013, the Missile Defense Agency completed the fifth flight of Boeing's Phantom Eye hydrogen-powered, high-altitude unmanned aircraft. During this flight, the aircraft reached an altitude of 28,000 feet and flew for just under four and a half hours. This flight included a payload from the Missile Defense Agency.

In July 2013, Northrop Grumman delivered the first MQ-8C Fire-X vertical-takeoff unmanned aircraft to the Navy. Ground and communications testing was completed during 2013, and the first flight was scheduled for early FY 2014. The

MQ-8C shares software, avionics, payloads, and ship ancillary equipment with the MQ-8B, while the upgraded airframe provides double the endurance and three times the payload.

An enhanced version of the MQ-1C version of General Atomics' Predator Remotely Piloted Aircraft (RPA) made its first flight in July. This was the first flight of the Army's Improved Gray Eagle (IGE), a next-generation derivative of the combat-proven Block 1 Gray Eagle Unmanned Aircraft System. The IGE provides increased endurance, with 23 additional hours for reconnaissance missions, over the Block 1 Gray Eagle. The aircraft's payload capacity is more than 50 percent greater than the Block 1 Gray Eagle's and has 50 percent more fuel capacity in its deep-belly fuselage. An upgraded centerline hardpoint offers the option of either a 500-pound external fuel tank or a 360-degree-sensor payload.

Aircraft Engines, Subsystems, Components, and Other Aeronautical Developments

The Army's High-Speed Container Delivery System (HSCDS) was used in Afghanistan beginning in April 2013 to deliver cargo to remote locations not easily accessible to overland convoys. The HSCDS is deployed from C-17 and C-130J aircraft flying at speeds of up to 250 knots to drop cargo loads from between 3,000 and 16,000 pounds at altitudes as low as 250 feet. The HSCDS is the product of a Joint Concept Technology Development program and provides greater aircraft maneuverability during airdrop, decreased ingress and egress time, and increased payload delivery accuracy compared to conventional airdrop technologies.

In concert with the universities of Alabama, San Jose, Idaho, Nevada-Reno, and Missouri, the Naval Postgraduate School conducted eight flight tests of an autonomous high-altitude, high-opening parafoil delivery system. This system is investigating balloon-borne, lower stratosphere deployments of ultralightweight payloads using 10-to-40-square-foot canopies. Potential applications for this technology include the retrieval of weather balloon and sounding rocket payloads.

The China Lake Naval Air Weapons Station built and performed structural tests on the Supersonic Inflatable Aerodynamic Decelerator. A rocket sled was used to perform the structural and inflation tests.

The Department of Defense's Computational Research and Engineering Acquisition Tools and Environments (CREATE) Air Vehicles program (CREATE-AV) released three multidisciplinary, physics-based computational engineering products in 2013: the fixed-wing analysis tool Kestrel 4.0, the rotorcraft analysis tool Helios 4.0, and the conceptual design tool DaVinci 2.0. CREATE is part of DOD's High Performance Computing Modernization Program (HPCMP).

In February 2013, the Air Force Research Laboratory completed testing of General Electric's engine under the ADaptive Versatile ENgine Technology (ADVENT) program, achieving the highest combination of compressor and turbine temperatures ever recorded. The accomplishment resulted from lightweight, heat-resistant ceramic matrix composite materials. This technology, combined with an adaptive low-pressure spool, yielded a 25 percent improvement in fuel efficiency, a 30 percent increase in operating range, and a 5 to 10 percent improvement in thrust compared to today's fixed-cycle engines.

Airborne Weapons Systems and Missiles

The Navy supported a U.K. Royal Navy Trident 2 D5 Fleet Ballistic Missile test in October 2012. This was the 143rd successful flight for the Trident 2 D5 since 1989.

In February 2013, the Standard Missile 3 (SM-3) Block 1A intercepted a medium-range ballistic missile target over the Pacific Ocean, demonstrating success of the upgraded third-stage rocket motor and solid divert attitude control system. The missile was launched from the USS Lake Erie. In May, an SM-3 Block 1A was also launched from a Navy Aegis-class cruiser off the coast of Hawaii, where it destroyed a complex, separating short-range ballistic missile. An SM-3 Block 1B missile was successfully fired in September 2013 and intercepted a complex, separating short-range ballistic missile launched from the Pacific Missile Range Facility on Kauai, Hawaii. The SM-3 Block 1B incorporates an enhanced two-color infrared seeker and throttleable divert attitude control system. This was the 28th intercept for the Aegis Ballistic Missile Defense program since flight testing began in 2002 and the 23rd successful intercept for the SM-3 missile family. In May 2013, Raytheon celebrated the 60th anniversary of the Standard Missile Family.

In June 2013, Raytheon achieved a production milestone with the delivery of the 5,000th AIM-X Sidewinder air-to-air missile to the Department of Defense.

In September 2013, the Missile Defense Agency led a series of tests called Flight Test Operational-01. The tests began with the launch of two medium-range ballistic missile targets on operationally realistic trajectories toward the Army's Reagan Test Site on Kwajalein Atoll. The USS Decatur detected, tracked, and developed firing solutions on the targets with the Aegis weapons system and intercepted the first target with an SM-3 Block 1A missile. An AN/TYP-2 radar located with the Terminal High-Altitude Area Defense (THAAD) weapons system acquired and tracked the targets and intercepted the second target with a THAAD missile.

A ground-based midcourse defense interceptor test in January 2013 verified the performance of the exo-atmospheric kill vehicle through two divert maneuvers. A subsequent attempt to intercept a long-range ballistic-missile target launched from the Kwajalein Atoll was not successful. The interceptor missile launched from Vandenberg Air Force Base, in California, experienced a separation failure between the upper stages of the interceptor. Across all Ballistic Missile Defense (BMD) programs from 2001 to 2013, there have been 64 hit-to-kill intercepts in 80 flight test attempts.

In April 2013, a Patriot Advanced Capability 3 (PAC-3) missile successfully detected, tracked, and intercepted a tactical ballistic missile (TBM) in a Lower Tier Project Office flight test at White Sands Missile Range, New Mexico. By current practice, two PAC-3 missiles were ripple-fired in the test. The first interceptor destroyed the target and the second PAC-3 missile self-destructed as planned. In June 2013, PAC-3 Missile Segment Enhancement (MSE) missiles successfully engaged, intercepted, and destroyed two different threat representative targets: an advanced tactical ballistic missile target and a cruise missile target.

In September, the Navy successfully launched its 40th Coyote Supersonic Sea-Skimming Target (SSST) vehicle from the Pacific Missile Range in Hawaii. The year 2013 marked the 10th year of the Coyote program.

Aircraft Safety and Survivability

Wright-Patterson Air Force Base supported NASA tests with multinational partners to investigate the effects of lasers on composite materials used on military

aircraft. Tests during 2013 were performed in simulated flight conditions, including high-speed airflow, but without fuel backing or laser-hardened coatings. The results from these tests will be used to improve laser hardening and fire suppression.

Wright-Patterson Air Force Base's Aerospace Survivability and Safety Operation Location designed, tested, and evaluated a low-profile, lightweight parachute intended to enable aircrews to eliminate the time required to don parachutes in emergency bailout situations. The new parachutes are designed to be small and light enough to be worn throughout the mission, and they are built to minimize their impact on crew mobility and performance.

Space Activities

Launch and Range Operations and Spacelift Developments

The Evolved Expendable Launch Vehicle program continued to place satellites into orbit successfully during FY 2013. With 11 launches in FY 2013, United Launch Alliance (ULA) continued its record of 100 percent success. Of these, 8 of the 11 were National Security Space missions, including a Wideband Global Satellite Communications launch.

On July 13, 2013, the Air Force launched the second Mobile User Objective System (MUOS) satellite for the Navy using an Atlas 5 launch vehicle. The launch vehicle was acquired and launched by United Launch Alliance under the Evolved Expendable Launch Vehicle program.

In a November 27, 2012, Acquisition Decision Memorandum, the Under Secretary of Defense for Acquisition, Technology, and Logistics authorized the Air Force to begin negotiations with United Launch Alliance for a requirements contract to procure 36 rocket cores for National Security Space missions across five years (fiscal years 2013 through 2017). On December 18, 2013, the Air Force awarded the Evolved Expendable Launch Vehicle (EELV) Launch Vehicle Production Services (LVPS) and Capability to United Launch Alliance. The Air Force also set aside up to 14 rocket cores, in addition to the above commitment, for competition as early as FY 2015 if new entrant launch service providers achieve certification to compete.

The Air Force funded two opportunities in FY 2013 for new launch service providers to qualify to compete for future contracts under the Evolved Expendable Launch Vehicle program and competitively awarded the Deep Space Climate Observatory and Space Test Program-2 launch missions to SpaceX on November 30, 2012. The Air Force and SpaceX signed a Cooperative Research and Development Agreement (CRADA) and a Certification Plan on June 7, 2013, for the EELV-class certification of the Falcon 9 v1.1 launch vehicle. SpaceX successfully completed one of the three flights required for certification with its successful launch of CASSIOPE and secondary payloads on the first flight of Falcon 9 v1.1 launched on September 29, 2013.

The Defense Advanced Research Projects Agency (DARPA) initiated a reusable first-stage program, XS-1, the Experimental Spaceplane. As envisioned, XS-1 will be an unmanned hypersonic craft comparable to traditional launch vehicles in terms of cost, operation, and reliability. The goal of the program is to fly 10 times in as many days. XS-1 is envisioned to carry payloads of 3,000 to 5,000 pounds.

The Air Force Research Laboratory completed designs for turbomachinery components for a full-scale, oxygen-rich, staged-combustion rocket engine. The AFRL also fabricated and tested a subscale pre-burner for this engine. AFRL's research in this area is conducted under the Integrated High-Payoff Rocket Propulsion Technology (IHPRPT) program.

Global Positioning System

The Air Force successfully launched a third Global Positioning System (GPS) IIF satellite in October 2012 and a fourth in May 2013. The GPS Enterprise also achieved 0.47-meter accuracy on June 8, 2013, the best constellation performance to date. In February of 2013, power was turned on for the first time to the first of the next-generation GPS satellites, the GPS III satellite 1. GPS III-1 successfully completed a third exercise with the Launch and Checkout System of the GPS Next Generation Operational Control System. The modernized GPS III satellite provides a Standard Positioning Service to a broad spectrum of civil users. It will also transmit a new civil signal (L1C), which is compatible with the European Galileo satellite navigation signal, E1. L1C is also compatible with signals planned

for broadcast on Japan's Quazi-Zenith Satellite System, a system meant to augment GPS services. Once implemented, the common civil signal will be jointly broadcast by up to 60 satellites from both GPS and Galileo constellations, further increasing accuracy and availability of civil position, navigation, and timing solutions.

In 2013, the GPS Modernized User Equipment (MUE) program successfully completed numerous GPS Military-Code (M-Code) receiver technology demonstrations. The MUE program greatly reduced technical and integration risks and established the technological foundation that the follow-on Military GPS User Equipment (MGUE) program is currently leveraging.

Satellite Communications

On September 18, 2013, the Air Force successfully launched the third Advanced Extremely High Frequency (AEHF-3) satellite to provide global protected communications to U.S. and international forces. The governments of Canada, the Netherlands, and the United Kingdom are key international partners with the United States in this program. The AEHF will replace the Milstar system to provide highly secure, protected communications under harsh environments, such as after a nuclear detonation.

On May 24, 2013, the Air Force launched the Wideband Global Satellite Communications (SATCOM) Satellite 5 (WGS-5) atop a Delta IV at Cape Canaveral, Florida. With the transfer into operations, the satellite constellation completed global coverage and led to a fully mission-capable WGS constellation. WGS-6 was launched on August 7, 2013, from Cape Canaveral. WGS-6 is entirely funded by the government of Australia under an international agreement that is the forerunner of key agreements with Canada, Denmark, Luxembourg, the Netherlands, and New Zealand to purchase WGS-9. WGS provides wideband military satellite communications capacity to extend the Department's networks among major ground and aerial nodes. Both satellites completed on-orbit testing procedures and are now operational. The U.S. Army Space and Missile Defense Command and U.S. Army Strategic Command perform the satellite control mission for WGS at Wideband SATCOM Operations Centers (WSOCs) at key worldwide locations.

The second of the Navy's Mobile User Objective System (MUOS-2) satellites was successfully launched in July. MUOS is designed to provide cellular telephone-like communications to mobile subscribers in the UHF band with a Wideband Code Division Multiple Access (WCDMA) waveform. In addition, three of the four ground stations have become operational to support an initial operating capability in FY 2014.

Space-Based Intelligence, Surveillance, and Reconnaissance

The Space Based Infrared System (SBIRS) is an integrated, incrementally deployed system that supports missile warning, missile defense, technical intelligence, and battlespace awareness mission areas. The nominal constellation consists of four Geosynchronous Earth Orbit (GEO) satellites, two hosted sensors in Highly Elliptical Orbit (HEO), and ground elements. GEO 1 and GEO 2 satellites are on orbit and were certified in August 2013 and December 2013, respectively. The HEO 3 payload was delivered to the classified host in June 2013. GEO 3, GEO 4, and HEO 4 are all in production with no outstanding issues. The Government is currently negotiating the contract award of GEO 5 and GEO 6 satellites to Lockheed Martin.

Satellite Control and Space Situation Awareness

The Space Threat Assessment Testbed (STAT), at the Arnold Engineering Development Complex in Tennessee, reached initial operational capability. STAT enables the Air Force to test space assets in high-fidelity simulated orbital environments. STAT can emulate numerous features of space weather and can reproduce self-induced effects such as material exhaust and thruster backflux.

In 2013, the Operationally Responsive Space (ORS) Office continued to support the on-orbit operations of the ORS-1 satellite, which launched in June 2011 from NASA's Wallops Flight Facility in Virginia. Although designed with a life of 2 years, ORS-1 continued to support U.S. Central Command through 2013. In addition to directly supporting the Joint Force Commander, ORS continued to advance technical, logistic, and launch objectives and abilities.

The Space Security and Defense Program (SSDP) is a joint Department of Defense and Office of the Director of National Intelligence (ODNI) organization established to function as the center of excellence for options and strategies (materiel and non-materiel) leading to a more resilient and enduring National Security Space (NSS) Enterprise. Formerly known as the Space Protection Program (SPP), the SSDP was chartered by DOD and ODNI on March 5, 2013, to expand the existing authorities and roles/responsibilities of the SPP. This transition effectively integrates and unifies space protection efforts on a national level to better meet the evolving threat to our NSS systems and capabilities.

In November 2012, the Joint Space Operations Center (JSpOC) Mission System (JMS) Increment 1 program delivered a space-situational-awareness system capable of command and control of space forces and predictive battlespace management to the JSpOC. JMS uses a service-oriented architecture infrastructure and common operating picture that are tailorable by the user. The JMS replaced the legacy systems with a modernized, scalable, extensible, and sustainable platform. JMS is an Agile IT program, delivering capabilities in a series of increments. Increment 1 has been in continuous use since November 2012 and has operated for over 8,000 hours without critical failure and supported multiple high-profile events throughout 2013.

On September 1, 2013, the Air Force Space Command shut down the Space Fence, a key part of the network for tracking satellites and orbital debris. Budget reductions led to the decision to close the system. A new project to develop an upgraded capability to replace the Space Fence is under review by the Department of Defense.

Other Space Developments

DARPA's Phoenix program completed phase 1 of its plan to develop a sustainable ecosystem of hardware delivery, capture, and transport using an on-orbit servicer/tender. The goal of Phoenix is to demonstrate the first on-orbit space assembly and harvesting of retired satellite antennas to create new space systems.

The Air Force launched the third test flight of its Orbital Test Vehicle in December 2012. OTV is a developmental space plane, the X-37B, built by the

Boeing Company. The first flight occurred in April 2010. The objective of the X-37 Program is to demonstrate technologies required to reuse a space vehicle.

Federal Aviation Administration

FAA

The Federal Aviation Administration continues furthering the goals of the Next Generation Air Transportation System (NextGen), which represents a comprehensive overhaul of the entire National Airspace System (NAS). NextGen will make air travel more convenient and dependable while ensuring that flights remain safe, secure, and as hassle-free as possible.

Making progress toward the next generation of aviation is being made possible by shifting to smarter, satellite-based, and digital technologies that incorporate new procedures to make air travel more convenient, predictable, and environmentally friendly.

- NextGen improvements will enable the FAA to guide and track aircraft more precisely on more direct routes. NextGen efficiencies will contribute to enhanced safety, reduced delays, increased fuel savings, and reduced aircraft exhaust emissions. NextGen will enable the sharing of real-time data, including weather, the location of aircraft and vehicles, and conditions throughout the NAS. The right information gets to the right people at the right time, helping controllers and operators make better decisions and improve on-time performance.
- NextGen is better for the environment because it will help to make flying quieter, cleaner, and more fuel-efficient. Operators are beginning to use alternative fuels and new equipment and procedures, reducing aviation's adverse impact on the environment. More precise flightpaths are also helping limit the number of people impacted by aircraft noise.

- NextGen enhances safety—the agency's top priority is ensuring safe skies and airfields. NextGen innovation and improvements are delivering just that by providing air traffic controllers and pilots with the tools to proactively identify and mitigate issues associated with weather and other hazards.

In FY 2013, the FAA continued its work toward safely increasing the efficiency of the NAS by improving efficiencies at metropolitan areas with complex air traffic flows using integrated solutions. A metroplex refers to a system of airports in close proximity and their shared airspace that serve one or more major cities. A metroplex has at least one but often two or more major commercial airports. As of January, the FAA's Optimization of Airspace and Procedures in the Metroplex (OAPM) program had eight active teams in various phases of development. OAPM is the FAA's fast-track initiative to implement Performance Based Navigation (PBN) procedures and airspace improvements to reduce fuel consumption and aircraft exhaust emissions in some of the United States' busiest airspace. The eight Metroplex studies completed in December 2012 estimated substantial potential savings from RNAV approaches and departures and airspace redesign—as much as 30 million gallons of fuel and 298 thousand metric tons of carbon dioxide emissions per year. The first three sites—Houston, including David Wayne Hooks Memorial Airport (DWH), William P. Hobby Airport (HOU), George Bush Intercontinental Airport (IAH), and Sugar Land Regional Airport (SGR); North Texas, including Dallas/Fort Worth International Airport (DFW) and Dallas Love Field Airport (DAL); and Washington, DC, including Dulles International Airport (IAD), Ronald Reagan Washington National Airport (DCA), Baltimore/Washington International Airport (BWI), Richmond International Airport (RIC), and Andrews Air Force Base (ADW)—are expected to have completed the design phase and to move into the implementation phase in FY 2014.

The many elements of PBN, mainstays of NextGen implementation from the start, continued to grow. In May 2013, the FAA launched the PBN Dashboard, a Web-based tool that provides deployment and usage data on every RNAV and RNP airport procedure in the NAS. This operational information will support analysis of current PBN performance and aid in developing new procedures.

The Automatic Dependent Surveillance Broadcast (ADS-B) program continues steady deployment of ground stations. As of February 2013, the FAA had installed more than 500 ADS-B ground stations, of which 445 were operational, providing traffic and weather information to properly equipped aircraft and supporting air traffic control separation services at 28 Terminal Radar Approach Control (TRACON) facilities. The FAA has mandated that aircraft flying in most controlled airspace be equipped with ADS-B Out—the ability to broadcast their position to the ADS-B network—by January 1, 2020. ADS-B Out avionics use on-board navigation equipment to derive an aircraft's position, which is then broadcast for air traffic control services and for use by other aircraft. The roughly once-per-second broadcast rate not only is automatic, but also depends on equipment on the aircraft for air traffic surveillance to occur—thus the cooperative and dependent nature of ADS-B. General aviation aircraft owners who decide to equip with optional ADS-B In reception and display capability, as well as with the mandated ADS-B Out transmission capability, will be able to see the location of nearby ADS-B Out aircraft via air-to-air reception or by relay from the ground. In addition, ADS-B In can display the location of transponder-equipped aircraft tracked by ground-based radar surveillance when this information is relayed from the ground to the cockpit, thus providing situational awareness of nearby aircraft that are not yet equipped with ADS-B Out. Making use of GPS and Wide Area Augmentation System technology, ADS-B is the NextGen successor to ground radar for tracking aircraft in the National Airspace System. The FAA continued to develop policy regarding ADS-B In avionics, from which operators will be able to draw significant benefits. ADS-B Out avionics receive positioning data from GPS satellites, process them, and transmit the aircraft's position to the ground. Ground stations send data on the aircraft's position to controller displays on the ground and to cockpit displays on aircraft that are equipped with ADS-B In. ADS-B In also will enable cockpit display of nearby ADS-B Out aircraft positions.

Just as the agency has seen significant progress in its efforts to advance NextGen, its commercial space program made great accomplishments in FY 2013.

The FAA 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, property, and

the national security and foreign policy interests of the United States. In addition, AST encourages, facilitates, and promotes U.S. commercial space transportation.

In FY 2013, there were a total of 18 FAA-licensed launches and zero permitted launches; this was a sixfold increase over FY 2012. No fatalities, serious injuries, or significant property damage to the uninvolved public occurred during these licensed events.

In FY 2013, AST issued four launch licenses to the following organizations:

- A launch-specific license to United Launch Alliance to conduct a Delta IV heavy launch of Orion (EFT-1 mission) from Cape Canaveral Air Force Station (CCAFS).
- A launch-operator license to Orbital Sciences Corporation (OSC) to conduct Minotaur launches of U.S. Government payloads from Wallops Flight Facility.
- A launch-specific license to SpaceX to conduct the F9-006 CASSIOPE mission from Vandenberg Air Force Base. This involved the inaugural launch of the F9 v1.1 launch vehicle and the first attempt of partial flyback of an expendable stage.
- A launch-specific license to OSC to conduct multiple Antares (vehicle configuration 120) launches from WFF.

AST issued two launch-site operator license renewals: one to the Virginia Commercial Space Flight Authority (VCSFA) for the Mid-Atlantic Regional Spaceport at WFF and another to the Alaska Aerospace Corporation (AAC) for the Kodiak Launch Complex at Kodiak Island, Alaska.

AST issued two experimental-permit renewals: the first to Scaled Composites for WhiteKnightTwo (WK2)/SpaceShipTwo (SS2) launches at the Mojave Air and Space Port and the second to SpaceX for Grasshopper launches in McGregor, Texas. One safety approval was granted to Black Sky Training for scenario-based physiology-altitude training.

AST conducted 142 safety inspections on over 54 different types. 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; Las Cruces, New Mexico; McGregor, Texas; Burns Flat, Oklahoma; Hawthorne and Long Beach, California; Jacksonville, Florida; Vienna and Dulles, Virginia; Black Rock, Nevada; Southampton, Pennsylvania; and the equator.

To support all new and renewed licenses in FY 2013, AST carried out several environmental reviews. Specifically, AST issued the draft Environmental Impact Statement (EIS) for the SpaceX launch site in Texas. Additionally, AST adopted NASA's final Environmental Impact Statement (EIS) for the Constellation Program and issued a Record of Decision (ROD) to support the issuance of a reentry license to Lockheed Martin Corporation for the Orion Multi-Purpose Crew Vehicle. AST also adopted the U.S. Air Force's supplemental Environmental Assessment (EA) for the SpaceX Falcon Program at Cape Canaveral Air Force Station, Florida, and issued a Finding of No Significant Impact (FONSI) and ROD to support the issuance of a launch and reentry license to SpaceX for Falcon 9 commercial launch operations at CCAFS. Similarly, AST adopted the USAF's EA for the SpaceX Falcon Program at Vandenberg Air Force Base, California, and issued a FONSI and ROD to support the issuance of a launch-and-reentry license to SpaceX for Falcon 9 commercial launch operations at VAFB. AST continued to monitor the New Mexico Spaceport Authority's compliance with Federal historic preservation requirements and other requirements related to biological resources for the development of Spaceport America.

The FAA's Center of Excellence for Commercial Space Transportation (COE-CST) is a partnership of academia, industry, and Government developed to address current and future challenges for commercial space transportation. In FY 13, the COE-CST conducted research and development efforts and produced 13 papers in four areas: space launch operations and traffic management; launch vehicle systems, payloads, technologies, and operations; commercial human spaceflight; and space transportation industry viability.

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

Department of Commerce

DOC

During FY 2013, DOC contributed to the development of the National Space Transportation Policy issued by the President in November 2013. DOC worked to ensure that the policy included provisions promoting the health, robustness, innovation, entrepreneurship, and competitiveness of U.S. commercial space businesses. DOC, working in cooperation with the Department of State, made significant strides towards reforming the U.S. satellite export control regime. DOC's Bureau of Industry and Security published and received comments on proposed regulations that would transfer many space-related items from State Department jurisdiction to the Commerce Department.

DOC continued to participate in the national management of the Global Positioning System as a member of the National Executive Committee for Space-Based Positioning, Navigation, and Timing, the senior body that advises and coordinates Federal agencies on GPS matters. DOC participated in the committee's June 2013 meeting and hosted three meetings of its Executive Steering Group to discuss major policy issues affecting GPS, including spectrum management and interference mitigation.

DOC continued to host the secretariat of the National Executive Committee and participate in its daily operations, including public outreach about GPS. DOC staff enhanced the *http://www.gps.gov* Web site at the center of the Government's GPS outreach campaign, adding a mobile-friendly format and new content for educational users. DOC helped develop new educational materials about GPS and disseminate them to over 22,000 science teachers and students.

DOC participated in bilateral consultations, led by the State Department, with Japan to discuss cooperation on space and GPS issues. DOC's Office of Space

Commercialization also continued to serve as the U.S. cochair of a U.S.-European working group on trade issues affecting satellite navigation markets.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration's (NOAA) environmental satellites are key tools for forecasting weather, analyzing climate, and monitoring hazards worldwide. In FY 2013, NOAA satellites were as critical as ever, this year helping the East Coast prepare for Hurricane Sandy. Twenty-four-hour global coverage from NOAA's satellites provides scientists and managers with a continuous stream of information used in preparation for events that will impact our climate, weather, and oceans. NOAA manages and operates three types of environmental satellites: Geostationary Operational Environmental Satellites (GOES), Polar-orbiting Operational Environmental Satellites (POES), and ocean altimetry (Jason).

NOAA's Geostationary Satellites

GOES continuously monitor the Western Hemisphere by circling Earth in a geosynchronous orbit 22,000 miles above the equator, meaning they remain over one position of the surface by orbiting at a speed matching Earth's rotation. Information from GOES is used for short-term weather forecasting and severe storm tracking. GOES imagery is also used to estimate rainfall during thunderstorms and hurricanes for flash flood warnings as well as snowfall accumulation and overall snow cover in cold climates. This information helps meteorologists issue winter storm warnings and spring snow melt advisories. In FY 2013, GOES-15 flew at 135° west longitude and served as "GOES-West," while GOES-13 flew at 75° W and served as "GOES-East." GOES-12, which most recently flew at 60° W and served as GOES-South America, was decommissioned in August 2013 after 12 years in space.

NOAA's Polar-Orbiting Satellites

POES circle Earth in an almost north-south orbit at an altitude of approximately 517 miles, passing close to both poles. Earth constantly rotates counterclockwise

underneath the path of the satellite, affording each satellite a different view with each orbit. It takes the satellite approximately 1.5 hours to complete a full orbit. In a 24-hour period, the 14 orbits of each polar-orbiting satellite provide two complete views of weather around the world. POES provides full global coverage with advanced sensors for weather and climate data, collecting information on temperature, atmospheric conditions, wind speed, cloud formation, and drought conditions over the entire Earth.

In FY 2013, NOAA-19 served as NOAA's primary polar-orbiting satellite, but NOAA continued to operationalize the first of its next generation of polar-orbiting satellites, the Suomi National Polar-orbiting Partnership (Suomi NPP). Two major milestones have been reached: on February 22, 2013, when operational control was transitioned from NASA to NOAA, and later in the year when NOAA's National Weather Service began using data from Suomi NPP in its numerical weather prediction models. Suomi NPP is a joint NOAA-NASA mission and serves as a bridge between NOAA's current fleet of polar-orbiting satellites and the upcoming next-generation Joint Polar Satellite System (JPSS).

NOAA's Ocean Altimetry Satellite

NOAA, along with its partners NASA, the Centre National d'Études Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), operates Jason-2, a sea surface topography mission that flies an altimeter to provide high-precision measurements of sea surface height. Because the temperature of the ocean and ocean currents can change the height of the sea and because these characteristics can affect the world's weather, including tropical storms, Jason-2 has been crucial to improvements in weather modeling and tropical storm–intensification forecasting. Its follow-on, Jason-3, is currently under development.

NOAA's Additional Space-Based Capabilities

In addition to those three main types of environmental satellites, NOAA also flies two types of additional instruments on some of its satellites together with international partners.

Argos is a data collection and location relay system administered under an agreement between NOAA and CNES initiated in 1974. Through the Argos program, CNES provides sensors for flight on NOAA and EUMETSAT satellites. These sensors collect a wide variety of in situ measurements, including data on atmospheric pressure, sea temperature, ocean-current velocity, animal migration patterns, and river water levels.

The Search and Rescue Satellite-Aided Tracking system (COSPAS-SARSAT) is an international effort that uses satellites to locate emergency beacons carried by ships, aircraft, or individuals and communicate location information to search-and-rescue authorities. The system has rescued over 35,000 people worldwide since 1982. The governing parties of the system are the United States (NOAA), France (CNES), Russia, and Canada. NOAA provides space on its polar-orbiting satellites for the French processor and Canadian receiver.

International Agreements

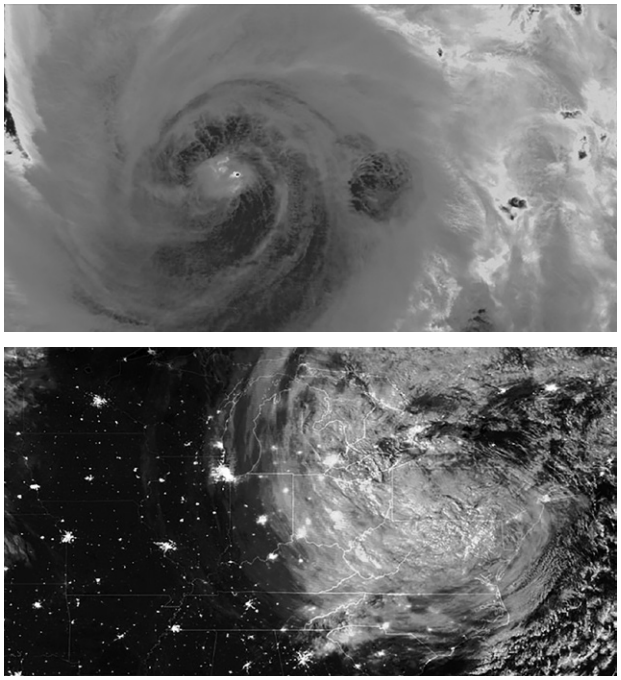
On August 27, 2013, building on a 30-year relationship, top officials from NOAA and EUMETSAT signed a long-term cooperative agreement, ensuring continued space-based weather, water, and climate monitoring. At a ceremony at the European Union (EU) Delegation in Washington, DC, Dr. Kathryn D. Sullivan, NOAA Acting Administrator, and Alain Ratier, EUMETSAT Director-General, signed the agreement. They were joined by Dr. François Rivasseau, Deputy Chief of Mission, EU Delegation to the United States.

Additionally, on September 18, 2013, NOAA joined top representatives from EUMETSAT and the European Space Policy Institute (ESPI) to participate in an event unveiling a detailed report by ESPI's Arne Lahcen on the tremendous benefits and long history of NOAA and EUMETSAT cooperation in geostationary, polar-orbiting, and ocean altimetry satellites. The report concludes with a cost-benefit impact assessment and states that the partnership "has enabled their user communities to benefit from more data products, increased accuracy and a better timeliness and robustness of the observing systems, all at a lower cost."

Other Accomplishments

In April 2013, at the 29th annual National Space Symposium in Colorado Springs, Colorado, NOAA was awarded the Space Achievement Award by the Space Foundation. This award is given every year in recognition of individuals or organizations for space achievement, breakthrough space technology, or program or product success representing critical milestones in the evolution of space exploration and development. NOAA was given this award for its use of space-based systems in making life-saving predictions and issuing early warnings of severe weather conditions, particularly in advance of Hurricane Sandy.

Hurricane Sandy hit the East Coast on October 29, 2012, causing widespread damage to numerous communities. These two images, taken from the Suomi NPP satellite, capture Sandy as it makes its way over the United States. The first is an infrared image, while the second is a "nighttime light" image, showing lights from U.S. cities and Sandy's clouds, lit by the moon.



Infrared and "nighttime light" satellite images of Hurricane Sandy. (NOAA)

National Institute of Standards and Technology

In FY 2013, the National Institute of Standards and Technology (NIST) continued to provide Federal agencies and the aerospace industry with the research, guidance, 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 SRMs and services to ensure the accuracy of their own instrument calibrations and the validity of their measurement methods. In FY 2013, aerospace companies purchased 127 SRMs: a wide variety of metal alloys, biological materials, calibration solutions, and environmental materials. NIST provides the tools, methodologies, standards, and measurement services needed by aerospace parts manufacturers, assemblers, and NASA to maintain their accurate and traceable use of the International System of Units (SI)—units of length, mass, and time, as well as their derived units (force, acceleration, sound pressure, and ultrasonic power). For example, NIST performed calibrations of length standards for U.S. aerospace companies to ensure that the dimensions of their manufactured parts conform to design specifications.

Traceable NIST measurements (mass, force, vibration, acoustics, electricity, thermometry, humidity, flow, pressure, viscosity, fluid density, radiometry, and length) are essential for aircraft manufacturing, according to a senior Boeing metrologist. Further, in the manufacture of the company's new 787 airplanes, every tool used in the assembly process has been calibrated in Boeing's metrology laboratories with direct traceability to NIST. Structural testing of the airplane is performed by scores of load cells with up to 3.54 meganewtons (MN) (800 kilopound force [klbf]) of capacity. These load cells are central to the structural testing of the first full-scale composite wing/titanium wing box. The load cells, used to analyze the integrity of the wing-box structure, are directly traceable to NIST either through direct comparison with NIST-calibrated load cells or through calibration in the Boeing 221-kilonewton (kN) (50 klbf) force-deadweight machine whose masses

were calibrated at NIST. Other direct applications of NIST measurements included the use of NIST-calibrated weights to support wind tunnel applications; weighing airplanes; and torque, pressure, and force measurements.

NIST continues to work with EMCORE Corporation of Albuquerque, New Mexico, a leading developer of high-efficiency solar-photovoltaic cells for space applications, to space-qualify its solar cells. EMCORE sent batches of solar cells for irradiation by an electron beam from the NIST Van de Graaff accelerator, where the equivalent electron fluence experienced by a satellite over several decades in Earth orbit may be delivered in less than 1 hour. Characterizing the degradation in performance of the solar cells as a result of irradiation is an important part of the qualification process, as is validating the performance of the cells in a space-radiation environment. The knowledge gained by irradiation of these devices assisted EMCORE in the development of its technology in terms of product reliability and functionality.

NIST worked with Goddard Space Flight Center to determine the radiation sensitivity of an ion mass spectrometer, which is designed to operate in the high-radiation environment of Jupiter's magnetosphere and icy moons. It is anticipated that this device will serve as one of the monitoring instruments in the upcoming NASA JUpiter ICy moons Explorer (JUICE) and Clipper missions, but it could also be deployed in other high-radiation environments such as Uranus. NIST's testing involves placing the instruments in a large vacuum chamber and bombarding the microchannel plate detectors with high-energy electrons using calibrated solid-state detectors as beam monitors. This allows the NASA experimental group to characterize the detector response to high-energy electron beams and to determine the effectiveness of the radiation shielding.

NIST used neutron imaging to study alkali metal heat pipes that cool the leading edge of hypersonic aircraft. In a project sponsored by Lockheed Martin in FY 2013, lithium heat pipes were designed and manufactured by Thermacore and the University of Tennessee. NIST's neutron imaging facility visualized the lithium fluid motion while the heat pipe operated at temperatures of up to 1,100°C. After cooling the lithium to room temperature, NIST acquired 3D images of the lithium concentration. This project utilized the unique capability of neutron imaging to help develop the next generation of high-speed aircraft.

NIST collaborated jointly with the National Transportation Safety Board (NTSB) and Boeing on investigating potential causes of the major battery thermal runaways that resulted in the grounding of the 787 Dreamliners by the Federal Aviation Administration in January 2013. The battery headers involved in the thermal runaway events were nondestructively analyzed. By using neutron tomography to produce 3D images, investigators were able to check for the presence of lithium salts on the battery header, which could have led to a short circuit of and subsequent runaway event in the battery pack. Neutron imaging has provided a new tool to the NTSB for enhanced aircraft-safety-related investigation.

NIST has recently begun work with DOD and Boeing on the applicability of laser-scanning technology for the dimensional measurement of aircraft components. This new technology offers potential cost savings and increased measurement throughput. The work includes developing calibration methodologies and facilities for laser-scanner systems and national and international standardization of their measurement accuracy.

NIST continues to develop and characterize measurement methods for advanced optics used in aerospace and space applications. Advanced optical elements are essential components of air- and space-borne imaging systems and telescopes. Such elements must incorporate features that yield vastly improved performance but pose significant measurement challenges. Examples include complex, highly accurate optical surfaces that are neither flat nor spherical or that have micro- and nanoscale surface structures. In collaboration with NASA, NIST developed a method that employs a mirror with a special height relief pattern to assess the capability of inspection equipment to measure fine surface features on optical surfaces. NIST also collaborated with NASA, supported by funding through NASA's Innovative Partnerships Program, to develop a new interferometric method to precisely measure the form errors of mandrels needed for the fabrication of x-ray mirrors for future space-borne x-ray telescopes. The new method, based on a pair of computer-generated holograms, has the potential to meet the metrology requirements for the next generation of x-ray mirrors, which cannot be met with the current probe-based metrology for mandrels. These collaborations built on prior joint developments by NIST and NASA for the calibration of reference optical flats for precision interferometry.

NIST also continues to work on the development of nanometrology for nanomanufacturing. The aerospace industry is interested in the potential benefits of nanotechnology. The development of accurate nanometrology of small particles and structures is critical to the success of this effort. For example, a reference material has been made available for scale calibration of optical, scanning probe, and scanning particle beam instruments to the same dimensional standard. The use of this standard has also been extended to the measurement and monitoring of beam-induced contamination in scanned particle beam instruments. Using this standard and the methods developed, NIST has virtually eliminated the deposition of contamination on the specimen, which is a common artifact in these instruments (which are critical to imaging, measurement, and characterization for nanotechnology). In addition, these methods have applications in other areas, such as to cleaning optical surfaces. NIST research is also being conducted to characterize and monitor instrumentation performance and standardization to ensure accurate dimensional metrology of carbon composites, carbon nanotubes, and cellulose nanocrystals. Nanocomposite material offers the advantage of lighter airframes giving better fuel economy; however, it still needs to be determined if the material provides the necessary high strength and durability. To facilitate this, NIST developed a new scanning electron microscope imaging technique to help to determine the carbon nanotube loading in composite materials.

Using instruments developed to help improve semiconductor electronics, NIST has worked with Johns Hopkins University and NASA to measure the optical constants of iron and nickel. Iron metal is a key component of many planetary surfaces. It is present as macroscopic grains (larger than the wavelength of light) in a variety of meteorites and is inferred to exist in the asteroidal parent bodies (e.g., S- and M-types). In addition, much smaller (nanometer to micrometer) grains of metallic iron are produced to varying degrees in the surfaces of airless solar system bodies by exposure to the space environment. Space weathering (which includes solar wind sputtering and micrometeoroid impact melting and vaporization) results in the reduction of ferrous iron in silicates to the metallic state and creation of nanophase blebs and coatings on and within regolith particles. The nanophase iron ($npFe^0$) is optically active and has a strong effect on the reflectance spectrum. For example, a mature lunar soil that has accumulated $npFe^0$ is much darker and

has a steeper spectral slope than a freshly ground powder of the same lithology; diagnostic absorption bands are also greatly attenuated in space-weathered material. In support of Johns Hopkins University's efforts to analyze remote and laboratory spectra of planetary surfaces, NIST has undertaken a program to measure the optical constants of iron and nickel. The optical constants (*n* and *k*) are fundamental physical parameters that govern the reflectance (and transmission) of light from a material. NIST has measured *n* and *k* from extended wavelengths ranging from 150 nanometers (nm) to 4,000 nm for high-purity iron films using ellipsometry, including bare films exposed to the atmosphere and films protected from the atmosphere via a novel technique involving an iron coating on a fused silica prism. Surprisingly, the air-exposed film exhibits optical constants that are markedly different from those of the protected film, despite the fact that the air-exposed film appears to the eye to be bright and mirror-like. Analysis of the air-exposed film by x-ray photoelectron spectroscopy confirms the presence of oxidized iron (Fe_2O_3) on the surface, and we conclude that oxidation layers form rapidly on the air-exposed metal and measurably alter the optical properties.

NIST, in partnership with the University of New Mexico, Harvard University, and the Smithsonian Institution, continued a research program to improve the absolute radiometric calibration of stars for applications that include satellite-sensor calibration, dark-energy research, and nighttime aerosol monitoring.

Scientists from NIST, the Jet Propulsion Laboratory, and the California Institute of Technology collaborated on the pre-launch and post-launch calibration of the Cosmic Infrared Background Experiment (CIBER), which was flown for the final time in June 2013. CIBER was designed to characterize various properties of the near-infrared background, including its absolute photometric spectrum and spatial anisotropy. These are critical measurements that constrain the overall stellar content of the universe, particularly at very early epochs when the first generation of stars were formed. The CIBER calibrations were performed using a transportable version of NIST Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources Facility (Traveling SIRCUS). The SIRCUS calibration provided the most accurate available measurements of the CIBER absolute spectral response and has allowed several critical science topics to be addressed. Primarily, the NIST calibration has enabled a detailed analysis of the CIBER data, allowing

the disentanglement of local contributions like the Zodiacal Diffuse Galactic Light from the much fainter and more distant extra-galactic background. Furthermore, the NIST calibrations are critical for allowing comparison of the CIBER data to previous measurements and models, some of which have already been excluded by the CIBER data. As a side-product of the exceptionally accurate calibration provided by SIRCUS, the CIBER team will release a catalog of several hundred calibrated stars to the astronomical community; the catalog will be a unique and valuable dataset due to the lack of atmospheric extinction over a broad spectral range. A second version of CIBER is being constructed that will allow even better spatial and spectral resolution of the background infrared light from the early stages of the universe.

NIST worked with the Air Force, NASA, the FAA, the Commercial Aviation Alternative Fuels Initiative (CAAFI), the Department of Energy (DOE) National Renewable Energy Laboratory (NREL), and industry in fuels research geared towards developing alternative fuels and generating an understanding upon which to base innovative designs for jet and rocket propulsion systems. Major foci of the work involved combustion kinetics, chemical characterization, microbial-induced corrosion, and thermophysical properties. In the past year, NIST has completed thermophysical property measurements on thermally stressed rocket propellant for Edwards Air Force Base. This required the design and construction of a thermal stress apparatus capable of producing liter quantities of stressed fluid required for multiple measurements of density, volatility, speed of sound, and viscosity. For this work, fuel was stressed at two temperatures: 475°C and 510°C. After the aforementioned measurements were completed this year, work began on a surrogate mixture model that will be capable of predicting thermodynamic and transport properties of the stressed fuel. In addition to the work on the thermal stress fluids, we have also applied two-dimensional gas chromatography to the characterization of rocket propellants, relating this detailed composition assay (with partial least squares chemometrics) to the NIST-developed measure of volatility by use of the advanced distillation curve metrology.

NIST is also working to certify SRM 1617b Sulfur in Kerosene (High Level) and will have a certified sulfur mass fraction (0.1250 percent) at level to help serve the needs of the aviation industry. Additionally, SRM 1617b will include reference

values for kinematic viscosity, density, and speed of sound at a range of temperatures to aid in the blending of jet fuel with biofuels. ASTM D7566 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons has paved the way for biofuels to be widely used in this capacity. However, polar biofuels blended with nonpolar traditional aviation fuels can significantly affect physical properties such as kinematic viscosity, affecting flow and delivery of a fuel blend to an engine. These new values planned for SRM 1617b can be used in conjunction with reference values for kinematic viscosity, density, and speed of sound already available for NIST biodiesel SRMs 2772 and 2773 to monitor blending and performance by the aviation industry.

Finally, NIST held a biocorrosion workshop in July 2013 that helped establish vital measurement needs in understanding microbial induced corrosion (MIC) mechanisms, pulling together experts in the areas of microbiology, metallurgy, and chemistry. This multidisciplinary approach allowed NIST to identify gaps in the areas of MIC detection and monitoring in materials, define the activity and impact of microbial presence, and measure the potentially detrimental degradation of fuels as a result of microbial contamination. As a result of the workshop, efforts to provide vital standards related to MIC and alternative fuel deployment will ultimately lead to developing prediction methods and minimizing the impact of MIC on key fuel infrastructure. NIST's Synchrotron Ultraviolet Radiation Facility (SURF) III was used as a source of soft x-rays and extreme ultraviolet (EUV) light to calibrate mirrors, filters, detectors, and spectrometers used in NASA and NOAA spacecraft. NASA and its contractors were the most prolific users of SURF III in 2013 and amassed over 800 hours of beam usage. Calibrations included rocket-borne instruments to maintain the accuracy of the instrumentation for the EUV Variability Experiment (EVE) aboard NASA's Solar Dynamics Observatory (SDO) and the EUV and X-ray Irradiance Sensor (EXIS) and Solar Ultraviolet Imager (SUVI) instrumentation now being built for NOAA's GOES-R satellite mission. These instruments are designed to study soft x-ray and EUV solar irradiance and its variability. NASA's EVE measurements are important to the National Space Weather Program (NSWP)—which tracks solar storms that impact space-based communications and navigation technologies—and to the NOAA EXIS and SUVI

instruments, both of which provide NOAA with data about the solar effects on Earth's atmosphere.

NIST continued to develop a Hyperspectral Image Projector (HIP) facility to enable preflight performance validation of future satellite sensors using realistic scenes. NIST extended the spectral range of this facility to cover the violet–near-violet region of the solar spectrum. Previously the HIP facility had covered only the blue-green-red–near-infrared spectral range.

NIST performed spectral irradiance measurements of the collimated output infrared beam from several space simulation chambers used in the aerospace industry for the calibration of infrared remote sensing systems for the Missile Defense Agency. For this work, NIST utilized the NIST-developed Missile Defense Transfer Radiometer (MDXR) and a portable cryogenic radiometer.

NIST continued its collaboration with NOAA on the calibration of the Marine Optical BuoY (MOBY) used in the vicarious calibration of ocean-color measurements provided by satellite sensors. NIST is participating in the MOBY Refresh effort, which will result in a new optical design and other improvements that will reduce the overall measurement uncertainties and allow the current system, which is beyond its design lifetime, to be retired.

NIST continued to collaborate with NASA on the calibration and characterization of the Ocean Radiometer for Carbon Assessment (ORCA), a hyperspectral ocean-color imaging system under development at NASA through the Instrument Incubator Program.

NIST continued to help NASA's Goddard Space Flight Center develop a version of SIRCUS. American Recovery and Reinvestment Act (ARRA) funding provided a tunable laser to NIST that has been loaned to Goddard for the last few years. The facility provides a source of tunable, high-power, uniform irradiance for calibrating satellite sensors. NIST has also calibrated transfer standards to characterize the source. This facility has been active in the calibration of ORCA and the reflective solar aspect of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) and the SOlar, Lunar for Absolute Reflectance Imaging Spectrometer (SOLARIS).

NIST also helped the University of Colorado Laboratory for Atmospheric and Space Physics to develop a version of the NIST SIRCUS facility. This facility has

been useful in calibrating the Spectral Irradiance Monitor (SIM), a future instrument to measure solar spectral irradiance from space. The first SIM was characterized at SIRCUS and is presently in space (although not operational).

NIST has started the calibration of the Stratospheric Aerosol and Gas Experiment (SAGE) III, a system designed to take long-term measurements of ozone, aerosols, water vapor, and other gases in Earth's atmosphere from the International Space Station. Traveling SIRCUS has been deployed to NASA's Langley Research Center and will make radiance responsivity measurements of sensor bands from 290 nm to 1,550 nm.

NIST provides air-speed, hydrocarbon-liquid-flow, and gas-flow measurements to support the aerospace sector. The air-speed calibration service performs calibrations of anemometers used at airports, on aircraft, and in wind tunnels for testing new aircraft. The hydrocarbon-liquid calibration service calibrates flow meters that are used to measure jet fuel (for example, turbine meters that are used to evaluate jet engine performance on test stands). During the past year, NIST studied the calibration stability of coriolis meters and their usage as transfer standards in comparisons between secondary calibration labs in the aerospace calibration chain. The Fluid Metrology Group advised NASA's Glenn Research Center on large (greater than 20 kilograms per second [kg/s]) gas flow calibrations and advanced the uncertainty calculations for large blowdown gas-flow calibration standards that they use.

NIST provided heat-flux gauge calibrations to the Federal Aviation Administration staff at the William J. Hughes Technical Center for setting regulations for heat resistance of materials used in aircraft. In addition, these gauges were used by the FAA for round-robin testing of the procedures for assessing thermal conductance at independent suppliers of materials used in aircraft. These calibrations were also utilized by Boeing.

NIST helped resolve long-standing discrepancies in the data used to determine temperature and other properties of hot astronomical objects observed by the Chandra X-ray Observatory and other x-ray missions. NIST created, in the laboratory, atoms in the same extremely hot form as that found in high-energy astrophysical environments. By analyzing x-ray emissions from these atoms and comparing them to detailed calculations, NIST provided the basic data needed to understand observations from deep space. NASA partially funded this effort carried out in

collaboration with the Harvard-Smithsonian Center for Astrophysics and the Argonne National Laboratory.

NIST began the construction of a new facility, the Controlled-Background System for Spectroradiometry and Spectrophotometry (CBS3). This facility will contain an evacuated, temperature-controlled infrared test chamber for studying the performance of sensors, calibration sources, and the optical properties of materials in the 5-micrometer to 50-micrometer infrared spectral region to provide the measurement standards and calibrations required for the next generation of infrared satellite sensors used for weather forecasting and climate research.

NIST initiated construction of a new facility to permit more rapid and accurate measurements of the bidirectional reflectance distribution function of materials, including polarization sensitivity, in support of ground- and space-based remote sensing throughout the solar-reflected region.

NIST is collaborating with NASA's Goddard Space Flight Center to develop photodetectors for space applications. With funding from NASA, NIST designed and fabricated nanotextured gallium nitride (GaN) and GaN nanowires that serve as raw material for photocathode detectors. Goddard collaborators activated the material with cesium and packaged the units into complete imaging systems. In FY 2013, NIST modeled and grew photocathode films with the addition of thin-surface heterostructures in an ongoing effort to eliminate the need for cesium oxide coatings on photocathode devices. While these coatings significantly improve the quantum efficiency, they require vacuum packaging, which limits their lifetime and application.

NIST collaborated with JPL on the development of superconducting nanowire single-photon detectors (SNSPDs). SNSPDs are a type of single-photon detector with extremely low noise and very-high-speed response. These devices are of interest to JPL for space communications and to NIST for various quantum information experiments. In FY 2013, NIST characterized various JPL devices. NIST also packaged some JPL devices with our self-aligned single-mode optical-fiber packaging scheme. In FY 2013, NIST began joint development with JPL of small arrays of SNSPDs, which increase the device area. This is an important development for future use of these detectors in laser communication systems.

NIST is teaming with Northrop Grumman and the University of Maryland to develop the next generation of high-sensitivity solar-blind UV photodetectors using robust wide-band-gap materials. This project successfully combines Northrop Grumman's expertise in nitride material growth, NIST's exceptional nanofabrication and characterization capabilities, and the University of Maryland's device design and fabrication expertise. Such radiation-hard, ultra-sensitive ultraviolet photodetectors are intended for use in radiation monitors, satellite-based imaging, and other space applications.

NASA's next-generation satellite observatories require new detectors with improved sensitivity and scalability. With NASA funding, NIST developed new detectors based on the voltage-biased superconducting transition-edge sensor (TES). TES offers new capabilities for the detection of electromagnetic signals, from millimeter waves through x-rays. Following on their successful development at NIST, TES has become the reference technology or a leading candidate for future NASA satellite missions at x-ray, millimeter, and submillimeter wavelengths, as well as for many NASA-funded ground-based and suborbital instruments (including balloon-borne instruments and instruments intended for the Stratospheric Observatory for Infrared Astronomy [SOFIA]). More recently, NIST has developed integrated TES polarimeters for measuring polarization of the cosmic microwave background (CMB). These devices incorporate multiple TESes per pixel to measure the power in the different polarizations of the CMB. This integrated detector utilizes fully micromachined silicon feedhorns for beam formation. This integrated detector technology was deployed on the South Pole Telescope (SPT) in early 2012, and the first of three imaging detector arrays was installed on the Atacama Cosmology Telescope (Chile) in 2013.

With NASA funding, NIST is also developing 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 is providing SQUID systems to many researchers, both at NASA Centers (Goddard, JPL) and in academia, working on NASA-funded projects (including the California Polytechnic State University; Stanford University; the Massachusetts Institute of Technology; the University of California, Berkeley; Princeton University; Cornell University; and others). SQUIDs and SQUID multiplexers developed at NIST are

currently deployed in many ground- and balloon-based instruments (including the Atacama Cosmology Telescope [ACT], the Background Imaging of Cosmic Extragalactic Polarization 2 [BICEP2]/Keck Array, the South Pole Telescope, the Background-Limited Infrared-Submillimeter Spectrograph [BLISS], the Goddard Institut de Radioastronomie Millimétrique [IRAM] Superconducting 2 Millimeter Observer [GISMO], Spider, the E and B Experiment [EBEX], and others) and will be used in most of NASA's future TES instruments. Recent developments for improved detector readout include the demonstration of TES readout with dissipationless microwave SQUID multiplexers, the demonstration of Code-Domain multiplexers with sub-frame sampling for the measurement of fast x-ray pulses, and new low-power SQUID amplifiers for use at focal-plane temperatures.

NIST's work in detector readout and multiplexing creates a path for truly large (up to 1 million) pixel arrays of TES detectors for use in a variety of astronomical instruments. NIST is also using its SQUID expertise to assist Goddard in the development of magnetic micro-calorimeters.

NIST continues 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 K to 0.1 K. Researchers at NIST have developed large-area coolers fabricated using standard microelectronic processes. These devices have demonstrated cooling power 100 to 1,000 times greater than in previous demonstrations. More recently, NIST demonstrated the first cooling by tunnel junctions of a macroscopic stage that can support user-supplied payloads.

With NASA funding, NIST has initiated the "NIST Participation in NASA's Support of ESA ISS Clock Projects"—an integrated program supporting science and operational goals of ESA's Atomic Clock Ensemble in Space (ACES) and the Space Optical Clock (SOC) program in close collaboration and coordination with ESA, NASA, and global participants. The ACES program will operate an atomic clock in orbit on the International Space Station with 1×10^{-16} uncertainty for tests of fundamental physics and for high-accuracy global intercomparison of ground clocks. The follow-on SOC program will operate a higher performance atomic clock in orbit on the ISS with 1×10^{-17} uncertainty for even more stringent tests of fundamental physics and for improved global intercomparison of ground

clocks. ACES is currently scheduled for flight in 2016, and NIST is currently supporting preparations for the program. NIST has initiated three primary projects as part of the broad program:

1. NIST continues preparations to host an ACES Microwave Link Ground Terminal (MWL GT) and to participate in ACES/Microwave Link (MWL) time and frequency transfers, international clock comparisons, and fundamental science goals based on precision time and frequency measurements.
2. NIST is performing research, development, and evaluation of an ytterbium (Yb) optical lattice clock as a candidate for the Space Optical Clock program. The NIST Yb lattice clock is expected to reach a fractional frequency uncertainty of better than 1×10^{-17}.
3. NIST continues to perform research, development, and evaluation of a highly miniaturized femtosecond-laser-frequency comb in the optical spectral region for potential future applications in the Space Optical Clock program. NIST will demonstrate a high-performance optical microcomb that could be used in space for direct comparisons of optical and microwave clocks, for referencing microwave time and frequency signals directly to optical standards, and for other applications. This project is being performed in collaboration with scientists at the California Institute of Technology.

NIST also works with NASA on secure communications. The NIST Cryptographic Module Validation Program and the Cryptographic Algorithm Validation Program (CAVP) have had an ongoing relationship with NASA in providing technical assistance with Federal Information Processing Standard (FIPS) 140-2: Security Requirements for Cryptographic Modules, as well as other cryptographic-based standards—specifically with NASA's Langley Research Center. NASA works with many vendors and other government space agencies, such as the Japan Aerospace Exploration Agency, to develop cryptographic modules for unique environments (i.e., space-based or ground telemetry) where interpretation of FIPS 140-2 is critical to both development and conformance to the standard. As a result, the NIST programs have successfully validated vendor-developed cryptographic modules for conformance to FIPS 140-2 and for deployment in space-based imaging and communication systems, including the Hughes

SPACEWAY Crypto Kernel, which is used in next-generation Ka-band broadband satellite systems. Cryptographic validations were in use on vehicles contracted to the International Space Station under NASA's Commercial Resupply Services program. The ongoing NIST collaboration with NASA and its suppliers continues, specifically with the Orion Multi-Purpose Crew Vehicle and NASA's Commercial Crew Development programs.

NIST supports NASA with its unique capabilities at the National Center for Neutron Research (NCNR). Scientists seek to utilize polymer nanocomposites to enhance the thermal, mechanical, and electrical properties of the base polymeric matrix material. Electrical properties of nanocomposites are crucial in many aerospace applications, including lightning-strike dissipation in air vehicles and electrical-charge mitigation in space vehicles in the charged space environment. In addition, robust mechanical properties are necessary in a wide range of temperatures for fundamental structural material components. NIST partnered with Edwards Air Force Base to use small-angle neutron scattering (SANS) to measure electrically conducting polyaniline nanofiber/polyimide nanocomposites. The study determined that the level of electrical conductivity in these heterogeneous materials depends primarily on the concentration and geometry of the conductive filler particles. The observed critical filler content that marks the onset of increase in conductivity in the majority of these composites falls between 15 and 25 percent volume/volume (vol/vol). At such high filler concentrations, many of the desirable mechanical properties of the matrix polymer are either compromised or lost. However, when the conductive components are reduced in size from macro- to nanosized, the concentration threshold for conductivity is dramatically reduced, with the additional advantage of preserving the bulk mechanical properties of the matrix polymer.

An additional collaboration with Glenn Research Center studied the synthesis and properties of several proton-exchange membranes for fuel-cell technology. SANS measurements were critical to understanding the morphology and distribution of small ionic clusters within these films, which impart their ability to exchange protons. The goal of this partnership is to produce materials with lower costs, higher conductivity, and improved temperature stability.

Other material-engineering projects include collaboration with Northwestern University to develop phase-equilibria and diffusion-mobility descriptions for the cobalt-aluminum-tungsten system, which are the basis for a new class of high-temperature superalloys. These alloys have the potential to significantly increase the efficiency of turbine engines by increasing operating temperatures and thus decreasing fuel consumption and lowering emissions. Simultaneously, these alloys hold the promise of improving wear-resistance for increased service life, thus lowering operational costs. Like the currently used nickel-based superalloys, these cobalt-based alloys depend on the precipitation of a second phase, phase γ', to strengthen the matrix (γ). NIST is providing data on the microstructure of evolution and stability of the primary strengthening phase, γ' phase, and data on the diffusion mobilities in the cobalt-aluminum-tungsten system. These data are being used to refine existing multicomponent thermodynamic and diffusion-mobility databases that are used to predict microstructure evolution and property behavior during processing and service. With NASA funding from the Planetary Instrument Definition and Development Program (PIDDP), NIST has worked to develop microsensor technology for use in planetary exploration missions. NIST's sensing technology for measuring trace gas-phase compounds is inherently small, with low mass and low power consumption, and these features are well suited to extraterrestrial deployment and operation on rovers, atmospheric sampling balloons, trend-monitoring weather stations, and networks. The fabricated devices include silicon-microelectromechanical system (Si-MEMS) array platforms that are populated with varied chemiresistive materials. Rapid thermal modulation is employed to greatly enhance signal densities from sets of individually addressable "microhotplate" elements within the arrays to sense multiple analytes. Nanostructured oxide-sensing materials provide the sensitivity required to detect targets of interest at relevant concentration levels. As a demonstration scenario, efforts were specifically directed to future exploration of the Martian surface—efforts that will seek to locate hotspots of methane and determine if there is also proximal sulfur dioxide (suggesting volcanic activity) or ethane or hydrogen (possibly indicating a biological origin).

As reported in a peer-reviewed journal publication and a final report to NASA, operation of the microsensor arrays was demonstrated under simulated Martian

conditions (CO_2-rich background, low temperature and pressure), including the ability to detect and quantify target compounds sub-micromole/mole (µmol/mol) (20 nanomole [nmol]/mol to 200 nmol/mol). We also reported on the pre-training and post-operation of microsensors for reliable target sensing and the transfer of training between array elements to extend sensor-measurement life. The adaptability of this emerging sensor technology has implications for the exploration of other space-exploration venues (besides Mars), as well as for analytical measurements of cabin environments in crewed space missions.

Suppliers to the aerospace industry, both commercial and defense, know that in order to be competitive, they need solutions that work across entire supply chains and production streams. The NIST Manufacturing Extension Partnership (MEP) works with the aerospace industry to develop systematic solutions for original equipment manufacturers (OEMs) as well as their suppliers and prime integrators. A proven leader in innovation, NIST MEP collaborates with aerospace executives to drive improvements in design, sourcing, and production.

NIST MEP's expertise, coupled with a national network of resources, including state and Federal agencies, enables it to provide a variety of services to aerospace companies. NIST MEP helps clients face many of today's biggest challenges, including reducing engineering change requirements, identifying and achieving affordability targets, reducing lead times, improving Request for Quotation (RFQ) results, mitigating risk, and improving quality and reliability.

In FY 2013, NIST MEP centers engaged in 226 business improvement projects with 143 individual manufacturing companies designated with an aerospace North American Industry Classification System number (NAICS 3364). The NIST MEP post-project, follow-up survey of aerospace NAICS companies revealed that MEP services resulted in the creation or retention of 5,200 aerospace jobs, over $138 million in new sales, nearly $251 million in retained sales, over $144 million in new investment, and nearly $51 million in cost savings.

In FY 2013, NIST MEP began partnering with the Bureau of Industry and Security (BIS) to take a proactive approach to assisting aerospace and space suppliers adversely affected by NASA's changing budget priorities. BIS recently concluded a survey of suppliers in the aerospace and space industries. The results of this in-depth study of the supply chain focused on supplier vulnerabilities in light

of NASA's spending reductions. MEP is using the results of the study for outreach and marketing to companies adversely affected by declines in the space industry. Identifying and assessing at-risk companies and developing a customized plan that addresses each company's unique set of circumstances will take a coordinated effort between MEP, BIS, and other state and local partners. By working together, these entities can not only identify struggling companies, but assist them in adapting to new economic realities to stay in business, retain employees, preserve key defense-critical capabilities, and grow profitability. Pilot efforts have begun in California and Texas.

National Ocean Service

NOAA's National Geodetic Survey (NGS) released a new Web application to allow users to easily and quickly view NGS geodetic control across the United States and its territories using Google Maps. The NGS Data Explorer map application (*http://geodesy.noaa.gov/NGSDataExplorer/*) is an innovative, interactive tool allowing users to explore NOAA's extensive geodetic control network, which provides the framework for all positioning activities in the Nation. This new map application provides access to control mark information including latitude, longitude, elevation, position source, and other available precise positioning data. The online application presents an easy and efficient way for users to download datasheets directly from a mapping application. Surveyors, engineers, and Geographic Information Systems (GIS) professionals will benefit from the rapid access to information that the application provides.

The NGS's Gravity for the Redefinition of the American Vertical Datum (GRAV-D) airborne-survey project completed data collection for more than 30 percent of the United States and its territories. Upon completion, the GRAV-D project will allow surveyors and scientists to employ GPS to determine more precise and accurate elevations than currently possible, in less time and with less effort. The current vertical datum is anchored by less accurate, more costly survey monuments, and there are elevation errors ranging from 16 inches to 6 feet relative to sea level. When GRAV-D is successfully completed and the new elevation system is accessible using the Continuously Operating Reference Station network,

these elevation errors will be reduced to just under 1 inch. Data coverage for 2013 includes Puerto Rico, most of the Great Lakes and Gulf Coast, a large part of Alaska, the Northeast United States, Northern California, and southern Florida.

NOAA's National Geodetic Survey completed a nearly 20-year effort to define the vertical datum of Puerto Rico (Puerto Rico Vertical Datum of 2002 [PRVD02]). The new elevations establish accurate and reliable heights consistent for the main island of Puerto Rico, where the majority of the population resides. The establishment of an enhanced geodetic framework for the Commonwealth will improve mapping, civil engineering, and land-surveying projects. With increased precision and accuracy in products such as floodplain maps, warning systems, and hurricane inundation models, the geospatial community can enhance the services they provide to the general population.

The U.S. Integrated Ocean Observing System (IOOS) increased ocean observation capabilities for the Nation. For example, the Caribbean Coastal Ocean Observing System (CariCOOS), one of 11 IOOS regions, deployed a new buoy and two new weather stations this year, making for a total of four buoys and 15 weather stations in CariCOOS. The new buoy, located in Vieques Sound, measures a multitude of meteorological and oceanographic parameters such as wave heights, wave direction, wind speed, wind direction, air temperature, salinity, barometric pressure, and ocean currents. This buoy will aid U.S. Coast Guard operations and inform the boating community of daily conditions. Also in 2013, CariCOOS delivered a number of new modeling products, including current forecasts based on U.S. Navy models and high-resolution current forecasts in the U.S. Virgin Islands and San Juan Bay. IOOS scientists also developed storm-surge inundation maps for the Virgin Islands and Puerto Rico. CariCOOS is working with state emergency managers for the publication of these maps. In addition, IOOS scientists are using satellite imagery from the European Space Agency to evaluate suspended sediments and display them online for water management applications. Over this past year, the CariCOOS data pages received more than one million views from links on the NOAA National Data Buoy Center and CariCOOS Web sites.

International Trade Administration (ITA)

Industry and Trade Policy

The Office of Transportation and Machinery (OTM) pursued multiple paths to promote exports of products and services that will support the Next Generation Air Transportation System. OTM created and published an online NextGen Solutions Vendors Guide to help foreign customers identify U.S. companies who can provide products that meet the requirements of the International Civil Aviation Organization's (ICAO) Aviation System Block Upgrade technology roadmaps. OTM participated in the first World Air Traffic Management Congress in Madrid, Spain, to learn about the specific air-navigation procurement needs of specific countries, counsel individual companies on NextGen-related prospects, and recruit participants for the NextGen Solutions Vendors Guide. OTM also participated in a number of domestic conferences and exhibitions to discuss the future of the NextGen market with individual companies.

Additionally, OTM worked with the FAA, the Transportation Security Administration (TSA), NASA, and the USAF in preparations for ICAO's 12th Air Navigation Conference (ANC-12) in Montreal in November 2012, providing the Commerce perspective on various topics that impact U.S. industry. These topics included required navigational performance, remotely piloted aircraft, and satellite navigation, among others. OTM worked with the FAA, Export-Import (Ex-Im) Bank, Millennium Challenge Corporation, U.S. Small Business Administration (SBA), Overseas Private Investment Corporation (OPIC), and U.S. Trade and Development Agency (USTDA) to produce and distribute at ANC-12, a brochure that lists Government sources of funding for air traffic management renovation projects around the world and provides information on U.S. vendors of NextGen equipment and services. The brochure allowed ICAO to address how members will finance required system upgrades. In addition, OTM worked with the FAA, TSA, and the State Department in preparation for the 38th ICAO Assembly in September 2013, providing the ITA perspective on aviation safety, aviation security, air-navigation policy and procurement, and the economics of air transportation.

OTM also participated in the Unmanned Aircraft Systems Symposium and the Association for Unmanned Vehicle Systems International (AUVSI) Unmanned Systems 2013 Conference to engage with Government, academic, and industry stakeholders within the UAS community, to learn more about the projected market for UAS, to hear about the latest roadmaps for the technology, and to recruit participants for the NextGen Solutions Vendors Guide (particularly the section on Remotely Piloted Aircraft).

OTM renewed a Memorandum of Agreement (MOA) with Embry-Riddle Aeronautical University (ERAU) to share data and aerospace information and to promote the competitiveness, sustainability, and innovation of the U.S. aerospace manufacturing industry. The renewed MOA includes an addendum detailing a new virtual research partnership program in which ERAU-Worldwide students will research topics suggested by ITA.

Throughout the year, OTM organized and led five meetings of the Industry Trade Advisory Committee for Aerospace Equipment (ITAC 1). The committee provides advice to the Secretary of Commerce and U.S. Trade Representative on aerospace-related trade policy issues.

ITA continues to support the Office of the U.S. Trade Representative on issues relating to the enforcement of U.S. rights under the World Trade Organization concerning trade in civil aircraft. In particular, OTM has provided support for the ongoing U.S.-EU trade dispute over subsidies to manufacturers of large civil aircraft, providing industry expertise in areas relating to changes in the market and actions of the major stakeholders.

ITA's OTM and Office of Financial Service Industries (OFSI) continued to participate in the Group on the Sector Understanding on Export Credits for Civil Aircraft (the "Aircraft Sector Understanding" or ASU) at the Organization for Economic Cooperation and Development (OECD). The governments of almost all countries with major aircraft manufacturers are signatories to the ASU, 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. A new ASU, which had been completed in early 2011, went into full effect in 2013. As a member of the U.S. delegation, ITA helped ensure

that the interests of industry were addressed as the new ASU was implemented and provided advice on how Ex-Im Bank programs affect the aerospace industry.

ITA and NOAA continued their active participation in the implementation of the current National Space Policies, which include industrial base and competitiveness issues. ITA's OTM actively participated in the implementation of several actions that were identified in the June 2010 National Space Policy, which revised and updated several aspects of the previous policies. In order to ensure that commercial interests continue to be adequately addressed, OTM and NOAA continued to ensure that all of the policies' implementation actions will improve U.S. industry's competitiveness, stimulate the American economy, increase exports, and create U.S. jobs. ITA actively participated in the review of Space Transportation Policy led by the White House and sought to ensure that the policy encouraged U.S. commercial growth in that sector.

OTM continues to represent 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 representatives to understand the impact on related businesses.

ITA continued to play 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, remote sensing satellites, commercial projects, and air traffic management projects.

In June 2013, ITA organized and supported the Commerce Department's participation in the Paris Air Show and arranged senior-level meetings for the Deputy Assistant Secretary for Manufacturing 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.

Industry and Trade Promotion

ITA's U.S. and Foreign Commercial Service (US&FCS) Aerospace Team recorded 350 export successes in FY 2013 valued at over $1.6 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 Bell Helicopter, Boeing, General Dynamics, Lockheed Martin, and United Technologies Corporation.

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 35 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 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, Aircraft Interior Show, and Aerospace and Defense Trade Mission to Turkey (led by Under Secretary of Commerce for International Trade Francisco Sanchez), among others. The CS Aerospace Team also released the first edition of its Aerospace Resource Guide, profiling market opportunities in over 40 countries. This resource was well received by industry and will be expanded upon in FY 2014.

OTM also worked with the Commercial Service and USTDA to put on a series of Webinars highlighting aviation opportunities in Latin America. The series was planned to support the U.S.-Latin America/Caribbean Aviation Summit hosted by USTDA in Miami. Commercial specialists from five countries in Latin America provided information on business prospects for U.S. companies for aircraft and for aviation infrastructure.

Bureau of Industry and Security

On May 24, 2013, the Departments of State and Commerce published proposed rules to transfer jurisdiction of commercial satellites and related items from State to Commerce. We expect that this transfer of jurisdiction will make an important difference for national security and the satellite industry by facilitating cooperation with U.S. allies, strengthening the competitiveness of sectors key to U.S. national security, and increasing U.S. exports—all while maintaining robust controls where needed to enhance our national security. The goal for publication of final rules is late March or early April 2014, with effective dates 180 days thereafter. The following items are those proposed for transfer from the U.S. Munitions List (USML) to the Commerce Control List:

- commercial satellites and commercial communication satellites;
- lower-performance remote sensing satellites; planetary rovers; planetary and interplanetary probes; and related systems such as ground control systems and training simulators;
- test, inspection, and production equipment; noncritical software for production, operation, or maintenance; noncritical technology for development, production, installation, operation, or maintenance; radiation-hardened microelectronics; and parts and components of satellite buses and payloads not listed on the USML.

Department of the Interior

DOI

Remotely sensed data and resources contribute significantly to mission-critical work across the Department of the Interior. Spanning data sources from aerial photography, to moderate-resolution satellite data, to highly specialized imaging sensors and platforms, DOI personnel use remote sensing capabilities to evaluate and monitor land-surface conditions over the vast areas for which DOI has responsibility. The following is a small sampling of DOI remote sensing activities in 2013.

U.S. Geological Survey

The U.S. Geological Survey (USGS) is both a user and a provider of remotely sensed data. The USGS manages the Landsat satellite series and a Web-enabled archive of global Landsat imagery dating back to 1972. The entire Landsat archive became available for download at no charge in December 2008, and by December of 2013, almost 15 million Landsat scenes had been downloaded by the user community. The USGS also distributes aerial photography through the National Map and archives and distributes historical aerial photography; LIght Detection And Ranging (LIDAR) data; declassified imagery; and hyperspectral imagery; as well as data collected by Unmanned Aircraft Systems and imagery from a variety of Government, foreign, and commercial satellites. These data are used for a wide variety of applications, including mineral resource development; U.S. and global ecosystem health monitoring; land use and climate change; emergency response; and the assessment of natural hazards such as fires, hurricanes, earthquakes, droughts, and floods.

Landsat Satellites

The Landsat Program (*http://landsat.usgs.gov/*) 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 in the development and launch of Earth-observing instruments and spacecraft, the USGS is responsible for flight operations, maintenance, and the management of all ground-data reception, processing, archiving, product generation, and distribution. For 41 years, the primary objective of the Landsat Program has been to record land-surface conditions across the global land surface through the collection of consistently calibrated image data.

In spring 2013, the USGS decommissioned Landsat 5 following an extraordinary 28 years of imaging operations, which earned it an official Guinness World Record. Shortly thereafter, the USGS assumed ownership and operation of Landsat 8 following NASA's launch and on-orbit checkout. Data from the new satellite proved to be in great demand, thanks in part to NASA's imaging-sensor improvements, which included a greatly improved signal-to-noise ratio, 12-bit quantization, a new coastal blue band (for the detection of water column constituents), a new cirrus band (for better cloud screening), and an additional thermal band (for more precise temperature measurements).

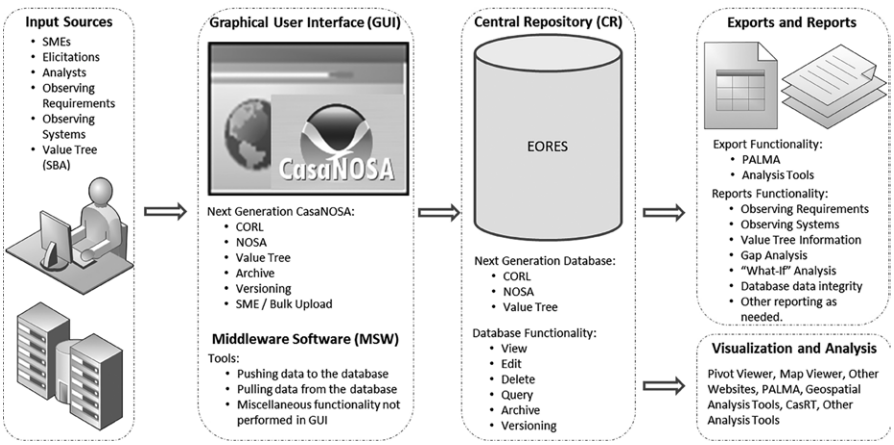
The Landsat team at the USGS Earth Resources Observation and Science Systems (EROS) Center ingested over 516,000 new images from Landsats 5, 7, and 8 into the Landsat archive during fiscal year 2013 and added nearly 1.4 million historical Landsat images provided by current or former International Cooperator receiving stations. During the same period, users downloaded nearly 4.4 million Landsat scenes from EROS's servers.

An Innovative Approach to Documenting User Requirements

The USGS initiated the National Land Imaging Requirements (NLIR) Project as a collaborative effort between the USGS Land Remote Sensing Program, the USGS Earth Resources Observation and Science Center, and the National Oceanic and Atmospheric Administration (NOAA). Under this project, the USGS and NOAA have partnered to design and develop a system to obtain, characterize,

manage, maintain, and prioritize user requirements for Earth Observation (EO) data. The comprehensive insight afforded by this capability will enable an unprecedented view of requirements and allow for the effective matching of EO capabilities and data to user needs.

Rather than defining needs in terms of a particular technology or solution, as has historically been the case, the NLIR Project gathers user requirements for specific EO information such as land surface temperature, land surface topography, and vegetation type. Each requirement includes relevant attributes that define where, when, and at what spatial and temporal resolution the information is needed. Through this approach, user requirements become "solution-agnostic" and can be evaluated against all potential solutions including existing and future technologies. The NLIR Project is changing the paradigm for analyzing EO science requirements and linking them to solutions.



An overview of the Earth Observation Requirements Evaluation System.

Landsat-Scale Evapotranspiration for the Apalachicola-Chattahoochee-Flint and Delaware River Basins

The USGS WaterSMART (Water for Sustainable Management of America's Resources for Tomorrow) Project aims to quantify the year-to-year variability of vegetation water use (consumptive use). WaterSMART focuses on irrigated lands and seeks to make previous-year consumptive use estimates available in a cost-effective and timely manner, before the next irrigation season starts. USGS

scientists improve upon existing hydrologic models to estimate and validate evapotranspiration (ET) from irrigated lands and the general landscape using a combination of satellite data and weather datasets. In the current effort, the first-ever basinwide ET estimate was produced for the Apalachicola-Chattahoochee-Flint (ACF) and Delaware River Basins (at a spatial resolution of 100 meters, corresponding to Landsat's thermal band) using the Operational Simplified Surface Energy Balance (SSEBop) approach.

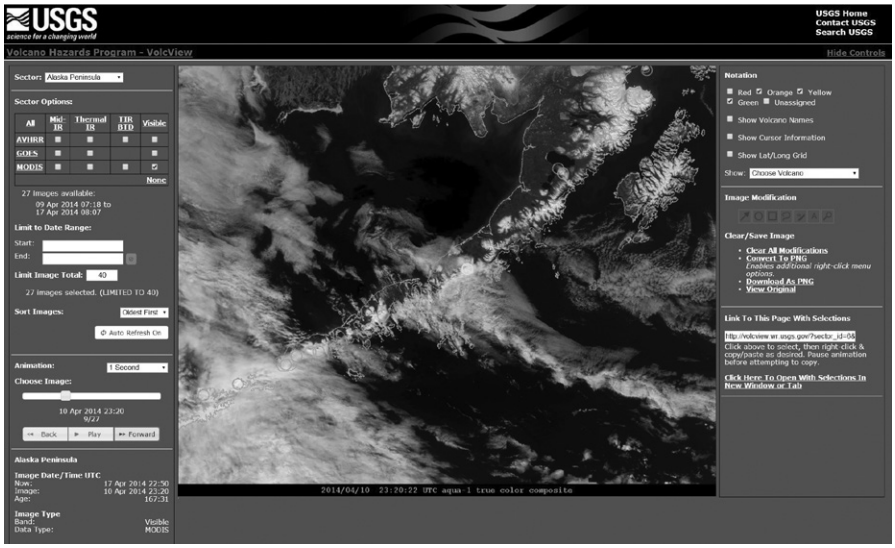
For the first time ever, seamless monthly and annual ET maps for 2010 were produced for the ACF and Delaware Basins. These products clearly show the spatial distribution of ET in the basin and magnitude differences associated with different land-cover types. The ability to estimate seamless ET at the Landsat scale will enable the creation of consistent, basinwide ET estimates for hydrological applications that are relevant for local decision making in water-resource planning and management. This project demonstrates the potential to create a nationwide ET at the Landsat scale using the Landsat 8 data stream.

USGS will continue to evaluate and apply Landsat-based ET for consumptive-use change detection, trend analysis, and groundwater recharge/withdrawal studies.

VolcView: A New Tool for Satellite Data Analysis

Volcanic ash poses a serious hazard to aviation, and the proximity of the 52 historically active volcanoes in Alaska-to-North Pacific air routes requires that the Alaska Volcano Observatory (AVO) use all available tools to monitor volcanic activity, detect eruptions, and work with the National Weather Service to characterize and track volcanic ash clouds. Satellite remote sensing is used in conjunction with in situ seismic and other geophysical monitoring (at 28 volcanoes) to meet this mission mandate. The AVO uses a variety of near-real-time data sources from the Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), and Geostationary Operational Environmental Satellite (GOES) sensors. During FY 2013, AVO worked with a Volcano Science Center (VSC) Web developer to produce a display and analysis tool for these data.

VolcView (*http://volcview.wr.usgs.gov*) allows AVO staff access to up-to-date image products of the North Pacific at the office, at home, and via smartphone. Partner agencies like the National Weather Service (NWS), Federal Aviation Administration (FAA), and Department of Defense (DOD), as well as the general public, can access the image products to observe and monitor volcanic activity. Data products have been developed by AVO to discriminate volcanic ash from meteorological clouds and to highlight volcanoes with elevated surface temperatures. AVO is actively engaged with the NWS to improve the analysis and visualization capabilities of VolcView. The overall goal of the VSC development is to extend the VolcView model to the other four USGS volcano observatories that include the California Volcano Observatory, Cascades Volcano Observatory, Hawaiian Volcano Observatory, and Yellowstone Volcano Observatory.



The interface of VolcView, a tool for displaying and analyzing satellite images of volcanoes in the North Pacific.

3D Elevation Program

The 3D Elevation Program (3DEP) initiative (*http://nationalmap.gov/3dep*) is a multi-year, multi-agency approach to systematically obtaining 3D elevation data for the Nation in an eight-year period. The data will be derived from high-resolution LIDAR (taken over the contiguous United States, Hawaii, and Trust Territories) and Interferometric Synthetic Aperture Radar (IFSAR) data (taken over Alaska).

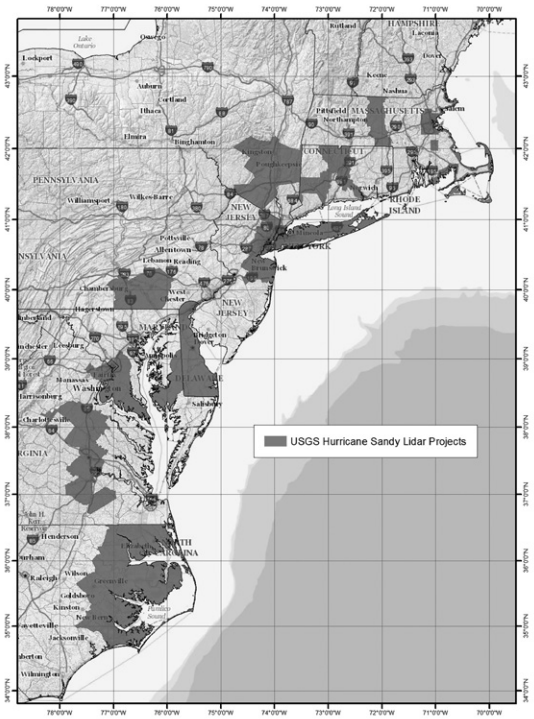
The National Geospatial (NGP) Program manages 3DEP as a collaborative effort among multiple Federal agencies, state and local governments, tribes, academia, and the private sector. In support of 3DEP, the USGS is implementing programmatic and infrastructure improvements to plan, acquire, store, and disseminate vast amounts of LIDAR and IFSAR data to support a wide range of user requirements for high-resolution elevation data. In FY 2013, the USGS actively participated in several data-acquisition activities directly supporting the goals and objectives of 3DEP. For example, for Hurricane Sandy response and mitigation, the NGP coordinated the acquisition of approximately 27,000 square miles of high-resolution LIDAR over the affected area through the Geospatial Products and Services Contract (GPSC). Additionally, for South Platte River flooding, the USGS assisted the Federal Emergency Management Agency (FEMA) and the Denver Regional Council of Governments in acquiring approximately 5,600 square miles of high-resolution LIDAR through GPSC.

Hurricane Sandy

Hurricane Sandy hit the Atlantic shoreline of New Jersey during several astronomical high-tide cycles in late October 2012. The eastern seaboard is subject to sea-level rise and an increased severity and frequency of storm events, prompting habitat and land-use planning changes. The National Wetlands Research Center (NWRC) is conducting detailed mapping of marine and estuarine wetlands and deepwater habitats—including beaches and tide flats, as well as upland land use/land cover—using specially acquired NOAA aerial imagery flown at 1-foot resolution. These efforts will assist the U.S. Fish and Wildlife Service (USFWS) in its continuing endeavors to map the barrier islands in accordance with the Coastal Barrier Resources Act (CBRA) guidelines. Land-use/land-cover classification will be based on the USFWS National Wetlands Inventory (NWI) and the USGS Anderson Land Use and Land Cover Classification System.

Mapping characterization is occurring with respect to potential storm surge and flooding impacts, which are anticipated to reshape rebuilding efforts. Mapping includes selected barrier islands and marshes from North Carolina to New York. These vital wetland areas are important for migratory waterfowl and neotropical

bird habitats, wildlife food-chain support, and nurseries for shellfish and finfish populations. Coastal wetlands also play an important function as storm-surge buffers. Activities include the mapping of dominant estuarine wetland plant species that are useful for wetland functional analysis and wildlife evaluation and management concerns. This project is intended to integrate with, and offer updated databases pertinent to, the USFWS, NWRC, and NWI programs; NOAA tide-flat and beach data; FEMA flood-zone data; natural heritage endangered and threatened species lists; watershed management; and state and local land-use planning.



The shaded areas show the locations of Hurricane Sandy LIDAR projects.

Hydrothermal Alteration Maps, U.S. Basin and Range

The Mineral Resources Program at the USGS has released a new set of maps compiled from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data that illustrate minerals deposited by hydrothermal alteration that are typically associated with copper, gold, silver, and molybdenum deposits. Some of the minerals mapped are also associated with rare-earth, element-rich carbonatite deposits. Map coverage of the basin and range includes Nevada; southern Arizona; and parts of California, New Mexico, and Utah. The maps help define new deposit targets for mineral assessments and exploration, delineate hydrothermal systems for further deposit formation study, and assist in identifying potential acid producing and acid-neutralizing rocks in watersheds. The maps and

map units can be downloaded from the USGS Web site server (*http://pubs.usgs.gov/of/2013/1139/*; *http://mrdata.usgs.gov/surficial-mineralogy/ofr-2013-1139/*).

Fish and Wildlife Service

The U.S. Fish and Wildlife Service (USFWS), in concert with its international, Federal, tribal, state, local, and nongovernmental organization partners, uses remote sensing images to find optimal solutions to monitor and manage our waters, wetlands, and landscapes. The USFWS utilizes a variety of remote sensing data products such as aerial, satellite optical, thermal, radar, sonar, and LIDAR imagery to map habitats, find invasive plants, determine flightpaths of birds and bats, conduct fish and wildlife inventories, reduce management costs, and monitor trust species.

Avian Radar Project

The U.S. Fish and Wildlife Service uses avian radar (*http://www.fws.gov/radar/*) along with multiple other methods to monitor bird and bat migration along the shorelines of the Great Lakes. Mobile avian radar units have been stationed around the Great Lakes since 2011. These radar units track birds and bats as they fly through the air. By combining data from the avian radar units, acoustic and ultrasonic monitors, and visual bird surveys, the USFWS can gain a broader picture of what is occurring on the landscape. Data from this project, along with the USFWS Voluntary Land-Based Wind Energy Guidelines, will help inform decisions to balance the needs of development and the need to protect wildlife.

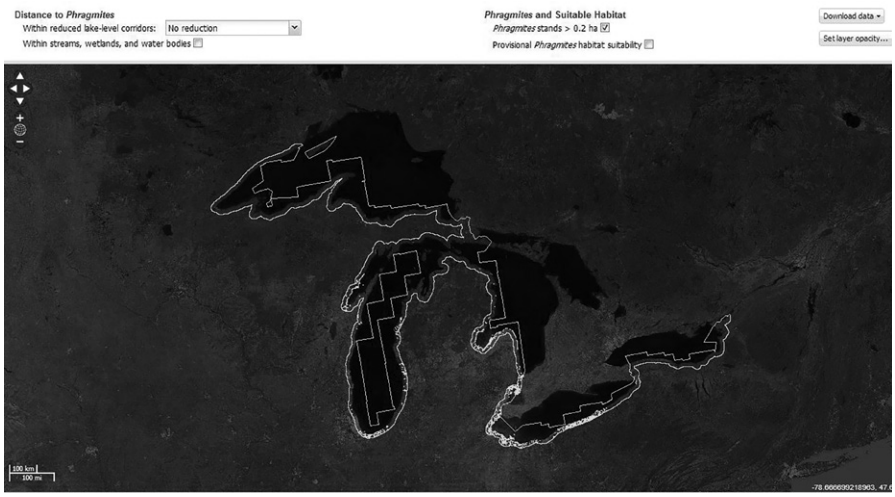
Through the use of avian radar to study migration, data can be gathered from a much larger range, with a more consistent effort, and without causing stress to the animals under study because they do not know that they are being monitored. Additionally, the avian radar units can collect data continuously and can easily collect data during times (such as at night) when visual surveys are difficult.

For each spring and fall migration season since 2011, the two MERLIN avian radar units and a variety of acoustic monitors have been placed around the Great Lakes to answer a variety of in-depth questions about bird and bat migration. The

radar units are each equipped with two antennas that allow data to be gathered simultaneously about the flight direction of migrants as well as their flight heights. With this information, the risk of collisions with humanmade structures such as wind turbines can be assessed.

Mapping Phragmites with PALSAR Radar Imagery

The invasive *Phragmites australis* forms dense stands that cause habitat degradation and reduced biological diversity on Great Lakes wetlands. Early detection and treatment are key to controlling *Phragmites*, so a map of the current distribution is needed (*http://www.mtri.org/monitoring_phragmites.html*). Phased Array type L-band Synthetic Aperture Radar (PALSAR) imagery was used to produce the first basin-wide distribution map showing the extent of large, dense, invasive-*Phragmites*-dominated habitats in wetlands and other coastal ecosystems along the U.S. shore of the Great Lakes. PALSAR is a satellite-imaging-radar sensor that is sensitive to differences in plant biomass structure and inundation patterns, allowing for the detection and delineation of these tall (up to 5 meters), high-density, high-biomass, invasive *Phragmites* stands. Classification was based on multi-season PALSAR L-band (23-centimeter wavelength) HH and HV polarization data. Seasonal (spring, summer, and fall) datasets were used to improve discrimination of *Phragmites* by taking advantage of phenological changes in vegetation and



A view of invasive *Phragmites* distribution in the Great Lakes.

inundation patterns over the seasons. Extensive field collections of training and randomly selected validation data were conducted in 2010–2011 to aid in mapping and for accuracy assessments. Overall basin-wide map accuracy was 87 percent. The invasive *Phragmites* maps are being used to identify major environmental drivers of this invader's distribution, to assess areas vulnerable to new invasion, and to provide information to regional stakeholders through a decision-support tool. The generation of these products was led by Dr. Laura Bourgeau-Chavez, of the Michigan Technological Research Institute, with funding support by the USFWS and USGS via the Great Lakes Restoration Initiative.

Chinook Salmon in the Togiak River, Alaska

Chinook salmon (*Oncorhynchus tshawytscha*) populations are declining throughout most of Alaska but remain a valuable resource for subsistence, sport, and commercial harvests. Traditional ecological knowledge indicates that the spawning distribution of Chinook salmon has shifted from tributaries to the main stem, with significantly more Chinook salmon spawning in the main stem than in tributaries. The goal of this project is to describe physical factors influencing Chinook salmon spawning habitat availability and distribution, which may influence overall abundance. The specific goals of this project are to (1) determine areas of high- and low-density Chinook salmon spawning and (2) describe the habitat characteristics associated with these areas. Telemetry data from Chinook salmon radio tagged in 2009–2012 was used to determine high- and low-density spawning in a GIS framework. Next, visible and forward-looking infrared (FLIR) imagery was collected over the Togiak River in two main stems and one tributary location. This imagery will be analyzed to describe and compare the physical habitat characteristics and temperature differences in high- and low-density spawning areas with the expectation that areas with a low density of Chinook salmon spawning activity will have different habitat characteristics than areas with a high density of spawning activity. Information from this project will aid in understanding habitat characteristics important for Chinook salmon spawning that can be derived from remote sensing imagery, which may provide an alternative method to ground-based studies.

LIDAR of Channeled Scablands Area and Turnbull National Wildlife Refuge

A LIDAR dataset is providing a high-resolution digital elevation model (DEM) for modeling various natural-resource-related issues. The data collection is facilitating the development of models for wetland management and restoration on the Turnbull National Wildlife Refuge (NWR) and private lands.

A Stewardship Area was identified during the development of the Turnbull National Wildlife Refuge's Comprehensive Conservation Plan to focus refuge acquisition and private-land-conservation programs in watersheds critical to the refuge water supply and its connectivity to the larger landscape. LIDAR data are being used to address multiple refuge-management questions related to hydrology, vegetation, habitat, and hydro-geomorphology. LIDAR bare-earth mapping of the Turnbull Stewardship Area has provided the USFWS with valuable data that have made substantial improvements to a number of refuge and partnership programs. The data will aid the USFWS and its partners (including the Bureau of Land Management and Ducks Unlimited) to make better planning decisions across this large landscape to effectively address the potential effects of climate change and other stressors such as agricultural land uses and urban development on critical habitat and species such as sage grouse. The use of these topographical data will facilitate the planning and design of potential habitat restoration or enhancement projects on both refuges and private lands.

Songbird Habitat Modeling Using LIDAR and NAIP-CIR

The golden-cheeked warbler and black-capped vireo were listed by the U.S. Fish and Wildlife Service as endangered in 1990 and 1987, respectively. In 1992, the 10,000-hectare Balcones Canyonlands National Wildlife Refuge (BCNWR) was established in Texas to protect the habitat for these two species. The warbler occupies later successional stages of oak and Ashe juniper woodland habitat during the breeding season, while the vireo prefers early successional shrublands. Contemporary habitat models for songbirds often lack fine-scale habitat information mapped over large areas. LIDAR data and high-spatial-resolution National Agriculture Imagery Program color infrared (NAIP-CIR) aerial photography were

used to characterize habitat structure and composition over the entire refuge. Habitat features such as successional stages, conifer and broadleaf tree canopy cover, tree density, and vertical and horizontal structural complexity were derived using machine learning and other statistical methods. These data layers were used as model covariates to develop empirical estimates of warbler and vireo population density and occupancy rates on and off refuge lands. Spatial model outputs are being used to prioritize conservation and habitat restoration activities that are part of endangered species and habitat recovery efforts.

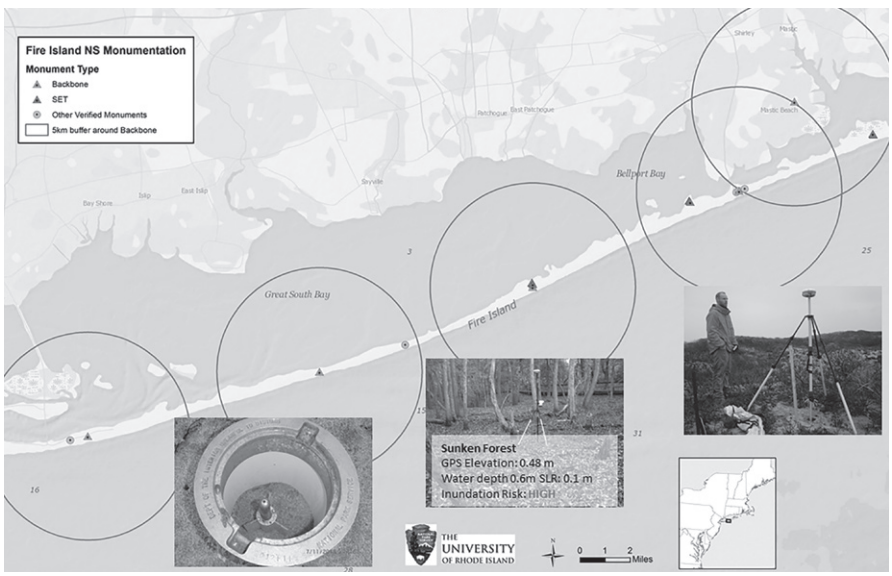
National Park Service

The National Park Service (NPS) has a significant investment and long history in using aerial and spaceborne remote sensing and GPS technologies. The NPS Inventory and Monitoring Program conducts baseline inventories for more than 270 parks spanning over 30 million acres of public lands. Remote sensing data are a critical source of information regarding geology, soils, vegetation, and infrastructure. Aerial photography and satellite imagery have been utilized to compile vegetation maps; 10 million acres are currently mapped and 8.5 million acres are under way, with 12 million remaining. These data are particularly critical for NPS activities in Alaska. The NPS takes advantage of the free Landsat archive to quantify decadal changes in glacier ice cover and document land-cover change in National Park units. NPS has been the DOI sponsoring agency to map all large wildland and prescribed fires as part of the DOI Monitoring Trends in Burn Severity project, using the Landsat archive. GPS supports field-data collection, navigation, and search-and-rescue operations across the agency.

Putting Some Backbone in Coastal National Parks

One of the key early steps in preparing for sea-level rise and storm surge is establishing the geodetic "backbone," a high-accuracy monumentation network with long-term viability. This task was just completed for the northeast coastal National Parks by the University of Rhode Island and the National Park Service (*http://www.edc.uri.edu/monumentation/*). Newly installed monuments and carefully screened

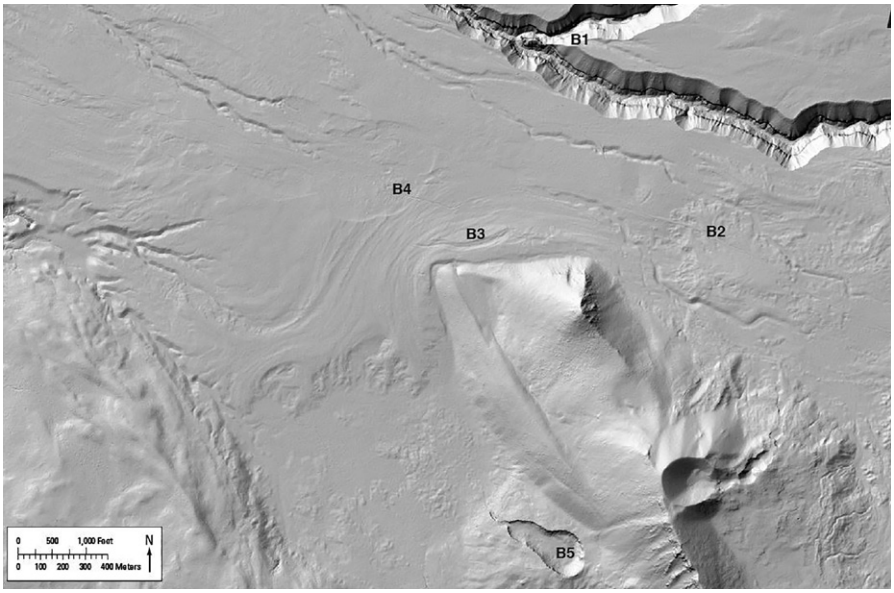
existing ones, positioned at 5-kilometer intervals to provide complete coverage of the coastal zone, each have 4 hours of Real Time Kinematic (RTK) GPS data collected and then processed with National Geodetic Survey tools to ascertain elevation values to within 2–4 centimeters. Results are available in a useful assortment of Web maps, viewers, databases, and services, including Online Positioning User Service (OPUS)—the NGS geodetic monumentation database—where they are maintained in perpetuity. The backbone provides ground control for many follow-on projects, including collecting interagency LIDAR imagery following Hurricane Sandy, determining the elevation of buildings in flood zones, and calculating sediment budgets for threatened salt marshes. Elevations for hundreds of additional sites, surveyed off the backbone, are used along with LIDAR (funded through the ARRA and Hurricane Sandy Recovery) and other data to model inundation risk for key resources and infrastructure in these parks. The benefiting National Parks, Monuments, and other sites include the Statue of Liberty National Monument; Ellis and Governors Islands; Gateway and Boston Harbor Islands National Recreation Areas; Acadia National Park; Assateague Island, Fire Island, and Cape Cod National Seashores; Colonial National Historical Park; and the George Washington Birthplace National Monument. NPS plans to extend this geodetic backbone throughout all coastal National Parks.



Geodetic backbone sites for Fire Island National Seashore.

Under Trees and Water at Crater Lake National Park

The 2010 LIDAR survey of Crater Lake National Park penetrated forested terrain to reveal surface features of the ignimbrite (pyroclastic-flow deposit) from the climactic caldera-forming eruption in fine detail. This eruption occurred over 7,000 years ago, culminating in the collapse of Mount Mazama to form Crater Lake. In late July, Charlie Bacon and Joel Robinson of the USGS in Menlo Park visited several unusual features observed in the LIDAR terrain image. "Ground truthing" showed that irregular surfaces east of Scoria Cone are long, linear ridges of lava smoothed by glaciers; while on Lloa Rock, late pyroclastic flows shaped the fine-grained ignimbrite into V-shaped mounds that point toward the caldera. Also imaged are meter-scale fault scarps near the western boundary of the park that were previously unidentified. The fault scarps cut lateral moraines but are overlain by climactic ignimbrite, suggesting that the last large earthquakes on these faults



LIDAR reveals geologic features beneath the heavily forested Castle Creek area in Crater Lake National Park. Two creeks, Little Castle and Castle, flow through gorges cut into Mount Mazama's climactic pyroclastic-flow deposit. At their confluence (B1), the ignimbrite is about 330 feet (100 meters) thick. Many thinner flow deposits have finger-shaped flow lobes (B2). An extensional rift (B3) at the nose of Castle Point scars the surface of the deposit. The deposit compacts, because of cooling and settling, and tilts away from the point toward the deposit's thickest part at the valley center, causing the rift. A 1-meter-tall arcuate scarp (B4) faces west, where the margin of a pyroclastic-flow deposit became unstable, collapsed, and fed a thin secondary pyroclastic flow to the northwest. South of Castle Point are crater vents for young basaltic flows, one round and one pear-shaped (B5). (Robinson and others, 2012)

occurred between deglaciation and the climactic eruption, or between ~14,000 and 7,700 years ago.

Mapping Permafrost Thaw Erosion Features

NPS used high-resolution IKONOS satellite images and a combination of manual and computer-assisted methods to map slumps and small landslides caused by the thaw of permafrost in Alaska's arctic National Parks (*http://science.nature.nps.gov/im/units/arcn/vitalsign.cfm?vsid*=9). These five NPS units cover over 8 million hectares, about a quarter of all the NPS-managed land in the USA. NPS found over 2,000 active-layer detachments (ALD) and over 700 retrogressive thaw slumps (RTS). Remapping at 5- to 10-year intervals is planned to determine trends in the number, area, and distribution of these features.

Fire Effects in the Santa Monica Mountains National Recreation Area

On February 11, 2013, Santa Monica Mountains National Recreation Area staff cheered when they saw rocket contrails from the launch of Landsat 8 a few miles north of the park. Barely three months later, the Springs Fire (May 2, 2013) burned 25,000 acres of parkland, and NPS GIS and remote sensing specialists were using the very first publicly released Landsat 8 images to map burn severity (*http://www.nps.gov/samo/parkmgmt/firemanagement.htm*) in the area. Maps visualizing Burned Area Reflectance Classification (BARC) imagery helped park scientists and resource managers assess the effects of the Springs Fire. Later that season, NPS did the same thing for the much smaller Old Fire (August 18, 2013). BARC provides a sensitive, spatially detailed, but unitless measure of how much vegetation is consumed by a fire. A geomorphologist used BARC imagery immediately after the fire to assess soil-erosion potential for the Burned Area Emergency Rehabilitation (BAER) program. This map (below) combines standard classes of burn-severity values derived from the BARC image with requested classes of slope-steepness values derived from a digital elevation model to provide the geomorphologist with needed inputs for his sediment yield calculations. It shows where critically steep slopes are and how much vegetative cover was lost there. Steep slopes with high burn-severity

values are especially vulnerable to soil erosion in the post-fire environment. Over the next several months, fire ecologists combined BARC imagery with pre-fire vegetation, road, trail, and terrain data, using GIS to determine where to locate and collect field data from several hundred burn-severity field plots. When the BARC imagery is calibrated with ground-based field plot data, meaningful comparisons can be made of fire effects from multiple fires burning under a range of weather and fuel conditions. The Springs Fire is interesting because it occurred out of fire season during the worst drought in at least a century.

Bureau of Land Management

The Bureau of Land Management (BLM) requires field-based measurements to support management decisions covering vast expanses of land. By integrating remote sensing into the BLM's Assessment, Inventory, and Monitoring strategy, field-based monitoring data are leveraged to generate information and maps that would otherwise be too expensive to produce. The BLM is developing a core set of integrated and scalable remote sensing tools that will provide an integrated, quantitative monitoring approach that will allow the BLM to efficiently and effectively document the impacts from authorized and unauthorized disturbance and land-treatment activities at local and regional scales.

Grazing Impacts on Wetland Surface Microtopography

Wyoming's high desert riparian areas cover less than 1 percent of the landscape but account for up to 20 percent of forage. Livestock spend disproportionate time in these areas, inflicting disproportionate ecological impact by grazing and trampling, as well as causing increased riparian erosion and hummocking. Wetland hummocks are elevated soil pedestals separated by inter-hummock channels draining the wetland and eroding the organic soils that are the "sponge" for holding water in the system and prolonging stream flow that wildlife (and humans) depend on. BLM and Agricultural Research Service researchers used a handheld camera to capture nadir stereo images 1.5 meters above transects located both inside and outside long-term grazing exclosures in four wetlands. They processed images into 5-millimeter digital

elevation models, detrended slope from the models, and used the standard deviation of all grid-cell elevations as a surface-roughness indicator. Data were verified by an independent erosion bridge field method. Surface roughness outside grazing exclosures was 50 percent higher than inside exclosures ($p<0.0001$, $n=4$), supporting a conclusion that livestock grazing significantly contributes to hummock formation in these high desert wetlands and that changes in grazing management are needed to ameliorate the situation. The utility of the monitoring method used could be enhanced by adaptation to aerial platforms.

Monitoring Change in the BLM National Monuments

A remote sensing project in cooperation with Northern Arizona University and the Bureau of Land Management is being conducted to assess the impact of illegal human activity: vehicular routes; human trails; and the accumulation of litter, debris, and hazardous materials. The project will assist in evaluating the health of the landscape and the public's enjoyment of national monuments.

Bureau of Reclamation

The Bureau of Reclamation's (BOR) Sedimentation and River Hydraulics Group uses LIDAR data in conjunction with river and reservoir bathymetric surveys to develop continuous topographic/bathymetric surfaces in support of 1D, 2D, and 3D hydraulic modeling (*http://www.usbr.gov/pmts/sediment/*). Hydraulic models use these data and user-specified flow rates to produce maps of wetted area, water surface profiles, and 3D velocity estimates. Results are used to analyze flood risk and to estimate patterns and rates of sedimentation in canals, rivers, and reservoirs.

The Bureau of Reclamation uses Landsat data to help monitor consumptive water use throughout the western United States. BOR analysts use Landsat imagery to map irrigated crops for estimating water demand and to monitor interstate and inter-basin water compact compliance. Reclamation is also involved in the ecological restoration of a number of rivers in the West. LIDAR, multispectral aerial imagery, and sonar data are used to generate maps of topography, vegetation, and river-channel bathymetry, which guide restoration activities.

Lower Colorado River Agriculture and Water Use Estimates

Reclamation routinely monitors more than 3.5 million acres of agriculture and riparian vegetation along the Lower Colorado River from the Hoover Dam to the Southerly International Border (*http://www.usbr.gov/lc/region/g4000/wtracct.html*). The generated data include crop and riparian types, acreages, and associated water-use estimates. Remote sensing and GIS are the primary tools used for this activity. These data assist Reclamation in accounting for water use by each state and individual water user, verifying fallowed lands for conservation programs, and analyzing other water management needs.

San Joaquin River Restoration Program

The San Joaquin River Restoration Program *http://www.restoresjr.net/background.html*) is a comprehensive long-term effort to restore flows to the San Joaquin River in California's Central Valley from Friant Dam to the confluence of the Merced River. Its goal is to restore a self-sustaining Chinook salmon fishery in the river while reducing or avoiding adverse water-supply impacts from restoration flows. Reclamation continues to investigate and develop remote-sensing-based methods to map and monitor vegetation and its response to flow restoration on the river. Current and possible future activities include the acquisition and use of hyperspectral imagery and LIDAR data to support this effort.

Irrigated Crop Mapping in the Upper Colorado Basin

Reclamation is charged with measuring consumptive water use (water that is physically removed, through either export or evaporation) within the Upper Colorado River Basin (*http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html*). Irrigated agriculture accounts for the majority of consumptive water use within the basin, and Reclamation measures this use by multiplying estimates of crop area (m^2) derived from remote sensing by daily crop-specific water use estimates ($m\ d^{-1}$), then summing these daily results to generate seasonal and annual values. Locally measured weather data (solar radiation, air temperature, wind speed, humidity,

and precipitation) define the daily water requirement of a clipped grass reference crop (ETo), while locally calibrated crop coefficients relate the daily water use of specific crops to that of the reference crop. Existing datasets are leveraged during the irrigated-crop-mapping procedure. Digital geographic databases of potentially irrigated land from the Upper Colorado River Basin states define the areas where Reclamation maps irrigation status, and crop types for irrigated areas are provided by the National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL). Reclamation maps irrigation status on a pixel-by-pixel basis using a multi-date Normalized Difference Vegetation Index (NDVI) thresholding procedure. NDVI images are generated from atmospherically corrected Landsat imagery provided by the USGS. For areas where cloud cover limits the number of successful image acquisitions, Landsat 7 data gaps can result in areas with an inadequate number of image "looks" to reliably ascertain irrigation status. For these areas, gaps in the Landsat 7 image data are filled with mean values of valid NDVI data occurring within polygons, defining individual agricultural fields.

The Office of Surface Mining

The Office of Surface Mining (OSM) remote sensing program provides OSM offices, states, and tribes with the necessary tools to use remote sensing technologies to support Titles IV (Abandoned Mine Lands) and V (Regulation of Current Mining) of the Surface Mining Control and Reclamation Act (SMCRA). As part of this support, the OSM remote sensing program provides high-resolution satellite imagery, aerial photography, and LIDAR data to conduct analysis of terrain, vegetation, and hydrologic function on active mine sites to ensure that reclamation is consistent with the approved mining permit. These data are also used to support the inventory, monitoring, and assessment of abandoned mine-land features to ensure that there is no threat to the environment or to health and human safety.

Use of UAS for Stream and Coal Waste Reclamation

The New Mexico Abandoned Mine Land Program (NMAMLP) is exploring remote sensing techniques to monitor change in land cover and stream morphology

at reclamation projects. The Program, as well as its reclamation projects, is funded through grants from the Office of Surface Mining Reclamation and Enforcement (OSMRE) based on the Surface Mining Control and Reclamation Act (SMCRA). Unmanned aircraft systems offer high-resolution imagery, flexible deployment, and relatively low cost at focused areas. NMAMLP examined the use of a UAS to supplement revegetation and stream channel morphology monitoring at the Dillon and Dutchman Canyons, once part of a larger coal mining site, of Vermejo Park Ranch in northern New Mexico. As a result of NMAMLP geomorphic reclamation work, meanders and dynamic stability have been restored to sections of streams once straightened and degraded by historic coal mining practices. Coal waste had been redistributed and covered with topsoil by earth-moving equipment, drainages were added, and conditions were created to reestablish wetlands to mitigate net loss. Seeding, planting, and natural establishment of native plants were used in the process of revegetation.

A Trimble UX5 Aerial Imaging Rover, a fixed-wing UAS with a 1-meter wingspan and electric pusher propeller, will be deployed at the site to map the topography of the postconstruction reclamation as well as the revegetation. A series of high-resolution stereo pairs of orthophotography taken with the UX5 will produce a point cloud of XYZ values after photogrammetric processing. A mosaic of

A view of first-season revegetation after geomorphic reclamation within Dillon Canyon at Vermejo Park Ranch in Raton, New Mexico. Plantings at the stream's edge survived a flooding event, and vegetation started to emerge from seeding below the mulch layer.

color-infrared (CIR) aerial photography will be used to help identify vegetation and subsequent mapping. Digital surface models of pre- and postreclamation topography will be compared. Also planned is the analysis of vegetation height based on point cloud values attributed with the CIR data. A mosaic of the four-band multispectral imagery, including the near-infrared band, will be used to help identify vegetation and subsequent mapping. These high-resolution aerial images will also aid subsequent vegetation classifications of a WorldView2 satellite image purchased by OSMRE Technical Innovation and Professional Services.

Ground validation includes vegetation transects and stream-channel profiles. The increased spatial resolution of a UAS compared to both traditional aerial photogrammetry and satellite imagery will add significant value to reclamation monitoring.

Remote Sensing for Computer-Aided Inspections

The Alton Field Division (AFD) has been working with the Mid-Continent Region (MCR) Program Technology Support Branch to incorporate geospatial technologies into field inspections. Multispectral imagery from sites in Missouri, Illinois, and Indiana is viewed on a tablet device, provided by TIPS, in the field during inspections, which provides the inspector with a better overall picture of the site and a mechanism to locate compliance issues more easily than by on-the-ground methods (e.g., walking the entire inspection site). After the inspection, the imagery is useful for identifying sediment ponds, water-monitoring wells, diversion channels, and other relevant features. AFD has stated that the addition of the imagery and the maps has enhanced the overall effectiveness of the inspection report and the inspection process in the field.

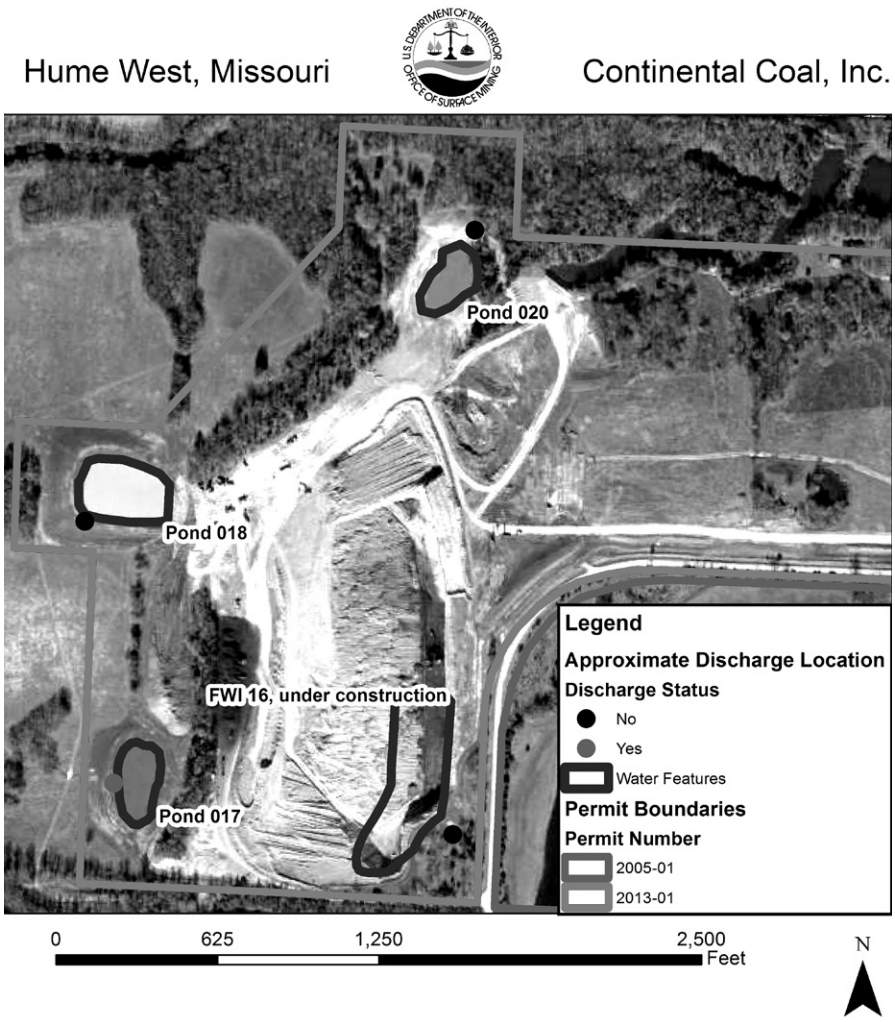
Bureau of Indian Affairs

The Bureau of Indian Affairs (BIA) applies remote sensing to issues such as land-use planning; pollution affecting subsistence hunting and fishing; and climate change impacts such as the prediction of sea-level rise for coastal tribes, the location and identification of potential dam hazards, and the generation of digital terrain data for the use of open-channel hydraulics. In FY 2011, the BIA started

integrating remote sensing into forest inventory and management-planning efforts in remote, low-timber-value, and inaccessible areas. A pilot project was started to see if remote sensing applications in timber typing could be utilized for a broad-level inventory of these lands. The BIA's goal is to see if remote sensing can alleviate the need for expensive ground-inventory operations.

Informing LANDFIRE Remotely Sensed Analyses

In 2013, several tribes and Bureau of Indian Affairs Regions contributed a variety of datasets to the Landscape Fire and Resource Management Planning Tools (LANDFIRE) program in order to assist with the update of a number of remotely sensed geospatial layers (e.g., vegetation type and fuels models). The contributed datasets included disturbance perimeters (wildfire and fuels treatments), vegetation plot data (forest inventory and Fire Effects Monitoring and Inventory Protocol [FIREMON]), and feedback information (e.g., observations regarding discrepancies between LANDFIRE fuel-model assignments and on-the-ground fuel-model determinations). The submittal of these datasets will improve LANDFIRE's decision-making process regarding changes from remotely sensed imagery analysis and will provide an underlying cause to the observed changes.



Satellite imagery aids the Alton Field Division in mapping and identifying features at coal-mine sites in the Mid-Continent Region.

Federal Communications Commission

FCC

The Federal Communications Commission formulates rules and administers proceedings 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 activities in FY 2013 related primarily to commercial communications satellites.

The FCC took several significant actions in administrative and rule-making proceedings in FY 2013. After a longstanding and contested proceeding, on October 7, 2012, the FCC amended its technical rules to enable the deployment of new broadband services in the 2.3-gigahertz (GHz) Wireless Communications Service (WCS) while continuing to protect satellite radio services and aeronautical mobile telemetry operations in adjacent bands and continuing to protect the Deep Space Network earth station in Goldstone, California.

On March 15, 2013, the FCC provided guidance concerning FCC licensing of nongovernmental small satellites, including satellites that fall within the categories of picosatellites, nanosatellites, and CubeSats. These new, small satellite designs have enabled a wider range of organizations, including universities and research organizations, to directly launch satellites. The FCC's guidance focused on educating participants who may be unfamiliar with FCC satellite licensing and identified scheduling and other requirements in an effort to aid satellite operators in planning for successful missions.

In a separate release on March 15, 2013, the FCC provided guidance on obtaining experimental authorizations for the use of radio frequencies for commercial (i.e., non–Federal Government) space-launch activities and for related ground stations and ground testing facilities. The guidance outlined types of authorizations, information requirements, noninterference conditions, and coordination with Federal agencies.

After a comprehensive review of licensing and operating rules for satellite services begun in September 2012, on August 9, 2013, the FCC adopted changes to Part 25 of the FCC rules. These changes revised over 150 rule provisions to better reflect evolving technology, eliminate unnecessary filing requirements, eliminate unnecessary technical restrictions, and improve clarity.

The FCC authorized a number of commercial communication satellite launches and operations. The authorizations include the following:

- October 9, 2012: To Intelsat License, LLC, to construct and launch a C-Ku-UHF-band satellite. The FCC also authorized operations of the C-Ku-band at the longitude 55.5° west orbit location.
- December 4, 2012: To DIRECTV Enterprises, LLC, to launch and operate a satellite at the longitude 99.235° west orbit location.
- April 18, 2013: To DIRECTV Enterprises, LLC, to launch and operate a satellite at the longitude 76.0° west orbit location.

The FCC granted a number of license modifications and Special Temporary Authorizations for satellite networks. Many involved routine testing or redeployment of satellites within a multi-satellite system. Several of these actions, however, warrant particular mention:

- October 2, 2012: The FCC granted ORBCOMM License Corp. a license modification to permit the launch of a satellite for use in the ORBCOMM satellite network. The satellite launched as a secondary payload on a commercial resupply mission, operated by SpaceX, to the International Space Station.
- October 16, 2012: The FCC granted Intelsat License, LLC, authorization to relocate satellite Intelsat 709 to operate at the longitude 47.5° east orbit location in accordance with International Telecommunication Union (ITU) filings of Germany.

- February 4, 2013: The FCC granted Iridium Constellation, LLC, an authorization, conditioned on completion of additional radio-frequency coordination, to provide an aeronautical safety service, primarily in currently unserved oceanic and polar regions.

The FCC added three non-U.S.-licensed space stations to its permitted space station list to allow these space stations to provide domestic and international satellite service to U.S. earth stations that have routine technical parameters. Specifically, on December 6, 2012, the FCC added Mexico's SATMEX 8 space station using the C-band and Ku-band at the longitude 116.8° west orbit location to the permitted list. On March 14, 2013, the FCC added Brazil's Amazonas 3 space station using the C-band and Ku-band at the longitude 61.0° west orbit location to the permitted list. On July 12, 2013, the FCC added the Netherlands' SES-6 space station using the C-band and Ku-band at the longitude 40.5° west orbit location to the permitted list.

The FCC also granted a request for non-U.S.-licensed space stations to provide service in the United States on a nonroutine basis, including the following:

- October 17, 2012: The FCC granted the Netherlands' planned space station for operator Spectrum Five LLC access to the United States market using the 17/24-GHz broadcast-satellite service band at the longitude 119.25° west orbit location.

U.S. Department of Agriculture

USDA

USDA Foreign Agricultural Service

The Foreign Agricultural Service's (FAS) Office of Global Analysis (OGA) served as a major source of objective and reliable global agricultural production information to the World Agricultural Outlook Board (WAOB), the primary source of the USDA's global commodity outlook. The outlook reports for FY 2013 provided public access to information and data affecting world food security and were crucial in decisions affecting U.S. agriculture, trade policy, and food aid. This included regional, national, and subnational monitoring and analysis of crop conditions, yield potential, and the impact of events affecting crop production.

Satellite imagery resources were managed through the USDA's Satellite Imagery Archive (SIA) program. The SIA program was established by the USDA's Remote Sensing Coordinating Committee (RSCC), which is chaired by the USDA's Office of the Chief Information Officer. The SIA fulfilled its mission of providing cost-effective sharing of satellite data through a centralized system for purchases, receipts, inventory, storage, and dissemination of satellite imagery to USDA agencies. The following agencies participated in the program: the Foreign Agricultural Service (FAS), Risk Management Agency (RMA), National Agricultural Statistics Service (NASS), Forestry Service (FS), Natural Resources Conservation Service (NRCS), Agricultural Research Service (ARS), and Farm Service Agency (FSA).

The success of the USDA's SIA was also a practical demonstration of collaborative agreements with NASA, NOAA, the USGS, and the National

Geospatial-Intelligence Agency (NGA). During FY 2013, the USDA satellite-imagery library continued to enable all USDA agencies to access satellite imagery at substantially reduced individual agency cost. The key performance indicators of the program were measured by timely distribution and receipt of requested satellite imagery and the provision of bulk satellite imagery at a measurable economic benefit to the USDA agencies. In addition, the FAS OGA performed the physical management of the SIA facility and the online Archive Explorer (AE) system at *http://www.pecad.fas.usda.gov/archive_explorer/Default.aspx*. The Archive Explorer, a Web-enabled browse-and-search tool, allowed users to browse, select, and retrieve the contents of the SIA.

In addition, the FAS OGA provided support and maintenance of the USDA's global database of crop area, production, supply, and distribution (PSD); weather and soil moisture; monthly crop growth stage and harvest calendars; Global Agricultural Monitoring (GLAM); global reservoir and lake monitoring; and vegetation index monitoring. The successful production of agricultural commodity outlook and the maintenance of global agricultural datasets were fulfilled using a variety of satellite Earth-observation data. This included NASA's satellite Earth-observing systems (Landsat, Moderate Resolution Imaging Spectroradiometer [MODIS] Aqua and Terra satellites, and the Jason and Tropical Rainfall Measuring Mission [TRMM] satellites from TOPEX/Poseidon), NOAA's satellite data (the Advanced Very High Resolution Radiometer), and other international datasets (the Indian Remote Sensing [IRS] Advanced Wide Field Sensor [AWiFS], the Linear Imaging Self Scanning Sensor [LISS], the Satellite for Observation of Earth [Satellite Pour l'Observation de la Terre, or SPOT] 4 and 5, and DEIMOS-1).

U.S. Forest Service

As the primary forestry agency of the United States and the largest agency in the USDA, the USDA Forest Service (USFS) continues to sustain the health, diversity, and productivity of the Nation's forests and grasslands. This work is conducted via three specific agency mission areas: Research and Development (USFS R&D), the National Forest System (NFS), and State and Private Forestry (USFS S&P).

USFS R&D conducts research to address forestry and natural-resource issues both internationally and domestically, including the development of relevant science and technologies. Partnerships with states, tribes, and other Federal agencies, as well as universities and private industry, are integral to the accomplishment of the USFS R&D mission. Additionally, the USFS administers and manages 155 national forests and 20 national grasslands collectively known as NFS lands. These lands encompass 193 million acres in 44 states and Puerto Rico and are managed for the purpose of sustainable multiple use to meet the diverse needs of people. Lastly, USFS S&P provides assistance to private landowners and state, tribal, and community forestry agencies in the stewardship of approximately 500 million acres of non-Federal forest lands throughout the United States. This assistance includes the provision of information and support to partner agencies to protect forests from wildland fires, insects, disease, and invasive plants.

To address the data needs of these USFS mission areas in FY 2013, the USFS collaborated with NASA, as well as NOAA, USGS, and other agencies, to apply operational satellite and airborne imagery and the most advanced remote sensing and geospatial technologies. Specific FY 2013 USFS accomplishments are summarized below.

- Collected comprehensive Earth Observation System (EOS) MODIS and Suomi National Polar-orbiting Partnership (Suomi NPP) Visible Infrared Imaging Radiometer Suite (Suomi NPP VIIRS) direct broadcast data for the United States and Canada; processed and disseminated relevant fire mapping and geospatial data products to fire managers and the general public (*http://activefiremaps.fs.fed.us*).
- Continued activities with NASA's Goddard Space Flight Center Direct Readout Laboratory under a USFS-NASA interagency agreement to test and operationally implement direct readout technologies to support resource management, including land, atmosphere, and ocean science processing algorithms for EOS and Suomi NPP sensors (*http://directreadout.fs.fed.us*).
- Continued utilizing MODIS imagery for operational detection of forest damage and changing forest health conditions in our Nation's forests (*http://foresthealth.fs.usda.gov/portal/Flex/FDM?dL=0*).

- Collaborated with NASA and USFS science partners to participate in Soil Moisture Active-Passive (SMAP) mission workshops and respond to NASA Research Opportunities in Space and Earth Sciences (ROSES) Request for Proposals (RFPs) for potential applications using SMAP observational data/science products.
- Continued to distribute 250-meter forest-attribute data surfaces derived from MODIS imagery and other geospatial predictor data using nearest neighbor imputation methods (*http://fsgeodata.fs.fed.us/rastergateway/forest_type/index.php*).
- Continued to distribute 250-meter forest-carbon estimates derived from MODIS imagery and other geospatial predictor data using nearest neighbor imputation methods (*http://fsgeodata.fs.fed.us/rastergateway/biomass/index.php*).
- Coordinated with NASA's Ames Research Center (ARC) in FY 2013 to successfully transfer the Autonomous Modular Sensor (AMS) sensor to the USFS and conducted AMS testing and integration flights on USFS aircraft for eventual operational use in FY 2014–2015.
- Continued coordination with NASA's Goddard Space Flight Center (GSFC) on testing and evaluation of the Multi-Angle Implementation of Atmospheric Correction (MAIAC) for MODIS and its potential use for land and atmosphere remote sensing applications.
- Coordinated with GSFC on evaluating test data collected by the Goddard LIDAR Hyperspectral and Thermal (G-LiHT) sensor for potential land remote sensing and resource management applications.
- Operationally applied Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM), and Landsat 8 Operational Land Imager (OLI) imagery to map the location, extent, and severity of approximately 200 large wildfires in FY 2013 to support post-fire emergency stabilization/hazard-mitigation activities and forest restoration planning/management activities (*http://www.fs.fed.us/eng/rsac/baer* and *http://www.fs.fed.us/postfirevegcondition*).
- Continued to operationally apply Landsat 4/5 TM and Landsat 7 ETM imagery to inventory, map, and characterize historical large fires to

assess the effectiveness of national fire management policies as part of the Monitoring Trends in Burn Severity (MTBS) project. MTBS mapping activities through FY 2013 include the completion of 17,025 historical fires (~120 million burned acres) spanning from 1984 to 2011 (*http://www.mtbs.gov*).

- Coordinated with the University of Maryland, NASA, and the USGS to execute and test Landsat 8 and VIIRS I-band prototype fire-detection algorithms and evaluate derived output products to support USFS operational fire-support activities.
- Continued technology transfer activities between the USFS and ARC regarding unmanned aircraft systems and related technologies under the auspices of the NASA-USFS Wildfire Research Applications Partnership and a USFS-NASA interagency agreement (*http://geo.arc.nasa.gov/sge/WRAP/index.html*).
- Coordinated with ARC on the final development of the Wide Area Imager (WAI) (developed under the NASA Small Business Innovation Research [SBIR] program) and subsequent fire-mapping-demonstration missions.
- Used Landsat 5 TM, Landsat 8 OLI, and National Agricultural Imagery Program (NAIP) imagery to initiate and complete mid-level vegetation-mapping products for National Forest lands and adjacent land areas throughout the country.
- Used Landsat 5 TM, Landsat 8 OLI, and NAIP imagery to model Tree Canopy Cover (TCC) for the entire continental United States as part of the Multi-resolution Land Characteristics Consortium (MRLC) National Land Cover Database 2011 update.
- Used Landsat TM/ETM/OLI and MODIS imagery to map and assess damage to forests in the immediate aftermath of severe storms and other catastrophic events during FY 2013 (e.g., Colorado flood event in 2013).
- Completed an assessment in coordination with the Environmental Protection Agency (EPA) of the effects of land-cover change on water quality using Landsat TM/ETM time-series stacks to detect and monitor forest land-cover change in the Lake Superior and Lake Michigan

watersheds from the mid-1980s to the present. This activity has been extended to include Lake Huron, Lake Erie, and Lake Ontario as well.

- Used Landsat TM/ETM/OLI and National Agricultural Imagery Program imagery in conjunction with other core geospatial datasets to conduct ecological and soil-type mapping on NFS lands that are used by the USFS, NRCS, and other agencies for resource management, planning, and decision making (*http://www.fs.fed.us/eng/rsac/programs/teui/about.html*).
- Continued to use Landsat TM/ETM time-series stacks, NAIP imagery, and USFS Forest Inventory and Analysis plot data to support carbon and biomass monitoring for 55 selected forested sites across the United States in support of the North American Forest Dynamics (NAFD) Project (*http://daac.ornl.gov/NACP/guides/NAFD_Disturbance_guide.html*).
- Continued to develop standards and practices for integrating LIDAR into forest and resource management (i.e., defining acquisition specifications, data quality assessment, analysis/modeling procedures for forest parameters, etc.). This is relevant to recent and potential USFS–NASA JPL LIDAR collaboration such as the acquisition and processing of hyperspectral imagery (Airborne Visible/Infrared Imaging Spectrometer, or AVIRIS) and LIDAR data for the 2013 Rim Fire in California.

National Agriculture Statistics Service

The remote sensing acreage estimation program used Disaster Monitoring Constellation (DMC) and USGS Landsat data to produce crop-acreage estimates for crops at the state and county levels for 41 states during the 2013 crop year. Acreage estimates were created for 17 different crops covering all market-sensitive crops and states. With the expanded coverage and timeliness, the National Agriculture Statistics Service's (NASS) Agricultural Statistics Board (ASB) was able to utilize the remote sensing acreage indications as independent input for setting the official estimates for their monthly Crop Production Reports. Analysts derived remote-sensing-based acreage indications from a crop-specific land-cover categorization called the Cropland Data Layer (CDL). As primary satellite imagery inputs, the Foreign Agricultural Service Satellite Imagery Archive provided 1,638

DMC images through a cooperative partnership while utilizing 5,906 Landsat 8 images from the U.S. Geological Survey. In addition, NASS distributed the CDL for 48 states to stakeholders for the previous 2012 crop season via the USDA Geospatial Data Gateway and the CropScape data visualization portal at *http://nassgeodata.gmu.edu/CropScape*.

NASS utilized MODIS Normalized Difference Vegetation Index (NDVI) products for modeling corn and soybean yield indications over the 12 largest production states. Updated yield estimates were delivered operationally to the ASB as an independent indication for setting official August, September, and October yield estimates by state, district, and county. MODIS land surface temperature (LST) products were again used to provide another independent variable for yield estimation.

NASS completed work with George Mason University on a NASA-funded science grant titled "A National Crop Progress Monitoring System Based on NASA Earth Science Results." Research focused on crop growth modeling, crop phenology stage detection algorithm development, system prototyping and implementation, and crop progress ground-truth data collection for validation. A new Web-based national vegetation condition geospatial portal named VegScape was implemented from this project during February 2013. The VegScape URL is *http://nassgeodata.gmu.edu/VegScape* and the site serves as a monitoring application based on MODIS daily, weekly, and biweekly products and incorporates several vegetation metric indices for vegetation greenness and drought anomaly assessment. Additionally, NASS continued work on a NASA science grant titled "Fallowed Area Mapping for Drought Impact Reporting and Decision Making," where NASS contributes monthly growing season CDL-based fallowed-land estimates for California water resource stakeholders.

USDA Farm Service Agency

The Farm Service Agency (FSA) administered farm commodity, credit, conservation, disaster, and loan programs as laid out by Congress through a network of Federal, state, and county offices. Geospatial systems and 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 used remotely sensed data for mission-related business intelligence projects, including products like the NASS Cropland Data Layer, for which the FSA CLU is used to ground-truth. FSA continued to use satellite and aerial imagery, locally collected datasets, and weather data for disaster preparation and response. A few examples of this activity in 2013 included support during Hurricane Sandy, flooding in Colorado, and the fires in the West and Southwest. During the recovery period, these data were used to support the administration of FSA Emergency Loan, Emergency Conservation, and Livestock Indemnity Programs.

As the primary source of aerial imagery for the USDA, FSA administered the National Agriculture Imagery Program, leveraging partnership funds from other Federal entities to acquire imagery during the growing season over the contiguous United States. In 2013, FSA collected imagery for 23 states under this program. The FSA AgSat Blanket Purchase Agreement was used to deliver satellite data not already available through other Federal sources for parts of Alaska, Hawaii, the Pacific Basin, and the U.S. Virgin Islands. The AgSat and NAIP data were used to provide image Web services for FSA enterprise spatially enabled applications. NAIP, as well as FSA's large imagery archive, was accessible to the public through the USDA Geospatial Data Gateway, Web services, and media, and is used by many other Federal, state, and local agencies as well as academia in their day-to-day business operations.

USDA Natural Resources Conservation Service

The Natural Resources Conservation Service (NRCS) is the primary Federal agency working with private landowners to help protect and conserve the Nation's natural resources. For more than 50 years, the NRCS has used remote sensing products to carry out conservation programs. Aerial and satellite imagery processed in the form of digital orthoimagery remained the primary remote sensing product

used by the NRCS to inventory, monitor, manage, and assess our natural resources in GIS nationwide.

Elevation

Continue developing an NRCS enterprise system including infrastructures for information technology; hardware; software; and data management integration, tools, and applications to make the LIDAR data an integral part of agency business.

LIDAR is used by several Federal agencies; however, the approach used has been project-centric, not nationwide, in scale. NRCS is working with partners to extend LIDAR nationwide and share the costs of LIDAR acquisition across several Federal agencies while ensuring that NRCS LIDAR business needs are maintained.

USGS is also actively pursuing the 3D Elevation Program (3DEP) initiative. It is being developed to respond to growing needs for high-quality topographic data and for a wide range of other three-dimensional representations of the Nation's natural and constructed features. The primary goal of 3DEP is to systematically collect enhanced elevation data in the form of high-quality LIDAR data over the conterminous United States, Hawaii, and U.S. territories, with data acquired over an 8-year period. Interferometric synthetic aperture radar (IFSAR) data will be collected over Alaska, where cloud cover and remote locations preclude the use of LIDAR over much of the state. The 3DEP initiative is based on the results of the National Enhanced Elevation Assessment (*http://nationalmap.gov/3DEP/neea.html*).

Aerial Imagery

By partnering with the USDA Farm Service Agency and other Federal and state agencies, the NRCS acquired statewide 1-meter orthoimagery for 23 states and parts of Alaska, Hawaii, and the Pacific Basin. NRCS participates in many Federal Government interagency coordination committees such as the National Digital Orthophoto Program and the National Digital Elevation Program to avoid duplication of orthoimagery and digital elevation acquisitions. The USDA Geospatial Data Gateway Web site made available all orthoimagery purchased by the NRCS to internal users and the general public.

NRCS orthoimagery acquisitions for Hawaii and the Pacific Basin use predominately high-resolution commercial satellites from DigitalGlobe. All acquisitions were contracted at USDA-FSA-APFO (Aerial Photography Field Office), USGS-EDC (Earth Resources Observation and Science [EROS] Data Center), or DOD-NGA (National Geospatial-Intelligence Agency). All orthoimagery acquisitions are at .6 meter or higher resolution and 4–8 multi-spectral bands depending on the satellite sensor. NRCS acquired coverage for these U.S. Pacific Basin areas in FY 2013: the Commonwealth of the Northern Mariana Islands, Palau, and the Federated States of Micronesia.

NRCS acquisitions for Alaska used a combination of aerial cameras and satellite sensors depending on the location. Aerial cameras at a 1-meter ground resolution were used at an area northeast of Fairbanks called Yukon Flats and an area southeast of Fairbanks called Delta Junction. NRCS used high-resolution commercial satellites from DigitalGlobe for Juneau, Nome, Bethel, and Port Clearance. These acquisitions were for .6 meter, 8-band digital orthoimagery. NRCS used satellite contracts with DOD-NGA and USDA-FSA-APFO.

The NRCS used the USDA Small Area Aerial Photography Contract to acquire high-resolution aerial photography (4-inch ground-resolving distance) and scans from over 72,988 confidential statistical sites to collect natural resource data for the annual National Resources Inventory (NRI) program in the Contiguous United States (CONUS). The NRCS also contracted for aerial photography over 450 NRI sites in Puerto Rico and the U.S. Virgin Islands and 375 sites in Hawaii. The NRCS also used the USDA Small Area Aerial Photography Contract to acquire 24,346 photos over 14,854 Stewardship Land easements in CONUS and Hawaii. Because of their remote location, nine easements in Alaska required the contracting of high-resolution satellite imagery from the USDA Satellite Imagery Blanket Purchase Agreement.

Satellite Remote Sensing

The NRCS continued using satellite imagery from the USGS Hazard Data Distribution System to respond to natural disasters. Major events in 2013 included the tornadoes that hit Moore, Oklahoma, and the flooding along the Colorado

Front Range. For the Colorado flooding, NRCS provided pre- and post-event imagery from satellite and aerial sources via Web services to state offices supporting their ability to deliver Emergency Watershed Protection assistance.

Positioning, Navigation, and Timing

With the completion of the Russian Federation's Global Navigation Satellite System (GLONASS) navigation constellation, the continued sustainment of a 28-satellite GPS constellation, and the increasing launch rate of the European Union's Galileo navigation constellation, the NRCS not only enjoys the benefits of space-based American Positioning, Navigation, and Timing (PNT), but also utilizes signals from the growing family of Global Navigation Satellite Systems (GNSS). Increasing availability of space-based GNSS PNT will provide the NRCS with greater operational performance in challenging environments and increase accuracy in open conditions. Greater operational efficiencies and reduced costs will accrue from the integration of space-based GNSS PNT into NRCS business areas. As vendors begin to produce and mass-market multi-GNSS equipment, the NRCS will assess offerings and invest in technology that streamlines equipment and increases operational efficiency.

- NRCS employees in field service centers across the country continue to utilize handheld GPS to perform day-to-day data collection for conservation planning. In FY 2013, the NRCS developed a strategic vision calling for technology investment not only to utilize the modernized GPS frequencies of L2C and L5 but also to utilize multiple GNSSes as they achieve full operational capability. The NRCS is working to fully refresh current technology with multiple GNSS and modernized GPS PNT technology by 2020.
- In FY 2013, the NRCS purchased over 500 handheld multi-GNSS receivers and handheld computers with GNSS. These receivers utilize the fully operational Russian Federation GLONASS as well as the enhanced GPS navigation constellations. The receivers replaced models purchased in 2001 that were failing and were vulnerable to jamming. The procurement of receivers with integrated geotagging digital cameras increased

operational efficiency for field users. The use of the dual constellation receivers will improve positioning results under tree canopy.

- The NRCS purchased 90 engineering PNT systems. Many of these systems are Real Time Kinematic (RTK), which means there is a rover system constantly receiving corrections from a base system. The NRCS also invested in systems that utilize corrections transmitted from cellular networks. By subscribing to networks operated by state agencies and private businesses, the NRCS can leverage the investment in a traditional RTK system and obtain two rovers. By utilizing multiple GNSS and cellular RTK, the NRCS has obtained the performance of two complete systems for the cost of one.

National Science Foundation

NSF

The National Science Foundation 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 and Geospace Sciences, Polar Programs, and Physics, 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—and Earth's atmosphere and space environment.

Division of Astronomical Sciences

The Division of Astronomical Sciences (AST) within the Mathematics and Physical Sciences (MPS) Directorate supported the development of advanced technologies and instrumentation for 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 NSF's national astronomical facilities included the National Radio Astronomy Observatory (NRAO), the Arecibo Observatory (AO), 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 2013 saw the delivery of the final antennas and receivers from all partners. A total of 66 antennas have been accepted. Science operations continued, concurrently with commissioning, using a 32-element subset of the full array.

AST continued its oversight of the Daniel K. Inouye Solar Telescope (DKIST, formerly the Advanced Technology Solar Telescope), 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, had previously earned the strong recommendation of the National Research Council of the National Academy of Sciences. When completed in 2019, the DKST will be the world's flagship ground-based telescope designed specifically for the study of solar magnetic fields on scales as small as 30 kilometers. In order to evaluate the impacts of a nearly 30-month delay in acquiring the relevant permits to construct, the baseline cost and schedule were re-evaluated in a comprehensive re-costing exercise. The resulting new baseline was approved by the National Science Board in August 2013. The total project cost is now $344.13 million, and the onset of full science operations is scheduled for July 2019. Fabrication of the major telescope subsystems and instruments are ongoing, as is construction on the Haleakala site where excavation and construction of the facility's foundation are nearing completion.

MPS/AST, along with its Federal partner, DOE's Office of High Energy Physics (HEP), supported further design and development of the Large Synoptic Survey Telescope (LSST) project in FY 2013. This project will produce a purpose-built wide-field survey telescope and use the attached 3.3-gigapixel camera to image the entire accessible sky repeatedly for at least 10 years, producing more than 20 terabytes of data nightly. The LSST database will enable breakthrough research not just in cosmology (dark energy and dark matter), but also in galactic structure and solar system astronomy. LSST also opens up the time domain and will revolutionize the study of transient events. The camera is a deliverable from DOE, led by

the SLAC National Accelerator Laboratory. FY 2013 funding for DOE precluded the beginning of Major Item of Equipment (MIE) funding for the LSST camera, so an MIE start was included in the budget request for FY 2014. In addition, a status review in June 2013 felt that the project should add additional schedule float. Bottom-up re-planning of the entire project led to a one-year increase in the duration of construction, installation, and commissioning over the schedule prepared in FY 2012. NSF's budget request for FY 2014 included the start of construction funding for LSST, and as a result, a Final Design Review was organized in accordance with NSF's procedures for approving large facility funding. This review will take place early in FY 2014. NSF's responsibilities include the telescope, site, and data management, including separate specialized access for research and for education and public outreach uses. The added duration increases the estimated cost above the original request, which led to significant discussion throughout the latter half of FY 2013. LSST continues to attract strong support within the research and education communities, and interest from other countries wishing to contribute to the project is growing, with a major European meeting held in September 2013.

The Atacama Cosmology Telescope (ACT) is a 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 the 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 and is equipped with a state-of-the-art customized camera with detectors cooled to one-tenth of a degree above absolute zero. In FY 2013, the major technical activity was to get the first of three arrays for the ACT Polarization Experiment (ACTPol) cryostat in the field observing the sky. At the end of the fiscal year, the camera was in the field and mounted on the telescope. The ACTPol receiver is a sophisticated new design based on a dilution refrigerator, which allows the detectors to operate with very low noise at a cryostat temperature of 100 millikelvins.

The Polarization of Background Radiation (POLARBEAR) telescope is a 3-meter-diameter off-axis millimeter-wave antenna designed to measure the polarization of the cosmic microwave background (CMB) radiation. The observatory is located

near the ACT and ALMA facilities on the Chilean Atacama plateau. The telescope is being used to measure the polarization of the cosmic microwave background to search for "B-modes," which will open up a new window on the early universe and the physics of inflation if detected. Unlike previous radio telescopes, POLARBEAR was designed for a very large field of view to accommodate a large imaging camera. Wide area coverage is key to obtaining a broad sampling of the microwave background sky and high signal-to-noise measurements. In FY 2013, the project was fully operational and accumulated more than 3,300 hours of CMB data and 500 hours of calibration data. These observations were focused on three patches in the sky, producing the most precise maps of the CMB polarization to date.

Division of Atmospheric and Geospace Sciences

The Division of Atmospheric and Geospace Sciences' (AGS) high-altitude aircraft, the Gulfstream V (GV), is a highly modified and instrumented midsize jet operated by the National Center for Atmospheric Research (NCAR), a Federally Funded Research and Development Center of the NSF. The GV is FAA-certified to operate at 51,000 feet, and its ability to fly for long durations (over 12 hours), fly long range (over 6,000 kilometers), and carry scientific payloads (up to 6,000 pounds) have enabled scientific research previously not possible with existing platforms. The GV 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 NSF's GV aircraft in scientific campaigns. During FY 2013, the DLR's 550 staff and the GV's staff continued collaboration on instrument pod development and shared instrumentation, and the GV continued to conduct long-duration flights for the High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) Pole-to-Pole Observations (HIPPO) deployment to study the carbon cycle and greenhouse gases as part of a multi-year campaign. The GV also participated in additional field projects during FY 2013 and remained one of the world's most advanced airborne research platforms.

NCAR's Research Aircraft Facility continued to operate and maintain GV through FY 2013. 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 operated and maintained NSF's heavy-lift C-130Q research aircraft.

The AGS Geospace Section (GS) supported a wide variety of research programs in space science in FY 2013. 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 GS-funded activities in FY 2013 included the Geospace Facilities (GF) program; the Space Weather Research (SWR) program; 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.

The National Space Weather Program (NSWP) is a multiagency 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.

Throughout FY 2013, the Community Coordinated Modeling Center (CCMC) for space weather research, cosponsored by the 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 transitioning research models into operational use.

Research facilities remained as the key component of GS efforts. The Geospace Facilities program in FY 2013 continued to enable 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. Throughout FY 2013, observations made by the Advanced Modular Incoherent-Scatter Radar (AMISR) at Poker Flat, Alaska, demonstrated the unique capabilities of this new instrument, including its 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 has been operating at Resolute Bay in Arctic Canada since 2009. 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.

In FY 2013, GS continued to support its program for CubeSat-based small satellite science missions for geospace and atmospheric research and education. During FY 2013, four projects continued to operate successfully in space and provided high-quality observations and scientific findings. Another two excellent CubeSat science projects were started in FY 2013, adding new capabilities and breadth to the overall CubeSat program that, with this addition, encompassed a total of 10 CubeSat projects.

GS continued support for the satellite-based Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) through FY 2013. AMPERE utilized the 66 networked satellites of the existing Iridium constellation to create a new facility for collecting geomagnetic field data. The AMPERE facility has provided the first-ever real-time observations of the electric currents that link Earth's magnetosphere and ionosphere and 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 AMPERE data server facility has been established and placed online, and data for the years of 2010–2013 have been made freely available to researchers, with new data being added continually. During FY 2013, the existing AMPERE award was completed, and negotiations between the university and industry partners for the continuation of the project were initiated.

The GS solar physics community also continued to benefit from the Division of Astronomical Sciences' ongoing efforts to develop and manage the DKIST being constructed in Hawaii. Also in FY 2013, GS continued to provide oversight for much-needed upgrades at the Owens Valley Solar Array in California.

In FY 2013, the AGS Atmosphere Section (AS) 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 the support and assistance of the USAF's Space Test Program (STP). Shortly

thereafter, data became available from the three payloads: the special space-based GPS radio occultation (RO) receivers, the so-called Tiny Ionosphere Photometers, and the Tri-Band Beacons. These data have been provided freely to the world scientific community.

COSMIC radio occultation data have been assimilated at many operational weather prediction centers, including the U.S. National Centers for Environmental Prediction (NCEP), the European Centre for Medium-Range Weather Forecasts (ECMWF), Météo France, the United Kingdom Met Office, the Meteorological Service of Canada, Taiwan's Central Weather Bureau, and others. All of these centers have reported that RO data are having a significant positive impact on numerical weather forecasts. In ionospheric studies, COSMIC RO data have accelerated the development of physical models for space weather prediction by providing dense, accurate, and global electron density measurements. These data are used for model testing and initialization, including the response of the global ionosphere to the impact of solar storms.

During FY 2013, all six COSMIC 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 has supported more than 1,100 registered users from 52 countries. In collaboration with UCAR's UNIDATA, COSMIC soundings have been provided in real time to support the university community.

Division of Polar Programs

For FY 2013, the primary activities of the Division of Polar Programs (PLR) in ground-based space science and astronomy included continued full-scale observations at the U.S. Amundsen-Scott South Pole Station with the 10-meter off-axis radio telescope and deployment of a battery of five small-aperture (25-centimeter) telescopes known as the Small Polarimeter Upgrade for DASI (Degree Angular Scale Interferometer), or SPUD. Both the South Pole Telescope (SPT) and SPUD are focused on cosmic microwave background polarization measurements. The High Elevation Antarctic Terahertz (HEAT) robotic telescope at Ridge A continued data collection through FY 2013. The IceCube Neutrino Observatory

(ICNO) also continued data collection of high-energy neutrino events through FY 2013.

Recent scientific results from SPT include a joint study with ALMA published in *Nature* ("Dusty starburst galaxies in the early Universe as revealed by gravitational lensing"). Bursts of star formation were discovered with energies of "a trillion suns." Another SPT result was a breakthrough in CMB B-mode polarization research: the team detected for the first time a subtle B-mode polarization signal in the CMB radiation caused by "gravitational lensing"—gravitational interactions of the CMB photons with matter along their journey to Earth.

The IceCube Neutrino Observatory (jointly operated at the South Pole by PLR and NSF's Division of Physics) has now collected data for almost three years from a complete array of 86 strings of optical photodetectors deployed in deep ice under the South Pole Station in Antarctica at a depth between 1.4 and 2.4 kilometers. The ICNO Collaboration in FY 2013 reported the first observation of 28 neutrino-induced events that correspond to some of the highest neutrino energies detected so far. The team analyzed neutrino events that exceed 50 teraelectronvolts (TeV) and come from anywhere in the sky (1 electronvolt [eV] is the energy an electron or proton gains when it is accelerated by a voltage of 1 volt; 1 TeV is a trillion eV; 2 eV is about the energy of a photon in the visible orange light band). While most of the neutrinos observed by IceCube exhibit energies in the range expected for atmospheric neutrinos from decays of particles produced in extensive air showers by cosmic rays, the energies of the discovered 28 events are much higher (from a hundred to a thousand TeV), indicating a likely origin from far away in our galaxy or even more distant places.

Department of State

DOS

The Department of State carries out diplomatic efforts to support U.S. space policies and programs internationally. DOS 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 activities and international organizations. DOS also maintains outreach programs to advance U.S. space and foreign policy objectives.

DOS continued to lead the U.S. delegation to the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) plenary and its two subcommittees: Legal (LSC) and Scientific and Technical (STSC). With numerous countries and private-sector entities now engaged in space activities, DOS considers promoting the safe and responsible use of space by all current and future spacefaring nations a vital goal. During COPUOS 2013, State continued U.S. participation in the Working Group on Long-Term Sustainability of Outer Space Activities (LTS). This working group was tasked with examining and proposing voluntary best practices guidelines to ensure the safe and sustainable use of outer space for peaceful purposes and the benefit of all countries. The LTS Terms of Reference were finalized in 2011, and the Working Group continued in 2013 with the four expert groups to discuss interrelated topics relevant to long-term space sustainability, such as the connection between sustainable development on Earth and the sustainability of space activities, space situational awareness, space debris, space weather, and regulatory issues.

Still building on the results of the International Heliophysical Year and the International Space Weather Initiative to improve international cooperation in understanding the impact of space weather on satellites and Earth's environment in

general, DOS continued to promote space weather as an important foreign policy topic worldwide and during COPUOS. The STSC completed its multi-year work plan in 2013 on the International Space Weather Initiative (ISWI), where the United States played a leading role. During this session, space weather became a regular agenda item, and State was fortunate to have an astronomer—an American Association for the Advancement of Science (AAAS) fellow—on board to coordinate and provide expert advice on U.S. space weather objectives and programs with other delegates and agencies.

During the 52nd session of the LSC in 2013, the State Department promoted the continuation of the item entitled "Review of the International Mechanisms for Cooperation in the Peaceful Exploration and Use of Outer Space" through the U.S. delegation, which allowed the United States to take a leadership role in shaping the course of the LSC. The item is based on a proposal introduced in 2012 by the United States and co-sponsored by China, Ecuador, Japan, Peru, and Saudi Arabia, and it provided other delegates with a comprehensive overview of the current status of national space laws and regulations and helped member states in understanding the different approaches taken at the national level to the development of national space-related regulatory frameworks.

The U.S. and EU continued close cooperation under the auspices of the 2004 GPS-Galileo Cooperation Agreement. In FY 2013, new Terms of Reference for the Working Groups formed under the agreement were drafted as a result of a decision taken at the July 2012 GPS-Galileo Plenary. Particular attention paid to protection of intellectual property developed as a result of our joint cooperation. These Terms of Reference were reviewed and approved during FY 2013. Working Group A continued its work on seeking coordination with the EU under ITU auspices for next-generation GPS III signals and power levels. Working Group C also continued its work on developing next-generation GNSS applications, particularly for aviation use.

During the 2012 U.S.-EU Space Policy Dialogue in Prague, the United States underscored its interest in negotiating access to the Galileo Public Regulated Service (PRS) signal. The EU requested a formal letter from the State Department to that effect, which was drafted and delivered to the EU in early 2013. Follow-up meetings on the PRS issue were held in June 2013 in

Washington, DC, and in July in Brussels, where the EU informed the United States of progress in its process to obtain a mandate to negotiate a possible access agreement with the United States on PRS.

In November 2012, the United States and Japan held a Technical Working Group meeting in Tokyo, where Japan detailed its planned expansion of the Quasi-Zenith Satellite System (QZSS) to add more satellites. This expansion requires technical consultations with the United States to ensure compatibility between QZSS and GPS signals. The United States and Japan held a plenary meeting of our bilateral civil space dialogue in July 2013 in Kyoto, Japan. The extension of U.S.-Japan agreements to host QZSS reference stations in Hawaii and Guam was discussed. The parties also discussed possible future directions for the International Committee on GNSS (ICG) and on holding workshops on interference detection and mitigation and spectrum protection.

The United States and Russia held several video teleconferences, as well as meetings on the margins of other international conferences to explore Russia's 2012 proposal to obtain monitoring station facilities in the United States to help improve the accuracy of its civil GLONASS satellite navigation system. Details of Russia's proposal kept changing in response to pointed questions for clarification from the United States By the end of FY 2013, discussions were focused on using existing, available data from scientific reference stations already in operation in the United States.

Finally, DOS continued to promote the use of GPS in the African continent, working through the AfricaArray consortium and the United Nations Office of Outer Space Affairs. AfricaArray is a public-private partnership led by academic researchers at the Universities of Witwatersrand in South Africa and Pennsylvania State University in the United States. The partnership is focused on supporting training and research in Earth, atmospheric, and space sciences in Africa. At the AfricaArray annual meeting held January 17–20, 2013, in Johannesburg, DOS facilitated the travel of scientists from Angola, Cameroon, the Democratic Republic of the Congo, Ethiopia, Ghana, Madagascar, Malawi, Mozambique, Rwanda, Sudan, Tanzania, and Zambia, as well as their participation in workshops on GPS applications on a broad spectrum of Earth and space sciences.

Department of Energy

DOE

The Department of Energy participates in the national effort to further U.S. interests in space. Three organizations within DOE provide this capability: the National Nuclear Security Administration's (NNSA) Office of Defense Nuclear Nonproliferation Research and Development (DNN R&D), the Office of Science (SC), and the Office of Nuclear Energy (NE).

Office of Defense Nuclear Nonproliferation Research and Development

The Nuclear Detonation Detection program builds the Nation's operational sensors to monitor the planet from space to detect and report surface, atmospheric, or space nuclear detonations (NuDets). The Space-based Nuclear Detonation Detection subprogram provides much of the Nation's capability to detect, report, locate, and identify nuclear explosions using orbiting satellites. The Office of Defense Nuclear Nonproliferation Research and Development develops, builds, and delivers these satellite payloads to meet interagency performance and schedule commitments and provides launch and on-orbit operational support for the current generation of the U.S. NuDet Detection System (USNDS).

Since the Vela satellite program in 1960, NNSA and its predecessors have provided the underlying science and technology capability for space-based detection of foreign nuclear weapon detonations to meet test-ban-treaty monitoring and missile warning needs. Today, these associations continue and have expanded to include military support missions and space control. These efforts span decades of overlapping generations of instruments deployed on multiple platforms in different

orbital configurations. NNSA continues full-scale production and delivery of sensor packages to ensure that payloads are ready, as needed, to meet national security requirements. To ensure that the technologies and capabilities developed for the program support stakeholder needs, DNN R&D actively engages in intergovernmental working groups that reduce duplication among agencies, bring new user requirements to the fore, and improve the quality of relevant technology across the funding agencies. Strong synergy exists between the work performed in the USNDS program and planetary science and astrophysics. The current gamma-ray spectrometers used for USNDS share their heritage with the NASA Swift mission, which evolved from earlier USNDS sensors. This mission exemplifies how collaboration between National Laboratories and NASA for astrophysics has benefited USNDS capabilities and vice versa. Additionally, the NASA Living With a Star program contributes to, and is benefited by, the NNSA-developed payloads that monitor and operate in the near-Earth space environment.

The NNSA weapons laboratories, most notably Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL), supply the science, technology, and engineering required for USNDS, with Lawrence Livermore National Laboratory (LLNL) contributing to the end-to-end testing of USNDS. These NNSA laboratories have unique and comprehensive capabilities in understanding nuclear weapons, as well as the signatures and observables associated with a nuclear detonation and the propagation of signals from the weapon to the sensor. Moreover, these laboratories provide capabilities in the design, construction, calibration, deployment, and operation of satellite-based detection instruments, along with detailed modeling and analysis. As the basis for 24/7/365 global monitoring, the user/operations communities routinely receive analysis, insights, and computer codes based on this research. These capabilities represent an important non-commercial source of national space expertise and competency that NNSA is committed to sustaining and nourishing.

Two payloads built by NNSA at these laboratories accomplish the NuDet reporting mission—the Global Burst Detector (GBD) and the Space and Atmospheric Burst Reporting System (SABRS). The GBD payload is hosted on all GPS satellites. The SABRS payload is carried on satellite hosts in geosynchronous orbit. In order to maintain a vital capability to design and implement these systems, DNN

R&D supports Demonstration-Validation payloads to explore new technologies and new sensing modalities and to increase the Technology Readiness Level (TRL) for parts that might be used in future payload designs.

Office of Science

The DOE Office of Science supports several activities that contribute to a broad range of space interests. These activities include SC fundamental research that is of mutual interest to the NASA mission and NASA researchers, collaborative research efforts with NASA, and the operation of SC scientific facilities that are available to NASA and the broader scientific community for space-related research.

SC supports fundamental research in plasma science that contributes to SC-NASA mutual interests in knowledge of magnetospheric/ionospheric, solar, and astrophysical systems. A major area of research supported by SC's Office of Fusion Energy Sciences (FES) is centered on developing a comprehensive understanding of astrophysical magnetized-plasma processes, including particle acceleration in cosmic gamma-ray bursts, magnetic reconnection and turbulent processes in Earth's magnetosphere and the solar corona, the formation and evolution of astrophysical jets, and the dynamo processes that create planetary/galactic magnetic-field structures. Some specific examples include (1) large-scale plasma simulation codes that are applied to study space weather; (2) the Large Plasma Device (LAPD) at the University of California, Los Angeles, which enables controlled studies of Alfven waves that carry energy and momentum from the sun to Earth and throughout the universe; (3) the Magnetic Reconnection Experiment (MRX) at the Princeton Plasma Physics Laboratory (PPPL), which permits laboratory studies of reconnection in Earth's magnetotail; (4) the Magneto-Rotational Instability (MRI) facility, also at PPPL, which elucidates the physics of accretion disks around black holes; and (5) a newly established center at PPPL in partnership with the Max Planck Society that specifically explores the application of plasma science to astrophysical problems. In addition, FES sponsors unmagnetized-plasma research that uses lasers and light-source x-rays to probe the properties of warm dense matter similar to that found in planetary cores.

Projects funded by the Office of Science and executed through joint collaboration with NASA include the development of experimental techniques of fundamental physics for use in space to investigate high-priority national science objectives. Examples of these efforts include the Alpha Magnetic Spectrometer (AMS) and the Fermi Gamma-ray Space Telescope (FGST). The AMS, also designated AMS-02, is a particle physics experiment designed and built primarily by SC and launched on the Space Shuttle in May 2011. AMS-02 is now mounted on the International Space Station, where it searches for various types of unusual matter by measuring cosmic rays. Among the experiment's science goals are the search for evidence of dark matter and cosmic domains of antimatter. The Large Area Telescope (LAT), the primary instrument on NASA's FGST, is a space-based particle-physics detector that helps researchers study the gamma-ray sky. SC managed the LAT fabrication and now operates the LAT Science Operations Center. Researchers use the data to learn about high-energy acceleration mechanisms generated by supermassive black holes and supernovae and to search for dark matter.

The Office of Science and NASA engage in collaborative research efforts in the area of atmospheric science and environmental phenomena. SC and NASA completed two joint experiments in 2013: the Two Column Aerosol Project (TCAP) and the Marginal Ice Zone Observations and Processes EXperiment (MIZOPEX). Supported under SC's Atmospheric Radiation Measurement (ARM) activity, TCAP utilized a fixed site on Cape Cod supplemented by aircraft in order to amass more refined aerosol observations in polluted air masses advecting eastward to the North Atlantic. MIZOPEX flew a NASA unmanned aerial vehicle (UAV) over Arctic sea ice to characterize the ocean surface, sea ice, and atmosphere at the critical Marginal Ice Zone, north of the ARM facility at Oliktok, Alaska. NASA currently uses the UAV, as well as ARM data, to advance NASA sensor parameterizations; SC uses the UAV data to test and validate improvements to sea ice models as part of the DOE investments in climate model development. SC's ARM activity also provides support at three sites (Southern Great Plains; Barrow, Alaska; and Manus Island, Papua New Guinea) for validation of the Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder that will fly on NASA's National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellite and will provide profiles of temperature and moisture.

Since astronauts are spending more time in space, NASA has long been engaged in working on ground-based studies to understand the possible risks to human beings exposed to space radiation. The Office of Science has been working with NASA in a couple of areas to help support NASA's mission interests in this area. SC provides scientific user facilities for the scientific community, including particle accelerators and ion beams for biological and electronic systems radiation studies. The NASA Space Radiation Laboratory (NSRL) was established at DOE's Brookhaven National Laboratory (BNL) to study the radiobiological effects of using beams of heavy ions extracted from BNL's Booster accelerator that are also produced to deliver into SC's Relativistic Heavy Ion Collider facility. Jointly managed during the four-year construction period by SC and NASA's Johnson Space Center, the NSRL facility provides a leading capability for radiobiology studies in the United States. In addition, since FY 2001, DOE and NASA have engaged in coordinated efforts to better understand and predict the health risks associated with exposure to low-dose radiation. SC's Low Dose Radiation Research Program has coordinated with NASA's Space Radiation Project within NASA's Human Research Program. The SC Low Dose program focuses on doses of radiation measured at or below current workplace exposure limits; current collaborations are limited due to a decreasing emphasis on human radiation research within SC's research portfolio.

Office of Nuclear Energy

The Office of Nuclear Energy supports NASA's space science and exploration programs by maintaining the necessary infrastructure capabilities of nuclear facilities to produce and deliver power systems for Federal user agencies, such as NASA. These capabilities, funded by DOE, support NE's production of space radioisotope power systems for current space mission applications. The Office of Nuclear Energy also conducts research and development for NASA-funded radioisotope power system (RPS) and space reactor power and propulsion system technology programs.

DOE and its predecessors have provided radioisotope power systems that have safely enabled deep space exploration and national security missions for over five decades. Radioisotope power systems convert the heat from the natural radioactive

decay of plutonium (Pu)-238 into electricity. RPSs are capable of producing either heat or electricity for decades under the harsh conditions encountered in deep space. They have proven safe, reliable, and maintenance-free in missions to study the moon and all the planets in the solar system except Mercury. Systems that utilize RPS-powered systems are currently in many different stages of their mission lives. The Mars Science Laboratory rover, named Curiosity, landed on Mars in August 2012. Curiosity is the largest and most capable rover ever sent to another planet and is powered by a Multi-Mission Thermoelectric Generator (MMRTG) that was designed, built, and delivered by DOE. It is currently exploring Mount Sharp in Gale Crater on Mars. Voyagers 1 and 2, each powered by three Multi-Hundred Watt (MHW)-RTGs, left Earth in 1977 to conduct a grand tour of the outer planets. Voyager 2 is continuing to explore the heliosheath on the edge of the solar system, while Voyager 1, at more than 11 billion miles from Earth, has traveled farther than any other humanmade object and, as of August 2012, was the first such object to enter interstellar space. Both spacecraft remain operational and are sending back useful scientific data after over 36 years of operation; they are expected to continue functioning until 2025. The Cassini mission launched in 1997 and entered orbit around Saturn in 2004. The Cassini spacecraft uses three DOE-supplied General Purpose Heat Source (GPHS)-RTGs and is the largest spacecraft ever launched to explore the outer planets. It is successfully returning data and images of Saturn and its surrounding moons by using a broad range of scientific instruments. Cassini is expected to continue to operate until at least 2017. The New Horizons spacecraft, launched in 2006 and powered by a single GPHS-RTG, is the fastest spacecraft to ever leave Earth. New Horizons has already returned images and scientific data from Jupiter and will continue its journey of three billion miles to study Pluto and its moon, Charon, in 2015. It may also go on to study one or more objects in the vast Kuiper Belt, the largest structure in our planetary system.

DOE is continuing to work with NASA to develop the Advanced Stirling Radioisotope Generator (ASRG). This radioisotope power system uses dynamic energy conversion for greater system efficiency than that of an RTG. Although ASRG was not selected last year for the competitive Discovery-12 Mission, ASRG system development continued for potential use in future missions.

The stockpile of plutonium-238 used to power these missions to explore the solar system and for other Government applications is limited. NE is working with NASA to reestablish domestic Pu-238 production in order to ensure the continued availability of these power systems for future science missions. NASA has fully funded the costs to reestablish this national production capability since FY 2011. The Pu-238 Supply Project will use existing facilities at the Oak Ridge National Laboratory (ORNL) and Idaho National Laboratory to produce Pu-238. In 2013, the project continued to qualify the neptunium (Np)-237 target design and to demonstrate production steps.

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 (CfA). 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.

In FY 2013, exoplanets, or planets orbiting distant stars, continued to be a hot topic. SAO astronomers analyzing data from NASA's Kepler spacecraft concluded that one out of every six stars in our galaxy has an Earth-sized planet. Since the Milky Way has about 100 billion stars, there are at least 17 billion Earth-sized worlds out there.

An Earth-sized world could be too hot or cold for life, so researchers also worked to calculate how many planets orbit in the warm "Goldilocks" zone of their stars. In a February 2013 press conference, SAO astronomers announced that Earth-like worlds are likely to be right next door, astronomically speaking. They found that six percent of red-dwarf stars have habitable, Earth-sized planets. Since red dwarfs are the most common stars in our galaxy, the closest Earth-like planet could be just 13 light-years away.

In an unusual twist, SAO researchers also gained new insight into the cosmic origin of gold. Gold is rare on Earth in part because it's also rare in the universe. Unlike elements like carbon or iron, it cannot be created within a star. Instead, it must be born in a more cataclysmic event like a gamma-ray burst. Observations of a gamma-ray burst that occurred in June 2013 showed that the star collision

that caused it also resulted in the production of enough gold to create 10 copies of Earth's moon in solid gold.

NASA's Spitzer Space Telescope, launched in August 2003, continues to produce exciting new views of the universe at infrared wavelengths. Spitzer is the fourth and final space telescope in NASA's Great Observatory series. Spitzer's Infrared Array Camera (IRAC) was developed at SAO and constructed at NASA's Goddard Space Flight Center. Spitzer is operated for NASA by the Jet Propulsion Laboratory. Spitzer's "cold mission" lasted more than 5.5 years and ended with the depletion of its liquid-helium coolant on May 15, 2009. However, two of the cameras at the 3.6- and 4.5-micron wavelengths in IRAC continue to operate during the new "warm mission" phase.

SAO scientists, in collaboration with the Spitzer Science Center, continue to play an important role in operating IRAC and analyzing its data for making astronomical observations.

In FY 2013, SAO scientists and their collaborators published data from the Spitzer-South Pole Telescope Deep Field (SSDF) survey. This survey covered almost 90 square degrees of a southern region of the sky known as the South Pole Telescope Deep Field. This field benefits from a wealth of supporting observations using other facilities. The main focus of this effort is to better understand galaxy clusters—the largest structures known to exist.

SAO astronomers also conducted a multi-wavelength study of galaxies with Spitzer. They specifically examined galaxies heavier than 1 billion suns at distances of 4 to 7 billion light-years. The results showed that massive quiescent galaxies were already in place by 5 billion years after the Big Bang but that lower-mass galaxies generally ceased their star formation at later epochs.

A combination of the Spitzer Extended Deep Survey and the Hubble Space Telescope Cosmic Assembly Near-Infrared Deep Extragalactic Legacy Survey was used to track galaxy evolution back to a time when the universe was only 600 million years old. These results show that the brightest galaxies are crowded more tightly than expected from previous estimates at this time in the universe's history. The Spitzer/IRAC images are the first such individual detections of galaxies at this time. From these observations, the first measurements of galaxies' masses were determined, implying a very efficient star formation at such an early time.

SAO astronomers also observed the asteroid (3552) Don Quixote as part of a Spitzer Space Telescope project to characterize a large sample of near-Earth objects (NEOs). The NEO population, which mainly consists of fragments from collisions between asteroids in the main asteroid belt, is thought to include contributions from short-period comets as well. Because comets' active lifetimes are significantly shorter than the dynamical lifetimes of NEOs, it is likely that the NEO population contains a significant number of extinct or dormant comets. Don Quixote was one of the most promising NEO candidates for a cometary origin, based on its comet-like orbit and albedo (reflectivity of its surface).

As hoped, SAO astronomers discovered cometary activity in Don Quixote. Images clearly showed the presence of a coma and a tail at a wavelength of 4.5 microns, but not in the 3.6-micron band, which is consistent with emission from carbon dioxide molecules from the comet. Computer models produced a diameter estimate of 11.4 miles, which confirms Don Quixote to be the third largest known NEO.

With its unrivaled ability to create high-resolution x-ray images, the Chandra X-ray Observatory plays a critical role in the exploration of the universe. The Smithsonian Astrophysical Observatory controls science and flight operations from the Chandra X-ray Center from its location in Cambridge, Massachusetts.

In FY 2013, researchers announced that a major observing campaign with Chandra and several other satellites showed that magnetars—the dense remains of dead stars that erupt sporadically with bursts of high-energy radiation—may be more diverse and common than previously thought. Magnetars are some of the most extreme objects in the universe and are created when a massive star runs out of fuel and collapses, leaving behind an ultradense object only 10 to 15 miles wide.

Later in the year, astronomers using Chandra discovered the first x-rays from a planet passing in front of a star outside of our solar system. The planet (named HD 189733b) is similar in size to Jupiter but is 30 times closer to its star than Earth is to the sun; HD 189733b orbits its star once just every 2.2 days. The Chandra results tell researchers about the planet's atmosphere as well as how the planet and star affect one another.

Also announced in FY 2013, data from Chandra suggest that the debris field from an exploded star may contain the most recent black hole formed in the Milky

Way Galaxy. This supernova remnant appears to be the product of a rare explosion in which matter is ejected at high speeds along the poles of a rotating star. The remnant, called W49B, is about a thousand years old as seen from Earth and located about 26,000 light-years away.

Astronomers also teamed Chandra up with the Hubble Space Telescope and optical telescopes on the ground to discover the densest galaxy in the nearby part of the universe. Packed with an extraordinary number of stars, this unusual galaxy is providing clues to its intriguing past and how it fits into the galactic evolutionary chain.

The Solar Dynamics Observatory provides better-than-HD-quality images of the sun's surface and outer atmosphere. SAO is a major partner in the Atmospheric Imaging Assembly (AIA)—a group of four telescopes that photograph the sun in 10 different wavelength bands, or colors, once every 12 seconds.

The Hinode mission is a joint U.S.-Japan-Europe mission designed to study the detailed physics of the sun's atmosphere. SAO is the lead institution on the X-ray Telescope (XRT) on the Hinode spacecraft. The XRT is a telescope that images energetic x-rays that are produced in the hottest parts of the sun's corona.

The AIA and Hinode XRT observations formed the basis of the thesis work by a graduate student supported by SAO. In this work, mathematical magnetic field models are constructed in ways that are consistent with the high-resolution AIA and XRT observations. These models show how magnetic energy is stored in the corona as well as the conditions that are needed to release the energy quickly in flares and coronal mass ejections.

In FY 2013, XRT provided stunning images of the structure of regions of activity in the sun's atmosphere. These regions are locations where large solar eruptions originate. The images from XRT allowed scientists to systematically study the structure and evolution of the magnetic fields within these regions, leading to a better understanding of the conditions that can cause large eruptions.

In FY 2013, the NASA Interface Region Imaging Spectrograph (IRIS) was successfully launched. SAO built the telescope feed and has an active role in IRIS operations and science. IRIS observations are helping us to understand how the magnetic fields threading the sun's atmosphere create the solar corona.

In public outreach, SAO continued its popular monthly "Observatory Night" lectures and observing sessions. Begun by observatory director Harlow Shapley in

1930, these public nights offer the local community an opportunity to learn about the latest advances in astronomy and view the moon, stars, and planets through a variety of telescopes. A second overflow room was added in order to accommodate attendance numbers that continue to outstrip the capacity of the main auditorium.

SAO also provided occasional "Author's Night" programs, as well as sci-fi movie nights that explore the theme "Everything I learned about science, I learned at the movies."

SAO made a concerted effort to boost its online presence in FY 2013. "Observatory Night" lectures, colloquia, and other public programs now are routinely Webcast live to reach a broader audience. SAO also created a YouTube channel in order to widely distribute its public talks, news features, and other video offerings.

In FY 2013, the Smithsonian National Air and Space Museum continued to educate and inspire the public through exhibits, research, and education programs, including discovery stations, lecture series, family educational events, publications, and intern training. In collaboration with the National Museum of American History, NASM opened a new major exhibition, "Time and Navigation," which includes topics of air navigation, space navigation, and satellite navigation. Also on exhibit this year was Leonardo da Vinci's original "Codex on the Flight of Birds." This treasured notebook was on loan to NASM from the Biblioteca Reale in Turin, Italy. It includes da Vinci's remarkable ideas and sketches related to mechanical flight.

Staff members in NASM's Center for Earth and Planetary Studies (CEPS) continued to participate on the science teams of several spacecraft missions. Three of six full-time CEPS scientists served on mission teams during the year. Dr. John Grant is a Participating Scientist for the Mars Exploration Rover (MER) mission that is currently operating on Mars. He is a chair of the MER Science Operations Working Group, in which he leads the day-to-day science planning for the Opportunity rover. He conducts real-time mission planning from a data station installed on site at CEPS. In addition, he is cochair of the Mars 2020 Landing Site Steering Committee. CEPS staff are also on the science teams for the Mars Science Laboratory (MSL); the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on Mars Express; both the High-Resolution

Imaging Science Experiment (HiRISE) and Shallow Subsurface Radar (SHARAD) instruments on the Mars Reconnaissance Orbiter (MRO); the radar sounder on ESA's Jupiter Icy Moons Explorer (JUICE); the Lunar Reconnaissance Orbiter (LRO); and the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission to Mercury.

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, Mercury, and Titan. Research topics included Martian and terrestrial Aeolian (wind impact) studies, comparative planetology, terrestrial volcanism, geomorphology of Mercury, Martian subsurface channels, and channel features on the surfaces of Mars and Titan.

In addition, during FY 2013, NASM completed 8 new books and a total of 25 articles in history. In science, NASM completed 19 articles (7 of which had CEPS lead authors) and 51 abstracts. Additionally, the NASM Fellowship Program hosted 10 fellows and 6 visiting scientists.

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
2010	15	0	0	0
2011	16	1	3	0
2012	13	0	0	0
2013 (through September 30, 2013)	15	0	0	0
TOTAL	**1,711**	**157**	**109**	**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	North Korea	South Korea
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	25	29			3	4			9	4		1		
2010	15	30			2	15			6	1	1			
2011	17	33			3	18			7	3		1		
2012	13	27			2	19			10	2		1	1	
2013*	15	21			3	8			6	2				1
*(through September 30, 2013)														
TOTAL	**1,462**	**2,967**	**10**	**8**	**84**	**179**	**1**	**1**	**220**	**36**	**6**	**3**	**1**	**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, 2012–September 30, 2013

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
October 4, 2012	Military navigation	20,236	Global Positioning System (GPS)
Navstar 67 (GPS 2F-3)		20,130	
2012-053A		718	
Delta 4M+4,2		54.8	
October 8, 2012	International Space Station	425	Secondary payload: Orbcomm OG2
Dragon CRS-1		402	(2012-054B, communications)
2012-054A		92.8	
Falcon 9		51.7	
December 11, 2012	Military/classified	358	U.S. Air Force test of unmanned
OTV-3 (X37B)		342	space plane
2012-071A		91.5	
Atlas 5-501		43.5	
January 31, 2013	Communications	35,817	Tracking and Data Relay Satellite
TDRS-K		35,758	(TDRS)
2013-004A		1,436.1	Renamed TDRS 11 after achieving
Atlas 5-401		6.6	orbit
February 11, 2013	Earth science	703	
Landsat 8		702	
2013-008A		98.8	
Atlas 5-401		98.2	
March 1, 2013	International Space Station	409	
Dragon CRS-2		380	
2013-010A		92.4	
Falcon 9		51.7	
March 19, 2013	Military	35,790	Space-Based Infra Red System (SBIR)
SBIRS GEO-2		35,770	missile detection satellite for
2013-011A		1,436.1	geosynchronous orbit
Atlas 5-401		6.5	
April 21, 2013	Rocket testing	150	Also launched CubeSats:
Cygnus Mass Simulator		144	Bell (2013-016A),
2013-016D		87.4	Dove 1 (2013-016B),
Antares 110		51.6	Alexander (2013-016C),
			Graham (2013-016E)
May 15, 2013	Navigation	20,212	
Navstar 68 (GPS 2F-4)		20,153	
2013-023A		718	
Atlas 5-401		55.2	
May 25, 2013	Communications	35,786	Wideband Global SATCOM (WGS)
WGS 5		35,785	
2013-024A		1,436.1	
Delta 4M+5,4		0	
June 28, 2013	Space science	659	Interface Region Imaging Spectrograph
IRIS		620	(IRIS)
2013-033A		97.5	
Pegasus XL		98	
July 19, 2013	Military communications	35,900	Mobile User Objective System
MUOS 2		35,800	(MUOS)
2013-036A		1,436.1	
Atlas 5-551			
August 8, 2013	Communications	35,786	Wideband Global SATCOM (WGS)
WGS 6		35,785	
2013-041A		1,436.1	
Delta 4M+5,4		0	

Appendix B (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2012–September 30, 2013

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
August 28, 2013	Military/classified	997	National Reconnaissance Office
USA 245 (NROL 65)		257	
2013-043A		97.3	
Delta 4H		97.8	
September 7, 2013	Planetary science		Lunar Atmosphere and Dust Environment Explorer (LADEE)
LADEE			
2013-047A			
Minotaur 5			
September 18, 2013	Military	35,700	Advanced Extremely High Frequency (AEHF)
AEHF 3		35,700	
2013-050A		1,306.3	
Atlas 5-531		20.4	
September 18, 2013	International Space Station	414	
Cygnus ORB-D1		411	
2013-051A		92.8	
Antares 110		51.7	
September 29, 2013	Communications/space science	1,440	Also launched CubeSats: CUSat (2013-055B), DANDE (Drag and Atmospheric Neutral Density Explorer, 2013-055C), POPACS 1-3 (Polar Orbiting Passive Atmospheric Calibration Sphere, 2013-055D-F)
Cassiope		326	
2013-055A		102.6	
Falcon 9 v1.1		81	

*U.N. Committee on Space Research

Appendix C
HUMAN SPACEFLIGHTS

October 1, 2012–September 30, 2013

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TMA-06M (Expedition 33)	October 23, 2012	Kevin Ford Oleg Novitskiy Evgeny Tarelkin	143:16:15	First Soyuz launch from Pad Number 31/6 since 1984
Soyuz-TMA-07M (Expedition 34)	December 19, 2012	Chris Hadfield Thomas Marshburn Roman Romanenko	145:15:19	First Canadian to lead an ISS Expedition crew (Hadfield) Robotic Refueling Mission demonstrated refueling in space for satellite servicing
Soyuz-TMA-08M (Expedition 35)	March 28, 2013	Christopher Cassidy Pavel Vinogradov Alexander Misurkin	166:06:15	First crewed four-orbit rendezvous Installed the Obstanovka plasma-wave experiment and a new Pump Flow Control Subassembly Completed a communications systems upgrade
Soyuz-TMA-09M (Expedition 36)	May 28, 2013	Fyodor Yurchikhin Karen Nyberg Luca Parmitano	166:05:18	Returned the Olympic torch for the 2014 Winter Games in Sochi, Russia
Shenzhou 10	June 11, 2013	Nie Haisheng Zhang Xiaoguang Wang Yaping	14:14:29	First Chinese lecture and demonstrations to students about physics from space
Soyuz-TMA-10M (Expedition 37)	September 25, 2013	Oleg Kotov Sergey Ryazanskiy Michael Hopkins	166:06:26	First Cygnus rendezvous Installed two UrtheCast High and Medium Resolution Cameras

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
2010	18,725	18,228	26,463	2,057	203	1,261	67	27	484	15	46,748
2011	18,432	17,898	27,234	2,186	229	1,444	66	20	412	15	47,318
2012	17,773	17,203	26,677	2,580	199	1,876	76	7	406	16	46,460
2013	17,395	16,865	10,818	2,578	185	1,865	84	20	409	15	30,261

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 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 the 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 2013 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	6.385	2,113	1,666	3,128	217	217						5,012
1960	6.294	3,298	2,908	3,531	271	271						6,710
1961	6.217	5,993	5,757	5,060	423	423						11,240
1962	6.128	11,184	11,012	7,954	1,219	907	313					20,186
1963	6.061	22,261	21,976	9,394	1,558	1,297	261					32,928
1964	5.986	30,526	30,023	9,571	1,275	1,257	18					40,869
1965	5.915	31,055	30,393	9,311	1,426	1,355	71					41,129
1966	5.814	30,089	29,450	9,820	1,244	1,087	157					40,514
1967	5.692	28,264	27,490	9,471	1,212	1,047	165					38,173
1968	5.515	25,299	24,434	10,601	961	800	154	1	6			35,995
1969	5.328	21,263	20,363	10,725	908	629	107	1	5	166		31,996
1970	5.096	19,089	18,075	8,551	719	525	41	5	5	143		27,344
1971	4.834	16,007	14,991	7,310	783	459	131	10	5	179		23,084
1972	4.604	15,225	14,139	6,478	614	253	143	28	9	181		21,230
1973	4.396	14,973	13,597	7,135	648	237	176	44	9	182		21,380
1974	4.212	12,793	11,622	7,439	666	177	253	38	13	186		19,726
1975	3.929	12,688	11,454	7,435	620	118	251	31	8	211		19,509
1976	3.557	12,627	11,471	7,053	599	82	256	36	14	211		19,122
TQ*	3.318	3,093	2,817	1,526	143	17	73	10	3	40		4,487
1977	3.217	12,283	11,067	7,760	623	71	293	32	19	208		19,449
1978	3.088	12,536	11,187	8,454	698	105	318	31	25	219		20,338
1979	2.893	13,295	11,657	8,782	717	171	283	29	23	211		21,157
1980	2.677	14,027	12,528	10,300	619	107	249	32	37	193		23,447
1981	2.460	13,573	12,279	11,876	576	101	214	30	39	193		24,731
1982	2.239	13,534	12,378	14,956	700	137	325	27	34	179		28,034
1983	2.096	14,409	13,263	18,903	685	82	373	10	42	178		32,851
1984	2.008	14,973	13,768	20,468	793	68	474	6	38	206		35,029
1985	1.936	14,660	13,406	24,717	1,130	66	819	4	29	212		39,253
1986	1.875	14,639	13,435	26,487	894	66	579	4	43	202		40,816
1987	1.833	20,018	17,977	29,849	854	88	509	15	35	205	2	48,679
1988	1.785	16,175	14,854	31,556	1,323	430	628	25	32	205	2	47,734
1989	1.730	18,971	17,463	30,969	969	168	521	29	36	209	5	49,401
1990	1.665	20,519	19,080	26,000	842	132	405	52	42	206	7	45,922
1991	1.606	22,508	20,950	22,773	1,240	403	403	47	42	339	6	44,963
1992	1.547	22,150	20,421	23,243	1,234	345	506	53	45	280	6	44,897
1993	1.508	21,578	19,699	21,270	1,102	249	489	50	38	271	6	42,071
1994	1.475	21,497	19,213	19,425	933	109	460	46	46	265	7	39,572
1995	1.445	20,017	18,123	15,379	1,096	86	509	45	46	402	9	34,599
1996	1.415	19,644	17,784	16,291	1,171	65	668	51	52	327	8	35,246
1997	1.388	19,030	17,292	16,278	1,096	49	622	58	54	305	8	34,666
1998	1.363	18,602	16,793	16,845	1,144	140	593	59	53	291	8	34,782
1999	1.346	18,375	16,768	17,770	1,322	141	774	79	50	269	8	35,860
2000	1.328	18,066	16,632	17,189	1,402	218	764	80	58	275	8	35,223
2001	1.302	18,534	17,328	18,659	1,383	189	752	78	47	302	16	37,370
2002	1.273	18,921	17,652	20,030	1,502	211	820	81	36	339	15	39,184
2003	1.252	19,233	17,976	24,270	1,634	239	812	93	53	422	15	43,880
2004	1.227	18,866	17,570	23,450	1,796	256	914	87	75	449	15	42,815
2005	1.196	19,381	18,227	23,559	1,856	274	966	84	87	431	14	43,642
2006	1.159	19,263	18,268	25,626	1,909	284	997	95	97	422	14	45,803
2007	1.121	18,251	17,447	25,124	1,883	224	1,022	98	73	453	13	44,454
2008	1.088	18,632	17,962	26,989	1,848	212	938	98	64	521	14	46,799
2009	1.064	18,909	18,377	28,221	1,987	213	1,147	68	29	516	15	48,585
2010	1.050	19,667	19,145	27,794	2,160	213	1,324	70	28	508	16	49,099
2011	1.040	19,165	18,609	28,317	2,272	238	1,501	69	20	428	16	49,198
2012	1.018	18,099	17,519	27,167	2,627	203	1,910	77	7	413	16	47,313
2013	1.000	17,395	16,865	10,818	2,578	185	1,865	84	20	409	15	30,261

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	**2011 actual**	**2012 actual**	**2013 actual[1]**	**2014 est.**	**2011 actual**	**2012 actual**	**2013 actual**	**2014 est.**
NASA[2]	17,898	17,203	16,865.2	17,646.5	17,017	16,606	16,989	17,643
DOD[3]	27,234	26,677	10,818	10,353	25,924	26,457	10,299	9,856
DOE[4]	229	199	185	173	177	158	183	173
DOC[5]	1,444	1,876	1,864.8	2,083.1	803.2	1,074.3	1,130.5	2,075
DOI	66	76	84	83	66	76	81	83
USDA	19.5	6.7	19.6	19.6	18.1	17.3	17	19.7
DOT	15	16	15	16	15	16	15	16
NSF[6]	412	406	409	451	543	489	387	389

1. FY 2013 figures incorporate the effect of sequestration.
2. 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. DOD FY 2011, 2012, and 2013 figures for Budget Authority and Outlays are estimated at the time of preparing this report. Improvements to the estimating methodology resulted in a change in estimated Budget Authority and Outlays starting in FY 2013.
4. 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.
5. Beginning in 2010, the Department of Commerce has defined the entire National Environmental Satellite, Data, and Information Service budget that is within the National Oceanic and Atmospheric Administration (NOAA) as a space activity. Prior years did not include some items, such as NOAA's National Climatic Data Center archives and Comprehensive Large Array-data Stewardship System (CLASS). The Budget Outlays columns reflect dollars "costed" in a fiscal year specific to that same fiscal year's appropriated dollars.
6. Totals for NSF include Large Synoptic Survey Telescope (LSST) and all telescope activities. Outlay information includes American Recovery and Reinvestment Act (ARRA).

Appendix D-3

Federal Aeronautics Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority 2011 actual	2012 actual	2013 actual[1]	2014 est.	Budget Outlays 2011 actual	2012 actual	2013 actual	2014 est.
NASA[2]	534	570	529.5	566	601	584	558.4	563
USDA	37.1	36.9	33.1	34.6	35.3	36.8	30.2	32.6
DOD[3]	14,170	14,221	82,730	75,910	13,577	13,509	91,120	75,610
DOI	24	27	29	29	25	27	28	29
DOT	2,905	2,884	2,758	2,717	2,895	3,102	2,990	2,918

1. FY 2013 figures incorporate the effect of sequestration.
2. 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. DOD FY 2011, 2012, and 2013 figures for Budget Authority and Outlays are estimated at the time of preparing this report. Improvements to the estimating methodology resulted in a change in estimated Budget Authority and Outlays starting in FY 2013.

Acronyms

3DEP	3D Elevation Program

A

AAC	Alaska Aerospace Corporation
ACES	Atomic Clock Ensemble in Space
ACF	Apalachicola-Chattahoochee-Flint
ACT	Atacama Cosmology Telescope
ACTPol	ACT Polarization Experiment
ADS-B	Automatic Dependent Surveillance Broadcast
ADVENT	ADaptive Versatile ENgine Technology
AE	Archive Explorer
AEHF	Advanced Extra High Frequency
AEM	Airborne Electromagnetic
AES	Advanced Exploration Systems
AFD	Alton Field Division
AFRL	Air Force Research Laboratory
AGS	Division of Atmospheric and Geospace Sciences
AIA	Atmospheric Imaging Assembly
AIM	Aeronomy of Ice in the Mesosphere
ALD	Active-Layer Detachments
ALMA	Atacama Large Millimeter/submillimeter Array
AMISR	Advanced Modular Incoherent-Scatter Radar
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMR	Advanced Microwave Radiometer
AMS	Alpha Magnetic Spectrometer
AMS	Autonomous Modular Sensor
ANC-12	12th Air Navigation Conference
ANOPP	Aircraft Noise Prediction Program
AO	Arecibo Observatory
APFO	Aerial Photography Field Office
ARC	Ames Research Center
ARM	Atmospheric Radiation Measurement
ARM	Asteroid Redirect Mission
ARMD	Aeronautics Research Mission Directorate
ARRA	American Recovery and Reinvestment Act
ARS	Agricultural Research Service
AS	Atmosphere Section
ASB	Agricultural Statistics Board
ASRG	Advanced Stirling Radioisotope Generator
AST	Division of Astronomical Sciences (NSF)
AST	Office of Commercial Space Transportation (FAA)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASU	Aircraft Sector Understanding
ATMS	Advanced Technology Microwave Sounder
ATST	Advanced Technology Solar Telescope
ATV	Automated Transfer Vehicle
AUVSI	Association for Unmanned Vehicle Systems International
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer

AVO	Alaska Volcano Observatory
AWiFS	Advanced Wide Field Sensor

B

BAER	Burned Area Emergency Rehabilitation
BARC	Burned Area Reflectance Classification
BARREL	Balloon Array for Radiation-belt Relativistic Electron Loss
BCNWR	Balcones Canyonlands National Wildlife Refuge
BIA	Bureau of Indian Affairs
BICEP2	Background Imaging of Cosmic Extragalactic Polarization 2
BIS	Bureau of Industry and Security
BLISS	Background-Limited Infrared-Submillimeter Spectrograph
BLM	Bureau of Land Management
BMD	Ballistic Missile Defense
BNL	Brookhaven National Laboratory
BOR	Bureau of Reclamation
BRDF	Bidirectional Reflectance Distribution Function

C

CAAFI	Commercial Aviation Alternative Fuels Initiative
CariCOOS	Caribbean Coastal Ocean Observing System
CASIS	Center for the Advancement of Science in Space
CAVP	Cryptographic Algorithm Validation Program
CBRA	Coastal Barrier Resources Act
CBS3	Controlled-Background System for Spectroradiometry and Spectrophotometry
CCAFS	Cape Canaveral Air Force Station
CCMC	Community Coordinated Modeling Center
CCSDS	Consultative Committee for Space Data Systems
CDL	Cropland Data Layer
CDM	Conjunction Data Message
CDR	Critical Design Review
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEPS	Center for Earth and Planetary Studies
CfA	Center for Astrophysics
CheMin	Chemical and Mineralogy
CIBER	Cosmic Infrared Background Experiment
CIR	Color-Infrared
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLU	Common Land Unit
CMB	Cosmic Microwave Background
CME	Coronal Mass Ejection
CNES	Centre National d'Études Spatiales [National Centre for Space Studies]
COE-CST	Center of Excellence for Commercial Space Transportation
CONUS	Contiguous United States
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COTS	Commercial Orbital Transportation Services
CPC	Certification Products Contracts
CRADA	Cooperative Research and Development Agreement
CREATE	Computational Research and Engineering Acquisition Tools and Environments
CREATE-AV	Computational Research and Engineering Acquisition Tools and Environments Air Vehicles
CrIS	Cross-track Infrared Sounder
CRS	Commercial Resupply Services
CS	Commercial Service
CSA	Canadian Space Agency
CSLC	21st Century Space Launch Complex

D

DARPA	Defense Advanced Research Projects Agency
DASI	Degree Angular Scale Interferometer
DEM	Digital Elevation Model
DKIST	Daniel K. Inouye Solar Telescope
DLR	German Aerospace Center [Deutsches Zentrum für Luft- und Raumfahrt]
DMC	Disaster Monitoring Constellation
DNN R&D	Office of Defense Nuclear Nonproliferation Research and Development
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DSCOVR	Deep Space Climate Observatory
DSN	Deep Space Network
DWR	Dynamic Weather Routing

E

EA	Environmental Assessment
EBEX	E and B Experiment
ECMWF	European Centre for Medium-Range Weather Forecasts
EDC	Earth Resources Observation and Science Data Center
EELV	Evolved Expendable Launch Vehicle
EFT-1	Exploration Flight Test-1
EGS	Exploration Ground Systems
EIS	Environmental Impact Statement
EM-1	Exploration Mission-1
EMU	Extravehicular Mobility Unit
EO	Earth Observation
EOS	Earth Observation System
EPA	Environmental Protection Agency
ERAU	Embry-Riddle Aeronautical University
EROS	Earth Resources Observation Systems
ESA	European Space Agency
ESD	Exploration Systems Development
ESPI	European Space Policy Institute
ET	Evapotranspiration
ETM	Enhanced Thematic Mapper
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUV	Extreme Ultraviolet
eV	electron volt
EVA	Extravehicular Activity
EVE	Extreme Ultraviolet Variability Experiment
Ex-Im	Export-Import
EXIS	Extreme Ultraviolet and X-ray Irradiance Sensor

F

FAA	Federal Aviation Administration
FAS	Foreign Agricultural Service
FEMA	Federal Emergency Management Agency
FES	Office of Fusion Energy Sciences
FGB	Functional Cargo Block
FGST	Fermi Gamma-ray Space Telescope
FIPS	Federal Information Processing Standard
FIREMON	Fire Effects Monitoring and Inventory Protocol
FLIR	Forward-Looking Infrared

FONSI	Finding of No Significant Impact
FS	Forestry Service
FSA	Farm Service Agency

G

G-LiHT	Goddard LIDAR Hyperspectral and Thermal
G&S	Geospace Section
GaN	Gallium Nitride
GBD	Global Burst Detector
GEM	Geospace Environment Modeling
GEO	Geosynchronous Earth Orbit
GF	Geospace Facilities
GHz	gigahertz
GIS	Geographic Information Systems
GISMO	Goddard IRAM Superconducting 2 Millimeter Observer
GLAM	Global Agricultural Monitoring
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GOES	Geostationary Operational Environmental Satellites
GPHS	General Purpose Heat Source
GPS	Global Positioning System
GPSC	Geospatial Products and Services Contract
GPSP	Global Positioning System Payload
GRACE	Gravity Recovery and Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GRAV-D	Gravity for the Redefinition of the American Vertical Datum
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
GV	Gulfstream V

H

HEAT	High Elevation Antarctic Terahertz
HEO	Highly Elliptical Orbit
HEO	Human Exploration and Operations
HEOMD	Human Exploration and Operations Mission Directorate
HERO	Human Exploration Research Opportunities
HIAPER	High-performance Instrumented Airborne Platform for Environmental Research
HIP	Hyperspectral Image Projector
HIPPO	HIAPER Pole-to-Pole Observations
HiRISE	High-Resolution Imaging Science Experiment
HPCMP	High Performance Computing Modernization Program
HPIW	High Pressure Industrial Water
HSCDS	High-Speed Container Delivery System
HST	Hubble Space Telescope
HWB	Hybrid Wing Body

I

IBEX	Interstellar Boundary Explorer
ICAO	International Civil Aviation Organization
ICESat	Ice, Cloud, and land Elevation Satellite
ICG	International Committee on GNSS
ICNO	IceCube Neutrino Observatory
IFSAR	Interferometric Synthetic Aperture Radar
IGE	Improved Gray Eagle
IHPRPT	Integrated High-Payoff Rocket Propulsion Technology

IOOS	Integrated Ocean Observing System
IRAC	Infrared Array Camera
IRIS	Interface Region Imaging Spectrograph
IRS	Indian Remote Sensing
ISECG	International Space Exploration Coordination Group
ISS	International Space Station
ISWI	International Space Weather Initiative
ITA	International Trade Administration
ITAC 1	Industry Trade Advisory Committee for Aerospace Equipment
ITU	International Telecommunication Union

J

JASD	Joint Agency Satellite Division
JAXA	Japanese Aerospace Exploration Agency
JLENS	Joint Land Attack Cruise Missile Defense Elevated Network Sensor
JMS	Joint Space Operations Center Mission System
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JSpOC	Joint Space Operations Center
JUICE	JUpiter ICy moons Explorer
JWST	James Webb Space Telescope

K

KDP	Key Decision Point
kg/s	kilograms per second
klbf	kilopound force
KSC	Kennedy Space Center

L

LADEE	Lunar Atmosphere and Dust Environment Explorer
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LANL	Los Alamos National Laboratory
LAPD	Large Plasma Device
LaRC	Langley Research Center
LAT	Large Area Telescope
LDCM	Landsat Data and Continuity Mission
LDEX	Lunar Dust EXperiment
LIDAR	Light Detection and Ranging
LEMV	Long Endurance Multi-Intelligence Vehicle
LISS	Linear Imaging Self Scanning Sensor
LLCD	Lunar Laser Communication Demonstration
LLNL	Lawrence Livermore National Laboratory
LRA	Laser Retroreflector Array
LRO	Lunar Reconnaissance Orbiter
LSC	Legal Subcommittee
LSETT	Large-Scale Scramjet Engine Testing Techniques
LSP	Launch Services Program
LSST	Large Synoptic Survey Telescope
LST	Land Surface Temperature
LTS	Working Group on Long-Term Sustainability of Outer Space Activities
LVC-DE	Live Virtual Constructive–Distributed Environment
LVPS	Launch Vehicle Production Services

M

M-Code	Military-Code
MAD	Multi-utility Aeroelastic Demonstration
MAF	Michoud Assembly Facility
MAHLI	Mars Hand Lens Imager
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MAVEN	Mars Atmosphere and Volatile EvolutioN
Mbps	megabits per second
MCR	Mid-Continent Region
MDXR	Missile Defense Transfer Radiometer
MEMS	Microelectromechanical Systems
MEP	Manufacturing Extension Partnership
MER	Mars Exploration Rover
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
mg/m	milligrams per meter
MGUE	Military GPS User Equipment
MHW	Multi-Hundred Watt
MIC	Microbial Induced Corrosion
MIE	Major Item of Equipment
MIZOPEX	Marginal Ice Zone Observations and Processes EXperiment
mK	millikelvin
MMRTG	Multi-Mission Thermoelectric Generator
MN	meganewton
MOA	Memorandum of Agreement
MOBY	Marine Optical BuoY
MODIS	Moderate Resolution Imaging Spectroradiometer
MoonKam	Moon Knowledge Acquired by Middle School Students
MPCV	Multi-Purpose Crew Vehicle
MPS	Mathematics and Physical Sciences Directorate
MRI	Magneto-Rotational Instability
MRLC	Multi-resolution Land Characteristics Consortium
MRX	Magnetic Reconnection Experiment
MSE	Missile Segment Enhancement
MSFC	Marshall Space Flight Center
MSL	Mars Science Laboratory
MTSB	Monitoring Trends in Burn Severity
MUE	Modernized User Equipment
MUOS	Mobile User Objective System
MWL	Microwave Link
MWL GT	Microwave Link Ground Terminal
nmol/mol	nanomole/mole
µm	microns
µmol/mol	sub-micromole/mole

N

NAFD	North American Forest Dynamics
NAICS	North American Industry Classification System
NAIP	National Agricultural Imagery Program
NAIP-CIR	National Agriculture Imagery Program color infrared
NAS	National Airspace System
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service
NCAR	National Center for Atmospheric Research
NCEP	U.S. National Centers for Environmental Prediction

NCNR	National Center for Neutron Research
NDVI	Normalized Difference Vegetation Index
NE	Office of Nuclear Energy
NEN	Near Earth Network
NEO	Near-Earth Object
NextGen	Next Generation Air Transportation System
NFS	National Forest System
NGA	National Geospatial-Intelligence Agency
NGP	National Geospatial Program
NGS	National Geodetic Survey
NIAC	NASA Innovative Advanced Concepts
NIRSpec	Near-Infrared Spectrograph
NIST	National Institute of Standards and Technology
NLIR	National Land Imaging Requirements
NMAMLP	New Mexico Abandoned Mine Land Program
NMS	Neutral Mass Spectrometer
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
Np	Neptunium
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPS	National Park Service
NRA	NASA Research Announcement
NRAO	National Radio Astronomy Observatory
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NRI	National Resources Inventory
NSCR	NASA Space Cancer Risk
NSO	National Solar Observatory
NSPO	National Space Organization
NSRL	NASA Space Radiation Laboratory
NSS	National Security Space
NSWP	National Space Weather Program
NTSB	National Transportation Safety Board
NuDets	Nuclear Detonations
NuSTAR	Nuclear Spectroscopic Telescope Array
NWI	National Wetlands Inventory
NWR	National Wildlife Refuge
NWRC	National Wetlands Research Center
NWS	National Weather Service

O

OAPM	Optimization of Airspace and Procedures in the Metroplex
ODNI	Office of the Director of National Intelligence
OECD	Organization for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
OFSI	Office of Financial Service Industries
OGA	Office of Global Analysis
OLI	Operational Land Imager
OPIC	Overseas Private Investment Corporation
OPUS	Online Positioning User Service
ORCA	Ocean Radiometer for Carbon Assessment
ORNL	Oak Ridge National Laboratory
ORS	Operationally Responsive Space
OSC	Orbital Sciences Corporation
OSM	Office of Surface Mining

OSMRE	Office of Surface Mining Reclamation and Enforcement
OTM	Office of Transportation and Machinery
OTV-3	Orbital Test Vehicle Three

P

PAC	Patriot Advanced Capability
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PBN	Performance Based Navigation
PDR	Preliminary Design Review
PDRC	Precision Departure Release Capability
PIDDP	Planetary Instrument Definition and Development Program
PLR	Division of Polar Programs
PMC	Polar Mesospheric Cloud
PNT	Positioning, Navigation, and Timing
POES	Polar-orbiting Operational Environmental Satellites
POLARBEAR	Polarization of Background Radiation
PPPL	Princeton Plasma Physics Laboratory
PRS	Public Regulated Service
PRVD02	Puerto Rico Vertical Datum of 2002
PSD	Production, Supply, and Distribution
PSL	Propulsion Systems Laboratory
Pu	Plutonium

Q

QuikSCAT	Quick Scatterometer
QZSS	Quasi-Zenith Satellite System

R

RFP	Request for Proposal
RFQ	Request for Quotation
RGB	Red, Green, Blue
RMA	Risk Management Agency
RNAV	Area Navigation
RO	Radio Occultation
ROD	Record of Decision
ROSES	Research Opportunities in Space and Earth Sciences
RPA	Remotely Piloted Aircraft
RPS	Radioisotope Power System
RPT	Rocket Propulsion Testing
RSCC	Remote Sensing Coordinating Committee
RSIWG	Remote Sensing Interagency Working Group
RTK	Real Time Kinematic
RTS	Retrogressive Thaw Slumps

S

SABRS	Space and Atmospheric Burst Reporting System
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Sample Analysis at Mars
SANS	Small-Angle Neutron Scattering
SAO	Smithsonian Astrophysical Observatory
$AVE	Surfing Aircraft Vortices for Energy
SARDA	Spot and Runway Departure Advisor
SBA	Small Business Administration
SBIR	Small Business Innovation Research

SBIRS	Space Based Infrared System
SC	Office of Science
SCaN	Space Communications and Navigation
SDO	Solar Dynamics Observatory
SHARAD	Shallow Subsurface Radar
SHINE	Solar, Heliosphere, and INterplanetary Environment
SI	International System of Units
SIA	Satellite Imagery Archive
SIM	Spectral Irradiance Monitor
SIRCUS	Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources Facility
Si-MEMS	Silicon-Microelectromechanical Systems
SLS	Space Launch System
SM	Standard Missile
SMAP	Soil Moisture Active-Passive
SMCRA	Surface Mining Control and Reclamation Act
SMD	Science Mission Directorate
SN	Space Network
SNL	Sandia National Laboratories
SNSPD	Superconducting Nanowire Single Photon Detectors
SOC	Space Optical Clock
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOLARIS	SOlar, Lunar for Absolute Reflectance Imaging Spectrometer
SPP	Space Protection Program
SPT	South Pole Telescope
SPUD	Small Polarimeter Upgrade for DASI
SQUIDs	Superconducting Quantum Interference Devices
SRM	Standard Reference Materials
SS2	SpaceShipTwo
SSC	Stennis Space Center
SSDF	Spitzer-South Pole Telescope Deep Field
SSDP	Space Security and Defense Program
SSEBop	Operational Simplified Surface Energy Balance
SSST	Supersonic Sea-Skimming Target
SSTI	Small Spacecraft Technology Initiative
STAT	Space Threat Assessment Testbed
STIM	Space Transportation Infrastructure Matching Grants
STMD	Space Technology Mission Directorate
STP	Space Test Program
STSC	Scientific and Technical Subcommittee
Suomi NPP	Suomi National Polar-orbiting Partnership
Suomi NPP VIIRS	Suomi Visible Infrared Imaging Radiometer Suite
SURF	Synchrotron Ultraviolet Radiation Facility
SUVI	Solar Ultraviolet Imager
SWR	Space Weather Research

T

TBM	Tactical Ballistic Missile
TCAP	Two Column Aerosol Project
TCC	Tree Canopy Cover
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TES	Transition-Edge Sensor
TeV	teraelectronvolt
THAAD	Terminal High-Altitude Area Defense
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIPS	Technical Innovation and Professional Services
TM	Thematic Mapper

TRACON	Terminal Radar Approach Control
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TSA	Transportation Security Administration

U

UAS	Unmanned Aircraft Systems
UCAR	University Corporation for Atmospheric Research
UCAS	Unmanned Combat Air System
UCAS-D	Unmanned Combat Air System Aircraft Carrier Demonstration
ULA	United Launch Alliance
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
US&FCS	U.S. and Foreign Commercial Service
USAF	U.S. Air Force
USFS	U.S. Forest Service
USFS R&D	U.S. Forest Service Research and Development
USFS S&P	U.S. Forest Service State and Private Forestry
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USML	U.S. Munitions List
USNDS	U.S. NuDet Detection System
USRA	Universities Space Research Association
USTDA	U.S. Trade and Development Agency
UVA	Unmanned Aerial Vehicle
UVS	Ultraviolet/Visible Spectrometer

V

VAC	Vertical Assembly Center
VAFB	Vandenberg Air Force Base
VCSFA	Virginia Commercial Space Flight Authority
VO2max	Maximum Oxygen Uptake
vol	volume
VSC	Volcano Science Center

W

WAI	Wide Area Imager
WAOB	World Agricultural Outlook Board
WaterSMART	Water for Sustainable Management of America's Resources for Tomorrow
WCDMA	Wideband Code Division Multiple Access
WCS	Wireless Communications Service
WFF	Wallops Flight Facility
WGS	Wideband Global Satellite Communications Satellite
WK2	WhiteKnightTwo
WSOCs	Wideband SATCOM Operations Centers

X

XMM	X-ray Multi-Mirror
XRT	X-ray Telescope

Y

Yb	Ytterbium

NP-2014-10-1283-HQ