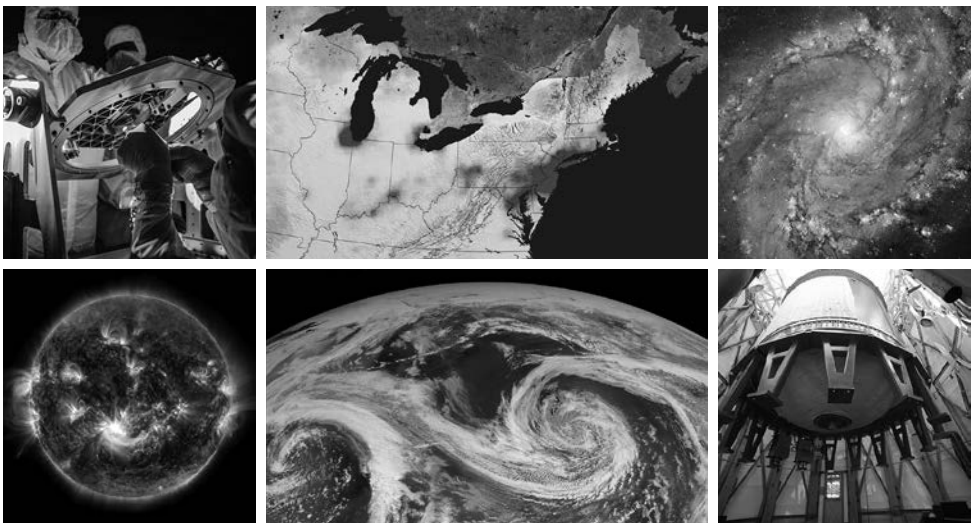
Aeronautics and Space Report of the President

Fiscal Year 2014 Activities



Aeronautics and Space Report
OF THE PRESIDENT

Fiscal Year 2014
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, 2013, through September 30, 2014. Please note that these activities reflect the Federal policies of that time and do not include subsequent events or changes in policy.

On the title page, clockwise from the top left: **1.** NASA engineers conducting low-light test on new technology for the NASA James Webb Space Telescope at NASA's Goddard Space Flight Center. Credit: NASA/Goddard/Chris Gunn. **2.** Nitrogen dioxide data, averaged over 2011 for the northeastern United States. Credit: Goddard's Scientific Visualization Studio. **3.** Hubble Space Telescope image of Messier 83, otherwise known as the Southern Pinwheel Galaxy. Credit: NASA, the European Space Agency, and the Hubble Heritage Team (STScI/AURA); acknowledgment: William Blair (Johns Hopkins University). **4.** Engineers at NASA's Marshall Space Flight Center in Huntsville, Alabama, lowering one of the largest composite cryotanks ever built into a structural test stand. Credit: NASA/Marshall. **5.** Image of the Gulf of Alaska collected on May 2, 2014, by Aqua–Moderate Resolution Imaging Spectroradiometer (MODIS). Credit: NASA/Goddard/OceanColor/MODIS. **6.** Mid-level solar-flare image captured by NASA's Solar Dynamics Observatory (SDO) on December 16, 2014. Credit: NASA/Goddard/SDO.

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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 2014. Space Exploration Technologies Corporation (SpaceX) and Orbital Sciences Corporation completed two commercial cargo missions apiece during FY 2014. The ISS also marked 15 years on orbit and 13 years of human presence on the ISS in November 2013. In January 2014, the Obama administration announced its intention to extend the life of the ISS, scheduled to end in 2020, to at least 2024. The extension presents new opportunities to develop the tools we need for future missions to deep space and to facilitate commercial low-Earth orbit (LEO) activity while reaping large benefits for humanity.

The ISS began FY 2014 with Expedition 37 ISS Commander Fyodor Yurchikhin (Roscosmos), Karen Nyberg (NASA), Luca Parmitano (European Space Agency [ESA]), Oleg Kotov (Roscosmos), Sergey Ryazanskiy (Roscosmos), and Mike "Hopper" Hopkins (NASA) on board. Two Russian Soyuz vehicles, one Russian Progress cargo spacecraft, a European Automated Transfer Vehicle (ATV), and an Orbital Sciences Corporation Cygnus vehicle were all attached to the ISS. The Cygnus spacecraft, on its first and only demonstration flight, with 1,300 pounds of cargo, including food, clothing, and student experiments, was berthed to the ISS. The Cygnus was unloaded and reloaded with trash during its short stay and

was released on October 22, 2013, then maneuvered away from the ISS and toward a destructive reentry into Earth's atmosphere on October 23, 2013. Similarly, the ATV spacecraft was also loaded with items no longer needed on board the ISS, undocked from the ISS, and maneuvered away from the ISS to make a planned destructive reentry into Earth's atmosphere on October 28, 2013. On November 1, 2013, ISS Commander Fyodor Yurchikhin, Karen Nyberg, and Luca Parmitano boarded their Soyuz to move it to another port on the ISS, opening up the primary docking port for the next arriving Soyuz.

On November 6, 2013, new ISS Commander Oleg Kotov, Sergey Ryazanskiy, Mike Hopkins, Fyodor Yurchikhin, Karen Nyberg, and Luca Parmitano were joined by Koichi Wakata (Japan Aerospace Exploration Agency [JAXA]), Rick Mastracchio (NASA), Mikhail Tyurin (Roscosmos), and the Olympic torch, which was taking an out-of-this-world route—as part of the torch relay—to Fisht Stadium in Sochi, Russia. Their arrival marked the first time since October 2009 that nine people had served together on board the ISS without the presence of a Space Shuttle. Cosmonauts Kotov and Ryazanskiy conducted a spacewalk on November 9, 2013, to participate in the Olympic torch relay, prepare a pointing platform for the installation of a high-resolution camera system on a future spacewalk, and deactivate an experiment package. On November 10, 2013, Fyodor Yurchikhin, Karen Nyberg, and Luca Parmitano returned to Earth after spending 166 days in space, ending Expedition 37. They returned the Olympic torch, which was then used to light the Olympic flame at Fisht Stadium in Sochi, Russia, marking the start of the 2014 Winter Games in February. On November 29, 2013, a Russian Progress vehicle carrying three tons of food, fuel, and supplies docked to the ISS. NASA astronauts Mastracchio and Hopkins conducted contingency spacewalks on December 21, 2013, and December 24, 2013, to repair a faulty pump module required for ISS cooling. On December 27, 2013, and January 27, 2014, Russian cosmonauts Kotov and Ryazanskiy conducted spacewalks to install two high-fidelity cameras, remove and install several experiments, and prepare worksites for future spacewalks. The spacewalk in December 2013 was the longest Russian spacewalk in history at eight hours and seven minutes. Orbital Sciences Corporation's first cargo delivery flight under the Commercial Resupply Services (CRS) contract, carrying 2,780 pounds of supplies, including vital science experiments, crew provisions, spare parts, and

other hardware, berthed to the ISS on January 12, 2014. After the crew unloaded this cargo and reloaded the cargo carrier with items no longer needed on the ISS, Cygnus was released using the robotic arm and maneuvered away from the ISS toward a destructive reentry on February 18, 2014. Prior to that, a Russian Progress vehicle also carrying trash undocked on February 3, 2014, and destructively reentered the atmosphere. Another Russian Progress vehicle carrying several tons of supplies replaced it on February 5, 2014. Finally, to close out Expedition 38, ISS Commander Oleg Kotov, Sergey Ryazanskiy, and Mike Hopkins undocked their Soyuz vehicle from the ISS and landed in Kazakhstan on March 10, 2014.

Expedition 39 began on March 10, 2014. ISS Commander Koichi Wakata, Rick Mastracchio, and Mikhail Tyurin remained on board and were joined on March 27, 2014, by Steve "Swanee" Swanson (NASA), Oleg Artemyev (Roscosmos), and Alexander Skvortsov (Roscosmos) when their Russian Soyuz docked to the ISS after a two-day rendezvous. On April 7, 2014, a Russian Progress vehicle carrying trash undocked from the ISS and headed toward a destructive reentry; it was replaced on April 9, 2014, with another Russian Progress vehicle carrying several tons of supplies. A SpaceX Dragon vehicle docked to the ISS on April 20, 2014, carrying 5,000 pounds of scientific equipment and supplies, departed on May 18, 2014, and splashed down in the Pacific Ocean off the Baja California coast, returning more than 3,500 pounds of scientific samples and equipment to Earth. The Russian Progress vehicle, 53P, undocked on April 23, 2014, and redocked on April 25, 2014, after performing testing for the Kurs-NA rendezvous and docking system. Also on April 23, 2014, NASA astronauts Mastracchio and Swanson performed a contingency spacewalk to replace a failed multiplexer/de-multiplexer. Expedition 39 ended on May 13, 2014, when Koichi Wakata, Rick Mastracchio, and Mikhail Tyurin undocked their Soyuz from the ISS and landed in Kazakhstan.

Expedition 40 began on May 13, 2014. ISS Commander Steve Swanson, Oleg Artemyev, and Alexander Skvortsov remained on board and were joined on May 28, 2014, by Max Suraev (Roscosmos), Reid Wiseman (NASA), and Alexander Gerst (ESA) when their Russian Soyuz vehicle docked to the ISS. On June 9, 2014, a Russian Progress vehicle containing trash undocked and destructively reentered the atmosphere. On June 19, 2014, cosmonauts Skvortsov and Artemyev performed a spacewalk to install an antenna and payload boom, remove and

jettison experiments, perform experiments, and take photos of the exterior of the Russian Segment. On July 16, 2014, Orbital's Cygnus berthed to the ISS, carrying additional supplies and experiments. On July 21, 2014, a Russian Progress vehicle undocked from the ISS and performed a destructive reentry. Another Russian Progress vehicle, carrying several tons of supplies, replaced it on July 23, 2014. On August 15, 2014, the Orbital Cygnus spacecraft was released and destructively reentered the atmosphere. On August 12, 2014, the fifth and final European ATV, carrying supplies, docked to the ISS. Cosmonauts Skvortsov and Artemyev performed a spacewalk on August 18, 2014, to install, perform, and retrieve experiments. Expedition 40 ended on September 10, 2014, when Steve Swanson, Oleg Artemyev, and Alexander Skvortsov undocked their Soyuz from the ISS and landed in Kazakhstan.

Expedition 41 began on September 10, 2014. ISS Commander Max Suraev (Roscosmos), Reid "Tonto" Wiseman (NASA), and Alexander Gerst (ESA) remained on board. On September 23, 2014, a SpaceX Dragon delivered more than 2.5 tons of scientific experiments and supplies to the ISS. Barry "Butch" Wilmore (NASA), Elena Serova (Roscosmos), and Alexander Samokutyaev (Roscosmos) joined them on September 25, 2014, when their Russian Soyuz vehicle docked to the ISS.

Research and technology development continued to be the primary focus of operations on board the ISS throughout FY 2014. The ISS capitalized on its Earth observation capabilities, installing the high-definition, Earth-viewing, four-camera suite and the ISS Rapid Scatterometer (RapidScat) for measuring ocean winds. Rodent research hardware and 20 mice were launched to the ISS, initiating a new era in biomedical research. Europe's fifth and final ATV launched supplies for research, as well as the Exposed Experiment Handrail Attachment Mechanism (ExHAM) multipurpose facility for external experiment exposure and the Electromagnetic Levitator (ELM) facility for containerless processing.

RapidScat will monitor ocean winds from the vantage point of the ISS. It will join other satellite scatterometers that make essential measurements used to support weather and marine forecasting, including the tracking of storms and hurricanes. It will also help improve our understanding of how interactions between Earth's oceans and atmosphere influence our climate. The high-definition, Earth-viewing,

commercially available cameras on the exterior of the ISS stream live video of Earth for viewing online. The cameras are enclosed in a temperature-specific housing and are exposed to the harsh radiation of space. Analysis of the effect of space on the video quality will help engineers decide which cameras are the best types to use on future missions.

The Zero Robotics challenge enabled students to utilize the Station as a laboratory to test programming codes from the ground using Synchronized Position Hold, Engage, Reorient Experimental Satellites (SPHERES) on the Station. The Massachusetts Institute of Technology led competition-engaged students in innovative, complementary learning opportunities, as well as increasing student interest in science, technology, engineering, and mathematics (STEM).

Small, relatively inexpensive satellites, collectively referred to as CubeSats, provided a variety of technology demonstrations using the NanoRacks Smallsat Deployment Program to launch the satellites from the Station's Japanese Experiment Module (JEM) airlock. The NanoRacks Smallsat Deployment Program provides inexpensive commercial access to space, via the ISS, for CubeSats to perform Earth and deep space observation. These CubeSats conducted Earth observation missions, tested technologies, and even tweeted from space!

A Veggie plant-growth chamber expanded the plant-growth research capabilities on the Station and demonstrated an on-orbit food-production capability for growing fresh produce and other large plants. As NASA moves toward long-duration exploration missions, food production will be a resource for crew food consumption and could be used by astronauts for recreational gardening activities during long-duration space missions.

The Optical Payload for Lasercomm Science (OPALS) investigation is NASA's first optical communication experiment on the ISS. Scientific instruments used in space missions increasingly require higher communication rates to transmit gathered data back to Earth to support high-data-rate applications and high-definition video streams. Optical communications—also referred to as "lasercom"—is an emerging technology in which data are sent via laser beams. This offers the promise of much higher data rates than what is achievable with current radio frequency (RF) transmissions.

NASA's Rodent Research Facility opens a new era in life science/biomedical research studies aboard the Space Station for both NASA scientists and researchers in the commercial sector. The rodent research system enables researchers to study the long-term effects of microgravity on mammalian physiology to understand better how microgravity affects various body systems—cardiovascular, endocrine, immune, musculoskeletal, nervous, reproductive, and sensorimotor—and to discover what cellular, genetic, and molecular mechanisms are responsible for spaceflight-induced changes. Biomedical research conducted in space is essential for us to gain a better understanding of the health risks of long-duration spaceflight and to develop ways to mitigate those risks.

A 3D printer—the first ever to be flown to space—could change the way NASA does business aboard the Space Station. This technology demonstration in space will show that a 3D printer can work normally in space and produce parts equal to those printed on the ground. Testing on the Station is the first step toward creating a working "machine shop" in space. This capability may decrease cost and risk on the Station and will be critical when space explorers venture far from Earth.

Planning started for the one-year mission, beginning in March 2015, to help scientists better understand the impacts of spaceflight on the human body through the study of a pair of identical twins. Astronaut Scott Kelly will spend one year in low-Earth orbit aboard the ISS while retired astronaut Mark Kelly, his identical twin, will remain on Earth. The twins' similarity will provide scientists with a reduced number of variables and an ideal control group, both important to scientific investigation.

In June 2014, the ISS Program cohosted the 3rd Annual ISS Research and Development Conference, including awards for most compelling results from the ISS in 2013; top results in biotechnology, health, and education; top discoveries in microgravity; and top exploration-related technology-development initiatives focusing on commercial and exploration applications.

Launch Services

During FY 2014, the Launch Services Program (LSP) successfully launched three major payloads: the Mars Atmosphere and Volatile Evolution (MAVEN),

the Tracking and Data Relay Satellite L (TDRS-L), and the Orbiting Carbon Observatory 2 (OCO-2). Both MAVEN and TDRS-L launched aboard an Atlas V rocket from Cape Canaveral Air Force Station in Florida. MAVEN launched on November 18, 2013, followed by the replenishment of NASA's Space Network with TDRS-L on January 23, 2014. On July 2, 2014, OCO-2 launched aboard a Delta II from Vandenberg Air Force Base (VAFB) in California. The LSP also continued to provide launch-related systems engineering, launch integration, and mission design and analysis support to over 40 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 2014, the program acquired launch services for three future science missions: the Interior Exploration Using Seismic Investigations, Geodesy and Heat Transport (InSight), the Cyclone Global Navigation Satellite System (CYGNSS), and Solar Orbiter. Both InSight and Solar Orbiter will be launched by United Launch Services on an Atlas V rocket. InSight will launch from VAFB in California followed by Solar Orbiter from the Cape. CYGNSS will also launch from the Cape on Orbital Sciences Corporation's Pegasus-XL.

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 29 states across the United States, with 32 launched and 22 manifested on NASA, National Reconnaissance Office, and U.S. Air Force missions. 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 SMD's Jason-3 mission in 2015.

Advanced Exploration Systems

The Advanced Exploration Systems (AES) Division is pioneering new ways to rapidly develop prototype systems, demonstrate key capabilities, and validate operational concepts to reduce the risk and cost of future human exploration missions. In FY 2014, the AES Division led the human spaceflight planning for the Agency through a detailed campaign and framework for expanding human presence across the solar system and to Mars. This framework was the focus of the Agency's efforts to communicate to all its stakeholders the short- and long-term plans for human spaceflight. AES also continued the successful execution of 30 research and technology development projects employing 560 civil servants spread across all NASA Centers. In FY 2014, the goal was to complete at least 80 percent of the 63 annual milestones that the program had established. The team accomplished 51 milestones (81 percent) on schedule and within the available resources. Specific achievements included the following:

- AES completed 14 flight tests of the Morpheus lander at Kennedy Space Center (KSC), including two closed-loop tests of the Autonomous Landing and Hazard Avoidance Technology (ALHAT) system. One of these tests was at night. Two more closed-loop flight tests are planned in November 2014 to verify a fix to the ALHAT navigation system. The likely cause of the navigation problem is obscuration of the Doppler light detection and ranging (lidar) by the lander's exhaust plume.
- AES's Spacecraft Fire Safety project completed the fabrication and assembly of the first of three Saffire flight experiments (Saffire-I) that will study large-scale fire propagation in microgravity on the Cygnus vehicle in 2016.
- AES's public-private partnership with Bigelow Aerospace to demonstrate the Bigelow Expandable Activity Module (BEAM) on the ISS progressed toward hardware delivery in February 2015. The project completed critical design reviews on the primary structure and flight support equipment and all structural qualification testing of the module. The Passive Common Berthing Mechanism will be integrated with the module in December 2015. The project remains on track with an aggressive 24-month schedule from contract signature to delivery of flight hardware.

- Working with NASA's SMD, AES defined system requirements for exploration technology demonstration payloads on the Mars 2020 mission. AES participated in the proposal evaluation process for the Mars 2020 Announcement of Opportunity that resulted in two payloads being competitively selected to address key Strategic Knowledge Gaps. The Mars Oxygen in situ resource utilization (ISRU) Experiment (MOXIE) will demonstrate the production of oxygen from the Martian atmosphere to enable in situ propellant production for future human missions. The Mars Environmental Dynamics Analyzer (MEDA) is a surface weather station that will measure temperature, pressure, winds, and dust to characterize the environmental conditions that may be encountered by human explorers. In addition, AES committed to re-flying the Mars Entry, Descent, and Landing Instrumentation (MEDLI) experiment to further characterize the entry environment for future landings on Mars by robotic and human missions.
- AES completed the initial formulation and Mission Concept Reviews for three CubeSats that will be launched as secondary payloads on Exploration Mission-1 (EM-1). The payloads include Biosentinel, which will investigate the effects of deep space radiation on simple organisms; the Lunar Flashlight, which will search for volatiles in shadowed craters on the Moon; and the Near-Earth Asteroid Scout, which will use a solar sail to fly by an asteroid.
- AES selected three commercial partners via the Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST) solicitation and awarded nonreimbursable Space Act Agreements to jointly develop lunar payload delivery capabilities. NASA will provide engineering expertise, test facilities, software, and loaned hardware to the partners.
- AES completed integrated chamber testing of ISS-derived life-support equipment, including a Carbon Dioxide Removal Assembly (CDRA), a Trace Contaminant Control (TCC) system, an Oxygen Generator Assembly (OGA), and environmental monitoring instruments. These life-support systems have less mass and better reliability than the systems used on the ISS.

- AES made advances in water-processing technologies, including the testing of a Cascade Distillation System (CDS) urine processor prototype, the preliminary design of a second-generation CDS, the development of a "green" (less toxic) urine pretreatment, the design of a urine brine processor, and research into the use of silver as a biocide.
- The AES Resource Prospector formulation progressed this year with the continued development of the prospecting instruments and a prototype rover, along with conducting a joint study with JAXA to develop concepts for the lunar lander.
- AES supported the Asteroid Redirect Mission (ARM) with $25.2 million of related content, including the Goldstone Radar, which has imaged 53 near-Earth asteroids (NEAs) over the past three years and which AES transitioned to SMD halfway through FY 2014. A Broad Agency Announcement resulted in 18 industry-led studies of asteroid capture systems, rendezvous sensors, commercial spacecraft buses, and partnership opportunities for secondary payloads and enhancing the crewed missions. In addition, AES continued efforts in neutral buoyancy testing of the Modified Advanced Crew Escape Suit (MACES) to enable short-duration extravehicular activity (EVA) from Orion, system concept studies, and the formulation of the NEA Scout asteroid precursor mission.
- AES continued to advance next-generation spacesuit capabilities through the execution of the Z-2 Suit garment contract, completed the assembly of the first Portable Life Support System (PLSS), and initiated testing of the PLSS with a mockup spacesuit and human metabolic simulator. AES continued to conduct several underwater tests of the MACES that astronauts will use for short-duration EVAs to explore the captured asteroid.
- The AES Core Flight Software team achieved Class A certification of core flight software for use on human spaceflight systems such as Orion.
- AES demonstrated automated loading of a 2,000-gallon liquid oxygen (LOX) propellant tank in tests at KSC. This capability will reduce ground-operations costs for fueling the Space Launch System (SLS).

- AES successfully completed ground testing and launch of extended-wear clothing for the ISS. The ISS crew is currently testing the extended-wear clothing to minimize the mass of clothing on long-duration missions.
- With funding partially provided by AES, the first 3D printer developed for use in space was delivered for launch on the SpaceX-4 mission to demonstrate in-space manufacturing of spare parts and tools on the ISS.
- With funding partially provided by AES, the Optical Payload for Lasercomm Science (OPALS) demonstrated optical downlink of a video file from the ISS and concepts of operation for laser communication from a LEO satellite.
- AES developed concepts for an Evolvable Mars Campaign encompassing the capabilities of the ISS, Orion, SLS, the Exploration Augmentation Module, and ARM. The campaign included a split-habitation-module approach, Phobos destinations for early mission capability development, and in situ resource utilization for propellant-centric architectures. The Evolvable Mars Campaign will ensure that future architectures have sustainable and evolvable capabilities at minimum cost and risk for human spaceflight missions.
- Under leadership from AES, the International Space Exploration Coordination Group (ISECG) held its semiannual meeting in Tokyo at the end of July 2014. The first Science Working Group met to identify the charter and strategic plans for ensuring that science goals are addressed across the Global Exploration Roadmap (GER). The GER II Workshop, held at the Applied Physics Laboratory (APL) in April 2014, successfully brought together stakeholders from across the aerospace community, with participation from a diverse group of international partners, industry, and academia in person and online.
- AES coordinated multiple integration and strategic planning discussions for Human Exploration and Operations Mission Directorate (HEOMD) leadership and provided content for NASA's Exploration Forum held on April 29, 2014. AES continued the development of the Pioneering Space document that is designed to capture and communicate the Agency's

human spaceflight plans with internal and external stakeholders and international partners.

- AES led the HEOMD System Maturation Teams to refine the capability investment prioritization process and provide data to the Office of the Chief Technologist as a foundation for their 2014 technology roadmapping effort. The work of the System Maturation Teams will guide future technology investments across HEOMD and the Agency. This information will also affect the Evolvable Mars Campaign effort that AES is leading to identify the decisions and pathways toward a sustainable human spaceflight campaign to put humans on Mars.
- AES completed the second international conference on sex and gender that assessed the medical effects of prolonged spaceflight on female astronauts. The conference and associated Google hangout were very successful and resulted in six papers for medical journals, including the *Journal of Women's Health*.
- Other AES activities included the selection of nine new investigator teams for the Solar System Exploration Research Virtual Institute to conduct research on the Moon and small bodies; additionally, the Radiation Assessment Detector team published a paper in the journal *Science* on the Mars surface radiation environment.

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 ISS. During FY 2014, our commercial partners continued to make progress maturing their respective commercial crew transportation systems while NASA initiated certification efforts with its partners with a goal of enabling crew transportation from U.S. soil in 2017.

Under Commercial Crew Integrated Capability (CCiCap) Space Act Agreements (SAAs), our three partners continued to successfully complete technical, programmatic, and financial milestones as they mature their respective commercial crew

transportation systems. During FY 2014, our partners successfully completed the following milestones:

- Boeing completed pilot-in-the-loop testing, the spacecraft phase 2 safety review, and multiple subsystem Critical Design Reviews (CDRs) leading to the completion of their CDR Board. During 2014, Boeing successfully completed all CCiCap milestones, and their SAA has been finalized.
- Sierra Nevada completed wind tunnel testing of the integrated spaceflight system, main propulsion and reaction control system (RCS) risk reduction and technology maturation, and RCS and propulsion system testing.
- SpaceX completed its safety review, flight review of the Falcon 9 1.1 launch vehicle, integrated crew vehicle CDR, operations CDR, and in-flight abort-test review.

In December 2013, NASA awarded the first phase of its commercial crew transportation certification effort, Certification Products Contracts (CPC). Under these contracts, our partners worked 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. All CPC activities were successfully completed and contracts were closed out during the third quarter of FY 2014.

In September 2014, NASA announced contracts with Boeing and SpaceX to continue development and certification efforts under the Commercial Crew Transportation Capabilities (CCtCap) effort, with a goal of ending, in 2017, the Nation's sole reliance on Russia for crew transportation to and from the ISS.

CCtCap will enable NASA to ensure that a partner's crew transportation system is safe, reliable, and cost-effective. The certification process will assess progress throughout the production and testing of one or more integrated space transportation systems, which include the launch vehicle, the spacecraft, and ground operations.

Space Communications and Navigation

In FY 2014, 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 2014, SCaN maintained at least 99 percent proficiency of all of its networks, providing communication and navigation services to approximately 35 spacecraft using the DSN, approximately 30 spacecraft using the SN, and approximately 30 spacecraft using the NEN. The DSN 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 SN consists of a space segment, composed of the Tracking and Data Relay Satellites (TDRSs), and a ground segment, which includes the White Sands Ground Terminals in New Mexico and the Guam Remote Ground Terminal. The SN provides communication and navigation services to the robotic missions (e.g., the Hubble Space Telescope); the ISS; and 25 NASA, U.S. Government, and commercial launches and servicing missions. Using antenna assets located around the world, the NEN provides tracking, telemetry, and communications services for orbital missions and occasionally suborbital missions.

SCaN completed some key milestones during FY 2014:

- The TDRS-L spacecraft was successfully launched, tested, and accepted from the contractor; it achieved its initial operating capability.
- TDRS-M successfully held its System Integration Review and started environmental testing.
- The Space Network Ground Segment Sustainment project continued to work toward the completion of its technical Critical Design Review.

- The NEN project successfully completed the new Alaska Satellite Facility (ASF) Antenna (AS3). The DSN Aperture Enhancement Project successfully completed its first new 34-meter deep space beam waveguide antenna in Canberra, Australia. The new Deep Space Station (DSS)-35 is now fully operational and meeting the requirements of NASA's missions.
- The Lunar Laser Communication Demonstration (LLCD) payload on the Lunar Atmosphere and Dust Environment Explorer (LADEE) completed its technical objective of transmitting over 600 million bits per second from the moon. The LLCD and LADEE mission accomplishments were recognized with the Popular Mechanics Breakthrough and the R&D 100 awards and was nominated for the Collier Trophy.
- The SCaN Test Bed achieved operational capability and began testing ways to change the functionality of radios during spaceflight. It demonstrated processing of both Global Positioning System (GPS) and Galileo navigation signals on orbit with the same receiver and has assisted the Department of Defense (DOD) in the checkout of the new GPS Civil signals.
- 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 the S-band spectrum occupied by TDRSS.
- The Consultative Committee for Space Data Systems (CCSDS) is a major international organization that develops internationally agreed-upon and interoperable space communications standards that enable joint international missions and reduce cost and risk to space missions. In 2014, SCaN engineers led CCSDS working groups in completing many new standards and are leading the new working group chartered to develop new standards for optical communications.

Human Spaceflight Capabilities

By the end of FY 2014, the Rocket Propulsion Test (RPT) Program had safely performed 322 tests. Test time totaled over 493,000 seconds, with more than 26,800 seconds of hot fire at various levels of thrust.

In FY 2014, Stennis Space Center (SSC) had several test programs under way, including the J-2X and RS-25 in support of the Space Launch System (SLS) Program, as well as flight certification testing for the AJ-26 engine in support of a reimbursable NASA SAA with Orbital Sciences Corporation. Development testing continued for NASA's Morpheus lander. New developmental testing for SpaceX Corporation began on a reimbursable basis. Refurbishment and repair activities continued for critical enabling infrastructure, including replacing both the B-leg and the A-leg of the high-pressure industrial water system and restoring the B-2 test stand for SLS core stage testing.

In April, the final test of the J-2X engine—a new version of a liquid upper stage rocket engine—was completed on the A-2 test stand at SSC, culminating with a 125-second test. After completion of that final test, work began on preparing the A-2 test stand to be placed in a mothball status for the coming year, FY 2015. Throughout FY 2014, after having completed its assigned testing of the J-2X engine, the SSC A-1 test stand underwent facility modifications to support testing of the RS-25 engine in FY 2015 in support of SLS.

Other activities at SSC included the Orbital Sciences Corporation and Aerojet Rocketdyne test firings of the AJ-26 engine. The AJ-26 engine powers the Orbital Antares rocket that launches from NASA's Wallops Flight Facility in support of the ISS Commercial Resupply Services project.

On May 22, 2014, an Orbital Sciences Corporation testing of an AJ-26 engine in the SSC E-1 Cell 3 test stand experienced a mishap due to an engine overpressure. Orbital Sciences Corporation and Aerojet Rocketdyne conducted an investigation in order to determine the root cause of the failure, and SSC assessed the resulting damage to the E-1 test stand. Repairs, activations, and verification were completed on the E-1 test stand by the end of September 2014, and AJ-26 engine E-18 was installed and readied for testing in the first week of October 2014.

At Marshall Space Flight Center, the SLS Scale Model Acoustic Testing (SMAT) was conducted to better understand the effects of sound during the launch of the new SLS vehicle. Additionally, several advanced rocket engine technologies, including components built using Select Laser Melting construction technology, were tested.

The Boeing Corporation conducted testing of its orbital maneuvering and reaction control system thruster at the White Sands Test Facility (WSTF) as part of NASA's Commercial Crew Program. Also at WSTF, engineers conducted tests to support DOD's Missile Defense Agency engine and thruster program, the Peacekeeper safing project, and hot fire test and decontamination efforts for the Minuteman life-extension program.

At Plum Brook Station, tests were performed at the B-2 facility to enable the testing of large electric propulsion thrusters that may be required for long-duration space activities.

Exploration Systems Development

NASA is continuing excellent progress toward developing the capability to send humans on exploration missions beyond LEO. The Orion Multi-Purpose Crew Vehicle, the SLS that will carry Orion beyond LEO, and the ground systems necessary to integrate and launch the flight systems all made great strides in 2014. The first test flight, Exploration Flight Test-1 (EFT-1), remains on schedule for an early December launch. The design, manufacturing, and procurement of SLS and Orion components for the next flight, Exploration Mission-1 (EM-1), are well under way, and construction of the ground support facilities is proceeding on schedule.

Orion: During FY 2014, the assembly of the EFT-1 spacecraft was completed, and the test article was delivered for ground operations at Kennedy Space Center (KSC) in September in preparation for the early December launch. Prior to delivery, thorough test and checkout steps were successfully completed, including the Service Module structural loads test and the Crew Module functional and multi-point random vibration tests. The Delta IV-H rocket that will carry Orion on its test flight is on the launch pad. The flight test will also include the proven Launch Abort system that has been installed on the EFT-1 Crew Module. This uncrewed

flight will test the effectiveness of the largest continuous heat shield ever installed on a spacecraft. Furthermore, design work for the EFT-1 spacecraft represents nearly 50 percent of the total Orion development work needed for the crew-capable version, which will fly for the first time on Exploration Mission 2 (EM-2) in the 2021 timeframe.

In addition to the EFT-1–related work, Orion accomplished several other major milestones in 2014 and accelerated progress toward EM-1 and EM-2. The program-level delta Preliminary Design Review (PDR), which thoroughly reviewed all new design work since 2009 and verified readiness to proceed to detailed design for the EM-1 and EM-2 spacecraft, was completed in the summer. Furthermore, Orion personnel are continuing to work with the European Space Agency on the Service Module, completing a major design review overseas. Negotiations with Orion's prime contractor for integrating the ESA-provided Service Module are expected to be complete this fall, with contract definitization by December 31, 2014. EM-1 critical path manufacturing is under way, including production of a Crew Module "pathfinder" pressure vessel.

SLS: In support of EFT-1, the SLS Program produced the stage adapter that connects the Orion spacecraft to the Delta IV-H launch vehicle's upper stage. This adapter will be a common design that is also used on EM-1. The adapter was completed in May, was delivered to KSC, and has been mated with the EFT-1 Orion Service Module.

For the SLS "Block 1" configuration to be flown on EM-1, the program successfully cleared the Agency's Key Decision Point C (KDP-C) milestone in August, marking the transition from program formulation into implementation. Both the Core Stage and Booster elements completed their Critical Design Reviews (CDRs) in July and August respectively, which keeps the program on track for the program-level CDR in 2015. Preparation for next year's CDR has been supported by a wide range of important hardware testing across NASA, including the last buffet wind tunnel test at Langley Research Center, testing of the Core Stage flight computers during the spring, and acoustic model testing of SLS during launch at Marshall Space Flight Center (MSFC) throughout the year. Production of the first pieces of test and actual EM-1 flight hardware is also under way. The Vertical Assembly Center (VAC) Tool activation at the Michoud Assembly Facility (MAF)

in Louisiana occurred in July, and the first full-duration test weld on the VAC took place in September. The VAC is the final of six major welding tools at the MAF that will produce the SLS Core Stage structure using less than half the labor of Space Shuttle External Tank production. Other major SLS facility work in 2014 includes the new structural test stands at MSFC, which broke ground in August 2014. The SLS Program also accomplished much in the area of acquisitions in 2014. Contracts for the Core Stage, Interim Cryogenic Propulsion Stage, and Launch Vehicle Stage Adapter were definitized during 2014, resulting in all major SLS development elements now being under contract.

Ground Systems Development and Operations (GSDO): In 2014, the GSDO Program finalized its preparations to recover the EFT-1 Orion spacecraft after splashdown. Recovery options, including a Navy landing platform/dock (LPD) well deck ship and a supervisor of salvage (SUPSALV) crane lift ship, were thoroughly tested in real ocean conditions using an Orion flightlike mock-up. The program selected the Navy LPD well deck ship as the primary EFT-1 recovery method, with the SUPSALV crane lift ship serving as a backup option.

Like SLS, the GSDO Program also completed its KDP-C review in 2014 and has moved from formulation to implementation of the Exploration Ground Systems. Preceding the KDP-C review in September, the program-level PDR was completed during the spring. Design and construction work on vehicle integration and launch facilities for the SLS-Orion flight systems made excellent progress in 2014. Modification of the Vertical Assembly Building's Highbay-3 for the SLS stacking and integration platforms was initiated, with demolition, lead paint and asbestos abatement, and installation of environmental testing equipment completed. The Mobile Launcher construction was approximately 58 percent complete at the end of FY 2014. The contract to modify the Ares-I Launch Tower for SLS was awarded in September, and construction work will continue into mid-2015.

Also in 2014, GSDO continued its work to establish and develop the 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 continued to pursue 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 environmental remediation of operations, and support the modernization of launch-range capabilities.

Space Life and Physical Sciences Research and Applications

Human Research Program (HRP): Astronaut crews typically spend about six months on the ISS. NASA's first one-year mission to the ISS is scheduled to begin in March 2015. In 2014, three key areas were identified as being of particular concern for longer missions and a one-year mission research plan was developed to focus on these areas: medical conditions with a temporal trend of increasing severity with time spent in space; behavior and performance issues related to extended periods of isolation and confinement; and physiological deconditioning, such as deficits in bone, muscle, cardiovascular function, and exercise performance. Due to the unique opportunity presented by having an identical twin, Scott Kelly, as one of the one-year mission participants while his identical twin brother, retired NASA astronaut Mark Kelly, remains on Earth, the HRP has also funded 10 short-term, first-of-their-kind investigations into the molecular, physiological, and psychological effects of spaceflight in a continuous effort to reduce the health impacts of human space exploration.

Visual Impairment Intracranial Pressure (VIIP) syndrome is currently NASA's number-one human spaceflight risk. The syndrome, which is related to microgravity exposure, manifests with changes in visual acuity and eye structure. In some cases, elevated cerebrospinal fluid pressure has been documented post-flight, reflecting increased intracranial pressure (ICP). The operational and research communities at NASA are working collaboratively in an effort to understand the mechanisms causing VIIP syndrome and to provide mitigation and countermeasures. About 25 VIIP studies are currently in progress, and five have been completed. Ongoing studies include data mining, animal analogs, bed rest and other human microgravity analogs, computer modeling, technology development and flight certification, and in-flight studies involving astronaut test subjects. These studies are aimed at understanding the interaction of the microgravity environment with the eye, the cardiovascular system, and the central nervous system. The main active flight

experiment at this time is the Ocular Health study, a prospective investigation that aims to identify underlying mechanisms and define the temporal pattern or timeline for the appearance and resolution of signs and symptoms.

The Integrated Cardiovascular (ICV) study concluded this year after four years on board the ISS. Objectives of the study were to investigate whether heart muscle would atrophy during long-duration spaceflight, whether the structure or performance of the heart would be affected, and whether these changes might predispose astronauts to the development of rhythm abnormalities. Data obtained during the study substantiated the well-described loss of circulating blood volume reflected as a change in cardiac filling. The heart also became more spherical. Detailed measures of "diastolic function" and "myocardial strain" demonstrated that cardiac function was preserved. ICV showed that the change in the work the heart did in space relative to the work done on Earth correlated directly with how much mass the heart lost or gained during the mission. Overall, ICV has provided one of the most comprehensive descriptions of the human heart during long-duration spaceflight.

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), named a new chair for its board of directors, General James Abrahamson (retired). The previous board chair, France Cordova, moved on to become director of the National Science Foundation (NSF).

CASIS also delivered the first commercial rodent research investigation to the ISS on the SpaceX-4 flight.

The new space-biology open-science campaign, GeneLab, successfully launched. A steering committee was formed comprising members from industry, academia, other Government agencies, and CASIS to learn from best practices and leverage existing capabilities while developing a collaborative forward implementation approach. A strategic plan was drafted and publicly released, and the platform Web site was launched: *http://genelab.nasa.gov.* The first spaceflight experiments that will contribute data to GeneLab launched on SpaceX-4 in September 2014.

A workshop for MaterialsLab, an open science pathfinder for the Physical Science Informatics System, was held in Washington, DC, in April 2014. Attendees included representatives from NASA, academia, industry, other Government

agencies, and CASIS. Recommendations were received for six research theme areas from the respective discussion groups: granular materials, glasses and ceramics, metals, polymers, biomaterials, and semiconductors. A report of the recommendations was produced. As a result, CASIS released a Materials Science Request for Proposals (RFP) of its own. This workshop has led to a Memorandum of Understanding (MOU) regarding materials science research on the ISS linking it to the Materials Genome Initiative. The workshop was a resounding success.

Multiple investigations for space biology and physical science were delivered to the ISS on the SpaceX-4 Dragon capsule.

Science Mission Directorate

NASA leads the Nation on a great journey of discovery, seeking new knowledge and understanding of our sun, Earth, solar system, and the universe—out to its farthest reaches and back to its earliest moments of existence. The NASA Science Mission Directorate (SMD) and the Nation's science community use space observatories to conduct scientific studies of Earth and the sun from space, to visit and return data and samples from other bodies in the solar system, and to peer out into the vast reaches of the universe and beyond. With these objectives in mind, SMD conducts scientific research and experiments to answer some of humankind's most basic questions. What drives variations in the sun, and how do these changes impact the solar system and drive space weather? How and why are Earth's climate and environment changing? How did our solar system originate and change over time? How did the universe begin and evolve, and what will be its destiny? How did life originate, and are we alone?

SMD uses a fleet of spacecraft and ground stations to observe and capture information about Earth, the sun, our solar system's planets, and deep space to help us learn, answer these and other compelling questions, and address the scientific challenges that lie before us. SMD has five program divisions: Astrophysics, Earth Science, Heliophysics, Planetary Science, and the Joint Agency Satellite Division (JASD). It also has a James Webb Space Telescope (JWST) program office. In FY 2014, SMD successfully launched four new space and Earth science missions designed to improve our understanding of solar processes, global precipitation, the

role of carbon dioxide in the Earth system, and the Martian atmosphere and its interactions with the sun and solar wind. SMD lays the intellectual foundation for the robotic and human expeditions of the future while meeting current 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 continue to learn and to be surprised by it. Earth, like the human body, comprises diverse components that interact to form a single, interconnected system. At NASA, we strive to understand that interconnectedness. We want to know how Earth's atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere work as a symbiotic system. We also want to comprehend how this complex system adapts and changes due to natural and other influences.

From space, NASA satellites can view Earth as a planet and study its myriad components, including life. With these tools, the Nation's scientific community can observe and track global-scale changes, connecting cause to effects; study regional changes in a global context; and observe how civilization acts as a force of change. NASA continues to partner with other agencies to study the Earth system—improving our ability to predict climate, weather, and natural hazards—manage resources, and inform policy makers. NASA's Earth Science program manages these efforts.

The Earth Science Division (ESD) had numerous successes in 2014, including launching the Global Precipitation Measurement (GPM) mission, part of a fleet of spacecraft designed to observe global precipitation every two to four hours, and the Orbiting Carbon Observatory (OCO-2) mission, which will provide the first complete picture of human and natural carbon dioxide sources and sinks and map their geographic distribution over time. In July 2014, the GPM mission's Precipitation Processing System at NASA's Goddard Space Flight Center in Greenbelt, Maryland, released the Level 2 GPM Microwave Imager (GMI) data to the public. The dataset includes precipitation rates, which show how much rain and snowfall accumulate over a given time period. NASA's OCO-2 mission completed its first 90 days of operations in space. The spacecraft meets or exceeds all functional and

performance specifications, and all planned instrument checkout activities have been completed. The instrument is making high-precision measurements, and data processing is proceeding on schedule. The observatory is now the sixth member of the international constellation of Earth-observing satellites commonly referred to as the Afternoon Constellation, or "A-Train."

In 2014, ESD also successfully concluded significant technical reviews for upcoming missions, including the Cyclone Global Navigation Satellite System (CYGNSS), which will measure ocean surface winds throughout the life cycle of tropical storms and hurricanes; the Soil Moisture Active-Passive (SMAP) mission, which will measure surface soil moisture and freeze-thaw states; the Ice, Cloud, and Land Elevation Satellite (ICESat-2), which will monitor and assess polar ice changes; and the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission, which will continue the measurement of Earth's magnetic field. The mission examples in the next section will demonstrate how Earth scientists use existing resources (spacecraft, aircraft, previous studies and data, ground stations, etc.) to find new knowledge.

Western Antarctic Ice-Sheet Melting

We know the Earth system is dynamic and changing. We know the planet's climate has changed over time, and today, scientific observations reveal a clear warming trend. A warming planet has global impacts, including rising water levels from melting polar ice. In May 2014, NASA and the University of California, Irvine (UCI), released a critical study that found a large section of the ice sheet in western Antarctica was irreversibly melting. The NASA-UCI study used radar observations captured between 1992 and 2011 by the European Earth Remote Sensing (ERS-1 and -2) satellites to map the grounding lines' retreat inland. The satellites use a technique called radar interferometry, which enables scientists to precisely measure—within less than a quarter of an inch—how much of Earth's surface is moving. Glaciers move horizontally as they flow downstream, but their floating portions also rise and fall vertically with changes in the tides. The science team mapped how far inland these vertical motions extend to locate the grounding lines. Typically, similar studies will view three principal lines of evidence in glacial demise: (1) the changes in their flow speeds; (2) how much each glacier floats on

seawater; and (3) the slope of the terrain that the glaciers are flowing over, as well as its depth below sea level. This study examined the latter two lines and showed that, in much the same way a grounded boat can float in shallow water if it sheds some weight, these glaciers have lost significant mass and are now floating above areas where they used to touch the ground.

To slow or stop these changes requires pinning points—bumps or hills rising from the glacier bed that snag the ice from underneath. To locate these points, researchers produced a more accurate map of bed elevation that combines ice velocity data from ERS-1 and -2 and ice thickness data from NASA's Operation IceBridge mission and other airborne campaigns. The results confirm no pinning points are present upstream of the present grounding lines in five of the six glaciers, which may ultimately result in the collapse of this sector of western Antarctica should these trends continue. NASA's Operation IceBridge will continue to monitor its evolution closely during this year's Antarctica deployment, which began in October 2014. IceBridge uses a specialized fleet of research aircraft and the most sophisticated suite of science instruments ever assembled to characterize changes in the thickness of glaciers, ice sheets, and sea ice.

GRACE Measures Colorado River Basin

Just as NASA's research shows the impact sea-level rise will have on our planet, other studies show how the lack of water is also creating impacts. A July 2014 NASA-UCI study found that more than 75 percent of the water loss in the drought-stricken Colorado River Basin came from underground resources. The study was the first to quantify the amount groundwater contributes to the water needs of western states.

The research team used data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellite mission to track changes in the mass of the Colorado River Basin. Monthly measurements of the change in water mass from December 2004 to November 2013 revealed that the basin lost nearly 53 million acre feet (65 cubic kilometers) of freshwater, almost double the volume of the Nation's largest reservoir, Nevada's Lake Mead. More than three-quarters of the total (about 41 million acre feet, or 50 cubic kilometers) was from groundwater. The basin has been suffering from prolonged, severe drought since 2000 and has

experienced the driest 14-year period in the last hundred years. The Colorado River Basin supplies water to about 40 million people in seven states. Major cities outside the basin also use water from the Colorado River.

Scientists used GRACE much like a scale. Changes in water reserves affect the strength of local gravitational attraction. By periodically measuring gravity regionally, GRACE revealed how much of the region's water storage changed over time. The study's authors used the data to see whether the region was relying on groundwater to make up for the limited surface-water supply, which it had. Combined with declining snowpack and a growing population, this reliance will likely threaten the long-term ability of the basin to meet the water needs of the region. The Colorado River is the only major river in the southwestern United States; its basin supplies water to about 40 million people in seven states and irrigates roughly four million acres of farmland.

Carbon Tetrachloride (CCl_4) Persists

NASA also devotes significant resources to studying the atmosphere's chemical composition. An August 2012 NASA study found that Earth's atmosphere contains an unexpectedly large amount of an ozone-depleting compound from an unknown source, even decades after governments banned the compound worldwide. Through the 1987 Montreal Protocol, governments created a worldwide ban on various chlorofluorocarbons, including carbon tetrachloride (CCl_4). From 2007 to 2012, parties to the Montreal Protocol reported zero new CCl_4 emissions. However, new NASA research showed that worldwide CCl_4 emissions averaged 39 kilotons annually, nearly 30 percent of its peak emissions prior to the Protocol going into effect. With those results, atmospheric concentrations of CCl_4 should have declined by four percent annually, not the one percent the observations indicated.

The surprising revelation led the study's authors to suggest that there were either unidentified industrial leakages, large emissions from contaminated sites, or unknown CCl_4 sources. To investigate the discrepancy, NASA used its 3-D Goddard Earth Observing System (GEOS) Chemistry Climate Model, data from global networks of ground-based observations, and CCl_4 measurements taken by the National Oceanic and Atmospheric Administration's (NOAA's) Earth System Research Laboratory and NOAA's Cooperative Institute for Research in

Environmental Sciences at the University of Colorado, Boulder. Not only did these model simulations indicate an unidentified source of CCl_4 and produce the first quantitative estimate of average global CCl_4 emission from 2000 to 2012, they also found that the chemical stays in the atmosphere 40 percent longer than previously thought.

Heliophysics Division

NASA's Heliophysics Division strives to understand the sun, heliosphere, and planetary environments as a single connected system. Our planet and its cousins exist under the influence of an active star, which brings both positive and potentially negative effects. While our sun enables and sustains life, it also produces streams of high-energy particles and radiation that can harm life or alter its evolution. The Heliophysics Division studies these phenomena to understand how the sun functions within its atmosphere and affects the solar system, including Earth. By studying the connections between the sun, solar wind, solar plasma, radiation, planetary space environments, and our place within the galaxy, we uncover the fundamental physical processes that occur throughout the universe. More practicably, understanding the connections between the sun and its planets enables us to predict the impacts of solar variability on humans, technological systems, and the presence of life itself.

The Heliophysics Division similarly had a successful 2014, which included passing key reviews in select missions, including the Magnetospheric Multiscale (MMS) Observatory mission, which will use four spacecraft to monitor magnetic reconnection, energetic particle acceleration, and turbulence within the magnetosphere; the Solar Orbiter Collaboration Heavy Ion Sensor (HIS), which will study the sun at a closer range than any spacecraft before it; and the Solar Probe Plus (SPP) mission, which will fly into the sun's corona. NASA will soon rely on these missions to produce numerous data and new science, but several active missions continued their successful investigations into 2014. The following examples are of current programs and missions involving our study of the sun and its effects on the planets and our solar system.

Van Allen Probes

This year, NASA celebrated two years of studying the sun's influence on our planet and near-Earth space with the Van Allen Probes, originally launched in August 2012. Shortly after their launch, the probes discovered a new, third radiation belt around Earth. These radiation belts are layers of energetic charged particles held in place by the magnetic field surrounding our planet. The new third belt occurred only occasionally but persisted for as long as a month, revealing to scientists the dynamic and variable nature of these belts and providing new insight into how they respond to solar activity. The Probes continue to elucidate how particles in the radiation belts form and change in response to the sun's energy.

Weighing less than 1,500 pounds (680 kilograms) and designed to weather the harsh radiation belt region around Earth, the Probes are providing NASA scientists with new information on the connection between this region and Earth's atmosphere, as well as how space-based technologies may be affected by solar storms and other space weather events. We know that solar storms and space weather affect communications and Global Positioning System (GPS) satellites and can pose risks to humans in low-Earth orbit, but they also affect the belts themselves and can cause them to swell dramatically.

The Probes also revealed how very-low-frequency plasma waves sometimes accelerate particles in the heart of the belts to nearly the speed of light. They also showed that Earth's rotation causes a common feature in the inner belt, whereby persistent stripe-like structures form, a mechanism previously thought to be incapable of such an effect. Both observations are helping scientists validate theories about plasma physics and the acceleration processes happening within the belts and are showing new structures and features previously not suspected.

Interface Region Imaging Spectrograph Data

The Van Allen Probes are not the only success story for Heliophysics. NASA's Interface Region Imaging Spectrograph (IRIS) has provided scientists with five new findings that improve our understanding of the sun.

The first result identified heat pockets of 200,000 degrees Fahrenheit, the lowest in the solar atmosphere observed by any spacecraft. Scientists refer to the pockets as solar heat bombs due to the amount of energy they release in such a short time.

Identifying such sources of unexpected heat offers a deeper understanding of the heating mechanisms throughout the solar atmosphere.

For its second finding, IRIS observed numerous, small, low-lying loops of solar material in the interface region for the first time. The unprecedented resolution provided by IRIS enables scientists to improve their understanding of how the solar atmosphere is energized.

In the third finding, scientists were surprised to see structures resembling mini-tornadoes occurring in solar active regions for the first time. These tornadoes move at speeds as fast as 12 miles per second and are scattered throughout the chromosphere, the layer of the sun just above the surface. These tornados provide a mechanism for transferring energy to power the million-degree temperatures in the corona.

In the fourth finding, researchers found evidence of high-speed jets at the root of the solar wind. These fountains of plasma shoot out of coronal holes, which are areas of less dense material in the solar atmosphere and typically thought to be a source of the solar wind.

The fifth finding showed the effects of nanoflares throughout the corona. When magnetic field lines cross, they explosively realign, causing large solar flares, which often send particles out into space at nearly the speed of light. Nanoflares are smaller versions that scientists believed were driving coronal heating. For the first time, IRIS observations showed that nanoflare events were generating high-energy particles that also impact the chromosphere.

Interstellar Boundary Explorer

Our ability to understand our sun and solar system very closely relates to our understanding of how the heliosphere and magnetosphere interact. Back in 2009, NASA researchers using the Interstellar Boundary Explorer (IBEX) found an uneven distribution of neutral atoms forming a ribbon along the heliospheric boundaries. Researchers wondered if this shape might also relate to an unevenness seen in cosmic rays. For decades, Earth spacecraft have detected more incoming high-energy cosmic rays on one side of the sun than the other. By combining observations from other parts of the Milky Way and IBEX, researchers found that there

is a magnetic field nearly perpendicular to the motion of our solar system through the galaxy. These results would explain the unevenness we have long observed.

To see if the IBEX data related to the cosmic ray observations, NASA researchers used IBEX data to build a computer model of what the interplanetary magnetic field would look like around the heliosphere. The heliosphere distorts the field lines, so without the heliosphere, the field lines would be straight and parallel. The simulations showed a non-uniform distribution of cosmic ray particles consistent with the unevenness seen in previous observations.

Though the simulation does show a potential correlation, it does not prove that the heliosphere and interstellar magnetic field are exclusively responsible for the cosmic ray distribution mystery. However, this research shows that the magnetic configuration of our neighborhood does offer a potential answer. And more, the data from IBEX and detectors looking at the cosmic ray distribution work to map what our magnetic fields outside the heliosphere look like. Scientists will continue to collect these and other pertinent data, particularly from Voyager 1, the only spacecraft to breach the outer limits of the heliosphere, to paint an even clearer picture.

Planetary Science Division

Earthbound scientists have long been observing, studying, and even discovering the solar system's planetary objects. NASA's Planetary Science Division continues to explore this fascinating field and push the limits of spacecraft and robotic engineering.

The Planetary Science Division had a successful 2014 that saw the launching of the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft, achieving complete mission success of the Mars Science Laboratory (MSL, known as Curiosity), and the passage of critical steps to newer missions, including the Origins Spectral Interpretation Resource Identification Security–Regolith Explorer (OSIRIS-REx), which will approach, map, and take a sample of a near-Earth asteroid; and the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission, which will place instruments on the surface of Mars to investigate whether Mars's core is solid or liquid.

These future missions will produce new information and discoveries, while current missions are providing today's scientists and researchers with ample data to develop new scientific knowledge. The following are some examples of how scientists are using NASA spacecraft to learn about our solar system's planets, particularly Mars.

Mars 2020

The Mars 2020 mission will send the next NASA rover to the planet, this time carrying even more sophisticated instruments to conduct unprecedented science and exploration investigations. In April 2014, NASA announced the selected Mars 2020 rover instruments. NASA chose the seven instruments from 58 proposals, twice the typical number submitted for similar competitions in the recent past, highlighting the strong interest from the broader scientific community.

Scientists will use the Mars 2020 rover to identify and select a collection of rock and soil samples that will be stored for potential return to Earth by a future mission. By helping us understand the hazards of Martian dust and by giving us the information we need to develop the technology to process carbon dioxide from the atmosphere to produce oxygen, the Mars 2020 rover will help advance our knowledge of how future human explorers could use natural resources while on the surface of the Red Planet. These experiments will help engineers learn how to use Martian resources to produce oxygen for human respiration and potentially as an oxidizer for rocket fuel.

Mars Atmosphere and Volatile Evolution

In September, NASA's MAVEN spacecraft entered Martian orbit to begin exploring the tenuous upper atmosphere of the Red Planet. After a 10-month journey, MAVEN was successfully inserted into orbit around Mars and began transmitting data back to Earth. MAVEN entered a six-week commissioning phase that included maneuvering into its final science orbit and testing the instruments and science-mapping commands. MAVEN then began its one-Earth-year primary mission, taking measurements of the composition, structure, and escape of gases in Mars's upper atmosphere and its interaction with the sun and solar wind.

MAVEN launched November 18, 2013, from Cape Canaveral Air Force Station in Florida, carrying three instrument packages. The Particles and Fields Package will characterize the solar wind and the ionosphere of the planet. The Remote Sensing Package will identify characteristics present throughout the upper atmosphere and ionosphere. The Neutral Gas and Ion Mass Spectrometer will measure the composition and isotopes of atomic particles. The primary mission includes five "deep-dip" campaigns, in which MAVEN's lowest orbit altitude (or periapsis) will be lowered from 93 miles (150 kilometers) to about 77 miles (125 kilometers). These measurements will provide information down to where the upper and lower atmospheres meet, giving scientists a full profile of the upper tier.

Mars Comet Flyby

In October, two NASA and one European spacecraft were privileged to have the opportunity to provide the first up-close observations of a comet flyby of Mars, gaining new information about the basic properties of the comet's nucleus and directly detecting the effects on the Martian atmosphere. Data from observations carried out by NASA's MAVEN mission, NASA's Mars Reconnaissance Orbiter (MRO), and a radar instrument on the European Space Agency's (ESA's) Mars Express spacecraft revealed that debris from the comet added a temporary and very strong layer of ions to the ionosphere, the electrically charged layer high above Mars. Using these observations, scientists were able to make a direct connection from the input of debris from a specific meteor shower to the formation of this kind of transient layer in response; that is a first on any planet, including Earth.

Comet C/2013 A1 Siding Spring traveled from the most distant region of our solar system and made a close approach to within about 87,000 miles (139,500 kilometers) of the Red Planet, less than half the distance between Earth and our moon, and less than one-tenth the distance of any known comet flyby of Earth. Dust from the comet impacted Mars and was vaporized high in the atmosphere, producing what was likely an impressive meteor shower. This debris resulted in significant temporary changes to the planet's upper atmosphere and possible longer-term perturbations. A host of space- and Earth-based telescopes also observed the unique celestial object.

The MAVEN spacecraft detected the comet encounter in two ways. The remote-sensing Imaging Ultraviolet Spectrograph observed intense ultraviolet emission from magnesium and iron ions high in the atmosphere in the aftermath of the meteor shower. Not even the most intense meteor storms on Earth have produced as strong a response as this one. The emission dominated Mars's ultraviolet spectrum for several hours after the encounter and then dissipated over the next two days. MAVEN also was able to directly sample and determine the composition of some of the comet dust in Mars's atmosphere. An analysis of these samples by the spacecraft's Neutral Gas and Ion Mass Spectrometer detected eight different types of metal ions, including sodium, magnesium, and iron. These are the first direct measurements of the composition of dust from an Oort Cloud comet; the Oort Cloud is a spherical region of icy objects believed to be material left over from the formation of the solar system, occupying space at a range of 5,000 to 100,000 times the distance from Earth to the sun.

Curiosity Arrives at Martian Mountain

On September 11, 2014, after a two-year, nine-kilometer journey, NASA's Mars Curiosity rover reached the base of Mars's Mount Sharp, a Mount Rainier–sized mountain at the center of the vast Gale Crater and the rover mission's long-term prime destination. Curiosity will next examine the mountain's lower slopes, starting at an entry point near an outcrop called Pahrump Hills. Curiosity currently is positioned at the base of the mountain along a pale, distinctive geological feature called the Murray Formation. Compared to neighboring crater-floor terrain, the rock of the Murray Formation is softer and does not preserve impact scars. As viewed from orbit, it is not as well-layered as other features at the base of Mount Sharp. Curiosity made its first close-up study of two Murray Formation outcrops, both revealing notable differences from the terrain explored by Curiosity during the past year. The first outcrop, called Bonanza King, proved too unstable for drilling but was examined by the rover's instruments and determined to have high silicon content. A second outcrop, examined with the rover's telephoto Mast Camera, revealed a fine-grained, platy surface laced with sulfate-filled veins.

While some of these terrain differences are not apparent in observations made by NASA's Mars orbiters, the rover team still relies heavily on images taken by the

Agency's Mars Reconnaissance Orbiter (MRO) to plan Curiosity's travel routes and locations for study. For example, MRO images helped the rover team locate mesas that are over 60 feet (18 meters) tall in an area of terrain shortly beyond Pahrump Hills; the images revealed an exposure of the Murray Formation uphill and toward the south. Though this valley has a sandy floor the length of two football fields, the team expects it will be an easier trek than the sandy-floored Hidden Valley, where, last month, Curiosity's wheels slipped too much for safe crossing.

Astrophysics Division

The Astrophysics Division looks to the deepest recesses of space to learn about the universe and its origins and our place in it. We are starting to investigate the very early universe and are close to learning the full history of stars and galaxies. We are discovering how planetary systems form and how environments hospitable to life develop. Furthermore, we will search for the signature of life on other worlds, perhaps to learn that we are not alone.

The Astrophysics Division also had a successful 2014, with the Nuclear Spectroscopic Telescope Array (NuSTAR) program fully meeting its mission criteria; the Stratospheric Observatory for Infrared Astronomy (SOFIA) collecting 258 hours of research; and two key programs passing review phases, including the James Webb Space Telescope (JWST), which will replace the Hubble Space Telescope to become NASA's largest space telescope, and the Transiting Exoplanet Survey Satellite (TESS), which will complete a two-year survey of our solar neighborhood to discover, potentially, thousands of more exoplanets (planets outside our solar system) in orbit around other stars. The following are a few examples of ongoing NASA astrophysics programs yielding great scientific discoveries.

Kepler Telescope Discovers First Earth-Sized Planet in "Habitable Zone"

Using NASA's Kepler Space Telescope, astronomers have discovered the first Earth-sized planet orbiting a star in the "habitable zone," the range of distance from a star where liquid water might pool on the surface of an orbiting planet. The discovery of Kepler-186f confirms that planets the size of Earth exist in the habitable zone of stars other than our sun. While planets have previously been found

in the habitable zone, they are all at least 40 percent larger in size than Earth, and understanding their makeup is challenging. Kepler-186f is more reminiscent of Earth. And although the size of Kepler-186f is known, its mass and composition are not. Previous research suggests that a planet the size of Kepler-186f is likely to be rocky.

Kepler-186f resides in the Kepler-186 system, about 500 light-years from Earth in the constellation Cygnus. The system is also home to four companion planets, which orbit a star half the size and mass of our sun. The star is classified as an M dwarf, or red dwarf, a class of stars that makes up 70 percent of the stars in the Milky Way Galaxy.

Kepler-186f orbits its star once every 130 days and receives just a third the energy from its star that Earth gets from the sun, placing it nearer the outer edge of the habitable zone. On the surface of Kepler-186f, the brightness of its star at high noon is only as bright as our sun appears to us about an hour before sunset. The four companion planets, Kepler-186b, Kepler-186c, Kepler-186d, and Kepler-186e, are very close to their sun (orbiting every 4, 7, 13, and 22 days, respectively), making them too hot for life as we know it. These four inner planets all measure less than 1.5 times the size of Earth.

The next steps in the search for distant life include looking for true Earth-twins—Earth-sized planets orbiting within the habitable zone of a sunlike star—and measuring their chemical compositions. The Kepler Space Telescope, which simultaneously and continuously measured the brightness of more than 150,000 stars, is NASA's first mission capable of detecting Earth-sized planets around stars like our sun.

Kepler Mission Announces a Planet Bonanza: 715 New Worlds

In February, NASA's Kepler mission announced the discovery of 715 new planets. These newly verified worlds orbit 305 stars, revealing multiple-planet systems much like our own solar system. Nearly 95 percent of these planets are smaller than Neptune, which is almost four times the size of Earth. This discovery marks a significant increase in the number of known small-sized planets more akin to Earth than previously identified exoplanets.

Since the discovery of the first planets outside our solar system roughly two decades ago, verification has been a laborious planet-by-planet process. Now, scientists have a statistical technique that can be applied to multiple planets simultaneously once they are found in systems that harbor more than one planet around the same star. To verify this bounty of planets, a research team at NASA's Ames Research Center analyzed stars with more than one potential planet, all of which were detected in the first two years of Kepler's observations—between May 2009 and March 2011. The research team used a technique called verification by multiplicity, which relies in part on the logic of probability. Kepler observes 150,000 stars and has found a few thousand of those to have planet candidates. If the candidates were randomly distributed among Kepler's stars, only a handful would have more than one planet candidate. However, Kepler observed hundreds of stars that have multiple planet candidates. Through a careful study of this sample, these 715 new planets were verified.

These multiple-planet systems are fertile grounds for studying individual planets and the configuration of planetary neighborhoods, providing clues to planet formation. Four of these new planets are less than 2.5 times the size of Earth and orbit in their sun's habitable zone, defined as the range of distance from a star where the surface temperature of an orbiting planet may be suitable for life-giving liquid water. One of these new habitable zone planets, called Kepler-296f, orbits a star half the size of and 5 percent as bright as our sun. Kepler-296f is twice the size of Earth, but scientists do not know whether the planet is a gaseous world with a thick hydrogen-helium envelope or if it is a water world surrounded by a deep ocean. This latest discovery brings the confirmed count of planets outside our solar system to nearly 1,700. As we continue to reach toward the stars, each discovery brings us one step closer to a more accurate understanding of our place in the galaxy.

NuSTAR Untangles Mystery of How Stars Explode

One of the biggest mysteries in astronomy, how stars blow up in supernova explosions, finally is being unraveled with the help of NASA's Nuclear Spectroscopic Telescope Array (NuSTAR). The high-energy X-ray observatory has created the first map of radioactive material in a supernova remnant. The results, from a remnant named Cassiopeia A (Cas A), reveal how shock waves likely rip massive dying

stars apart. Cas A was created when a massive star blew up as a supernova, leaving a dense stellar corpse and its ejected remains. The light from the explosion reached Earth a few hundred years ago, so we are seeing the stellar remnant when it was fresh and young.

Supernovas seed the universe with many elements, including the gold in jewelry, the calcium in bones, and the iron in blood. While small stars like our sun die less violent deaths, stars at least eight times as massive as our sun blow up in supernova explosions. The high temperatures and particles created in the blast fuse light elements together to create heavier elements.

NuSTAR is the first telescope capable of producing maps of radioactive elements in supernova remnants. In this case, the element is titanium-44, which has an unstable nucleus produced at the heart of the exploding star. The NuSTAR map of Cas A shows the titanium concentrated in clumps at the remnant's center and points to a possible solution to the mystery of how the star met its demise. When researchers simulate supernova blasts with computers, as a massive star dies and collapses, the main shock wave often stalls out and the star fails to shatter. The latest findings strongly suggest that the exploding star literally sloshed around, re-energizing the stalled shock wave and allowing the star to finally blast off its outer layers.

The NuSTAR map also casts doubt on other models of supernova explosions in which the star is rapidly rotating just before it dies and launches narrow streams of gas that drive the stellar blast. Though imprints of jets have been seen before around Cas A, it was not known if they were triggering the explosion. NuSTAR did not see the titanium, essentially the radioactive ash from the explosion, in narrow regions matching the jets, so the jets were not the explosive trigger.

James Webb Space Telescope

The James Webb Space Telescope (JWST) aims to continue with great scientific observations, much like its predecessor, the Hubble Space Telescope (HST). The JWST will be a large (with a 6.5-meter-diameter mirror), infrared-optimized telescope designed to study and answer fundamental astrophysical questions ranging from the formation and structure of the universe to the origin of planetary

systems and the origins of life. A scientific successor to the HST and the Spitzer Space Telescope, the JWST observatory will be used by international teams of astronomers to conduct imaging and spectroscopic observations in the wavelength range of 0.6–27 microns. JWST will help develop, launch, and operate a state-of-the-art observatory for use by the international astronomy community to significantly 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 characteristics of planetary systems, including our own.

The JWST remains on schedule for launch in October 2018. The program achieved several important milestones during FY 2014. During the period of October through December 2013, the JWST program completed major pieces of ground support equipment for the Integrated Science Instrument Module (ISIM) to be used during testing at Johnson Space Center in 2016, delivered the last Primary Mirror Segment to Goddard Space Flight Center, and installed new detector focal plane arrays into the Near Infrared Camera (NIRCam) earlier than forecasted. JWST also completed its Spacecraft Critical Design Review (CDR) in June 2014. During the final quarter of FY 2014, two important milestones were accomplished in the Integrated Science Instrument Module element: the completion of the new near-infrared detectors for the Near InfraRed Spectrograph (NIRSpec) and the combined Fine Guidance Sensor (FGS)/Near Infrared Imager and Slitless Spectrograph (NIRISS). Additionally, the successful completion of the new NIRSpec microshutters means that hardware is well ahead of their need dates. With the completion of these items, all hardware elements are now ready for the activities that will occur in the first and second quarters of FY 2015 to change out science instrument hardware in preparation for the final science instrument cryovacuum tests.

Joint Agency Satellite Division

The Joint Agency Satellite Division (JASD) was established in 2010 to more efficiently manage NASA's fully reimbursable satellite and instrument development program, which includes NOAA-funded missions. JASD offers Federal

agencies a single interface for planning, development, and management of their satellite projects.

In FY 2014, JASD, in partnership with NOAA and the Air Force, launched the Total Solar Irradiance Calibration Transfer Experiment (TCTE), which was designed to continue measurements of the Total Solar Irradiance (TSI). These measurements are used to measure energy output from the sun at all wavelengths, which is the primary energy source that drives climate on Earth and determines if solar energy changes influence Earth's climate. The successful launch of TCTE allowed the continuity of a 34-year-long data record of this critical TSI measurement.

Aeronautics Research Mission Directorate

The Aeronautics Research Mission Directorate (ARMD) established a new strategic vision in the FY 2014 NASA Strategic Plan, which identified six new strategic research thrusts: safe, efficient growth in global operations; innovation in commercial supersonic aircraft; ultra-efficient commercial vehicles; a transition to low-carbon propulsion; real-time, systemwide safety assurance; and assured autonomy for aviation transformation. Each thrust (described below) is designed to address an important area of research and technology development that will further U.S. leadership in the aviation industry and enhance global mobility. NASA's research is performed with an emphasis on multi-disciplinary collaboration focused on the critical, integrated challenges (aligned to the six research thrusts) referred to by NASA as convergent research. Together, these research thrusts combine to enable safe, sustainable growth in the overall global aviation system while pioneering transformative capabilities that will create game-changing opportunities. Significant planning for the reorganization of ARMD research programs to align with the new strategic thrusts took place during FY 2014. The new program structure resulting from this effort is planned to be implemented starting in FY 2015.

Thrust 1—Safe, Efficient Growth in Global Operation: Within the United States, the Next Generation Air Transportation System, or NextGen, remains the focus for a modernized air transportation system that will achieve much greater capacity and operational efficiency while maintaining or improving safety and

other performance measures. ARMD will contribute specific research and technology to enable the continued development of NextGen and beyond. Internationally, similar developments, such as the European Union's Single European Sky Air Traffic Management Research effort, are under way and are being globally harmonized through the International Civil Aviation Organization. The projected significant growth in air travel also requires sustained focus on reducing safety risks to maintain acceptable levels of safety as demand for air service continues to grow. ARMD will work with the Federal Aviation Administration (FAA), the Commercial Aviation Safety Team (CAST), and others to contribute research and technology addressing current and future safety risks.

Thrust 2—Innovation in Commercial Supersonic Aircraft: Not only could the development of efficient, cost-effective, and environmentally sound commercial supersonic transports be a game changer for transcontinental and intercontinental transportation, but it also could provide an opportunity to maintain U.S. leadership in aviation systems. Since commercial overland supersonic flight is currently prohibited, ARMD's strategy for the near term (2015–25) is to focus on enabling the establishment of a standard for allowable sonic boom. Because international routes compose a major share of the potential market for supersonic service, ARMD will work with the international standards community to define sonic boom levels that will be acceptable to the public. In parallel, ARMD will develop and validate analysis tools and technologies intended to enable the design and development of supersonic aircraft with low sonic boom.

Thrust 3—Ultra-Efficient Commercial Vehicles: Large leaps in aircraft efficiency, coupled with reductions in noise and harmful emissions, are critical to aviation's roadmap for greatly improved environmental sustainability. ARMD will develop critical technologies to enable future generations of subsonic fixed-wing and vertical-lift commercial aircraft that demonstrate the needed improvements in environmental impacts.

Thrust 4—Transition to Low-Carbon Propulsion: While high levels of aircraft and operational efficiency are required for the future, they will not be enough to produce absolute reductions in carbon emissions. Therefore, ARMD seeks both to enable the use of alternative fuels and to foster a fundamental shift to aircraft

propulsion systems that have the potential to produce very low levels of carbon emissions relative to the energy used.

Thrust 5—Real-Time Systemwide Safety Assurance: Commercial aviation is the safest mode of travel. This accomplishment results from decades of continuous improvement through proactively managing hazards, incidents, and risk of accidents. With technology advancements in sensors, networking, data mining, prognostics, and other analytic techniques, the aviation community can now envision a day when it can recognize safety risks as they develop in real time in order to implement strategies that prevent risks from becoming safety issues. ARMD will lead systems research in this technology area and demonstrate the feasibility of integrated, systemwide safety assurance.

Thrust 6—Assured Autonomy for Aviation Transformation: Ever-increasing levels of automation and autonomy are transforming aviation, and this trend will continue to accelerate. The safe integration of unmanned aircraft systems (UAS) into the National Airspace System (NAS), for example, requires research in several areas, including communications, human-machine interfaces, sense-and-avoid capabilities, and separation assurance. ARMD will lead in the research and development of new technologies for the safe integration of UAS in the NAS, innovative systems verification and validation, advanced human-machine interface harmonization, and highly reliable trusted systems.

A report titled "Autonomy Research for Civil Aviation: Toward a New Era of Flight" was published by the National Research Council (NRC) in FY 2014 as a result of ARMD's request to convene a committee to develop a national research agenda for autonomy in civil aviation. Increasingly Autonomous (IA) systems—characterized by their ability to perform more complex mission-related tasks with substantially less human intervention for more extended periods of time, sometimes at remote distances—are being envisioned for aircraft and for air traffic management and other ground-based elements of the NAS. The report recommended a national research agenda in autonomy including eight high-priority research projects that should be executed by those in government, industry, and academia who are involved in the research, development, manufacture, certification, and regulation of IA technologies. In a parallel effort to the NRC study, ARMD established an Inter-Center Autonomy Study Team (ICAST) to assess what technical

challenge areas NASA should address. The results of the ICAST effort were combined with the NRC study and will be used to further define research efforts related to autonomy in aviation.

Aviation Safety Program

The simulation of large transport airplanes in upset conditions remains a topic of high interest to commercial aviation as part of the effort to reduce the risk of fatal loss-of-control accidents. During FY 2014, the Aviation Safety Program demonstrated an aerodynamic model that can enable stall recovery training for commercial airline pilots, surpassing the capabilities of current-day simulators. The model was determined to be of sufficient fidelity for application to a flight training simulator environment, based on recommended simulator certification criteria for stalls, being developed by relevant technical research and training organizations. The model data were validated by subscale aircraft flight tests, as well as other flight test and accident data.

NASA has partnered with engine manufacturers and other Government agencies to conduct Vehicle Integrated Propulsion Research (VIPR) testing with the goal of advancing the commercialization and acceptance of propulsion health management technologies. This partnership provides a means to test and evaluate emerging health-management technologies on a commercial engine, incorporating new sensors directly into the engine and evaluating advances in engine diagnostics. During FY 2014, NASA and its partners engaged in detailed planning for VIPR testing scheduled for FY 2015. This will be the third in a series of three tests, begun in FY 2011, that are related to propulsion health management and will include the planned ingestion of volcanic ash into an aircraft-mounted engine during a ground test.

Current methods of lightning protection for composites result in unwanted additional weight. NASA is conducting research on a new multifunctional lightning strike protection method for aircraft that can also detect and diagnose damage to composite structures. Since composites do not have the conductivity of aluminum, manufacturers embed a metal mesh (typically aluminum or copper) on the surface of the composite material. The mesh adds conductivity that helps prevent

lightning from creating catastrophic damage, but it also adds weight. The new method applies a SansEC (sans [without] electric connection) sensor, made of a thin, lightweight copper foil, to an aircraft surface, forming a "Smart Skin" layer. The conductive, damage-tolerant sensors are capable of determining the physical characteristics of the material upon which they are placed, and they can detect and diagnose damage in composite materials. Research conducted in FY 2014 demonstrated that the new method successfully meets lightning strike protection requirements with less weight than current methods, and it also detected and diagnosed damage scenarios including delamination, punctures, and rips.

During the past 20 years, the aviation industry has documented more than 200 incidents in which turbofan jet engines have lost power during high-altitude flights. For many of these events, the aircraft were flying in the vicinity of heavy storm clouds, but with little activity showing on the weather radar at their flight altitude. NASA is part of an international team working to improve aviation safety by analyzing high-altitude ice crystals using a specially equipped French Falcon 20 aircraft. The primary goal of the FY 2014 flight campaign, conducted in Darwin, Australia, during its summer months, was to collect data on the characteristics of weather known to produce high ice water icing conditions. Investigators tested the theory that the damage to the engines occurs when planes fly through clouds with high concentrations of small ice crystals. The crystals are drawn into the engines, where they melt on the warm surfaces inside. This liquid moisture cools the engine interior enough to allow ice formation, which degrades engine performance. NASA contributed to the European-led High Altitude Ice Crystals (HAIC)/ High Ice Water Content (HIWC) flight campaign by providing instrument and meteorological ground support, sensors expertise, satellite imagery, data analysis from the Falcon's onboard weather radar, and cloud expertise using flight data to improve modeling algorithms to predict the high ice concentrations. NASA also supplied an isokinetic probe that measured the total water content in clouds that have high concentrations of ice crystals in the vicinity of oceanic and continental thunderstorms. The data captured during this campaign add to the ground-based icing research that NASA has already conducted on a full-scale engine under high-altitude ice crystal icing conditions in NASA's Propulsion Systems Laboratory. This research will help the aviation community to better understand the meteorological

conditions that cause high concentrations of crystals in certain areas, advancing the development of technologies that may someday be able to detect the presence of ice crystals or lessen their effects in flight.

NASA's data-mining research focuses on identifying precursors that often provide an early indication of an impending event that could pose a safety concern. Accurate and timely identification of precursor conditions will be a key capability in the drive toward more real-time systemwide safety assurance. NASA has developed a suite of capable algorithms that can look for precursors among different data types across thousands of recorded flights. In FY 2014, NASA developed methods to improve the reliability of predicting future events through the identification of specific precursors. In particular, NASA examined connections between overspeeds and underspeeds (potential safety events) and data patterns occurring earlier in the flight (precursors). NASA also expanded its capability to identify unusual events (anomalies) in radar track data. This class of algorithms will be instrumental in developing broader systemwide safety capabilities that consider both onboard and air traffic data.

Through development and testing, NASA also is addressing key challenges associated with verification and validation (V&V) methods essential for meeting the extremely high levels of safety required for flight-critical systems operating in NextGen. During FY 2014, NASA demonstrated use of one of these advanced software assurance techniques, Compositional Verification, through the testing of an entire flight control system. Compositional Verification enables a system-level software safety assessment by breaking down the system into component parts and examining the safety properties of each of those components. Formal methods such as Compositional Verification allow for more comprehensive and more efficient verification and validation of flight-critical systems.

Airspace Systems Program

During FY 2014, NASA continued progress toward Air Traffic Management Technology Demonstration-1 (ATD-1), which aims to improve arrival operations efficiency while increasing arrival throughput using integrated aircraft-based and ground-based automation technologies. The Airspace Systems Program successfully

completed a full-scale simulation of air traffic operations utilizing all technologies and procedures under development for ATD-1. This marks the end of the first phase of demonstration activities that involved the development of prototype systems, the integration of all of the technologies, and initial human-in-the-loop (HITL) simulations in NASA laboratories. The next phase will involve the development of the demonstration systems, follow-on simulations using FAA facilities and personnel, the flight testing of avionics, and the shadow testing of the integrated system. The last phase will finalize the demonstration plans and culminate in a field trial in a controlled yet realistic operational environment. Initiated by ARMD in FY 2011, ATD-1 is planned to be completed in FY 2017 with a final technology transfer to the FAA of an integrated set of terminal arrival tools that will allow arriving aircraft to safely fly closer together on more fuel-efficient routes to increase capacity; reduce delay; and minimize fuel burn, noise, and greenhouse gas emissions. One of the ATD-1 tools, Terminal Sequencing and Spacing (TSS), was delivered to the FAA's Time-Based Flow Management Program and included more than 100 technical and programmatic documents. The official ceremony of transfer to the FAA was held in July 2014. TSS technology provides information to controllers about the speeds they should assign to aircraft as they follow fuel-efficient, continuous-descent arrival procedures while passing through a region of airspace covering a distance from an airport of about 50 miles.

NASA's Spot and Runway Departure Advisor (SARDA) is designed to help tower controllers improve the efficiency of airport surface operations. Reducing taxi times will help to eliminate unnecessary fuel burn, resulting in fewer emissions and less impact on the environment. During FY 2014, NASA completed three in a series of six HITL experiments using the Agency's Future Flight Central facility to simulate SARDA-enabled operations at the US Airways ramp tower at Charlotte-Douglas International Airport. The simulations focused on using a four-sector (ramp) configuration during 2-hour-long scenarios that included arrival and departure rushes and turnaround traffic. Arrival and departure rushes examined the usability and functionality of NASA's new touchscreen-based user interface for ramp controllers, known as the Ramp Traffic Console, while turnaround traffic evaluated the first build of the ramp scheduler, which provides gate pushback advisory times to ramp controllers. NASA received positive feedback from the simulation participants.

The next HITL simulation will incorporate a more advanced scheduler, providing new and enhanced advisories to ramp and tower controllers.

Transition to NextGen is vital to improving system performance, meeting continued growth in air traffic, and increasing the Nation's mobility to support economic progress. Current modernization of the National Airspace System (NAS) is based on evolutionary changes; only one or two major system or technology upgrades are introduced at a time to ensure seamless integration and transition. There are significant technical risks to inserting multiple technologies simultaneously because the combined integrated impact of future concepts and technologies cannot be fully anticipated with current state-of-the-art modeling and simulation capabilities. To accelerate the transformation of the NAS, NASA is developing the Shadow Mode Assessments Using Realistic Technologies for the National Airspace System (SMART-NAS) capability, a live, virtual, and constructive environment where alternative future concepts, technologies, air-ground, and human-machine architectures can be examined in an integrated fashion to assess NAS-level performance and benefits. As a first step toward development, NASA made awards in FY 2014 to four teams tasked with developing an innovative NAS modeling architecture that will use a real-time, one-way feed of live aircraft traffic data and allow shadow mode testing of advanced, gate-to-gate concepts in an integrated fashion to accelerate the application of NextGen technologies.

The Precision Departure Release Capability (PDRC) reduces departure delays, fuel consumption, and emissions by enabling efficient aircraft departure and merging into open slots in the congested overhead traffic stream. During FY 2014, the Airspace Systems Program conducted research to develop and evaluate PDRC enhancements and extend the PDRC concept toward an Integrated Arrival/Departure/Surface (IADS) scheduling capability. Significant progress was made in the development of an operational concept, scheduling algorithm, and prototype decision-support tool for Tactical Departure Scheduling–Terminal (TDS-T)—a key component of an IADS scheduling concept. TDS-T builds on the PDRC core foundation to extend the time-based control of departures to multiple airports, with various levels of surveillance equipage, within a terminal area. An initial shadow evaluation was conducted at the NASA North Texas Research Station, during which traffic management supervisors and front-line managers from the

Dallas/Fort Worth (DFW) Terminal Radar Approach Control (TRACON) facility, as well as control towers at DFW and Dallas Love airports, all interacted with the TDS-T prototype. Provided feedback will be used to further refine the concept and technology.

Fundamental Aeronautics Program

During FY 2014, NASA's Fundamental Aeronautics Program continued to conduct research and provide leadership in efforts to overcome the barriers to successful commercial supersonic aircraft. These include environmental barriers such as sonic boom, airport noise, and high-altitude emissions, as well as efficiency barriers related to airframe, propulsion, and supersonic operations in the National Airspace System. Although work continues in all of these areas, NASA's current focus is on the most significant barrier: sonic boom noise caused by the presence of shock waves when an aircraft flies faster than sound. The disturbance caused by sonic-boom noise led to the implementation of FAA and international restrictions that essentially banned commercial supersonic flight over land, which in turn severely limited the potential market for civil supersonic aircraft. The program's sonic boom research addresses two of the most important aspects of the problem with the goal of creating key data that regulators can use to create a noise-based standard for certifying overland flight. The first aspect is understanding the sonic boom's acoustics and its impact on a community below, including how people react to hearing sonic booms when outside or indoors, and how quiet a boom needs to be before it is not considered an annoyance. The second aspect is developing and validating tools and techniques to enable the design of supersonic aircraft that produce acceptable sonic-boom noise.

In the sonic-boom response area, the FY 2014 efforts focused on understanding people's response to sonic booms heard indoors. The NASA Interior Effects Room (IER) was used during FY 2014 to study people's levels of annoyance in reaction to simulated sonic-boom noise of varying degrees. A major accomplishment in FY 2014 was the development and validation of software that can simulate sonic-boom-induced exterior pressure loading on buildings, transmission through building partitions (walls, windows, etc.), interior radiation of the transmitted pressures,

and the resulting indoor acoustic environment. This software will enable researchers to generalize results from the IER to a wider variety of building sizes and types.

In FY 2014, the low-sonic-boom design tool research continued to progress toward the completion of a set of enhanced capabilities for full supersonic vehicle analysis. Building on previous airframe tool development, the team conducted a series of wind tunnel tests to validate tools used to predict the impact of engine inlet and nozzle flow on the overall sonic-boom signature.

Continued success in research into the two key aspects of the sonic-boom barrier has led NASA to consider what the next logical step toward the development of a sonic-boom standard might be. The conclusion reached is that a flight demonstration of low-boom technology is the only way to achieve full validation and collect the required community response data in the most realistic environment—that of people in their own homes in any typical community. In FY 2014, the program completed a feasibility study for a Low Boom Flight Demonstration (LBFD). The purposes of this study were to develop a solid set of requirements for an LBFD, study conceptual designs that could meet these requirements, and determine if such a demonstration would be affordable. Two airframe contractor teams and an internal NASA team participated. The teams were able to identify feasible approaches based on new low-boom airframe designs that utilize a significant amount of existing components, such as engines, landing gear, and cockpit systems. The teams determined that the requirements of the LBFD could be accomplished with a relatively small and therefore affordable demonstrator aircraft. Follow-on efforts, aimed at refining the proposed concepts and identifying design risk areas, have been initiated. This effort is part of NASA's overall approach to making informed decisions about a future LBFD.

The Fundamental Aeronautics Program conducted detailed structural analyses and wind tunnel testing for the truss-braced-wing airliner concept in NASA's Transonic Dynamics Tunnel. This concept was developed in partnership with Boeing as part of the Subsonic Ultra Green Aircraft Research (SUGAR) effort under NASA's Advanced Concept Studies for 2035 Subsonic Commercial Transport (N+3).[1] The truss-braced wing is a promising technology for lighter-

1. The vehicles represent a research and development generation known as "N+3," denoting three generations beyond the current commercial transport fleet.

weight, lower-drag capability in transport aircraft. Post-test analysis verified the high-fidelity finite element model of the structure, as well as the favorable weight estimates of the wing concept that support the fuel-burn benefits of this aircraft configuration.

Additionally, the Fundamental Aeronautics Program conducted analysis and testing in NASA's 14×22-Foot Subsonic Wind Tunnel, which showed the aerodynamic benefits of the D8 concept with its "double-bubble" lifting fuselage and unique propulsion system placement. This concept was developed in partnership with the Massachusetts Institute of Technology (MIT), also as part of NASA's Advanced Concept Studies for 2035 Subsonic Commercial Transport (N+3). The design replaces the traditional cylindrical fuselage with two partial cylinders placed side by side, and the engines sit atop the rear of the fuselage, rather than slung beneath the wing, to make use of a technique called Boundary Layer Ingestion, where slower-moving air from the wake of the fuselage enters the engines, resulting in less fuel consumption for the same amount of thrust. The analysis indicated an approximate seven percent benefit in mechanical power of the propulsor when comparing a podded engine configuration to the integrated engine configuration. Additional tests and analyses are planned in order to expand the characterization of the aerodynamic benefit and reduce uncertainty.

Further, the Fundamental Aeronautics Program released a report called "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences,"[2] which discussed the need to substantially improve the current computational fluid dynamics, or CFD, tools in order to meet the challenge of designing future air vehicles that will cut fuel consumption, reduce polluting emissions, and fly more quietly. The dilemma is that today's CFD, which simulates airflow around an airplane and through its jet engines, is largely designed to deal with aircraft sporting traditional tube-and-wing configurations. And even then, CFD's full effectiveness through all phases of flight is limited. The report also discussed how new algorithms must be written to take advantage of the ever-increasing speed and complexity of future supercomputers.

Alternative Fuel Effects on Contrails and Cruise Emissions II (ACCESS II) flight testing, staged in FY 2014 from Palmdale, California, was the latest in a

2. Available at *http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf*.

series of ground and flight tests that began in 2009 to study emissions and contrail formation from new blends of aviation fuels that include biofuel from renewable sources. The ACCESS II campaign is a joint effort under the Fundamental Aeronautics Program involving NASA and international partners including the German Aerospace Agency (DLR) and the National Research Council (NRC) of Canada.

ACCESS I testing, conducted in 2013, showed that the biofuel blends tested may substantially reduce the emissions of black carbon, sulfates, and organics. The ACCESS II experiment gathered additional data, confirming the results of ACCESS I. Information also was gathered to aid in developing theories about contrail formation.

Four research aircraft were involved in the ACCESS II campaign: DLR's Falcon 20-E5, NRC's CT-133, NASA's four-engine DC-8 flying laboratory, and NASA's HU-25C Guardian. Flying as high as 40,000 feet, the DC-8's four CFM56 engines burned a mix of different fuel blends (either traditional Jet A fuel or a 50-50 blend of Jet A and renewable alternative fuel of hydro-processed esters and fatty acids produced from camelina plant oil), while the Falcon, Guardian, and CT-133 measured emissions and observed contrail formation from the DC-8.

Understanding the characteristics of burning alternative fuel could enable their widespread use as they become more readily available and cost-competitive with conventional jet fuels. This research supports the strategic vision of NASA's Aeronautics Research Mission Directorate, part of which is to enable the transition of the aviation industry to alternative fuels and low-carbon propulsion systems. As part of an international team involved in this research, NASA will share its findings with the 24 member nations that make up the International Forum for Aviation Research (IFAR). DLR and NRC are participating members of IFAR, and NASA is the current chair.

As a promising technology for improving the efficiency of N+3 aircraft designs, the Fundamental Aeronautics Program is investing in hybrid gas-electric propulsion system technologies. In FY 2014, studies were completed that resulted in a viable conceptual design for a superconducting generator, and work was begun to establish a superconductor alternating current (AC) loss facility at the Center for Advanced Power Systems (Florida State University). The generator concept

established the feasibility of a fully superconducting electric generator to be used in a distributed propulsion aircraft configuration. This is a concept that would allow multiple electric motors to drive many distributed fans to be used in an ultra-efficient hybrid electric aircraft. Additionally, a selection was made to begin contractual work on a low-emission, fuel-flexible combustor through the NASA Research Announcement process.

Integrated Systems Research Program

The Integrated Systems Research Program's Environmentally Responsible Aviation project focuses on technologies that can simultaneously reduce aircraft fuel burn, noise, and emissions. During FY 2014, the project demonstrated, through analysis and testing, that the Ultra High Bypass (UHB) propulsion systems can be integrated with Hybrid Wing Body (HWB) concepts to meet fuel-burn and noise goals. HWB configurations hold the promise of significantly reducing the environmental impact for commercial transport aircraft, offering advantages in noise reduction and fuel-burn reduction not available to today's more standard tube-and-wing aircraft configurations. Additionally, the UHB engine offers the potential to dramatically reduce fuel burn and noise compared to the version of the aircraft engine commonly used by airliners today. In FY 2014, NASA continued its investigation of UHB technologies by conducting a wind tunnel test of a second-generation UHB engine model with optimized fan exit guide vanes. NASA used this test to determine the effectiveness of those configurations to reduce noise and their impact on the performance of the engine. The wind tunnel results agreed with those predicted by state-of-the-art tools. Data from the test will contribute to a comprehensive performance database for Modern Ultra High Bypass Propulsor technologies that will be used by NASA and industry to update systems studies.

The integration of UAS into the NAS will represent a significant step in enabling more automation throughout the NAS. ARMD's UAS-NAS project contributes capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS civil access to the NAS. During FY 2014, NASA's UAS-NAS project conducted an integrated human-in-the-loop simulation as a precursor to a series of flight test campaigns, which will

progressively increase the complexity of UAS integration testing that will occur over the next two years. The FY 2014 test campaign had three objectives. The first was to evaluate air traffic controllers' acceptance of UAS maneuvers performed in order to remain "well clear" of other traffic. The second objective was to examine the effects of advanced traffic displays and tools on the ability of UAS pilots to remain well clear of traffic. Finally, the test collected performance metrics to determine the interoperability of the UAS sense-and-avoid algorithms and current collision-avoidance algorithms. This testing featured the use of the project's operationally relevant environment, called the Live Virtual Constructive-Distributed Environment (LVC-DE). For this test campaign, the LVC-DE included a proof-of-concept UAS Ground Control Station and virtual traffic. UAS pilots and air traffic controllers participated as test subjects. This was a significant step in the development of findings and data associated with the sense-and-avoid, communications, and human system integration performance requirements and guidelines.

In addition, the Integrated Systems Research Program successfully conducted a formulation review that approved the implementation of the Advanced Composites project. The goal of this five-year project is to reduce the time required for the certification of innovative composite materials and structures.

Aeronautics Test Program

During FY 2014, NASA continued to plan and execute targeted investments in its capabilities so that the Nation's aeronautics community would have the tools to deliver technology innovations and breakthroughs necessary to address the increasingly complex research and development challenges associated with safe and effective real-world flight.

Two major activities centered on improvements to data acquisition, capability control systems, and the testing of flow quality. First, NASA validated upgrades in the data acquisition and control systems for the 10×10-Foot Supersonic Wind Tunnel (10×10′ SWT). This upgrade was part of an aggressive program to replace obsolete data acquisition and controls, and the 10×10′ SWT was selected as the "pilot" tunnel for the wider implementation of a state-of-the-art high-speed data acquisition system. The performance of the upgraded 10×10′ SWT will enable

ARMD to address the Supersonics Thrust and Technical Challenges in the new Strategic Implementation Plan and answers a recommendation from the Department of Defense (DOD)–NASA National Partnership for Aeronautical Testing Supersonic Assessment for improved supersonic testing capability.

NASA also validated improvements to data accuracy and repeatability, flow quality, and productivity at the National Transonic Facility (NTF). These investments improved the tunnel's speed measurement system through upgraded sensors and improved flow quality and repeatability through hardware upgrades. The performance range of a test model was extended through active vibration dampening and continuous movement capability. Data accuracy and repeatability were also improved through enhanced data-processing equipment and techniques. These upgrades enable NASA to increase the accuracy, productivity, and reliability of high-Reynolds-number testing at one of the Nation's most specialized facilities.

Investments in the 10×10′ SWT and NTF will extend the relevancy and availability of current ground-testing capabilities to support the research, development, testing, and engineering milestones of NASA and DOD programs and are representative of the strategy to utilize targeted investments to sustain the relevancy of testing capabilities for the Nation's aeronautics community.

Space Technology Mission Directorate

NASA's Space Technology Mission Directorate (STMD) made major strides in 2014, pioneering new technologies and capabilities that added breadth to the Nation's space activities, as well as advancing current and future NASA missions. The Directorate is engaged in nine major technology-development programs that are under way at each of NASA's ten Centers located across the United States. STMD plays a key role in NASA's contribution to the Nation's innovation economy through its involvement in several national initiatives, including the Advanced Manufacturing Partnership and the National Robotics Initiative.

The Low Density Supersonic Decelerator (LDSD) crosscutting demonstration mission successfully flew a rocket-powered, saucer-shaped test vehicle into near space in late June from the U.S. Navy's Pacific Missile Range Facility on Kauai, Hawaii. The first of the three experimental test flights planned for this project was

designed to determine if the vehicle could reach the altitudes and airspeeds needed to test two new breakthrough technologies for landing large payloads on the surface of Mars: the Supersonic Inflatable Decelerator (SIAD) and the Supersonic Disk Sail Parachute.

In FY 2014, NASA's commercial partners completed the testing and validation of two new, advanced solar-array systems to further its Solar Electric Propulsion project. NASA is working with private companies to develop large, flexible, radiation-resistant solar arrays that can be stowed into small, lightweight packages for launch. Once deployed, the arrays will provide greater solar power to spacecraft than ever attained before. This advanced propulsion project is developing critical technologies to enable cost-effective new trips to asteroids, Mars, and beyond. Solar electric propulsion also will support a wide variety of commercial spaceflight activities, helping power and guide American commercial spacecraft well into the 21st century. NASA's new system will use ten times less propellant than a comparable, conventional chemical propulsion system.

NASA completed the fabrication and integration of a 12.5-kilowatt-class Hall thruster in 2014, providing more than twice the power of the current state-of-the-art designs. The integration and testing of a 300-volt Power Processing Unit also were completed in an effort to more efficiently convert energy on solar electric propulsion–powered spacecraft.

The Game Changing Development (GCD) Program produced over 26 new technical "first-in-the-world accomplishments" across a variety of technical areas and more than 150 technical papers at 116 technical conferences. In 2014, NASA and Boeing collaborated to successfully design and fabricate the largest out-of-autoclave composite cryogenic propellant tank ever manufactured. The 18-foot (5.5-meter)-diameter tank endured a rigorous series of tests over the course of five months to replicate the physical stresses launch vehicles experience during flight. This structurally efficient design has verified NASA's capability to develop a large-scale cryogenic tank that is 30 percent lighter than the state of the art, with a 25 percent reduction in production costs.

The GCD program also had the opportunity to test its technologies in space as payloads delivered to the International Space Station via commercial supply missions. In August, high-tech legs were attached to the torso of Robonaut 2; these

will provide the mobility and flexibility the humanoid robot needs to help astronauts with regular and repetitive tasks inside the Space Station. The NASA 3D Printer, developed by Made in Space, arrived at the ISS in September aboard a commercial carrier. Matured and tested through the Small Business Innovation Research (SBIR) and Flight Opportunities programs, this revolutionary manufacturing technology could provide the capability for the in-space production of replacement parts and tools.

NASA selected 522 proposals for a projected total investment of $142 million in awards in FY 2014, including 312 SBIR and 32 Small Business Technology Transfer (STTR) General Phase I proposals for award to 257 U.S. small businesses to conduct feasibility studies. In addition, 109 SBIR and 23 STTR General Phase II proposals were selected for negotiations to further expand upon their Phase I proposals. The year 2014 also marked the start of the Commercialization Readiness Program at NASA, which contributed $3.1 million to nine infusion and commercialization projects, five of which fell within Space Technology Mission Directorate technology areas.

In the Small Spacecraft Technology area, the program completed the demonstration of PhoneSat CubeSats, both off-the-shelf smartphones serving as an onboard control system to create an extremely low-cost but capable satellite. The program sponsored 13 collaborative projects teaming universities and NASA researchers in small spacecraft technology development. In 2014, through STMD's Flight Opportunities Program, commercial partners flew 38 technologies on four different commercial platforms. NASA also contracted with four companies to integrate and fly technology payloads on commercial suborbital reusable platforms.

STMD fostered 45 activities with 43 other Government agencies. It also evaluated over 2,000 proposals and funded more than 600 selections for awards.

Since 2011, STMD has engaged in more than 450 activities with over 120 accredited universities throughout the country to enable future missions and maintain NASA's continued leadership in space. The Space Technology Research Grants (STRG) Program continues to engage the entire spectrum of academic researchers; the program has funded research at 86 universities across 38 states with a total of 284 grants since its inception. STRG funded 71 new grants during the previous fiscal year to address the Agency's most difficult space technology challenges,

including 54 graduate research fellowships, seven early-career faculty awards, and ten early-stage innovation awards. Technical highlights of the awards included a robotic field testing of autonomous science and navigation software, the assembly of a full six-cell 2D truss using intelligent robots that guide placement and alignment and provide support during the welding of truss members, and the testing of first-generation corrosion-resistant membranes to recover water from urine and urine brines through osmosis.

Department of Defense

DOD

Aeronautics Activities

Fixed-Wing Aircraft

The Department of Defense continued flight test evaluations of the three F-35 Joint Strike Fighter (JSF) variants: the F-35A conventional takeoff and landing, the F-35B short takeoff and vertical landing, and the F-35C aircraft carrier variant. The first live-fire launch of an AIM-120 air-to-air missile from an F-35A occurred on October 30, 2013.

The Navy's F-35C carrier aircraft completed its initial sea trials aboard the USS Nimitz. This was a major achievement following the redesign of the arresting hook system in 2012. While the Navy has been operating tactical jet aircraft from aircraft carriers for many decades, the F-35C represents a new frontier for naval aviation, integrating a stealth aircraft with an aircraft carrier. As such, many geometric challenges result from the shape of a low observable platform coupled with the need to retract the arresting hook within an enclosed bay and a single engine configuration. The combination of these constraints creates an arresting hook that is significantly shorter in length and positioned closer to the main landing gear than in legacy platforms. To further complicate the matter, the volume available in the arresting hook bay is so tight that complicated, folding mechanisms are required, necessitating a robust balancing of system performance and strength requirements. These factors make what is a seemingly routine task, engaging the Cross Deck Pendant (CDP) of an Arresting Gear System on an aircraft carrier, a much more significant engineering challenge. To meet the challenge, the Government/

industry team had to develop new modeling and analytical techniques to guide the design iterations and predict performance ahead of testing. The successful developmental tests during initial sea trials build confidence in the analytical methods, which translates into improved future aircraft designs (e.g., Unmanned Carrier Launched Airborne Surveillance and Strike aircraft), and preserve the viability of the F-35C.

Looking at large aircraft development, the Air Force continued work on the KC-46 aerial tanker and C-5 cargo aircraft. The KC-46 program initiated the build of four Engineering and Manufacturing Development aircraft in 2014. The Air Force started the Reliability Enhancement and Re-engining Program (RERP) modification on the first of two C-5C aircraft used to transport outsized NASA cargo. The RERP-modified C-5C aircraft will be redesignated as the C-5M. The C-5M will have increased range, payload, takeoff thrust, climb performance, and fuel efficiency while extending service life until at least 2040.

Rotorcraft

Rotorcraft acquisition, in FY 2014, was highlighted with the Air Force award to Sikorsky Aircraft Corporation of a contract to develop a personnel recovery vehicle, the HH-60W, based upon the UH-60M platform. The HH-60W will support the Combat Search and Rescue mission.

Rotorcraft development advanced significantly in 2014. The Joint Multi-Role (JMR) Technology Demonstrator (TD) program progressed toward flight test. This program is a Science and Technology effort designed to demonstrate transformational vertical lift capabilities to prepare DOD for decisions regarding the replacement of the current vertical lift fleet. The TD is composed of two main efforts. First, the Air Vehicle Demonstration (AVD) contributed to the design and evolution of enabling technologies for next-generation rotorcraft. Second, the Mission Systems Architecture Demonstration (MSAD) will define and exercise architectures and processes for acquisition of a next-generation mission equipment package.

The TD aircraft configurations and technologies will demonstrate vehicle concepts that have a carrying payload of 12 troops and four crewmembers, hover out of ground effect (HOGE) at an ambient condition of 6,000 feet and 95 degrees

Fahrenheit, 2,100-nautical-mile self-deployment range, and speed of at least 230 knots. The real challenge is to meet the hover, cruise, and speed specifications at an affordable cost. JMR TD efforts were tailored to characterize vehicle flight performance and efficiency, verify analytical tools and methods, and reduce the technical risk of continued vehicle development in expectation of the Future Vertical Lift (FVL) program of record.

The aircraft flown during the AVD effort is a technology demonstrator, as opposed to a prototype (Y-plane) or an X-plane. The TD is an aircraft sized to a realistic, representative set of capabilities that demonstrate innovative features and advanced technologies to meet specific goals. The aircraft is sized appropriately to understand interactional aerodynamics and loads along with stability and control issues.

Technology Investment Agreements (TIAs) were awarded to four industry teams to cover the entire scope of work through the flight test. The initial design and risk reduction (ID&RR) work was completed in FY 2014, and two of the four vendors will continue the program through flight testing.

Through this program, the Army demonstrated significant advances in technologies that will improve helicopter safety, survivability, mission performance, and maintainability.

DOD conducted significant research and development efforts in 2014 with the goal of increasing operational capabilities in degraded visual environments (DVE). Together with the Air Force and industry partners, the Army completed the 3D Landing Zone (3D-LZ) Joint Capability Demonstration at Yuma Proving Ground. The 3D-LZ system integrates advanced pilot display symbology with digital terrain elevation data (DTED), advanced guidance algorithms, and Laser Detection and Ranging (LADAR) sensor imagery on a panel-mounted display to enhance pilot situational awareness and cueing in DVE. Significant improvements in landing performance and reductions in pilot workload were demonstrated in full brownout landings of the UH-60 Black Hawk at Yuma. The Army also demonstrated Modernized Control Laws (MCLAWS) for the Black Hawk that further improve flight performance and reduce pilot workload in DVE as part of the test at Yuma. The Air Force Research Laboratory also successfully tested a first-of-its-kind,

LADAR-based system, as part of a Joint Capability Technology Demonstration, which allows for rotary wing operations in DVE.

In addition to the service efforts, DARPA's Multifunction Radio Frequency (MFRF) program also seeks to overcome the challenges of operating helicopters in DVE encountered in severe weather, in dust kicked up during takeoff and landing, and in conditions of poor visual terrain contrast. During 2014, MFRF completed successful flight demonstrations on a UH-60L Black Hawk combat helicopter. MFRF enhances the survivability and combat effectiveness of helicopters facing degraded visibility. The program develops multifunction sensor technology that powers sensor packages small, light, and efficient enough for installation on existing and future helicopter designs, enabling pilots to do the following:

- Take off, fly, and land safely in degraded and zero-visibility conditions.
- Avoid collisions with other aircraft, terrain, and humanmade obstacles (e.g., power lines).
- Improve target detection, identification, and engagement.

The Synthetic Vision Avionics Backbone (SVAB) technology portion of the program provides these capabilities. The SVAB technology demonstration fused millimeter-wave radar with multiple terrain databases and onboard platform navigation to create high-resolution 2D and 3D visualizations of local environmental conditions. Pilots referred to the visualizations, in real time, to distinguish terrain features (slope, roughness, landing suitability), detect objects in a landing zone, detect and avoid obstacles, and navigate in GPS-denied conditions. The software architecture of the SVAB also demonstrated plug-and-play sensor control and display.

In a related effort, the Army demonstrated a complete autonomous resupply mission on a Black Hawk helicopter and developed Obstacle Field Navigation (OFN) and Safe Landing Area Determination (SLAD) algorithms, which were integrated with a long-range LADAR sensor on the RASCAL JUH-60 research helicopter, enabling high-speed autonomous flight in mountainous terrain.

Aerodynamic developments in rotorcraft were highlighted by the Army's Active Rotor Components Demonstration (ARCD) Hub Mounted Vibration Suppressor (HMVS) and their Active Flow Control research. In conjunction with Sikorsky Aircraft, ARCD demonstrated significant reductions in structural loads and

vibration on a Black Hawk helicopter. The ability to significantly reduce loads with Load Alleviating and Damage Adaptive Control Laws was also part of the Combat Tempered Platform Demonstration (CTPD) program. Active Flow Control research demonstrated 20 percent reductions in helicopter drag and downloading in forward flight using the NASA Langley 14×22-Foot Subsonic Wind Tunnel. This research is aiding the development of the next generation of active flow control actuators for rotary wing applications. The Army is collaborating with the Israel Ministry of Defense (MOD) on this development.

In software development, the Army released version 4.2 of its "Helios" modeling and simulation software for rotorcraft aeromechanics. In addition to previously existing capabilities for high-fidelity simulations of full-vehicle rotor and fuselage combinations, Helios v4.2 adds an option to bring NASA's overset grid computational fluid dynamics flow solver (OVERFLOW) into the Helios framework. This addition of OVERFLOW to Helios allows for faster and more accurate simulations of rotor blade aerodynamics.

Hypersonics

The U.S. Army Space and Missile Defense Command/Army Forces Strategic Command conducted extensive wind tunnel testing at three U.S. facilities during FY 2014 in preparation for the Office of the Secretary of Defense (OSD) Conventional Prompt Global Strike (CPGS) funded Advanced Hypersonic Weapon (AHW) Flight Test-2 (FT-2). This test was designed to collect data on hypersonic boost-glide technologies for long-range atmospheric flight. NASA's Data Parallel Line Relaxation (DPLR) Computational Fluid Dynamic (CFD) code was used to develop aerodynamic and aerothermal flight predictions. The glide-body model (with extensive instrumentation) was tested in continuous flow and blow-down wind tunnel facilities at high Mach numbers. This testing provided valuable data used to verify CFD modeling and simulation results and identify aerodynamic uncertainties.

The Air Force Research Lab (AFRL) partnered with NASA Langley Research Center and NASA Glenn Research Center on hypersonic research in 2014. AFRL in-house resources, combined with funding provided to NASA, enabled near-term

expendable weapons and far-term reusable vehicles for atmospheric flight and access to space. Accomplishments from this arrangement include CFD analysis of the scramjet engines for AFRL's missile-sized X-51A Scramjet Engine Demonstrator (SED) program and the Robust Scramjet program, and testing and analysis to characterize the distortion of the air entering a high-speed turbine engine.

Unmanned Aircraft Systems (UAS)

On May 29, 2014, the Navy and Northrup Grumman X-47B team were presented with the 2013 Robert J. Collier Trophy. The Collier Trophy is awarded annually by the National Aeronautic Association "for the greatest achievement in aeronautics or astronautics in America, with respect to improving the performance, efficiency, and safety of air or space vehicles, the value of which has been thoroughly demonstrated by actual use during the preceding year." The X-47B Unmanned Combat Air System Demonstrator (UCAS-D) has shown the feasibility of operating unmanned aircraft from Navy aircraft carriers. This demonstration program has paved the way for the Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) program that is developing the first unmanned aircraft that will be fully integrated into the carrier air wing and represents a major milestone in the evolution of naval aviation.

Other naval UAS developments in 2014 included the Autonomous Airborne Cargo Utility System (AACUS) Innovative Naval Prototype (INP) being developed under a five-year program. This program will deliver a sensor package and software suite designed to enable unmanned rotary wing aircraft to perform autonomous takeoff, navigation, approach, and landing to an unprepared landing site while performing the assault support mission. Two successful Phase I demonstrations of the prototype were held at Marine Corps Base Quantico in Virginia during February and March 2014.

Aurora Flight Sciences demonstrated its Tactical Autonomous Aerial Logistics System (TALOS) on the Boeing Unmanned Little Bird aircraft, and Lockheed Martin demonstrated the Open-Architecture Planning and Trajectory Intelligence for Managing Unmanned Systems (OPTIMUS) on the Kaman K-Max aircraft. Aurora Flight Science's contract option was exercised (April 30, 2014) to perform

Phase II, which focuses on capability expansion and technology maturation on the same aircraft.

Flight testing of the Orion UAV progressed following the aircraft's first flight on August 24, 2013. The aircraft has made ten successful test flights. Orion has expanded its flight-testing envelope to allow for low-speed flight, which is important as Orion has now demonstrated flight at its speed for maximum endurance. Performance estimates from these low-speed flights indicate that the goal of five-day endurance at 20,000 feet with a 1,000-pound payload is now attainable.

The first not-under-live-local-control flight of the Air Force's QF-16 target drone was accomplished on September 19, 2013. This significant flight was a critical part of the Air Force's efforts to replace the aging QF-4.

In FY 2014, the Aerial Reconfigurable Embedded System (ARES) program (formerly, the Transformer [TX] program) completed the critical design review, conducted component wind tunnel testing, fabricated custom components, and acquired power plant and drive-train components. ARES is a vertical takeoff and landing (VTOL) flight module designed to operate as an unmanned platform capable of transporting a variety of payloads up to 3,000 pounds. The ARES VTOL flight module is designed to have its own power system, fuel, digital flight controls, and remote command-and-control interfaces. Twin tilting ducted fans provide efficient hovering and landing capabilities in a compact configuration, with rapid conversion to high-speed cruise flight.

Aircraft Engines, Subsystems, Components, and Other Aeronautical Developments

The Air Force Research Laboratory's Adaptive Versatile Engine Technology (ADVENT) program successfully completed ground testing of core and engine technology demonstrators in FY 2014. The ADVENT technologies will enable a 25 percent reduction in specific fuel consumption and a 30 percent increase in operating range for next-generation combat aircraft. The core engine achieved all major test objectives while demonstrating key technologies such as lightweight, heat-resistant ceramic matrix composite materials, cooled cooling air, and advanced compressor aerodynamics. Following the core testing, the world's first

adaptive cycle engine completed testing and accomplished nearly all critical test objectives, including a demonstration of the adaptive fan technology, variable engine features, and three-stream heat sink capacity throughout the engine operating range. A fully detailed assessment of the engine's performance is in progress at AFRL.

Risk reduction component testing and core engine preliminary design reviews were completed under AFRL's Adaptive Engine Technology Development (AETD) program. AETD provides technology maturation and risk reduction for fuel-efficient adaptive component technologies for low-risk accelerated engine developments supporting multiple future combat aircraft. Key deliverables include an acquisition quality engine preliminary design and critical risk-reduction ground testing of adaptive fans and core components by 2016.

Airborne Weapons Systems and Missiles

The B-2 Defensive Management System (DMS) is a principal enabler for aircraft survivability for the B-2 stealth bomber. The legacy DMS Threat Emitter Locator System (TELS) detects, identifies, and locates enemy radar systems and provides real-time threat avoidance, threat warning, and threat situational awareness information to the aircrew via the Tactical Situation Display. The B-2 DMS Modernization program will address current system limitations by replacing TELS and its associated antennas with a more current electronic support measures subsystem and antennas for improved threat detection.

Aircraft Safety and Survivability

The Navy recently completed a technology demonstration of the Joint Precision Approach and Landing System (JPALS). The ship-based JPALS included auto landings by F/A-18C Hornets on the deck of the aircraft carrier USS Theodore Roosevelt. JPALS is a GPS-based precision approach and landing system that will help ship-based aircraft land in all weather conditions, initially providing guidance to a decision height of 200 feet and half-nautical-mile visibility. While JPALS was originally a tri-service program with multiple increments, it has been restructured

into one increment to support the F-35B and F-35C, as well as UCLASS aircraft. JPALS will allow for coupled, auto-landing functionality via two-way data link.

A dramatic reduction in pilot workload during F/A-18 carrier landings was demonstrated in flight simulations at the Naval Air Warfare Center, Aircraft Division, Patuxent River, Maryland. Sponsored by the Office of Naval Research, the Maritime Augmented Guidance with Integrated Controls for Carrier Approach and Recovery Precision Enabling Technologies (MAGIC CARPET) project developed a combination of integrated direct lift control, flight path control augmentation, and ship-relative heads-up display, which allowed pilots to consistently conduct precision landings on the carrier with minimal pilot compensation. This capability is now planned for implementation in operational F/A-18E/F/G and F-35C aircraft. Greater ease in carrier landings will result in enhanced safety and the ability to shift valuable training resources from carrier qualification to complex mission training.

The Air Force completed testing and began fielding of the Automatic Ground Collision Avoidance System (Auto GCAS) on its Block 40/50 F-16s. If the system determines that there is an impending controlled flight into terrain (CFIT), the flight controls automatically roll the aircraft upright and pull up to avoid a ground collision. Auto GCAS is a significant improvement to F-16 flight safety since an estimated 25 percent of aircraft losses and 75 percent of all F-16 fatalities are caused by CFIT.

Automatic Air Collision Avoidance System (Auto ACAS), flight testing was performed at Edwards Air Force Base (AFB) from March to September of 2014. A total of 32 flight test missions were conducted. Twelve of the flights consisted of flying a single F-16 against a virtual target to gather an initial assessment on algorithm performance and act as a safety buildup to two-ship testing. The remainder of the testing consisted of 19 two-ship flights and 1 three-ship flight where the collision avoidance algorithm was evaluated for both collision avoidance performance and nuisance potential.

Space Activities

Launch and Range Operations and Spacelift Developments

The Evolved Expendable Launch Vehicle (EELV) program continued to successfully place satellites into orbit during FY 2014. United Launch Alliance (ULA) continued its record of 100 percent success, with 12 launches. Eight of these launches were national security space (NSS) missions. These launches included three GPS IIF launches.

In FY 2014, the Airborne Launch Assist Space Access (ALASA) completed the preliminary design review for the demonstration system, developed detailed planning and operations concepts for testing, and conducted second- and third-generation engine tests.

The ALASA program makes access to space more affordable by reducing the cost per launch to less than $1 million per flight, improves the responsiveness of space access by reducing the interval from call-up to launch to a single day, escapes the limitations of fixed launch sites by achieving a greater flexibility in the direction and location of launch, and demonstrates the ability to move its operations from one airfield to another in 12 hours.

Range modernization efforts continued in FY 2014 with the following activities:

- The awarding of the Modernization Eastern Range Network (MEN) contract ($44 million) in November 2013, which will upgrade the Eastern Range (ER) mission communications core to address obsolescence issues and improve cyber protection.
- The awarding of the ER Command Destruct Modernization (ERCDM) contract ($45 million) in September 2014, which will resolve obsolete range safety and positive control assets used to terminate an errant vehicle, if necessary, in order to ensure public safety during space and ballistic missile launches. Additionally, ERCDM will improve the ER cyber posture with the introduction of newer, more secure destruct codes for NSS missions.

- The delivery of a new weather computer at the Eastern Range, which resolved an obsolescence issue and eliminated a constant threat of launch delay with the legacy computer.
- The commissioning of a new 44-foot antenna and a new Command Transmitter site on the Western Range.
- The successful transitioning of EELVs to GPS Metric Tracking, which eliminated the reliance on legacy radars for tracking EELV launches for the purposes of protecting public safety.
- The continued development of multiple recapitalization projects designed to improve various range assets conducted under the Air Force's Spacelift Range System Contract (SLRSC). The Spacelift Range System (SLRS, which is also known as the Launch and Test Range System [LTRS]) is composed of 11 subsystems at the Eastern and Western Ranges (headquartered at Patrick AFB, Florida, and Vandenberg AFB, California, respectively) that provide tracking, telemetry, flight safety, and other support to space launches, ballistic missile tests, and aeronautical testing. SLRS supports NASA satellite and International Space Station (ISS) crew resupply launches.

The National Space Transportation Policy (NSTP) signed by the President on November 21, 2013, included guidance for DOD and NASA to continue to enhance the space launch infrastructure, including investing in the modernization of current infrastructure to meet evolving space transportation needs and capabilities.

Position, Navigation, and Timing (PNT)

In September 2014, the GPS III Navigation Panel arrived at the Lockheed Martin facility in Denver to undergo thermal vacuum testing. The modernized GPS III satellite program provides a Standard Positioning Service to a broad spectrum of civil and Government 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 those signals planned for broadcast on Japan's Quasi-Zenith Satellite System, which is 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 the accuracy and availability of civil PNT solutions. In addition, the Air Force successfully launched a fifth, sixth, and seventh GPS Block IIF satellite in February, May, and August.

In 2014, the Air Force moved forward with a revised acquisition approach that will put M-Code (military) GPS receivers into users' hands up to five years ahead of schedule. The Military GPS User Equipment (MGUE) Increment 1 program began in September 2012. It is the first increment of M-Code-capable GPS user equipment that will deliver significantly improved capability to counter current and emerging PNT threats and enable military operations in GPS-denied and Navigation Warfare environments, where current and legacy receiver performance would be compromised.

Satellite Communications (SATCOM)

The Advanced Extremely High Frequency (AEHF) satellite 3 was launched on September 18, 2013, and was transferred to operational control in March 2014. The constellation achieved early operational use of AEHF satellites 1–3 in May 2014. The AEHF Program Office also successfully completed Integrated Multi-Service Operational Test and Evaluation (MOT&E) on September 26, 2014. Furthermore, the Program Executive Officer (PEO) for Space Systems certified the AEHF system ready for Air Force Operational Test and Evaluation Center (AFOTEC)–Dedicated MOT&E on October 16, 2014.

The Enhanced Polar System (EPS) successfully achieved its acquisition Milestone B on April 30 and passed its critical design review (CDR) on July 22. In support of these acquisition milestones, the first payload was successfully integrated onto the host spacecraft in FY 2014 and is now ready to support the host's launch date in FY 2015. EPS will replace the interim polar system (IPS) to ensure that critical protected communications requirements, above 65° north latitude, are satisfied for joint warfighters.

The Wideband Global SATCOM (WGS) system declared Full Operational Capability (FOC) on May 12, 2014. The WGS system met all requirements for FOC declaration as outlined in the approved WGS Initial Operating Capability (IOC)/FOC Plan. WGS is a high-capacity and very flexible, "commercial-like" SATCOM

system supporting various missions of the Unified Combatant Commanders (UCCs), military services, and other agencies. The WGS is composed of space, control, and terminal segments. The space segment consists of five DOD-owned "commercial-like" communication satellites that supplement existing DOD-owned Wideband SATCOM systems by providing military X-band and Ka-band broadcast services.

The Navy's Satellite Communications program office oversaw continued production of three Mobile User Objective System (MUOS) satellites at the Lockheed Martin Space Systems facility in Sunnyvale, California. Two MUOS satellites are already on orbit and available for operational use, two satellites are scheduled to launch in 2015, and the last scheduled launch is set for 2016. MUOS provides narrowband communications using two separate payloads, a legacy UHF capability and a new Wideband Code Division Multiple Access (WCDMA) payload. The MUOS constellation will replace the aging UHF Follow-On (UFO) constellation and allow time for the joint force to transition from UFO and other legacy systems to WCDMA's more modern cellular phone technology and its increased capability.

Indications and Warning

The Space Based Infrared System (SBIRS) provides missile warning and supports 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 associated ground elements.

GEO-1 and GEO-2 satellites are operating on orbit, having been certified for operations in August 2013 and December 2013, respectively. GEO-3 and GEO-4 satellites and HEO-4 replenishment payload all continue production with no major issues. After extensive negotiations, the Air Force awarded a fixed-price contract for a block buy of GEO-5 and GEO-6 satellite production in June 2014 that saved the Government 1.5 billion dollars compared to the initial cost estimate for two individual satellite buys. The Air Force also continued development of the ground segment with a goal of consolidating the operations into a single source for processing and dissemination of fused Overhead Persistent Infrared (OPIR) data. With an

eye towards maintaining this vital national capability, the department also initiated an analysis of alternatives in 2014 to examine the way ahead for the OPIR enterprise beyond GEO-6.

Satellite Control and Space Situational Awareness

The Air Force Satellite Control Network (AFSCN) is a globally distributed network of control nodes and tracking stations that deploys, commands, and controls over 170 satellites. NASA is one of the many customers utilizing the AFSCN for launch and on-orbit satellite operations.

The AFSCN consists of 15 antennas in eight locations around the globe. In January 2014, Air Force Space Command (AFSPC) operationally accepted four Remote Tracking Station Block Change (RBC) upgrades, replacing the end-of-life tracking systems with new electronics, antennas, and radomes (Oakhanger, England; Kaena Point, Hawaii; New Boston, New Hampshire; and Guam, Northern Mariana Islands). For the remaining seven systems, the Air Force will retain the legacy antennas and replace the electronics so that all 15 antennas will have the same core system of electronics. In FY 2014, the Air Force installed and initiated checkout of two of the seven hybrid RBCs (Diego Garcia and Hawaii) and awarded a contract for a third hybrid RBC at Vandenberg AFB, California.

In FY 2014, the Air Force awarded a contract to Honeywell to develop a new Enhanced High Power Amplifier (eHPA). The AFSCN is considered the "9-1-1" of space because its high power capability can be used to make contact with tumbling and nonresponsive satellites when normal power levels are inadequate. The eHPA project develops a replacement for the obsolete, existing HPAs to ensure this capability is available to the worldwide network and 170 satellites well into the next decade. This effort will develop a single article and will be the basis for future eHPA procurements in the out years.

In August 2014, the Air Force awarded a $13 million Unified S-Band (USB) contract to Honeywell to incorporate dual-band capability into the Transportable Remote Tracking Stations (RTS) for S-band waveform uplink and downlink of command, ranging, telemetry, and tracking of spacecraft. This award is for a single article only.

Following the program's restructure in 2012, the Family of Beyond Line of Sight Terminals (FAB-T) program selected Raytheon as the production contractor for the FAB-T Command Post Terminals (CPTs) in June 2014. The program completed flight testing in 2014. The FAB-T CPT will provide command and control of the AEHF constellation of protected, survivable SATCOM satellites and provide command and control of nuclear forces to the President.

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 JSpOC. JMS uses a service-oriented architecture and common operating picture that is tailorable by the user. 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 10,000 hours without critical failure and supported multiple high-profile events throughout 2013. In 2014, Increment 2 is replacing the legacy systems with a modernized, scalable, extensible, and sustainable platform.

Two Geosynchronous Space Situational Awareness Program (GSSAP) satellites were launched aboard AFSPC-4 from Cape Canaveral Air Force Station, Florida, on July 28, 2014. GSSAP satellites support Joint Functional Component Command for Space (JFCC Space) tasking to collect Space Situational Awareness (SSA) data, allowing for more accurate tracking and characterization of human-made orbiting objects. From a near-geosynchronous orbit, they have a clear, unobstructed, and distinct vantage point for viewing Resident Space Objects (RSOs) without the interruption of weather or the atmospheric distortion that can limit ground-based systems.

The Space Fence engineering, manufacturing, development, production, and deployment contract was awarded to Lockheed Martin on June 2, 2014. The Space Fence radar system will improve SSA ground capabilities by providing un-cued surveillance of small objects and satellites in low- and medium-Earth orbit to provide spaceflight safety, early detection and custody of threats, and awareness to satellite operators in the crewed spaceflight regime. IOC is planned for FY 2019, and site 1 will be located on Kwajalein Atoll, Republic of Marshall Islands.

In early FY 2014, Secretary of Defense Chuck Hagel and Australian Defense Minister David Johnston signed a Memorandum of Understanding (MOU)

approving the relocation of the Space Surveillance Telescope (SST) from White Sands Missile Range, New Mexico, to the Harold E. Holt Naval Communication Station in Exmouth, Western Australia. This move represents a significant initiative under the Australia-U.S. Space Situational Awareness Partnership and will provide an important capability for both Australia and the United States. The United States and Australia enjoy an increasingly fruitful relationship in the SSA mission area. C-band radar is the first major shared capability for both nations. The radar will soon become the only U.S. near-Earth-dedicated SSA sensor in the Southern Hemisphere. C-band radar will provide excellent satellite detection tracking and identification capability along with extremely accurate space object positional data, as well as the ability to increase maneuver detection and conjunction assessment capabilities. SST technology enables faster discovery and tracking of previously unseen, hard-to-find small objects in geosynchronous orbits. SST is another step forward with Australia and is a cornerstone to fulfilling SSA requirements to find, fix, track, and characterize deep space small objects. In 2014, an MOU was signed by the Air Force and the Defense Advanced Research Projects Agency (DARPA) outlining a cooperation plan between the organizations in the deployment of SST. The system leverages multiple technology improvements to provide orders-of-magnitude enhancements in search rate and sensitivity compared to existing ground telescopes. Australia will operate both systems in partnership with the United States.

In 2014, other SSA modernization efforts included the successful operational acceptance of the Ground-based Electro Optics Deep Space Surveillance (GEODSS) Sensor Controller Group Service Life Extension Program (SLEP). This capability replaces aging and unsupportable mission-critical subsystems with modern sustainable components to allow the system to continue providing time-critical deep space tracking information. The system is currently starting the design process for an additional SLEP of its Data Processing Group. In addition, the Eglin Radar is nearing completion of a SLEP of its Control and Signal Processor to extend the life of the phased array radar dedicated to finding and tracking near-Earth and deep space objects.

Other Space Developments

In 2014, 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 service life of two years, ORS-1 continued to support U.S. Central Command through 2014. Additionally, ORS continued to directly support Joint Force Commander needs with the development of ORS-5 to satisfy a validated U.S. Strategic Command need. ORS-5 will demonstrate SSA (wide-area search capability) of the geosynchronous orbit belt with a small satellite in low-Earth orbit. ORS-5, scheduled to launch in 2017, will also provide risk reduction to the Space Based Space Surveillance Follow-On (SBSS FO) program and develop and demonstrate ORS enablers and principles. Beyond ORS-5, the ORS Office will continue operations at Kirtland AFB, New Mexico, providing enabler development; continuing the transferring of technology, lessons learned, ideologies, etc., to existing space programs; and infusing the ORS precepts into all space programs.

The Air Force Ground Based Strategic Deterrent team completed a low-cost, reduced-scope Analysis of Alternatives to examine options for a follow-on to the Minuteman III intercontinental ballistic missile (ICBM). The analysis was completed on time and recommended a new missile system to provide increased capability while complementing Minuteman III basing and physical specifications.

The Space Security and Defense Program (SSDP) is a joint DOD and Office of the Director of National Intelligence (ODNI) organization established to function as the center of excellence for options and strategies (materiel and nonmateriel), leading to a more resilient and enduring National Security Space Enterprise. In the past year, the program implemented cyber support to defensive space alternatives and provided assessments and solutions for hosted payloads. Additionally, SSDP is conducting a number of campaign-specific efforts that integrated intelligence with operations to ensure the resilience of space systems in a contested environment. As a result of SSDP efforts, rapid prototyping capabilities were developed and integrated for key space mission areas. SSDP developed and delivered validated response options to Combatant Commanders (COCOMs) for emerging threats

and fully incorporated a pathfinder process for integrating new and revised space concepts into U.S. Strategic Command (USSTRATCOM) operations and plans.

In the last few years, the Army has been involved in research and technology efforts to explore military utility for small satellite concepts. The Army is exploring ways that space-based information can be shared quickly and in direct response to communications and/or imagery needs of the tactical ground force commander. The goal is for small satellites to be under the direct control of a tactical ground force commander who has a mobile antenna and handheld device or laptop computer. Persistent capability can be provided through optimized constellations of these small satellites arrayed to support designated regions of interest.

In FY 2014, five of these small satellites were placed in orbit by two different launch vehicles. The five satellites represented four different designs and all used the standard 3U cube satellite structural configuration. The results of these flights were mixed, but all continued to substantiate the thesis that small CubeSat-class satellites can perform relevant military functions for U.S. ground warfighters. In FY 2014, three advanced versions of the U.S. Army Space and Missile Defense Command (SMDC) Nanosatellite Program (SNaP) communications CubeSat were developed and built. All three were manifested for an Atlas V launch during FY 2015. The deployment of these advanced CubeSats will commence the Military Utility Assessment of SNaP. The two Kestrel Eye Block II imaging spacecraft are nearing completion and also are manifested for launch in FY 2015. Like SNaP, Kestrel Eye will be the focus of a Military Utility Assessment. The Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS) small tactical launch system successfully completed initial first stage engine testing on a test stand at the Marshall Space Flight Center. Work completed on SWORDS will be made available to future launch vehicle technology.

Federal Aviation Administration

FAA

NextGen

Houston Metroplex

In 2014, the Federal Aviation Administration's (FAA) Next Generation Air Transportation System, or NextGen, saw tremendous successes with its Metroplex project. A metroplex is a large, metropolitan area with multiple airports in close proximity, with shared airspace, that form a system serving one or more major cities. A metroplex has at least one, but often two or more, major commercial airports.

Each metroplex has its own unique system of airports, aircraft, weather patterns, and geography that have to be considered. Additionally, each metroplex contends with multiple airports that share the same airspace. All of these factors can lead to congestion, reduced efficiencies, and delays.

In collaboration with the aviation industry, the FAA has identified 14 metroplexes where improved performance will benefit not only the region, but the entire national airspace system.

The FAA's goal is to improve the way aircraft navigate these complex areas to make flight routes and airport access more efficient. This new way of operating can reduce fuel burn and emissions and improve on-time performance.

The solutions, built on precise satellite-based navigation, smooth out flightpaths and limit costly level-offs. By realigning conventional routes and shifting airspace boundaries, the FAA continues to use NextGen solutions to make air travel more

efficient. This includes improving traffic flow on the airport surface, using new standards to increase arrival and departure options, and creating faster connections to the most efficient flightpaths.

In one of the agency's first airspace redesigns, Houston Metroplex launched 61 new routes into and out of the area's four airports in spring 2014. The initiative includes an improved merging technique that begins aligning planes hundreds of miles away.

The new flightpaths streamline arrivals and departures at George Bush Intercontinental, David Wayne Hooks Memorial, William P. Hobby, and Sugar Land Regional airports. These procedures no longer use the familiar zigzag pattern to cross over a series of navigation aids installed on the ground. Instead, aircraft using the Global Positioning System (GPS) for satellite navigation can now fly directly on paths that FAA designers and controllers, as well as airlines, have determined to be the best courses. New arrival paths allow for a continuous descent instead of the frequent level-offs required in the past. Guidance systems know where the aircraft is located to within a matter of feet.

This new technology allows for greater predictability, which may provide pilots and controllers with more time to focus on landing.

The FAA is also using the clock to get the best use possible of the new procedures. The agency leveraged an existing tool that is being upgraded with Time Based Flow Management (TBFM) capability to help manage an aircraft's flight to Houston—in some cases, even before the plane takes off.

Today, a flight leaving Hartsfield-Jackson Atlanta International will get NextGen help from TBFM as controllers in the tower consult with controllers who will clear departing aircraft into an overhead stream of air traffic.

One of the functions of TBFM is to determine the best takeoff time for a departing aircraft to merge into high-altitude traffic. Aircraft merging is similar to a car on a ramp merging with fast-moving cars on a highway.

Once the aircraft is cruising along smoothly at high altitude, TBFM keeps an eye on things.

As the aircraft gets within a few hundred miles of Houston, TBFM is crunching numbers to look at the route of flight, speed, and how winds at cruising altitude are affecting the aircraft's progress. The goal is to establish the time at which the

aircraft should arrive on the runway. When the aircraft begins flying one of the new arrival procedures, it is not likely to need to hold, which burns time and fuel while the aircraft waits to land.

Houston Metroplex data have yet to be aggregated and analyzed, but so far, the new approach seems to be living up to its promise of increased fuel efficiency, less noise, and reduced emissions.

ADS-B in the Gulf of Mexico

In February 2014, aircraft equipped with Automatic Dependent Surveillance—Broadcast (ADS-B), a key NextGen technology, began taking advantage of more direct routes over the Gulf of Mexico.

When other flights have to divert around thunderstorms in the Gulf, ADS-B–equipped flights maintain direct routes, saving time and fuel. There are radar coverage gaps offshore in the Gulf of Mexico, so air traffic controllers cannot normally track aircraft continuously with the necessary precision to enable such slight diversions to the south. A thunderstorm would normally require controllers to reroute a flight to where there is radar coverage, thus adding time to a trip and causing the airliner to burn extra gallons of jet fuel, pumping additional pounds of exhaust emissions into the atmosphere.

But flights equipped with ADS-B transmit the aircraft's position to radio stations on the ground—or, in the case of the Gulf of Mexico, to ADS-B radio stations installed on offshore oil rigs—every second. ADS-B has position accuracy to within a few feet—much more accurate than radar tracking. Additionally, radar can track aircraft only up to about 200 miles offshore.

Performance-Based Navigation

Performance-Based Navigation (PBN) addresses ways to leverage emerging technologies, such as satellite-based Area Navigation (RNAV) and Required Navigation Performance, to improve access and flexibility for point-to-point operations.

Throughput is the average number of flights that pass through an airport on a daily basis. When you increase the throughput during busy periods, more

passengers and cargo get off the ground and to their destinations on time. In January 2014, at Dallas/Fort Worth International Airport, the FAA put in place a NextGen procedure that triples the number of departures the airport can accommodate, a significant increase in the airport's throughput.

This NextGen procedure makes it possible for flights to take off with less distance between each aircraft—one nautical mile compared to the standard three nautical miles. This shorter distance enables an increase of 15 to 20 percent in departures per hour when the airport is congested compared to conventional methodology.

The majority of aircraft operating at Dallas/Fort Worth are equipped to fly this RNAV procedure, which uses satellites and onboard equipment to ensure that the aircraft navigate and remain on a precise path. RNAV procedures for both departures and arrivals are available at many airports around the country. The difference at Dallas/Fort Worth is that the RNAV procedure starts on the runway and continues as the aircraft ascends into high-altitude airspace, whereas conventional RNAV procedures begin once the aircraft is airborne.

"RNAV off the ground" is especially helpful during peak traffic hours or when traffic picks up following periods of bad weather, such as thunderstorms. Once the weather clears, aircraft can take off faster than before the implementation of RNAV off the ground.

Because aircraft do not have to wait as long on the taxiways, with their engines running, before they can take off, RNAV off the ground means aircraft burn less fuel—which also means reduced exhaust emissions.

Another RNAV off the ground benefit is that there is less communication necessary between controllers and departing pilots. With conventional departures, controllers tell the pilots what their heading will be and the pilots acknowledge the heading instruction by repeating it back to the controller. The RNAV procedure has a predetermined flight track programmed into the aircraft's flight management system, which reduces the number of verbal communications required and the risk of miscommunication.

Office of Commercial Space Transportation

In 2014, the FAA's Office of Commercial Space Transportation (AST) continued to promote U.S. commercial space transportation, licensing 12 orbital commercial space launches: a Minotaur launch from Wallops Flight Facility (WFF) in Virginia; three Falcon 9 launches from Cape Canaveral Air Force Station (CCAFS) in Florida; an Antares launch from WFF; a Zenit-3SL from Sea Launch's floating launch platform in the Pacific Ocean; an Antares 120 launch from WFF; four Falcon 9 Version 1.1 (Falcon 9 v1.1) launches from CCAFS; and an Atlas V-401 from Vandenberg Air Force Base (VAFB) in California. There were seven permitted suborbital commercial space launches: a Grasshopper launch from the Space Exploration Technologies Corporation's (SpaceX) test facility in McGregor, Texas; a SpaceShipTwo launch from Mojave Air and Space Port in California; and five Falcon 9-R launches from the Space X test facility in McGregor, Texas. No fatalities, serious injuries, or significant property damage to the uninvolved public occurred during any of these events. AST safety inspectors were on-site for each launch, ensuring public safety by verifying operator compliance with FAA regulations and with the terms and conditions of their specific licenses or permits.

AST granted six new launch licenses for SpaceX Falcon 9 v1.1 launches from CCAFS; for SpaceX Dragon pad abort testing from CCAFS; for SpaceX to conduct two Falcon 9 v1.1 launches of SES-8 and Thaicom-6 from CCAFS; to SpaceX for Falcon 9 v1.1 launches of Orbcomm-1 and Orbcomm-2 from CCAFS; to SpaceX for Falcon 9 v1.1 launches of AsiaSat-8, AsiaSat-6, and TurkmenSat-1 from CCAFS; and to Orbital Sciences Corporation (OSC) for Antares 130 launches from WFF. Two reentry licenses were granted: to SpaceX for the reentry of its Dragon Capsules and to United Launch Alliance (ULA) for the reentry of its Orion capsule. One launch license renewal was granted to OSC for Pegasus launches from the U.S. Army Kwajalein Atoll/Ronald Reagan Ballistic Missile Test Site. A launch site operator license was granted to the Midland International Airport in Texas, bringing the total number of FAA licensed "spaceports" to nine. Launch site operator licenses were renewed for Spaceport America in New Mexico and the Mojave Air and Space Port.

AST issued new experimental permits to Blue Origin for New Shepard launches at its West Texas site and to SpaceX for Falcon 9-R launches from its test facility in McGregor, Texas. A permit renewal was granted to SpaceShipTwo launches from Mojave Air and Space Port. AST also issued two safety approvals for commercial spaceflight training services: one to Black Sky Training and one to Waypoint 2 Space.

AST inspectors conducted 223 safety inspections on over 57 different types of FAA-regulated activities. The goal of every AST safety inspection is to ensure public safety by verifying FAA licensee and permittee compliance with FAA regulations and license/permit terms and conditions. Inspections were conducted at various locations, including Cape Canaveral Air Force Station, Florida; Vandenberg Air Force Base, California; Wallops Flight Facility, Virginia; Kodiak, Alaska; and other sites in Texas, California, Florida, and New Mexico.

To support all new and renewed licenses in FY 2014, AST carried out several environmental reviews, including the Final Environmental Impact Statement (EIS) and Record of Decision (ROD) for the SpaceX launch facility in Texas; the Final Environmental Assessment (EA) and Finding of No Significant Impact (FONSI) for Midland International Air and Spaceport, Texas; the Final Supplemental EA and FONSI for Blue Origin's West Texas Launch Site; and the Final EA and FONSI for SpaceX's Dragon Fly Operations at the McGregor Test Site, Texas. AST also issued FONSIs for the Final EA for SpaceX's Dragon Crew Pad Abort Tests at CCAFS, Florida, and a Supplemental EA for SpaceX's Falcon 9 Vehicle Operations at CCAFS.

Also in 2014, the FAA continued support of its Center of Excellence for Commercial Space Transportation (COE CST), which enables the FAA to work with universities and their industry partners to conduct research in environment and aviation safety, as well as other activities to ensure a safe and efficient air transportation system. The COE CST, working with nine member universities, provides grants in four distinct research areas: space traffic management and operations; space transportation operations, technologies, and payloads; human spaceflight; and space transportation industry viability. A unique attribute of the COE program is the one-to-one matching requirement for every Federal dollar granted to a COE university. The matching requirement can be satisfied through direct or

in-kind contributions from any non-Federal funding source, including industry, universities, or state and local government organizations. Researchers from the University of Texas Medical Branch (UTMB), one of the COE CST member universities, received special recognition in 2014 for research on space travel effects on individuals with preexisting conditions.

In FY 2014, no new Space Transportation Infrastructure Matching (STIM) grant proposals were solicited and no new awards were made.

Another AST accomplishment in 2014 was the publication *Recommended Practices for Human Spaceflight Occupant Safety*. The document is intended to facilitate discussions between Government, industry, and academia on how best to increase the safety of commercial human spaceflights. It gathers data and lessons learned from more than 50 years of human spaceflight and 100 years of aviation. The publication marked the culmination of a three-year effort performed in partnership with stakeholders from Government, industry, and academia. Further, these recommended practices offer a framework that space vehicle developers and operators may find useful in the preparation of industry consensus standards.

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

Department of Commerce

DOC

During FY 2014, the Department of Commerce (DOC) continued its cooperation with the Department of State and other Federal agencies to dramatically reform the U.S. satellite export control regime. In May 2014, DOC's Bureau of Industry and Security published interim final regulations updating the Commerce Control List to include many space-related items that were previously controlled as defense articles under the U.S. Munitions List of the International Traffic in Arms Regulations. The new rules took effect in June and November of 2014, delivering tremendous regulatory relief to the U.S. space industry following 15 years of highly restrictive export controls.

In June 2014, the Secretary of Commerce informed U.S. remote sensing company DigitalGlobe of the Government's decision to reduce the resolution limits on the sale of U.S. satellite imagery. DOC played a pivotal role in the interagency deliberations leading to the establishment of the new 0.25-meter-resolution limit for electro-optical, panchromatic imagery sold by U.S. firms on the open, commercial market. The ability to sell sharper imagery internationally will help U.S. industry maintain its global leadership in commercial remote sensing, consistent with the U.S. Commercial Remote Sensing Space Policy.

In November 2013, DOC participated in the rollout of the President's National Space Transportation Policy, which provides updated guidance to Federal departments and agencies on the development and use of commercial and Government space transportation systems. DOC contributed to the development of the policy, including its commercial guidelines designed to promote U.S. launch industry robustness, cost effectiveness, innovation, entrepreneurship, and international competitiveness.

Throughout FY 2014, DOC continued to participate in the national management of the Global Positioning System (GPS) 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 March 2014 meeting and participated in interagency working groups established to ensure the resilience of U.S. critical infrastructure against potential GPS disruptions. DOC continued to host the secretariat of the National Executive Committee and participate in its daily operations, including hosting the *http://www.gps.gov* Web site.

DOC participated in bilateral consultations, led by the State Department, with Europe to discuss cooperation on space and satellite navigation. DOC also cochaired two meetings of a U.S.-European working group on trade issues affecting GPS and Europe's Galileo satellite navigation system.

In February 2014, DOC's Bureau of Industry and Security published the first set of analytical results from its "Deep Dive" survey of the U.S. space industrial base.

In 2012–13, the Bureau of Industry and Security (BIS), in partnership with the United States Air Force, NASA, and the National Reconnaissance Office (NRO), led an interagency effort to study the U.S. space industrial base; the study culminated in 2014. The principal goal of the assessment was to gain an understanding of the intricate supply-chain network supporting the development, production, and sustainment of products and services across the defense, intelligence, civil, and commercial space sectors. This joint effort, called the U.S. Space Industry "Deep Dive" Assessment, allowed BIS to map the space industrial-base supply chain in unprecedented detail while also benchmarking trends in business practices, competitiveness issues, financial health, and other areas, across many tiers of the industrial base. This project provided defense, intelligence, and civil U.S. Government (USG) stakeholders with a single, consistent source of information highlighting interdependencies between agencies and over 200 USG space programs, including several National Oceanic and Atmospheric Administration (NOAA) programs.

The "Deep Dive" study was designed to generate a consistent source of data to support the objectives of different space-related stakeholders across the USG while also providing information on issues that have traditionally been supported only by anecdotal evidence. BIS utilized its authority delegated under the Defense

Production Act of 1950, as amended (50 U.S.C. app. Sec. 2155), to design, distribute, and collect surveys of commercial companies, universities, nonprofit organizations, and USG agencies with equities in the space industrial base. Overall, nearly 3,800 organizations submitted complete survey responses, which detailed not only the specific products and services they provided but also their critical suppliers, financial statement line items, R&D and capital investments, employment data, and other performance criteria.

Key findings from the "Deep Dive" assessment include the following:

- There is a high degree of subcontractor overlap across the space industrial base.
- High financial risk among a portion of suppliers is evident not only between defense, intelligence, and civil space programs but also across all 16 major categories of space-related products and services.
- Organizations that are more dependent on space-related business exhibit greater signs of financial stress.
- Uncertainty about the long-term outlook of the USG space program limits industry's ability to plan investment and R&D and inhibits their desire to enter/remain in the space market.
- An aging workforce and lack of properly skilled workers are major challenges to the long-term health of the U.S. space industrial base, especially for space-related national security programs and participating USG agencies.
- USG space acquisition practices are costly, hinder competition, and limit industry's desire to remain in or enter the space market.

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 2014, NOAA satellites were as critical as ever, monitoring the severe drought and wildfires in the West, a crippling ice storm in Atlanta, and multiple hurricanes near and over the Hawaiian islands. 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 primary 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 on the surface by orbiting at a speed matching that of Earth's rotation. Imagery and data from GOES are 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 2014, GOES-15 flew at 135° west longitude and served as "GOES-West," while GOES-13 flew at 75° west and served as "GOES-East."

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 satellites, affording each satellite a different view with each orbit. It takes the satellites 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. These data are used by all major numerical weather prediction (NWP) centers around the world, forming the basis of nearly every medium-term weather forecast.

On May 1, 2014, the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite took over as NOAA's primary operational polar-orbiting satellite. 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-19, NOAA's previous primary operational polar-orbiting satellite, remains a critical part of NOAA's polar constellation and provides valuable contributions to National Weather Service forecasts.

NOAA's Ocean Altimetry Satellite

NOAA, in partnership with NASA, 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. In October 2013, the Jason-2 partners agreed to extend Jason-2 operations until June 2015.

NOAA's Additional Space-Based Capabilities

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

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, EUMETSAT, and Indian Space Research Organisation (ISRO) 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 system 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 37,000 people worldwide since 1982. The governing parties of the system are the United States (NOAA), France (CNES), Russia (Federal State Unitary Enterprise Morsviazsputnik), and Canada (National Search and Rescue Secretariat). NOAA provides space on its polar-orbiting satellites for the French processor and Canadian receiver.

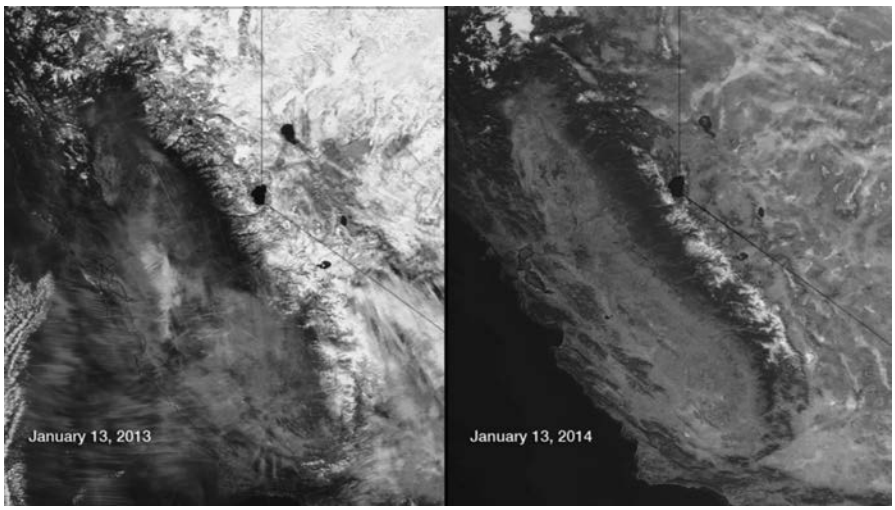
Additionally, on November 19, 2013, NOAA's Total solar irradiance Calibration Transfer Experiment (TCTE) was launched from NASA's Wallops Flight Facility. TCTE, developed in partnership with NASA, is a JPSS-funded mission designed to continue measurements from space of the total energy output of the sun. These measurements are used to measure light from the sun at all wavelengths, which is the primary energy source that drives climate on Earth, and determine if solar changes influence Earth's climate.

International Agreements

On October 31, 2013, NOAA and the European Space Agency (ESA) completed an exchange of letters to facilitate continued collaboration on ESA's CryoSat mission. ESA has made data from CryoSat, a remarkable satellite designed to study ice, available to the world on a free, full, and open basis. Thanks to this data policy and the efforts of scientists from ESA and NOAA's Center for Satellite Applications and Research (STAR), NOAA created CryoSat ocean products that are now employed by ocean modeling and forecast centers worldwide, including NOAA's National Weather Service, to enhance near-real-time marine and hurricane forecasts. This is a great example of the benefits of international partnerships and open data policies, and this new arrangement will allow our collaboration with ESA to continue and grow.

Other Accomplishments

In May 2014, the COSPAS-SARSAT rescue network was one of two inductees into the Space Foundation's Space Technology Hall of Fame at the Space



Extreme drought worsened in California's Central Valley throughout FY 2014. This image compares January 13, 2013, and January 13, 2014, snow cover, a vital source of water for the region, as seen by the Suomi NPP satellite's VIIRS instrument. (NOAA)

Foundation's 30th Space Symposium. The honor recognizes technologies originally developed for space applications that now improve life on Earth.

National Institute of Standards and Technology

In FY 2014, 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 aeronautics and space agenda. These wide-ranging outputs fall into four main categories: 1. calibrations and measurements for the aerospace industry, 2. calibrations of satellite sensors, 3. development of astronomical and satellite sensors, and 4. support of manufacturing technology.

NIST Calibrations and Measurements for the Aerospace Industry

According to Boeing, traceable NIST measurements (mass, force, vibration, acoustics, electricity, thermometry, humidity, flow, pressure, viscosity, fluid density, radiometry, and length) are essential for aircraft manufacturing. For instance, 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. 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 is working with the Department of Defense (DOD) and Boeing on the applicability of laser-scanning technology for the dimensional measurement of aircraft components. The work includes developing calibration methodologies and facilities for laser-scanner systems and national and international standardization of their measurement accuracy. NIST collaborated jointly with the National Transportation Safety Board (NTSB) and Boeing on the investigation of potential sources of the major battery thermal runaways that resulted in the grounding of the 787 airplanes by the Federal Aviation Administration (FAA) in January of 2013.

NIST provides airspeed, hydrocarbon-liquid-flow, and gas-flow measurements through calibrations of anemometers used at airports, on aircraft, and in wind tunnels. The hydrocarbon-liquid calibration service tests flow meters that are used to measure jet fuel (for example, turbine meters that are used to evaluate jet engine performance on test stands).

NIST conducted joint research with Pratt & Whitney to develop and validate new standard measurement methods to evaluate the performance of complex (5-axis) machine tools. The results of this joint research were used in the development of American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) and International Organization for Standardization (ISO) standards for 5-axis machine tool evaluation and geometric error correction.

NIST contributed to discussions with the Federal Aviation Administration (FAA); the Department of Defense (DOD); the National Aeronautics and Space Administration (NASA); and aerospace industry representatives, including Honeywell Aerospace, Lockheed Martin, and Northrop Grumman, to identify proposed approaches for the qualification and certification of additive manufacturing materials, processes, and parts for use in load-bearing and mission-critical applications. NIST is collaborating with NASA Glenn Research Center (GRC) on spacecraft fire-detection research. NASA and NIST first developed the Smoke Aerosol Measurement Experiment (SAME) with smoke and aerosol measurement instruments to characterize smoke properties from overheated spacecraft materials

aboard the International Space Station (ISS). NIST is also working with the Boeing Company to understand the suppression of fires in aircraft cargo bays.

NIST collaborated with members of the Additive Manufacturing Consortium (AMC), including aerospace companies General Electric Aviation, Rolls-Royce, and United Technologies Aerospace, to conduct round-robin testing and determine the mechanical properties of Inconel 625 parts made using the direct metal laser sintering process.

NIST collaborated with the U.S. Department of Energy to develop measurement methods and experimental data to improve the machining of high-performance materials, such as titanium and nickel-based alloys. The preliminary reference data will be disseminated for review through industry members of the NIST Smart Machining Consortium, which includes key aerospace companies such as Boeing, Pratt & Whitney, and General Electric, prior to official publication.

Several partners in the aerospace community took advantage of the unique capabilities of the NIST Center for Neutron Research to study a number of aerospace challenges.

- Researchers used neutron imaging in continuing studies of alkali metal heat pipes that cool the leading edge of hypersonic aircraft.
- NIST, along with members from Marshall Space Flight Center, used neutron imaging to study the water distribution in proton-exchange membrane fuel-cell flow fields and gas diffusion layer, and they are collaborating with the NIST imaging group to develop a neutron microscope. NIST also partnered with Edwards Air Force Base to use small-angle neutron scattering (SANS) to measure electrically conducting nanocomposites.
- A collaboration with Glenn Research Center studied the synthesis and properties of several proton-exchange membranes for fuel-cell technology. Other material-engineering projects include collaboration with Northwestern University to develop phase-equilibria and diffusion-mobility descriptions of a new class of high-temperature superalloys for turbine engines.

NIST continues to develop and characterize measurement methods for advanced optics used in aerospace and space applications. 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 spaceborne x-ray telescopes.

NIST continues to work with EMCORE Corporation of Albuquerque, New Mexico, to space-qualify its solar cells' irradiation by an electron beam from the NIST Van de Graaff accelerator. NIST also worked with Goddard Space Flight Center to determine the radiation sensitivity of an ion mass spectrometer.

NIST Calibrations of Satellite Sensors

NIST provided calibration support for the infrared and optical sensors for several satellite missions under development: the Joint Polar Satellite System (JPSS), the Geostationary Operational Environmental Satellite-R Series (GOES-R), and the Landsat Data Continuity Mission (LDCM). NIST-calibrated optical apertures were flown on the latest Total Irradiance Monitor (TIM) launched into space in 2014, which made measurements of the amount of solar power per unit area that reaches Earth.

NIST, in partnership with the University of New Mexico, Harvard University, and the Smithsonian Institution, continued a program to improve the absolute radiometric calibration of stars for applications that include satellite-sensor calibration, dark-energy research, and nighttime aerosol monitoring. NIST began making accurate measurements of the amount of light from the moon with the goal of enabling the moon to serve as a calibration source for satellite sensors while they are in space.

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. The NIST calibration has enabled a detailed analysis of the CIBER data, and with the analysis, the CIBER team will release a catalog of several hundred calibrated stars to the astronomical community.

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. 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 has started the calibration of the Stratospheric Aerosol and Gas Experiment (SAGE) III.

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 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) now being built for NOAA's GOES-R satellite mission.

NIST performed calibrations necessary to support the infrared remote sensing systems for the Missile Defense Agency.

NIST continued the development and deployment of measurement methods to provide for microwave radiometers as deployed on numerous U.S. operational weather and research satellite assets within NOAA, NASA, and DOD. Working with colleagues at NASA Goddard Space Flight Center through an ongoing Memorandum of Understanding (MOU), NIST demonstrated microwave brightness-temperature (radiance) calibrations for the remote sensing bands.

NIST Development of Astronomical and Satellite Sensors

NIST is collaborating with NASA's Goddard Space Flight Center to develop photodetectors for space applications. NIST designed and fabricated nanotextured gallium nitride (GaN) and GaN nanowires that serve as raw materials for photocathode detectors. Goddard collaborators activated the material with cesium and packaged the units into complete imaging systems.

NIST is teaming with Northrop Grumman and the University of Maryland to develop the next generation of high-sensitivity solar-blind ultraviolet (UV) photodetectors using robust wide-band-gap materials.

NIST collaborated with the Jet Propulsion Laboratory (JPL) on the development of superconducting nanowire single-photon detectors (SNSPDs). In FY 2013, NIST characterized various JPL devices. NIST also packaged some JPL devices with NIST's self-aligned single-mode optical-fiber packaging program. NIST also began joint development with JPL of small arrays of SNSPDs.

NIST developed new detectors based on the voltage-biased superconducting transition-edge sensor (TES). NIST has developed integrated TES polarimeters for measuring polarization of the cosmic microwave background (CMB). NIST is providing Superconducting Quantum Interference Devices (SQUIDs) and SQUID-based multiplexers to many researchers, both at NASA Centers (Goddard, JPL) and in academia. 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. More recently, NIST demonstrated the first cooling by tunnel junctions of a macroscopic stage that can support user-supplied payloads.

NIST has worked to develop microsensor technology for use in planetary exploration missions. With NASA funding from the Planetary Instrument Definition and Development Program (PIDDP), operation of the microsensor arrays was demonstrated under simulated Martian conditions (CO_2-rich background, low temperature and pressure).

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. 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, as well as international clock comparisons. NIST is performing research, development, and evaluation of an ytterbium (Yb) optical lattice clock as a candidate for 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, in collaboration with scientists at the California Institute of Technology.

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. NASA partially funded this effort, which was carried out in collaboration with the Harvard-Smithsonian Center for Astrophysics and the Argonne National Laboratory.

NIST Manufacturing Extension Partnership

In FY 2014, NIST Manufacturing Extension Partnership (MEP) centers engaged in 230 projects with 158 individual manufacturing companies designated with an aerospace North American Industry Classification System number (NAICS 3364). The NIST MEP post-project, followup 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.

International Trade Administration

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 that can provide products that meet the requirements of the International Civil Aviation Organization's (ICAO) Aviation System Block Upgrade (ASBU) technology roadmaps. In 2014, OTM participated in the 2nd World Air Traffic Management Congress in Madrid, Spain, to cohost (with the Aerospace Industries Association) a networking reception for foreign Air Navigation Service Providers to meet with

industry and hear from the senior Federal Aviation Administration (FAA) leadership, such as the Assistant Administrator for NextGen, Ed Bolton. OTM also took the opportunity to learn about the particular air-navigation procurement needs of specific countries, counsel individual companies on NextGen-related prospects, and recruit participants for the NextGen Solutions Vendors Guide while at the Congress. OTM also participated in a number of domestic conferences and exhibitions (such as the 58th Air Traffic Control Association Conference and Exhibition and the 2014 Air Transportation Information Exchange Conference) to discuss the future of the NextGen market with individual companies.

Additionally, OTM worked with the FAA, the Transportation Security Administration (TSA), and the State Department in preparation for the 38th ICAO Assembly in September 2013, providing the International Trade Administration (ITA) perspective on aviation safety, aviation security, air-navigation policy and procurement, and the economics of air transportation. ICAO formally endorsed the ASBU roadmaps at the Assembly.

OTM also participated in the Unmanned Aircraft Systems (UASes) Symposium and the Association for Unmanned Vehicle Systems International (AUVSI) Unmanned Systems 2014 Conference to engage with Government, academic, and industry stakeholders within the UAS community, to learn more about the projected market for UASes, 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). Specifically, OTM cultivated contacts with various state business-development offices at Unmanned Systems 2014, with particular emphasis on the regions represented in the FAA's six UAS test sites.

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 three meetings of the Industry Trade Advisory Committee for Aerospace Equipment (ITAC 1). The committee

provides advice to the Secretary of Commerce and the 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 Finance and Insurance Industries (OFII) 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, and its effects were still being observed in 2014. 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 monitored; ITA also provided advice on how Export-Import (Ex-Im) Bank programs affect the aerospace industry.

In May 2014, ITA organized an aerospace and aviation equipment trade mission to Brazil. The purpose of the mission was to introduce U.S. firms to Brazil's readily expanding market for aerospace and aviation products and services. The mission to Brazil was designed for U.S. aviation and aerospace manufacturers and service providers, particularly small- and medium-sized enterprises (SMEs), interested in long-term business opportunities in Brazil, as well as the trade associations/organizations that represent them. Targeted sectors included aircraft parts (particularly for the aftermarket), business aviation, general aviation and helicopters, airspace and air traffic flow management, ground support equipment, baggage handling systems, meteorological information management, surveillance and satellite navigation, and airport/aviation security.

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 would improve U.S. industry's competitiveness, stimulate the American economy, increase exports, and create U.S. jobs. ITA actively participated in the review of November 2013 National Space Transportation Policy, led by the White House, and, within that review, 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 July 2014, ITA organized and supported the Commerce Department's participation in the Farnborough International Air Show and arranged senior-level meetings for the Deputy Under Secretary for International Trade with foreign government and industry officials as well as U.S. industry executives. ITA's 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 Global Aerospace and Defense Team recorded approximately 200 export successes in FY 2014. 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 facilitated 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 Global Team held over 800 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 Global Team participated in over 35 domestic and international aerospace trade events at which 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 Farnborough International Air Show, the Seoul Airshow, the Singapore Airshow, La Feria Internacional del Aire y del Espacio in South America (FIDAE), the Aircraft Interior Show, and the Africa Aerospace and Defense Summit, among others. The Global Team also released the second 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 2015.

Bureau of Industry and Security

On May 13, 2014, the Department of Commerce published an interim final rule adding controls to the Export Administration Regulations (EAR) for spacecraft and related items that the President has determined no longer warrant control under United States Munitions List (USML) Category XV—spacecraft and related items. New Export Control Classification Numbers (ECCNs) 9A515, 9B515, 9D515,

and 9E515, created by this rule, and existing ECCNs on the Commerce Control List (CCL) now control such items. This rule also revised various sections of the EAR to provide the proper level of control for the new ECCNs. This rule was published in conjunction with the publication of a Department of State Directorate of Defense Trade Controls rule revising USML Category XV to control those articles the President has determined warrant control on the USML. Both rules are part of the President's Export Control Reform Initiative. This rule was published as an interim final rule because the Departments of Commerce and State acknowledged that additional internal analysis of and industry input regarding the control threshold for various aspects of the amendments were warranted, particularly with respect to civil and commercial remote sensing satellites and civil and commercial spaceflight-related items. The Departments did not want to wait until this review was done to publish this rule in final form because of the substantial national and economic security benefits that will flow from the various amendments to the controls on satellites and related items. This rule had two effective dates: June 27, 2014, for controls on radiation-hardened microelectronic circuits and November 10, 2014, for the remainder of the rule. The following items were transferred from the USML to the Commerce Control List:

- Satellites
  - Commercial communication satellites
  - Lower-performance remote sensing satellites
  - Planetary rovers
  - Planetary and interplanetary probes
- Related systems for the above
  - Ground control systems
  - 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
- Parts and components of satellite buses and payloads not listed on the USML

Department of the Interior

DOI

Remotely sensed data and derived information contribute significantly to mission-critical work across the Department of the Interior (DOI). Satellite and other remotely sensed data allow an unparalleled synoptic view of Earth and Earth processes that can be collected routinely in a calibrated and standardized manner. Translating these data into information that is meaningful and useful to land managers is an important focus of DOI employees. This section highlights a sample of DOI remote sensing applications and illustrates a range of technology, platforms, and specialized sensors employed. DOI personnel use remote sensing technology to evaluate and monitor changing land-surface and natural-resource conditions over the vast areas for which DOI has responsibility.

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 downloading at no charge in December 2008, and by the end of September 2014, more than 20 million Landsat scenes had been downloaded by the user community. The USGS also distributes current and historical aerial photography and light detection and ranging (lidar) data; declassified satellite imagery; hyperspectral imagery; 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 U.S. and global ecosystem health monitoring; land-use and climate-change analysis; emergency response; mineral

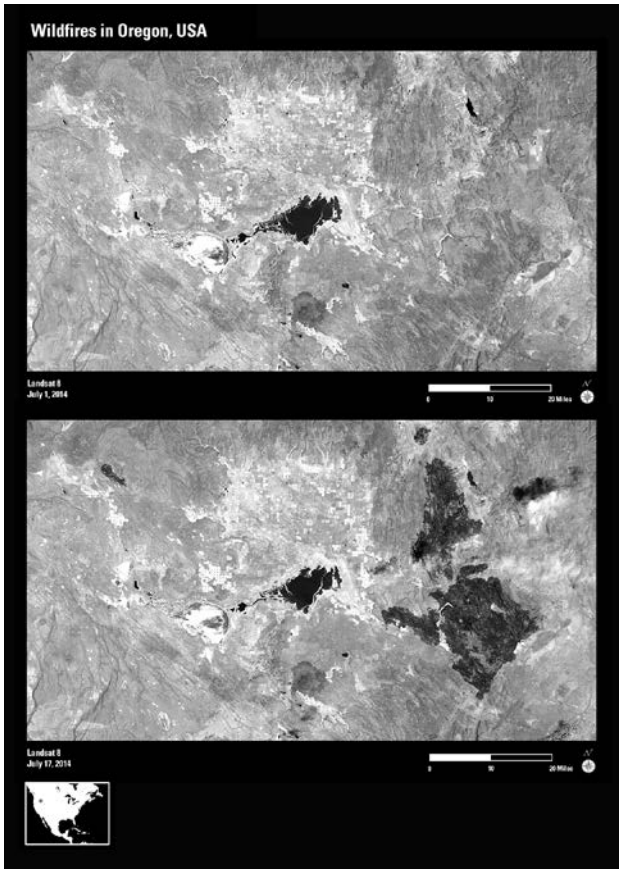
resource development; and the assessment of natural hazards such as fires, hurricanes, earthquakes, droughts, and floods.

Landsat Satellites

The Landsat Program is a joint effort of the USGS and the National Aeronautics and Space Administration (NASA) to use Earth-observing satellites to capture, process, and freely distribute land-surface image data. Landsat imagery enables users to derive information about local and global conditions, including land use, land cover, crop vigor, forest health, invasive plant and insect spread, surface-water area and quality, irrigation water use, flood extent, drought-status, wildfire, and many other image-data applications.

Under the Landsat Program partnership, NASA develops and launches Earth-observing instruments and spacecraft, and the USGS develops the associated satellite ground systems. In addition, the USGS conducts satellite flight operations; operates and maintains the ground systems; and manages image-data reception, processing, archiving, and distribution. For 42 years, a primary objective of the Landsat Program has been to record changing land-surface conditions across the global land surface through the collection of consistently calibrated image data.

Each image in the Landsat archive at the USGS Earth Resources Observation and Science (EROS) Center near Sioux Falls, South Dakota, covers over 12,000 square miles at a resolution of 30 meters, wherein each image pixel covers about the same area as a 90- by 90-foot baseball diamond. In 2014, the USGS gradually increased the collection and processing volume for Landsat 7 to over 400 images per day and increased Landsat 8 (launched by NASA in February 2013) from a post-launch 400 per day to over 700. By comparison, when Landsat 7 was launched in 1999, 100 images per day were added to the archive. With increasing amounts of current and historical imagery available from the Landsat archive, and thanks to NASA's improvements for Landsat 8 that include crisper images, better resolution of snow- and ice-covered regions, improved detection of water-column constituents such as algae, and better cloud screening, users downloaded 5.6 million images in the six-month period from March through August 2014. For more information, visit *http://landsat.usgs.gov/*.

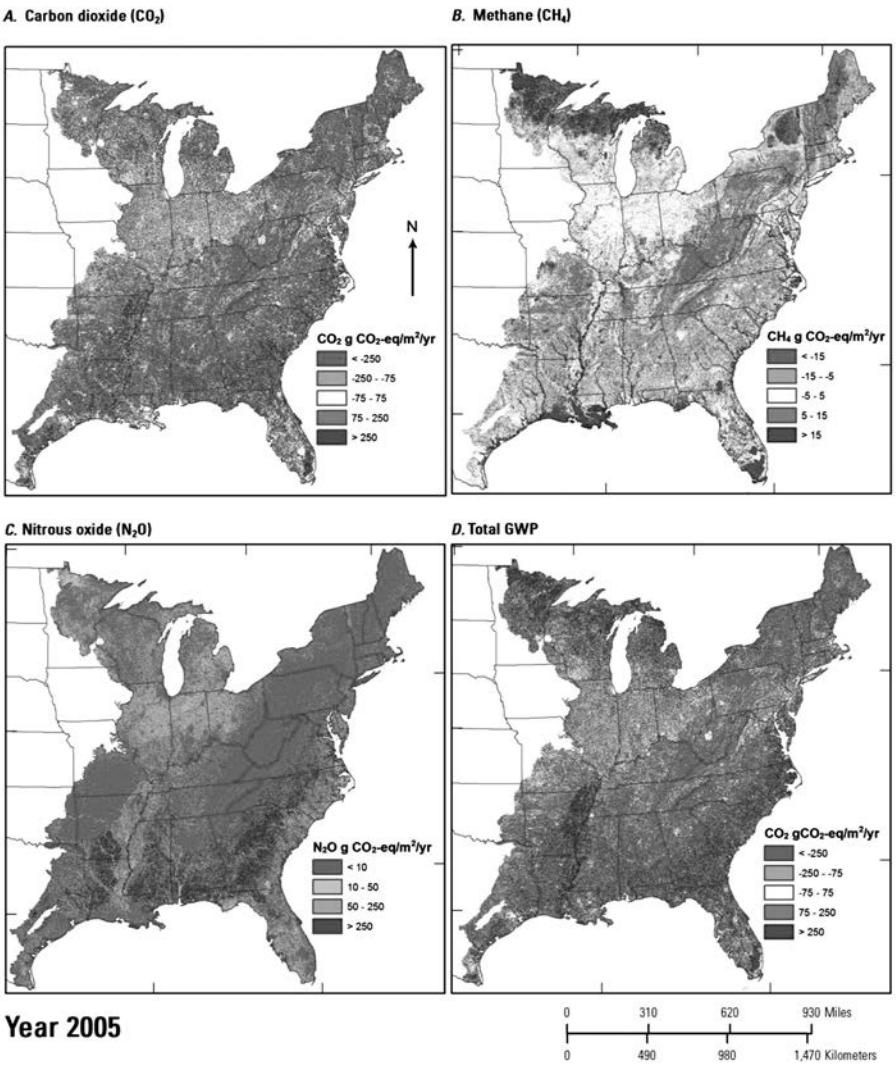


Responders in semi-arid east-central Oregon fought several separate fires that were started by lightning near Malheur Lake on July 14, 2014. The combination of high winds, low humidity, and high temperatures made firefighting work difficult. These Landsat images were acquired on July 1, 2014 (top image), and again on July 17, 2014 (bottom image). Malheur Lake is in the center of both images. The large fire scars visible in the lower image show the area burned within the Buzzard Complex fire event as of July 17.

Landsat imagery can be an important tool to help evaluate the areas altered by fire and can assist in response planning and identifying areas of further risk. Future images from Landsat will also be helpful for monitoring the land recovery after major fires such as this.

Assessment of Carbon Sequestration Potentials in the Eastern United States

As part of an effort to fulfill the requirements of section 712 of the Energy Independence and Security Act (EISA) of 2007, the USGS is conducting a comprehensive national assessment of potentials for carbon (C) sequestration and reduction of emissions of greenhouse gases (GHG) (carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O]). This assessment covers all major terrestrial ecosystems (forests, grasslands/shrublands, agricultural lands, and wetlands) and aquatic



These maps show the spatial distribution of the average annual carbon dioxide, methane, and nitrous oxide fluxes and their total global warming potential from 2001 to 2005 in the eastern United States.

ecosystems (rivers, streams, lakes, estuaries, and coastal waters) from 2001 to 2050 in the eastern United States.

Like two previous regional assessments—Great Plains and the western United States—this project applies the General Ensemble biogeochemical Modeling System (GEMS) to simulate ecosystem biogeochemical cycles, including carbon stock and fluxes and GHG emissions under various land-use/land-cover change and climate-change scenarios. The scenarios were developed in accordance with storyline A1B, A2, or B1 from the Intergovernmental Panel on Climate Change

Special Report on Emissions Scenarios (*http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/index.htm*). More detailed information on the assessment of carbon sequestration potentials in the eastern United States can be found in the U.S. Geological Survey report of Zhu and Reed, 2014, at *http://dx.doi.org/10.3133/pp1804*.

National Land Cover Database 2011

The USGS, working in partnership with the Federal interagency Multi-Resolution Land Characteristics Consortium (MRLC), has completed the production of the National Land Cover Database (NLCD) 2011 for the contiguous United States. The NLCD serves as the definitive Landsat-based, 30-meter-pixel-resolution, land-cover database for the Nation. NLCD 2011 products derived from nominal 2011 Landsat data depict 16 classes of land cover, define the degree of surface imperviousness in urban areas, and quantify the amount of tree canopy cover.

NLCD 2011 innovations include integration with previous NLCD versions to provide a 10-year land-cover change story for our Nation at five-year intervals, a quicker production time over previous efforts, more comprehensive change and image analysis methods resulting in more accurate products, a more comprehensive update of the imperviousness product resulting in more accurate products for each era in the last 10 years, and the first-ever change analysis of Alaska. In late 2014, NLCD 2011 will be released for Alaska, quantifying land-cover change within the state between 2001 and 2011. Overall, NLCD remains a substantially evolving and important database to a wide range of users, making it essential to thousands of applications. It is used to inform a variety of investigations, from monitoring forests to modeling water runoff in urban areas. For more information on NLCD and to obtain NLCD data, visit *http://www.mrlc.gov/*.

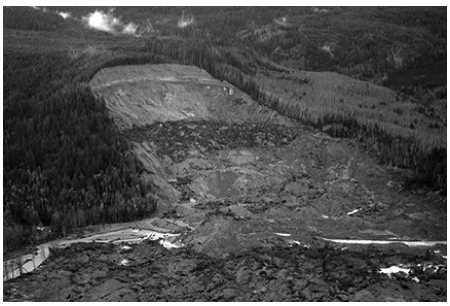
Using the Moon to Calibrate Earth Observations

The USGS Astrogeology program maintains the highest-quality data on the brightness of the moon via the Lunar Calibration Program. These data are used to calibrate many spaceborne Earth-observing instruments, including the Operational

Land Imager (OLI) on Landsat 8, as well as the NASA remote sensing instruments Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite and Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites. Lunar calibration is planned by virtually all future operational satellite missions, including those belonging to the National Oceanic and Atmospheric Administration (NOAA) (GOES-R Advanced Baseline Imager); NASA (VIIRS on the Joint Polar Satellite System); the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) (Meteosat Third Generation Flexible Combined Imager and EUMETSAT Polar System); and Japanese, Chinese, and Indian meteorological agencies. Consistent calibration is essential for comparing data collected by different instruments over decadal timescales, thus allowing climate and land-use changes to be accurately assessed. Lunar calibration provides a reliable method for maintaining long-term and consistent calibration of visible and near-infrared imaging instruments. For more information, visit *http://www.moon-cal.org/*.

Response to Landslide Emergencies

Remotely sensed data and technologies are critical for a science-driven emergency response to landslide disasters. Topography derived from lidar and Interferometric Synthetic Aperture Radar (IFSAR), optical imagery, and the Global Positioning System (GPS) can provide fundamental information to aid in the forecasting of and response to landslide activity. High-resolution topography collected before and after landslide movement can be differenced to obtain estimates of deposit thickness. For example, maps of deposit thickness derived from lidar data were used to develop safer and more efficient search strategies following the March 2014 landslide near Oso, Washington. The response to the Oso landslide relied on GPS technologies, which were used to

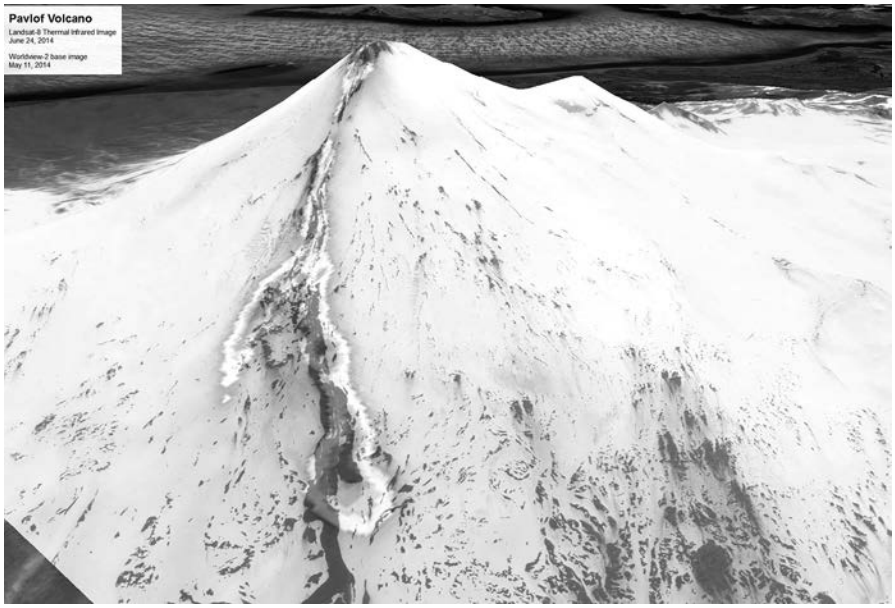


Photograph from aerial survey showing the upper parts of the landslide that occurred near Oso, Washington, on March 22, 2014. This photo was taken on March 27, 2014. Credit: Jonathan Godt, USGS

detect small (less than a few centimeters) displacements in and around the slide. This information was critical to the near-real-time assessment of additional landslide movement, which potentially threatened the month-long search operations there. Similar maps were developed for the Collbran landslide in western Colorado in May of 2014 by taking the difference between pre- and post-event IFSAR and lidar data. Color optical imagery is being used to map the occurrence and extent of debris flows generated by record-breaking rainfall in September 2013 in the Colorado Front Range. These maps, combined with new lidar topography, are a basis for debris-flow hazard assessments.

Alaska Volcano Observatory

The Alaska Volcano Observatory utilizes satellite remote sensing to aid in monitoring the 52 historically active volcanoes that comprise the 2,500-kilometer-long Aleutian Arc in Alaska. The primary volcanic hazard is to aviation along the



Composite satellite image of Pavlof Volcano showing the extent of the lava flows on the northeast flank. The base image was collected by DigitalGlobe's Worldview-2 satellite on May 9, 2014 (prior to the onset of eruptive activity), and is overlaid with a Landsat 8 thermal infrared image collected early in the morning on June 24, 2014. The thermal infrared sensor measured the heat given off by the still-warm lava flow. The length of the longest branch of the lava flow is about 5 kilometers (3 miles). Note that the lava flow appears to have traveled under the ice on the upper flank of the volcano.

busy North Pacific air routes, and remote sensing provides information that is used to detect volcanic unrest, to characterize the magnitude of the activity, and to determine whether hazardous ash (rock) is being erupted. For more information, visit *https://www.avo.alaska.edu/*.

Lower Colorado River Spring Pulse Flow

The Lower Colorado River High Flow Experiment in Mexico is a collaborative monitoring project with teams of scientists from governments, universities, and nonprofits on both sides of the border. The goal of the project is to document post-flow changes in the vegetation and riparian habitat along the lower Colorado River in response to a pulse flow mandated by the "Minute 319" international agreement.

Satellite-based vegetation indices (NDVI and EVI) derived from MODIS (daily coverage at 250-meter resolution) and Landsat 8 (30-meter resolution at 16-day intervals) data are mathematically combined to produce synthetic images with high spatial and temporal resolution. NDVI and EVI data for each river reach from 2000 to the present were collected for specific target areas that included restoration sites, vegetation transect sites, and bird observation sites.

The Colorado River is identifiable as a stream ending in the upper middle portion of this image, in the U.S.-Mexico border area. The dark feature (lower left) is not a stream, but a tributary of the main body of the Sea of Cortez in Mexico, which is just beyond the lower edge of the image. Credit: Francisco Zamora, Sonoran Institute, with aerial support by Lighthawk

The time series of satellite data revealed a steady decrease of green vegetation in all river reaches since the flood years of 1997–2000. The loss of vegetation vigor has been accompanied by a loss of bird habitat from 2002 to the present and has led to a lowering of evapotranspiration (ET) in each river reach. The pulse

flood was designed to restore some of the vegetation vigor and to germinate new cohorts of native trees throughout the river reaches. Early positive results are apparent in the zones of inundation. Over time, upstream groundwater recharge is expected to restore productivity in downstream river reaches. Over a period of years, a pulse flow should enhance the productivity of the groundwater-dependent riparian vegetation. The riparian vegetation along the Colorado River provides important habitat for many species and is a critical fly-way for many migratory birds.

Estimating the Temperature Response of 2,368 Lakes to Climate Change

Surface freshwaters support rich biodiversity and provide many important ecosystem services. Documented warming of inland waters is widespread and can reduce water quality and negatively impact cold-water fish. While national-scale monitoring programs exist for the Nation's rivers and streams (*http://waterdata.usgs.gov/*), lake temperature monitoring is comparatively rare. In order to evaluate climate impacts on lake temperatures from 1979 to 2011, mechanistic models for thousands of lakes were automatically parameterized using two primary sources of remote sensing data: Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) elevation data were used to estimate the degree of wind sheltering for lakes due to local canopy and topography effects, and water clarity was calculated based on Landsat imagery. This effort resulted in the publication of the article "Simulating 2,368 Temperate Lakes Reveals Weak Coherence in Stratification Phenology," available online at *http://www.sciencedirect.com/science/article/pii/S0304380014003664*.

U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS), in concert with its international, Federal, tribal, state, local, and nongovernmental organization partners, uses a large number of remote sensing technologies to find optimal solutions to watch over and manage our fish and wildlife populations, habitats, waters, wetlands, and landscapes. The FWS utilizes acoustic GPS, as well as radio telemetry sensors, on fish and wildlife for time and location information tied to a variety of remote

sensing image products, such as aerial and satellite optical imagery, in addition to thermal, radar, sonar, and lidar imagery. This temporal and geospatial system of imagery and location is used to map habitats, find invasive plants, determine flightpaths of birds and bats, conduct fish and wildlife inventories, watch over refuge lands, and monitor trust species.

Finding the Elusive and Endangered Iowa Pleistocene Snail

The Iowa Pleistocene Snail is a remnant of the last Ice Age and was believed to be extinct; however, it was discovered in 1955 and placed on the Endangered Species List in 1977. The only known living populations are found on several north-facing algific talus slopes in northeastern Iowa and northwestern Illinois. Although the snails' known populations appear to be somewhat stable over the last few decades, the larger question is whether they will survive climatic changes in the future. Since the last survey was over a decade ago, resurveys are being conducted to assess the stability of the existing populations and attempt to find additional groups. Thermal, lidar, aerial, and satellite imagery are being used to search for additional algific habitats and snail populations and to document

This image shows an Iowa Pleistocene Snail on a leaf in northeast Iowa.

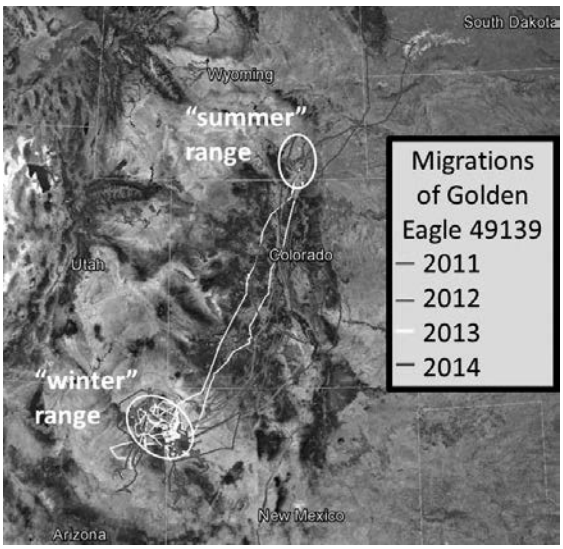
current habitat conditions. For more information, visit *http://www.fws.gov/midwest/endangered/Snails/iops_fct.html*.

Using Lidar-Derived Metrics for Habitat Management Plans

Airborne lidar can be processed to yield a broad array of forest canopy structure metrics that are important for wildlife management. These high-quality data layers can be assessed in models to identify important habitat relationships. For golden-cheeked warblers at Balcones Canyonlands National Wildlife Refuge near Austin, Texas, the amount of canopy cover at greater than or equal to 1 meter above ground was an important predictor of population density. The draft Habitat Management Plan for the Refuge is incorporating this knowledge by including an objective of increasing canopy cover at this level across the 7,500 hectares of juniper-oak woodlands managed for this species. The successional stage of each refuge tract was assessed from the lidar-derived canopy cover layer using zonal statistics in ArcGIS. Canopy cover greater than 80 percent (i.e., the highest quality habitat) was found over about 45 percent of the warbler management areas. About 22 percent of the warbler management areas had canopy cover between 60 and 80 percent, indicating a successional vegetation stage, and the remaining third hosted lower-quality habitat. These analyses are critical for helping management know where to focus efforts to maximize the growth of diverse juniper-oak woodlands.

Ecology of Southwestern Golden Eagles Based on Satellite Telemetry

Shortages of data on survival rates, mortality factors, habitat selection, and dispersal and migration movements hinder decisions for managing golden eagle populations in the western United States. To help fill these information gaps, 83 golden eagle nestlings were fitted with satellite transmitters in the Southern Rockies/Colorado Plateau region during 2010–14. Nearly one-half million hourly GPS locations of the eagles, accurate to within 20 meters, have been collected via the Argos satellite system.



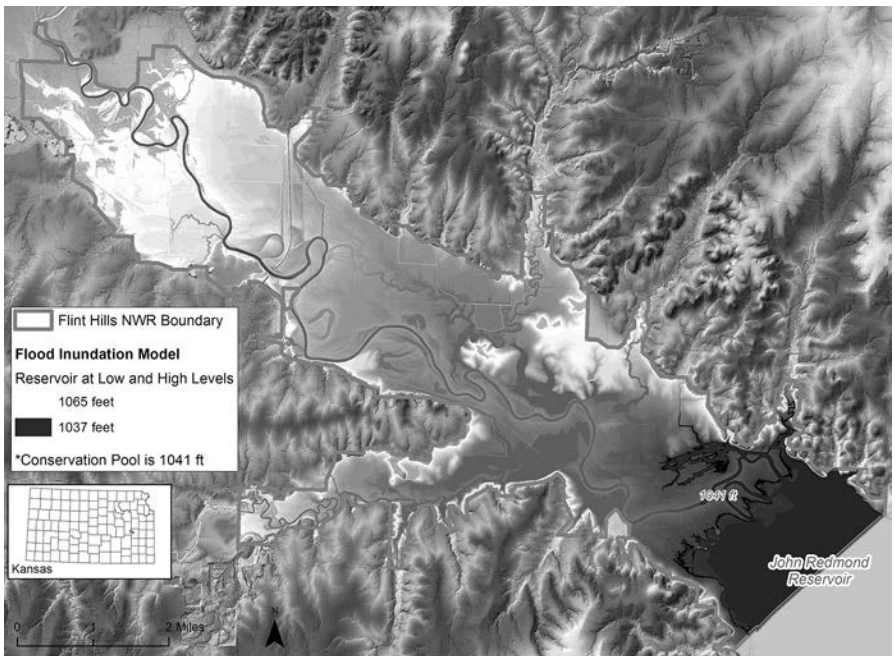
In this image, satellite telemetry shows the annual migrations between Arizona and Wyoming by a subadult female golden eagle.

Initial findings indicate relatively low first-year survival but greater survival thereafter. Chief mortality factors include power-line electrocution or collision, shooting, and poisoning, though cause of death is unknown in some cases. Nearly all eagles remain within 60 miles of their sites of origin as juveniles and subadults. However, about 40 percent of the eagles annually migrate northward 250 to 750 miles for summer, movement behavior previously unknown for the species and one having key implications for risk and population mixing.

Project data are helping to form underpinnings of continental-scale "meta-analyses." For example, identifying key migration corridors or overlap between highly valued habitat and potential development can aid decisions for conserving areas most important to the eagle. The FWS and collaborators currently are expanding this work in other western regions.

Utilizing Lidar to Model Flood Inundation on Flint Hills National Wildlife Refuge

Flint Hills National Wildlife Refuge is located in east-central Kansas near the town of Hartford and sits within and upstream of the John Redmond Reservoir, which is managed by the Army Corps of Engineers for flood control. Dramatic fluctuations in the reservoir are common with large rain events, which adds



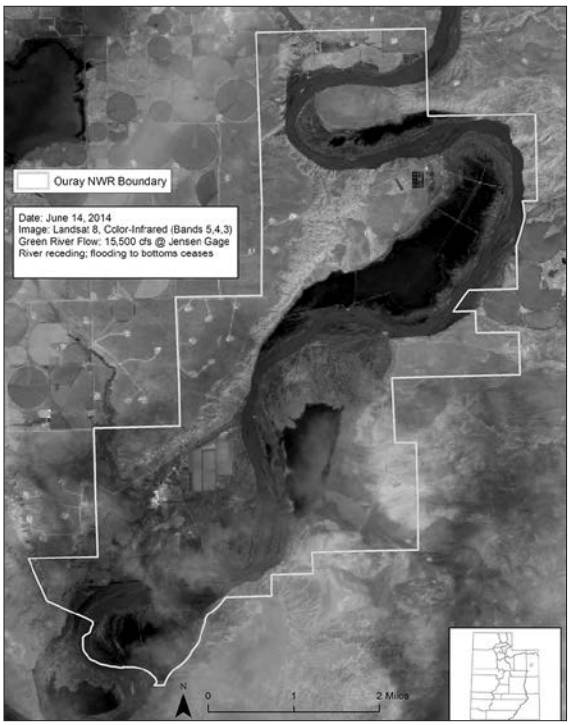
This flood inundation model shows low and high reservoir levels on Flint Hills National Wildlife Refuge.

complexity to effectively managing the refuge for migratory birds and other wildlife. In addition, the base conservation pool level was recently raised 2 feet to 1,041.

To better understand these fluctuations and their impact, the FWS used lidar-derived elevation data collected in 2010 and 2011 to model inundation across the refuge at all reservoir levels. Combining historical reservoir elevation allows flooding frequency and duration to be estimated and visualized by refuge staff. This information is being used by refuge staff as they develop goals and objectives for habitat management and inventory and monitoring plans; it also helps to facilitate continued communication between staff and the Army Corps of Engineers.

Documenting 2014 Flood Event on Ouray National Wildlife Refuge Using Landsat 8

Ouray National Wildlife Refuge is located in northeastern Utah along the Green River near the town of Vernal. River dynamics are a major driver in forming and sustaining ecological processes that directly influence floodplain habitats and the wildlife they support. In addition to supporting numerous migratory birds, the refuge also plays an important role in conservation efforts for four endangered Colorado River fish, particularly razorback suckers. Refuge floodplain bottoms fill



This Landsat 8 image, captured June 14, 2014, shows the maximum extent of flooding.

when the river floods, providing key brood-rearing habitat for juvenile fish.

The refuge is located in the overlap region between two Landsat 8 satellite footprints; therefore, the refuge is imaged every 7 to 9 days instead of every 16 days. The frequent coverage and relatively cloud-free conditions of this dryland environment provide a time series of imagery that is useful for documenting flooding events. Because of the rapid processing and posting of the Landsat data by the USGS (typically less than 12 hours after image capture), staff can compare the images with on-the-ground observations in near-real time, which enhances their knowledge of the flooding event and the floodplain system itself. Flood entry points and duration and extent of flooding are also documented from this imagery.

Helicopter Unmanned Aerial System to Map Pitcher's Thistle

Pitcher's thistle, a threatened native plant that grows on beaches and grassland dunes along the shorelines of Lake Michigan, Lake Superior, and Lake Huron, is an important food source for certain birds and small mammals. Although once fairly common in the sand dune ecosystems of Michigan, its numbers have declined in recent decades due to habitat destruction associated with shoreline development, recreational use, and invasive plant species. The FWS classified the thistle as a threatened species in 1996.

Benjamin Heumann, director of CMU's Center for Geographic Information Science at Wilderness State Park, flies an unmanned aerial vehicle along the Lake Michigan shoreline. The helicopter's onboard camera took thousands of aerial photos that the researchers will use to map all locations of Pitcher's thistle, a threatened native plant that grows on beaches and grassland dunes along the shoreline of Lake Michigan. Credit: Steve Jessmore/Central Michigan University

Benjamin Heumann, director of Central Michigan University's Center for Geographic Information Science, led a team of geography graduate students at Wilderness State Park near Carp Lake. They flew a vertical camera on board a helicopter UAS, which took thousands of aerial photos that the researchers will use to map all locations of Pitcher's thistle.

For more information, visit *http://media.cmich.edu/news/science-in-the-sky*.

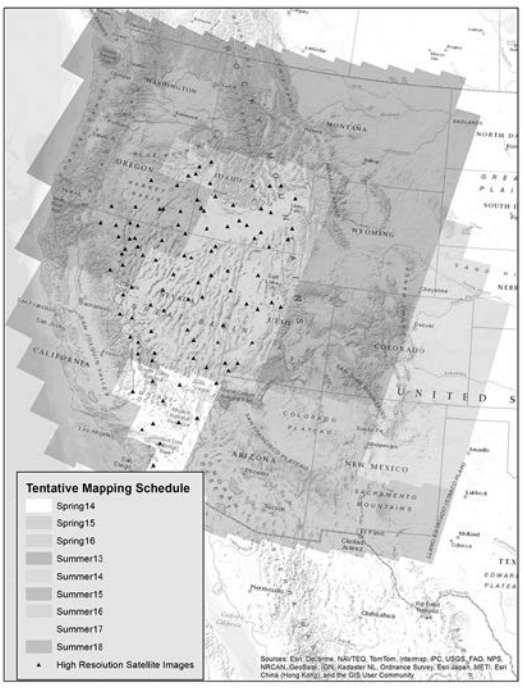
Bureau of Land Management

The Bureau of Land Management (BLM) requires field-based measurements to support management decisions covering vast expanses of land. By integrating remote sensing into 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. BLM is developing a core set of integrated and scalable remote sensing tools that will provide an integrated, quantitative monitoring approach to efficiently and effectively documenting the impacts from authorized and unauthorized disturbance and land-treatment activities at local and regional scales.

Remote Sensing Characterization and Monitoring of Shrubland/Grassland Components Across the Western United States

BLM has partnered with the USGS and the Multi-Resolution Land Characteristics Consortium (MRLC) in a multi-year mapping and monitoring program to better characterize shrubland and grassland ecosystems in the western United States. For several management objectives in semi-arid to arid ecosystems,

BLM requires more detailed information about land cover and vegetation than is currently offered in existing national products (e.g., the National Land Cover Database [NLCD] and the Landscape Fire and Resource Management Planning Tools Project [LANDFIRE]).



This map depicts the tentative schedule for the grass/shrub mapping effort.

To address this need, BLM began collaborating in 2013 with the USGS and MRLC to create remote sensing–based products showing western shrublands and grasslands at 2-meter and 30-meter spatial resolutions that quantify per-pixel estimates of several main shrubland components, including total shrubs, sagebrush, herbaceous cover, annual vegetation cover, litter, bare ground, and shrub height. Although mapping the entire western United States with these methods will take approximately five years to complete, the project will provide valuable baseline data and the ability to monitor the landscape components long-term. This project is a key component of BLM's landscape monitoring strategy and integral to the Bureau's efforts within the sage-grouse initiative.

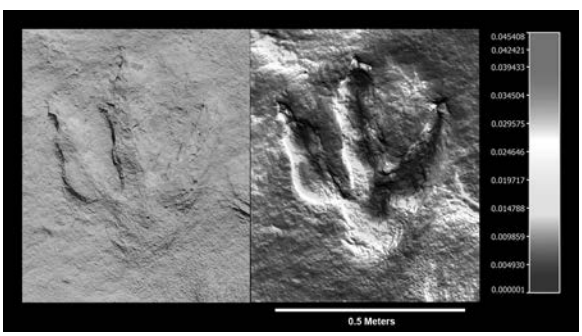
Initial products were developed in 2013 for southwestern Idaho, southeastern Oregon, northwestern Nevada, and northeastern California. This initial mapping area was used to develop and refine operational procedures for mapping in subsequent years. The 2014 products include the Mojave Desert, the Great Basin, western Utah, and southern Idaho, which cover significant portions of greater sage-grouse and desert tortoise habitats. The products derived from this mapping effort will be integrated into the NLCD for future updates and used to improve characterization of grassland and shrubland ecological systems within the LANDFIRE program.

BLM/BIA Cadastral Surveys with Remote Sensing Imagery Assistance

BLM Utah is currently involved in ongoing survey projects with the Bureau of Indian Affairs (BIA). Many of the rivers are located in very steep sandstone cliff formations that are hundreds of feet deep and are dangerous or inaccessible to surveyors. To delineate the current shorelines of some of the most challenging areas along the San Juan and Green Rivers, we used National Agriculture Imagery Program (NAIP) 2011 imagery. The imagery was georectified using ground survey data—X, Y, and Z coordinates—collected at accessible field points that were distinctive on the aerial photographs. We used image processing within a Geographic Information System (GIS) environment to georectify the NAIP 1-meter imagery by matching control point locations on the imagery model to the survey data. The shoreline was manually digitized from the rectified aerial photography, creating a linear dataset, which was then reincorporated into the cadastral model.

State-of-the-Art Techniques Used to Document New Dinosaur Tracksite in Moab Field Office

In 2009, a remarkable new dinosaur tracksite was discovered by BLM staff on lands administered by the Moab Field Office. The Mill Canyon Dinosaur Tracksite is one of the largest multitaxic tracksites in North America, preserving 10 different types of tracks, including those of various dinosaurs, birds, and crocodiles. Over 200 tracks are preserved in an area of approximately 500 square meters in the 112-million-year-old Lower Cretaceous Ruby Ranch Member of



On the left is a photogrammetric image of a large theropod track from the Mill Canyon Tracksite. Distortions from camera lens have been removed from this image, making precise direct measurements of length and width possible. On the right is a photogrammetrically derived, three-dimensional digital-point cloud that duplicates the surface at a submillimeter level. This track is just over 3 centimeters at the deepest point.

the Cedar Mountain Formation. The site is being studied by an international team, led by Dr. Martin Lockley of the University of Colorado at Denver.

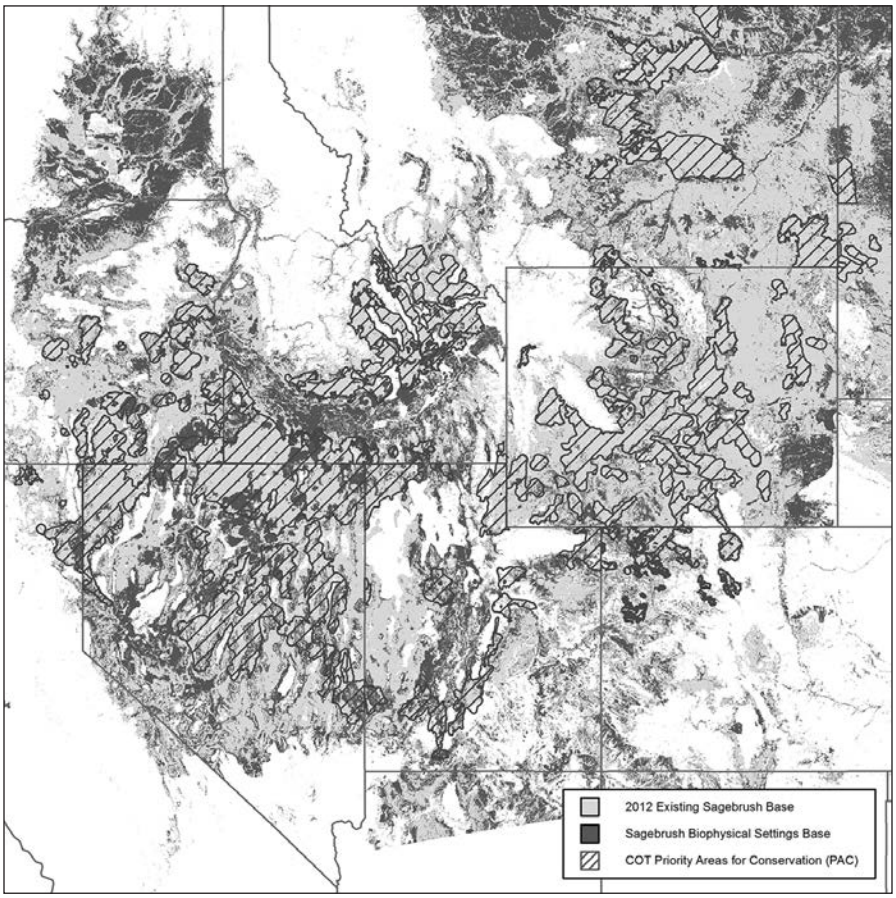
Starting in 2013, BLM's National Operations Center (NOC) and Wyoming State Office worked to thoroughly document the site with stereo photography. Digital images were processed using photogrammetric software to render high-resolution, three-dimensional images of the surface and associated tracks. This imagery will be used by BLM for documentation, research, monitoring, and management purposes.

Remote Sensing–Based Indicator for Mid-Scale Monitoring of Sagebrush Habitat

The BLM and USFS Greater Sage-Grouse Monitoring Plan is designed to monitor the implementation and evaluate the effectiveness of actions to conserve the species and its habitat. A multi-scale monitoring approach is necessary as sage-grouse are a landscape species, locating themselves within the environment based on a hierarchy of features from broad-scale to site-specific. Conservation is therefore scale-dependent, and conservation actions to benefit populations are implemented within seasonal habitats.

Sage-grouse populations have been found to be more resilient in areas where an adequate percentage of the landscape is sagebrush. The current geographic extent of sagebrush vegetation within the rangewide distribution of sage-grouse populations was derived from the Existing Vegetation Type (EVT) layer in LANDFIRE (version 1.2). From LANDFIRE EVT, sage-grouse experts identified the ecological system attributes that could potentially support sagebrush vegetation and provide suitable seasonal habitat for the sage-grouse. A total of 20 ecological systems were used to derive the sagebrush vegetation layer.

This sagebrush layer (see figure) allows the estimation of existing sagebrush percentage, as well as other landscape indicators, such as patch size and number, patch connectivity, linkage areas, and landscape matrix and edge effects. As conservation and restoration efforts change land use and land cover, the sagebrush layer will be updated in synchrony with LANDFIRE updates, allowing the determination of trends in cover across a variety of reporting scales.



This map displays the final 2012 sagebrush base layer, which shall be updated over time to monitor the availability of sagebrush for sage-grouse planning efforts. For reference purposes, the LANDFIRE BioPhysical Setting is also displayed and highlights large chunks of sagebrush that have been lost.

U.S. Bureau of Reclamation

The Bureau of Reclamation (BOR) 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 interbasin water compact compliance. The BOR 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 Monitoring and Water-Use Estimates

The Colorado River is the principal source of water for irrigation and domestic use in Arizona, southern California, and southern Nevada. In order to account for water use by each state and individual water user and to verify fallowed lands for conservation programs and other water management analysis needs, the Bureau of Reclamation routinely monitors more than 3.5 million acres of agriculture and riparian vegetation along the Lower Colorado River from the Hoover Dam south to the international border. Multispectral satellite images are analyzed in combination with other spatial data in a GIS environment to generate information regarding crop and riparian types, acreages, and associated water-use estimates. This information assists the BOR in meeting its U.S. Supreme Court mandate to provide detailed and accurate records of diversions, return flows, and consumptive use estimates of water diverted from the mainstream of the Lower Colorado River. For more information, visit *http://www.usbr.gov/lc/region/g4000/wtracct.html*.

Siletz River Terrain

The Siletz River is located in west-central Oregon. The Siletz Tribe has requested technical assistance through the BOR's Tribal Assistance Program to evaluate hydraulic and geomorphic processes along the Siletz River. Historical aerial photos of the river will be evaluated to document geomorphological changes and the spread of invasive species over several decades. Bathymetric survey data will be combined with lidar data to build a complete topographic surface from which cross-section geometry data will be extracted and used to support hydrologic modeling of the river. The technical information from the evaluation will help guide the development of management alternatives to improve salmonid habitat in the study area.

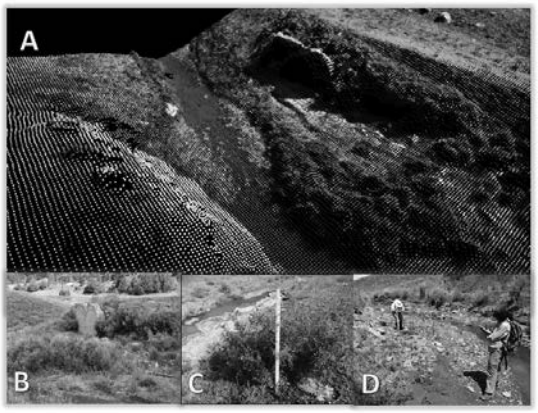
Office of Surface Mining Reclamation and Enforcement

The Office of Surface Mining Reclamation and Enforcement (OSMRE) remote sensing program provides OSMRE 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 of 1977 (SMCRA). As part of this support, the OSMRE remote sensing program provides high-resolution satellite imagery, aerial photography, and lidar data to conduct analyses 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.

Unmanned Aircraft System for Stream and Coal Waste Reclamation

This project explores the use of a UAS to map stream channel morphology and monitor revegetation at the Dillon and Dutchman Canyons, which were once part of a larger coal-mining site in Vermejo Park Ranch, near Raton, New Mexico. A fixed-wing Trimble UX5 Aerial Imaging Rover UAS with a 1-meter wingspan and electric pusher propeller was deployed at the site in August 2014. A 16.1-megapixel compact camera (with a 15-millimeter lens) mounted in the UX5 was used to take high-resolution images along a programmed 30-minute flightpath over the 0.16-square-mile reclamation study area. Several geographically overlapping images were used to generate a dataset of points with XYZ values. Each point was attributed with Red, Green, and Blue spectral values and classified as either bare ground or vegetation. Vegetation height was summarized by subtracting the elevation between points classified as bare ground from those classified as vegetation. Ground



A. This image shows a point cloud of XYZ locations of a section of the stream in Dillon Canyon. The 3D representation is viewed in Global Mapper version 15.2. B. This photo shows the ground of the same section with a close-up of willows (5–10 feet tall) and archaeological structure. C. This image displays data validation of vegetation species, height, diameter, and GPS location. D. Researchers take stream cross-section measurements to compare with a topographic surface model.

control produced a mean 0.44 (± 0.23)-foot vertical accuracy, and at-ground sensor resolution was 0.13 foot. Ground validation included vegetation sampling and stream channel cross-sections. The data will be used to map the topography of the post-construction reclamation and aid the vegetation classification of a WorldView2 satellite image acquired within two weeks of the UAS deployment. Compared to both traditional aerial photogrammetry and satellite imagery, the increased spatial resolution of UAS-acquired imagery is anticipated to add significant value to reclamation monitoring as well as the detection of mining and archaeological features. For more information, visit *http://www.emnrd.state.nm.us/MMD/AML/amlmain.html*.

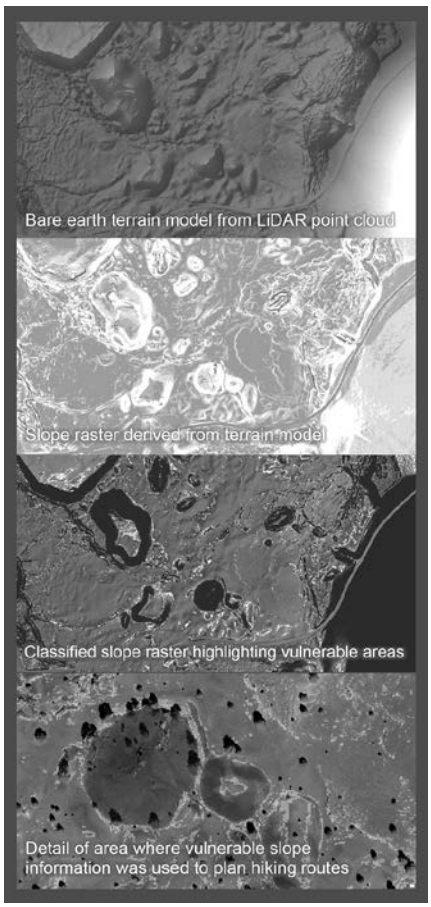
National Park Service

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. The 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.

Classifying Slope in Sensitive Volcanic Terrain Using Aerial Lidar Data

Sunset Crater Volcano National Monument, located near Flagstaff, Arizona, is composed of many unique and sensitive volcanic features. Recreational activities, such as off-trail hiking, have the potential to degrade these features, especially on steep and barren slopes of unconsolidated volcanic scoria, cinder, and ash. Many of

these features are on a scale not captured in the available 10-meter-resolution elevation models. Funding from the NPS Intermountain Region Natural Resource Small Park Program was used to acquire new aerial lidar over 10,000 acres at an average density of 8 points per meter. The 0.5-meter-resolution data were classified to generate bare-earth terrain models. Based upon observations of erosion on existing trails, areas classified with slope exceeding a threshold of 14 percent were identified as vulnerable to erosion. Monument managers are using this information to plan trails and backcountry access. The lidar dataset covered the entire monument area and has potential uses for other programs, such as preserving cultural resources, managing vegetation, and planning for new facilities.



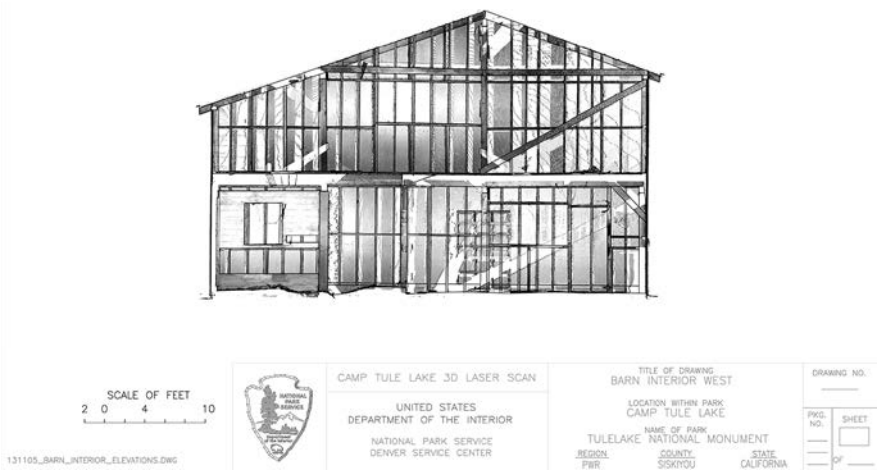
This figure shows a general analysis sequence used to identify vulnerable areas.

Terrestrial Lidar Scanning to Document Historic Structures at Camp Tulelake

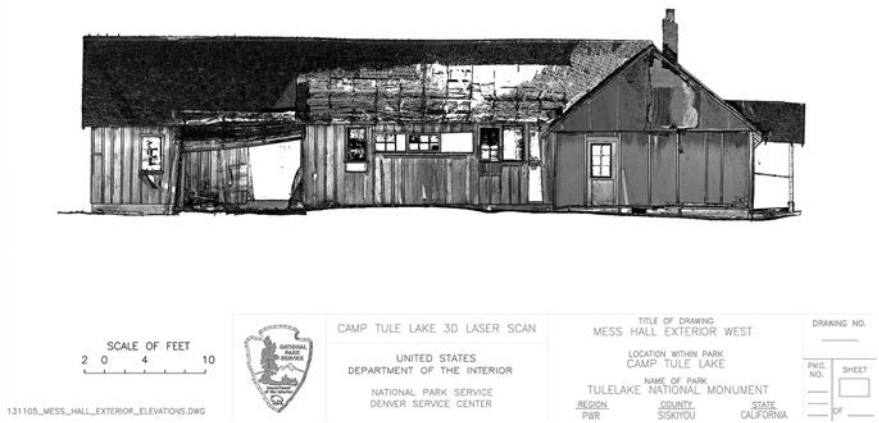
The Tule Lake Unit of the World War II (WWII) Valor in the Pacific National Monument is documenting the current condition of three historic structures at the Camp Tulelake area of the monument using terrestrial lidar. The lidar data were acquired by Epic Scan of Medford, Oregon, in cooperation with the Oregon Institute of Technology. During WWII, Camp Tulelake was converted from a former California Conservation Corps camp to a high-security prisoner of war (POW) camp, first housing Italian POWs and then German POWs. The camp was also used at various times to house Japanese American strikebreakers and other prisoners from the nearby Tule Lake Segregation Center, a Japanese American

confinement site during WWII. The monument's staff is developing a General Management Plan to determine the future disposition and use of these structures.

To support management planning and the process of nominating the site to the National Register of Historic Places, detailed drawings of the structure's existing conditions are required. The three structures are in varying stages of deterioration, and high-resolution laser scan data were collected to create orthographic drawings and 3D visualizations of the three structures. Data collected from this project, along with the drawings, will be crucial for the development of plans for stabilization and possible restoration of the structures.



This barn interior elevation view shows surface coverings and extracted framing.



This mess hall exterior elevation view shows surface coverings and extracted building feature outlines.

Federal Communications Commission

FCC

The Federal Communications Commission (FCC) formulates rules to facilitate the provision of commercial satellite services in the United States. It also issues licenses for the deployment and operation of all nongovernmental U.S. satellites. Internationally, the FCC coordinates satellite radio-frequency usage with other countries. The FCC's accomplishments for FY 2014 related primarily to commercial communications and remote sensing satellites, as well as amateur and experimental satellites.

The FCC took several significant actions in administrative and rule-making proceedings in FY 2014. On November 1, 2013, the FCC proposed rule changes that would allow GlobalStar, Inc., to operate a low-power, terrestrial-based network using portions of the radio-frequency spectrum licensed to it in the 2.4-gigahertz (GHz) range, as well as adjacent unlicensed frequencies in that range.

On December 12, 2013, the FCC proposed rules to modify restrictions on the airborne use of mobile devices. The proposed rule changes addressed radio-frequency aspects of such operations, but consumer use of mobile devices aboard airborne aircraft would be subject to individual deployment decisions by airlines and by any Federal Aviation Administration (FAA) and Department of Transportation (DOT) rules limiting such use. Also relevant to communications during flight, the FCC issued rules on April 17, 2014, giving primary status in the 14.0- to 14.5-GHz radio-frequency band to earth stations aboard aircraft. This primary allocation will facilitate the availability of in-flight Internet service for passengers and crew aboard commercial and private airplanes.

On September 30, 2014, the FCC proposed changes to satellite licensing rules. The proposed changes sought to revise or streamline many licensing and operating rules for satellites and earth stations in order to facilitate the introduction of new satellite services, lower costs and regulatory burdens, and promote competition among satellite communication service providers. One proposal sought to reduce delays for U.S. satellite operators filing with the International Telecommunication Union (ITU) and thereby achieve an improved negotiating posture in the international coordination process. Other proposed revisions focused on the performance bond required in connection with satellite authorizations and on technical rules concerning 2° spacing between certain geostationary satellites.

The FCC authorized a number of commercial communication satellite deployments and operations. These authorizations included the following:

- December 16, 2013: To Intelsat License, LLC, to construct, deploy, and operate a Ka-band satellite at the longitude 89.1° west orbit location. Intelsat License, LLC, subsequently surrendered that authorization at the deadline for submitting the required performance bond.
- April 4, 2014: To SES Americom, Inc., to operate the SES-3 satellite, located at the longitude 103.1° west orbit location, for telemetry, tracking, and command, and to use the Ku-band to prepare for later operations as a replacement C-/Ku-band satellite. The FCC also exchanged letters with Canada's licensing authority, Industry Canada, concerning the current and anticipated operations of the SES-3 satellite, which includes a station licensed by Industry Canada.
- August 14, 2014: To Intelsat License, LLC, to construct, deploy, and operate a C-/Ku-band satellite at the longitude 95.05° west orbit location.

During FY 2014, the FCC continued to authorize amateur and experimental operations by nongovernmental small satellites, which includes satellites within the categories of picosatellites, nanosatellites, and CubeSats. These satellites operate in low-Earth orbit. Many of the experimental licenses were given to universities and research institutions seeking to provide educational opportunities for engineering students or for purposes of technology demonstration. The satellites' missions included performing geospatial imaging, monitoring solar radiation, detecting particles, testing two-way communications between satellites, gathering data that

may be useful in predicting meteorological events, and testing emerging technologies for future missions. On December 3, 2013, the FCC granted its first commercial service license involving CubeSats to Planet Labs, Inc., for the deployment and operation of multiple CubeSats for Earth imaging. This initial authorization involved the deployment of the satellites from the International Space Station. The FCC authorized an additional deployment on June 18, 2014. During a three-month period in late 2013 and early 2014, three launches placed more than 100 small satellites in orbit for a variety of U.S. and international operators. More than half of the satellites were authorized by the FCC.

In FY 2014, the FCC also authorized communications operations for commercial space launches by Orbital Sciences Corporation and SpaceX, including for cargo supply missions to the International Space Station and for the launch of the commercial SES-8 satellite to geostationary orbit.

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 23, 2013: The FCC granted authority to Intelsat License, LLC, to operate its satellite, Intelsat 10, at the longitude 47.5° east orbit location in accordance with the ITU filings of Germany.
- January 30, 2014: The FCC granted Iridium Constellation, LLC, authority to reconfigure its constellation of low-Earth orbit satellites by operating some satellites in tandem arrangements with existing satellites that are partially impaired.
- February 20, 2014: The FCC authorized DIRECTV to reorient its DIRECTV 5 satellite in order to improve signal reception in Puerto Rico.
- June 6, 2014: The FCC authorized DG Consents Sub, Inc., to modify the orbit of a satellite within its system of Earth exploration satellites in order to achieve optimal imaging and satisfy its contractual agreements with other Federal agencies.
- July 30, 2014: The FCC authorized EchoStar to repoint its EchoStar 15 satellite at the longitude 45.1° west orbit location in order to optimize service coverage for Brazil.

- July 31, 2014: The FCC authorized Iridium Constellation, LLC, to modify its orbital debris mitigation plan for up to 10 satellites in its existing low-Earth orbit satellite system. The revised plan involves the disposal of the satellites in an orbit that will result in reentry into Earth's atmosphere within 25 years, rather than the approximately 2 years specified in the prior plan. This modification enables that group of 10 satellites to continue providing service after the originally planned date for disposal while Iridium Constellation, LLC, constructs and launches new satellites, planned for deployment by May 2017. The remainder of the original satellites in the system will be disposed of according to the prior plan.
- August 11, 2014: The FCC authorized EchoStar Satellite Operating Corporation to operate its EchoStar 6 satellite at the longitude 96.2° west orbit location. The operations are part of a cooperative arrangement between EchoStar and SES Satellites (Bermuda), Ltd., which is authorized by Bermuda to operate a satellite network at the longitude 96.2° west orbit location.

The FCC added several non-U.S.-licensed space stations to its permitted space station list to allow the space stations to provide domestic and international satellite service to U.S. earth stations that have routine technical parameters, as follows:

- December 12, 2013: The FCC added ViaSat, Inc.'s planned VIASAT-2 satellite to the permitted list, operating under the authority of the United Kingdom and using the Ka-band at the longitude 69.9° west orbit location.
- December 12, 2013: The FCC added ViaSat, Inc.'s planned VIASAT-3 satellite to the permitted list, operating under the authority of the United Kingdom and using the Ka-band at the longitude 79.3° west orbit location. ViaSat, Inc., subsequently declined that grant at the deadline for submitting a required performance bond.
- December 20, 2013: The FCC added HISPASAT, S.A.'s satellite Amazonas-1 to the permitted list, operating under the authority of Spain and using the Ku-band at the longitude 36.0° west orbit location. Amazonas-1 was subsequently removed from the permitted list on June 12, 2014, because it was no longer operating at the longitude 36.0° west orbit location.

- February 4, 2014: The FCC modified the permitted list to reflect the relocation of the New Skies Satellites B.V. NSS-806 satellite, operating under the authority of the Netherlands and using the C-/Ku-band, to the longitude 47.5° west orbit location.
- June 18, 2014: The FCC added ViaSat, Inc.'s planned VIASAT-KA 89W satellite, operating under the authority of the United Kingdom and using the Ka-band at the longitude 88.9° west orbit location, to the permitted list.
- September 18, 2014: The FCC added Inmarsat Hawaii's planned INMARSAT-KA 63W satellite to the permitted list, operating under the authority of the United Kingdom and using the Ka-band at the longitude 62.85° west orbit location. Inmarsat Hawaii subsequently surrendered that authorization at the deadline for submitting a required performance bond.

On May 14, 2014, the FCC also granted O3b Limited a rule waiver to permit it to test a new maritime satellite communication service to passengers and crew. The O3b satellite system is authorized by the United Kingdom to operate in the Ka-band.

U.S. Department of Agriculture

USDA

Farm Service Agency

Geospatial systems and data played a fundamental role in the management of Farm Service Agency (FSA) programs in 2014. Since the 1930s, the agency has been tasked with administering farm commodity, credit, conservation, disaster, and loan programs as laid out by Congress through a network of Federal, state, and county offices.

FSA's core spatial dataset, the Common Land Unit (CLU) layer, a nationally consistent digital dataset representing farm and field boundaries, was integrated with associated nonspatial farm data in a common foundational system in 2014. This major modernization effort allowed field offices to update farm, producer, and CLU records through a common process, improving data accuracy and update timeliness.

Remotely sensed data, such as from Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Wide Field Sensor (AWiFS), and locally collected high-resolution aerial imagery are examples of imagery sources used during periods of 2014 disaster recovery to support disaster programs such as Emergency Loan and Emergency Conservation Programs.

As the primary source of aerial imagery for the U.S. Department of Agriculture (USDA), FSA administered the National Agriculture Imagery Program (NAIP), leveraging partnership funds from other Federal, state, and local entities to acquire imagery during the growing season over the continental United States. In 2014,

FSA acquired nearly 1.5 million square miles of four-band (natural color and near-color infrared) imagery in 23 states. FSA also began to pilot a unique and innovative addition to NAIP in 2014 called the Early Access Web Services (EAWS). EAWS provided minimally processed NAIP imagery via Web service protocols on average between two and seven days after acquisition. This practice allowed FSA and partner agencies to perform time-sensitive work with the most current imagery available months in advance of receiving production-level NAIP imagery. In addition to distributing the most up-to-date NAIP imagery, FSA also hosted a large imagery archive that was accessible to Federal agencies and the public through the USDA Geospatial Data Gateway.

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 for the World Agricultural Outlook Board (WAOB), the primary source of the USDA's global commodity outlook. The outlook reports provided public access to information affecting world food security and were crucial in decisions affecting U.S. agriculture, trade policy, and food aid. The reports' contents included regional, national, and subnational monitoring and analysis of crop conditions, yield potential, and the impact of events affecting crop production.

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 monitor; and vegetation index monitor. The successful production of agricultural commodity outlook and the maintenance of global agricultural datasets were fulfilled using a variety of satellite Earth observation data. These included information from NASA's Earth satellite-observing systems (Landsat, MODIS Aqua and Terra, Topography Experiment [TOPEX]/Poseidon, Jason, and Tropical Rainfall Measuring Mission [TRMM] satellites), NOAA's satellite data (Advanced Very High Resolution Radiometer [AVHRR]), and other international datasets (Indian Remote Sensing [IRS]–AWiFS, Linear Imaging Self-Scanner [LISS], Satellite Pour l'Observation de

la Terre [SPOT] 4 and 5, Deimos-1, and UK-DMC2). The Deimos-1 and UK-DMC2 satellite imagery was primarily used to study and analyze the 2014 U.S. crop season, an annual comprehensive program undertaken by the National Agricultural Statistics Service (NASS).

The 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 USDA-wide cost-effective data-sharing of satellite data through the centralized purchasing, receipt, inventory, storage, and dissemination of satellite imagery to USDA agencies. The following agencies participated in the program: the Foreign Agricultural Service (FAS), the Risk Management Agency (RMA), the National Agricultural Statistics Service (NASS), the Forestry Service (FS), the Natural Resources Conservation Service (NRCS), the Agricultural Research Service (ARS), and the 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 this period of reporting, the USDA satellite imagery library enabled 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/*. The Archive Explorer, a Web-enabled browse-and-search tool, allowed users to browse, select, and retrieve the contents of the Satellite Imagery Archive.

USDA National Agricultural Statistics Service

NASS used remote sensing data to construct and sample area frames for agricultural statistical surveys, estimated crop area and yield, and continued contributing to a NASA science grant on fallowed California agricultural land. Additionally,

NASS published papers on a new automatic stratification method, enhancing agricultural geospatial data dissemination using geospatial Web services. and making the Cropland Data Layer (CDL) accessible and actionable in education. NASS used remote sensing data and techniques to improve the quality and accuracy of its agricultural statistics. For example, NASS used Landsat imagery, digital NAIP orthophoto quadrangles, and other remotely sensed inputs for the contiguous United States (CONUS) and Puerto Rico to select the yearly area-based samples for the June Agricultural Survey. In addition, NASS updated new area-based sampling frames for Alabama and North Carolina.

NASS fully implemented the CDL-based automated stratification method into area frame operations, with new state area frames built at reduced cost with improved objectivity, efficiency, and accuracy. The CDL data are used as the basis for the objective stratification of NASS Area Frame primary sampling units rather than visual interpretation of aerial photography or satellite data.

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 2014 crop year. Acreage estimates were created for 17 different crops covering all market-sensitive crops and states. With the expanded coverage and timeliness, NASS's Agricultural Statistics Board (ASB) was able to utilize the remote sensing acreage indications as independent input for setting the official estimates for its monthly Crop Production Reports. Analysts derived remote sensing–based acreage indications from the CDL. Primary satellite imagery inputs were from the Foreign Agricultural Service's Satellite Imagery Archive, which provided 1,562 DMC images through a cooperative partnership while utilizing 6,624 Landsat 8 images from the U.S. Geological Survey. In addition, NASS distributed the CDL for 48 states to stakeholders for the previous 2013 crop season via the USDA Geospatial Data Gateway and the CropScape data visualization portal at *http://nassgeodata.gmu.edu/CropScape*.

NASS utilized NASA 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 served as an independent variable for yield estimation.

The Web-based national vegetation condition geospatial portal VegScape (*http://nassgeodata.gmu.edu/VegScape*) continued to deliver timely crop condition vegetation indices based on MODIS daily, weekly, and biweekly products throughout the growing season. VegScape showed crop condition/vegetation greenness and drought anomaly assessments. NASS continued work on a NASA science grant titled "Fallowed Area Mapping for Drought Impact Reporting and Decision Making," to which NASS contributed monthly growing season CDL-based fallowed land estimates for California water resource stakeholders.

Forest Service

As the primary forestry agency of the United States and the largest agency in the USDA, the U.S. 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 accomplishing 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 uses to meet the diverse needs of people. Lastly, USFS S&P provides assistance to private land owners 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 information needs of these USFS mission areas in FY 2014, the USFS collaborated with NASA, NOAA, the USGS, and other agencies to apply

operational satellite and airborne imagery and the most advanced remote sensing and geospatial technologies. Specific FY 2014 USFS accomplishments are summarized below.

- Collected comprehensive Earth Observing System (EOS) MODIS and Suomi National Polar-orbiting Partnership (Suomi NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) direct broadcast data for the United States and Canada, as well as operational processing and dissemination of near-real-time fire mapping and geospatial data products to fire managers and the general public (*http://activefiremaps.fs.fed.us*).
- Continued activities with NASA Goddard Space Flight Center's 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 operational processing and analysis of MODIS imagery for detection of forest damage and changing forest health conditions in our Nation's forests (*http://foresthealth.fs.usda.gov/portal/Flex/FDM?dL=0*).
- Continued to distribute 250-meter forest attribute data surfaces derived from MODIS imagery and other geospatial predictor data using nearest neighbor imputation methods (*http://data.fs.usda.gov/geodata/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://data.fs.usda.gov/geodata/rastergateway/biomass/index.php*).
- Continued conducting operational crewed wildfire mapping missions in FY 2014 using the Autonomous Modular Sensor (AMS) via coordination between the USFS, NASA Ames Research Center, and the NASA Airborne Sciences Program.
- Coordinated with NASA Ames Research Center in FY 2014 to further develop the AMS onboard processing system capabilities and user

interface to support additional testing and integration flights on USFS aircraft for eventual operational use in FY 2015.

- Continued coordination with NASA Goddard Space Flight Center 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 NASA Goddard Space Flight Center to evaluate test data collected by the Goddard LiDAR Hyperspectral and Thermal (G-LiHT) sensor for potential land remote sensing and resource management applications.
- Operationally applied Earth Observing-1 (EO-1) Advanced Land Imager (ALI), Landsat 7 Enhanced Thematic Mapper (ETM), and Landsat 8 Operational Land Imager (OLI) imagery to respond to approximately 160 requests by the USFS to map the location, extent, and severity of large wildfires in 2013 and 2014 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 Thematic Mapper (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 2014 include the completion of 18,500 historical fires (~130 million burned acres) spanning 1984 to 2013 (*http://www.mtbs.gov*).
- Coordinated with the University of Maryland and NASA to implement the 375-meter VIIRS I-band active fire detection product as part of operational USFS strategic fire detection and monitoring program activities (*http://activefiremaps.fs.fed.us*).
- Coordinated with the University of Maryland, NASA, and the USGS to execute and test Landsat 8 prototype active fire detection algorithms and evaluate derived output products to support USFS operational fire support activities.

- Continued technology transfer activities between the USFS and NASA Ames Research Center regarding unmanned aircraft systems (UASes) 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 NASA Ames Research Center on advancing the Wide Area Imager (WAI) (developed under the NASA Small Business Innovation Research [SBIR] program) to a higher technical readiness level (TRL) and phasing into USFS tactical fire-mapping operations in FY 2015–16.
- Used Landsat 5 TM, Landsat 8 OLI, and National Agriculture 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 contiguous United States and Alaska as part of the Multi-resolution Land Characteristics Consortium (MRLC) National Land Cover Database 2011 update.
- 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 present. This activity has been extended to include Lake Huron, Lake Erie, and Lake Ontario and will include implementing automated change-detection capabilities in Google Earth Engine.
- Used Landsat TM/ETM/OLI and NAIP imagery in conjunction with other core geospatial datasets to conduct ecological and soil-type mapping on NFS lands, which 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 generate forest-disturbance products based on analysis of Landsat TM/ETM time-series stacks using the Vegetation Change Tracker (VCT) 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 (e.g., defining acquisition specifications, performing data quality assessment, and creating analysis/modeling procedures for forest parameters). This work is relevant to recent and potential USFS–NASA JPL lidar collaboration, such as the acquisition and processing of hyperspectral imagery (AVIRIS) and lidar data for the 2013 Rim Fire and 2014 King Fire in California.
- Identified potential partnership opportunities with the NASA Applied Remote Sensing Training (ARSET) program that would enhance NASA and Forest Service Remote Sensing training programs and leverage existing Forest Service training investments to increase awareness about emerging technologies and practical resource applications.

National Science Foundation

NSF

The National Science Foundation (NSF) continued to serve as the lead Federal agency for the support of ground-based astronomy and space science. Through the divisions of Astronomical Sciences, Atmospheric 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.

AST, in partnership with Europe, Canada, Japan, and Taiwan, brought construction close to completion on the Atacama Large Millimeter/submillimeter Array (ALMA), an interferometer located near San Pedro de Atacama, Chile. FY 2014 saw the delivery of the remaining site infrastructure. 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; previously referred to as the Advanced Technology Solar Telescope, or ATST), the next-generation U.S. ground-based solar telescope. The DKIST, the result of collaboration by scientists from more than 20 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 DKIST 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 August of 2013, the National Science Board approved a new baseline cost for the DKIST project of $344.13M. The fabrication of the major telescope subsystems and instruments is ongoing, as is construction of the facility on the Haleakala site. The project is currently on budget and is scheduled to begin operations by mid-2019. Construction of the DKIST facility is led by the National Solar Observatory (NSO). In August of 2014, the National Science Board approved the renewal of the cooperative agreement for the operations and management of the NSO for a period of 10 years. The approved budget includes a funding ramp for the DKIST operations beginning in FY 2015 and increasing to a steady-state cost of approximately $17 million in FY 2019, with costs beyond 2019 adjusted for inflation.

Through its funding of the NSO, AST also supports continuous long-term observations of the sun vital to the accurate prediction of space weather. The NSO Integrated Synoptic Program (NISP) consists of the Synoptic Optical Investigations of the Sun (SOLIS) telescope and the six international stations of the Global Oscillations Network Group (GONG) located in California, Hawaii, Western Australia, India, the Canary Islands, and Chile. The NISP program provides detailed synoptic solar data to support space weather researchers in their

efforts to understand solar eruptions and their effect upon Earth and to apply that knowledge to the protection of satellites, astronauts, land-based power systems, and Earth's climate.

FY 2014 was a very successful year for the Large Synoptic Survey Telescope (LSST) project, starting with NSF's Final Design Review in December 2013, leading to National Science Board approval in May, and culminating in a construction award from NSF's Major Research Equipment and Facilities Construction account on August 1, 2014. This project will use a purpose-built wide-field survey telescope and a 3.3-gigapixel camera supplied by NSF's Federal partner, the Department of Energy (DOE) Office of High Energy Physics (HEP), to image the entire accessible sky repeatedly for at least 10 years, producing 20 to 40 terabytes of data every night. 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. As well, LSST opens up the time domain and will revolutionize the study of transient events. DOE's camera, led by the Stanford Linear Accelerator Center (SLAC) National Accelerator Laboratory, has been under development for several years and will shortly start Major Item of Equipment funding. The review to set the final camera cost and the approval of that not-to-exceed number are planned for early in FY 2015. Planning and coordination between the agencies have led to the current construction schedule, with engineering "first light" expected in FY 2020. Two years of commissioning is needed to ensure robust, reliable functioning of the end-to-end system so that the survey can start relentless observing, night after night, in 2022. The NSF's responsibilities include the telescope, the site, and data management, including separate specialized access for research and for education and public outreach uses. As noted, DOE's HEP is supplying the camera. Private funding has been crucial for early, long-lead-time items, especially the innovative primary-tertiary mirror. The two agencies will support installation and commissioning. Operations funding from the agencies will be augmented by several international partners, whose contributions are currently being negotiated. LSST continues to attract strong support from the research and education communities worldwide.

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 (CMB, 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 2014, the project fielded, observed with, and analyzed data from a new type of camera called ACT Polarimeter (ACTPol), measuring the best spectrum of cosmic background E-mode polarization yet made. 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, like ACTPol, the polarization of 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 cosmic inflation if detected. Unlike previous CMB 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 2014, the project made the first independent (i.e., not reliant on correlations with other datasets) detection of B-modes caused by gravitational lensing of the CMB. This is an interesting finding in itself and a step toward the detection of primordial B-modes that are a signal of gravitational waves produced during inflation. The lensing B-modes are at smaller angular scales than the hypothesized primordial ones, and by being somewhat less challenging to detect, they are an excellent test of the telescope and detector systems. (Other news on B-mode investigations can be found in the Division of Polar Programs section below.)

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 altitudes of up to 51,000 feet, and its ability to fly for long durations (over 12 hours) and long distances (over 6,000 kilometers) while carrying scientific payloads of up to 6,000 pounds has enabled scientific research previously not possible with existing platforms. During FY 2014, the GV conducted long-duration flights for the Deep-Propagating Gravity Wave Experiment over New Zealand (DEEPWAVE-NZ), carrying airborne lidars and a mesospheric temperature mapper to study the dynamics of gravity waves from Earth's surface through the lower thermosphere. The GV also participated in the Convective TRansport of Active Species in the Tropics (CONTRAST) campaign, in conjunction with NASA's Airborne Tropical TRopopause EXperiment (ATTREX) study using the Global Hawk aircraft based in Guam.

The AGS Geospace Section (GS) supported a wide variety of research programs in space science in FY 2014. 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 2014 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 2014, 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 2014 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 2014, 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 2014, GS continued to support its program for CubeSat-based small satellite science missions for geospace and atmospheric research and education. During FY 2014, two projects continued to operate successfully in space and two new missions were launched. All provided high-quality observations and scientific findings. Another two excellent CubeSat science projects were started in FY 2014, adding new capabilities and breadth to the overall CubeSat program that, with this addition, encompassed a total of 12 CubeSat projects.

GS continued support for the satellite-based Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) through FY 2014. 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 2010–13 have been made freely available to researchers, with new data being added continually. During FY 2014, a new five-year award was made for the continuation of the project as AMPERE-II.

The GS solar physics community also continued to benefit from the Division of Astronomical Sciences' ongoing efforts to develop and manage the DKIST (Daniel K. Inouye Solar Telescope) being constructed in Hawaii. Also in FY 2014, GS continued to provide oversight for much-needed upgrades at the Owens Valley Solar Array in California.

In FY 2014, 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 U.S. Air Force's (USAF) 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 2014, 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 2014, 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 with the battery of five small-aperture (25-centimeter) telescopes called the Small Polarimeter Upgrade for DASI (Degree Angular Scale Interferometer) (SPUD)/Keck Array. Currently, both the South Pole Telescope (SPT, with the SPTpol receiver) and SPUD are focused on cosmic microwave background (CMB) polarization measurements. The High Elevation Antarctic Terahertz (HEAT) robotic telescope at Ridge A continued data collection through FY 2014. The IceCube Neutrino Observatory (ICNO) also continued data collection of high-energy neutrino events through FY 2014.

Recent scientific results from SPT include publications on the rest-frame submillimeter spectrum of high-redshift dusty star-forming galaxies, as well as on the measurements of secondary CMB anisotropies from the 2,500-square-degree SPT-Sunyaev-Zel'dovich (SZ) effect survey. The SPT team is working hard at characterizing the CMB's B-mode polarization spectrum, cross-correlating their observations with the B-mode polarization data recently published by the Background Imaging of Cosmic Extragalactic Polarization 2 (BICEP2)/SPUD team. In March 2014, this team announced the detection of B-mode polarization at degree angular scales by BICEP2 and published a paper on the subject in *Physics Review Letters*. This announcement caused news headlines worldwide as the BICEP2 group claimed that they might have provided the first direct evidence of cosmic inflation by detecting in their data the imprints of primordial gravitational waves. These results are currently under scrutiny by other experiments, including SPTpol, POLARBEAR, and ACTPol instruments.

The IceCube Neutrino Observatory (jointly operated at the South Pole by PLR and the NSF's Division of Physics) has now collected data for almost four 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 reported in FY 2014 that more neutrino-induced, very-high-energy events were added to the previously published 28 events; a new

paper will be submitted for publication shortly. The team analyzed neutrino events that exceeded 50 teraelectronvolts (TeV) and came from anywhere in the sky. (One 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 recently discovered events are indicating that their likely origin is either from far away in the Milky Way Galaxy or from extragalactic events.

Department of State

DOS

The Department of State (DOS) 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 with 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 to make measured progress in this year's STSC and COPUOS sessions. Most notably, the Working Group's four expert groups completed their work on consensus reports containing recommendations for long-term sustainability guidelines. The work of the expert groups formed the basis for an extended set of informal and formal sessions of the full LTS Working Group during this year's COPUOS STSC and plenary sessions. These sessions provided an opportunity for all COPUOS members to review the chair's proposed consolidation of guidelines. DOS will continue with

its participation in the Working Group and informal meetings in FY 2015 to seek consensus on the guidelines.

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, in which the United States played a leading role. As a follow-on to the International Space Weather Initiative (ISWI), and with support from the United Nations (UN) Office for Outer Space Affairs, the U.S. organized a two-day expert meeting on the margins of STSC in 2014 titled "Improving Space Weather Forecasting in the Next Decade," which brought together 42 scientists from 21 countries. The meeting recommended continued access to observations of transients in the inner heliosphere; the hosting and sharing of data for space weather research and forecasting facilitated through existing virtual observatories; the continued deployment of new instruments, along with education and public outreach, through ISWI; and the improvement of forecasting and "nowcasting," including for space weather at other planets, with emphasis on supporting robotic exploration. The United States proposed to hold a special one-day workshop titled "Space Weather Services to Build Global Resilience," on the margins of the 52nd session of the STSC in 2015, as part of the Space Weather agenda item. The proposed workshop aims to enhance the participation of COPUOS member states in space weather service activities, consistent with the LTS proposed draft guidelines. The U.S. also engaged in side meetings with delegations from Canada, Japan, India, Pakistan, Iraq, South Africa, the Republic of Korea, and Saudi Arabia to promote cooperation in space weather research.

During the 53rd session of the LSC in 2014, 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," which has allowed the United States to maintain a leadership role in shaping the course of the LSC. The review 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. Also, during this year's LSC, under the agenda item entitled "General Exchange of Information on Non-Legally

Binding United Nations Instruments on Outer Space," DOS highlighted positive examples of U.S. cooperation and participation in international mechanisms and forums, demonstrating that much productive cooperation occurs through legally nonbinding mechanisms and providing information that may be useful to states with less experience in civil space cooperation.

The United States hosted the first-ever International Space Exploration Forum (ISEF) at the U.S. Department of State in Washington, DC, on January 9, 2014. DOS organized and chaired the forum, bringing together ministers and high-level officials from 35 spacefaring nations and international bodies to talk about the opportunities and challenges they share. It featured high-level policy discussions about the future of space exploration, developments in robotic space exploration, extending humanity's reach beyond low-Earth orbit, the role of commercial industry in space exploration, and the importance of international cooperation.

Keynote speeches were made by Deputy Secretary of State William Burns, NASA Administrator Charles Bolden, and Presidential Science Advisor John Holdren, who announced that the United States was committed to extending operations on the International Space Station until 2024. The ISEF participants agreed that space exploration benefits all humankind and that it is essential for governments to work together internationally to advance shared objectives for space exploration. Such collaboration has facilitated the development of new technologies, realized commercial opportunities, identified opportunities for shared missions such as the ISS, and inspired younger generations to undertake the challenge of space exploration.

In June 2014, the United States and the European Union (EU) held the third plenary session under the 2004 U.S.-EU Global Positioning System (GPS)-Galileo Cooperation Agreement. The goal of the plenary, chaired for the United States by the State Department, was to hear progress reports from working groups and provide updated guidance for future working group activities. Progress has been made in the working groups since the second plenary meeting on radio-frequency compatibility coordination, the use of GPS-Galileo Time Offset (GGOT) messages to improve interoperability, market access issues, the publication of an assessment of joint GPS-Galileo performance, the provision of integrity on the basis of combined

use of GPS and Galileo, and the definition of a global navigation satellite system (GNSS) Space Service Volume (SSV) to enable the use of GNSS services in the space domain out to geostationary orbit (GEO) altitudes.

The United States and the EU also held their seventh Civil Space Dialogue meeting in June 2014, chaired by the DOS and the European Commission. Topics of discussion included satellite-based search and rescue; future space research projects; and mutual concerns about space weather, Earth observation, and data-sharing policies. The parties also discussed preparations for the ninth meeting of the International Committee on GNSS (ICG), which will take place November 10–14, 2014, in Prague, noting European regulatory body development of standards for pseudolites that could potentially create harmful interference for GNSS signals and agreeing to closely coordinate in the run-up to the ICG meeting. The United States also affirmed its interest in negotiating possible access to the EU Galileo Public Regulated Service (PRS) signal and undertook exploratory talks with the EU Commission and various member states.

The DOS organized a half-day "U.S.-Japan Workshop on Satellite Remote Sensing" in Washington with a Japanese delegation of more than 20 officials and remote sensing experts. The workshop allowed a comprehensive discussion of U.S. and Japanese Earth observation programs including data policy and a long-awaited Japanese policy for licensing commercial remote sensing satellite systems. U.S. and Japanese civil remote sensing agencies restated their commitment to continue one of the world's most productive bilateral relationships on Earth observation.

In May 2014, the United States participated in the first formal bilateral meeting with China to discuss civil GNSS cooperation. Topics discussed at this meeting included compatibility and interoperability of civil signals between the BeiDou Navigation Satellite System (BDS) and GPS; their respective augmentation systems and civil aviation applications; monitoring and assessment; spectrum protection; interference detection and mitigation; ICG and associated Providers' Forum activities; and activities related to the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), the International Telecommunication Union (ITU), and other pertinent international multilateral forums. Following the meeting, a joint statement was signed, highlighting the intent to continue discussions and cooperation through regular meetings.

The DOS organized and cochaired the first U.S. and Republic of Korea civil space bilateral dialogue on July 1. The central focus of the dialogue was to discuss respective national space policy developments and explore potential areas of bilateral cooperation.

Finally, DOS continued to promote the use of GPS in Africa, 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 University of the Witwatersrand in South Africa and Pennsylvania State University in the United States; it is focused on supporting training and research in Earth, atmospheric, and space sciences in Africa. At the ninth AfricaArray annual meeting, held in January 2014 in Johannesburg, DOS facilitated the travel of scientists from many African countries to participate in workshops on GPS applications on a broad spectrum of Earth and space sciences.

Department of Energy

DOE

The Department of Energy (DOE) 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, the Office of Science, and the Office of Nuclear Energy.

Office of Defense Nuclear Nonproliferation Research and Development

The Nuclear Detonation Detection program builds the Nation's operational sensors to monitor the entire 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 (DNN R&D) 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 needs. Modern systems include capabilities to support military missions. 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 noncommercial 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 NuDets 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 (SC) 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 dynamo processes creating planetary/galactic magnetic field structures. Some specific examples are 1) large-scale plasma simulation codes that are applied to study space weather; 2) the Large Plasma Device (LAPD) at the Basic Plasma Science Facility (BaPSF) 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 Princeton Plasma Physics Laboratory (PPPL), which permits laboratory studies of magnetic reconnection and particle energization processes in Earth's magnetotail and solar flares; 4) the Magneto-Rotational Instability (MRI) facility, also at PPPL, which elucidates the physics of accretion disks around black holes; and 5) the Max Planck–Princeton Plasma Physics Center, which is a newly established center at PPPL in partnership with the Max Planck Society in Germany that specifically explores the application of plasma science to astrophysical problems and their connections to fusion science. 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 NASA 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. A Memorandum of Understanding between DOE and NASA defines NASA's responsibilities to include provision of power, data handling, and other services on the International Space Station, while DOE's responsibilities include experiment operation and data analysis. Recent results (September 2014) of precision measurements by AMS of the positron fraction in primary cosmic rays, based on the analysis of 41 billion particles detected, provide new insights into the nature of the mysterious excess of positrons observed in the flux of cosmic rays, which could be due to dark matter. The Large Area Telescope (LAT), the primary instrument on NASA's FGST, is a particle physics detector in space to 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. Their December 2013 results on the origin of cosmic rays were one of *Science* magazine's 2013 "Top 10 Science Breakthroughs of the Year." Results on indirect searches for dark matter are expected in the coming year.

The Office of Science and NASA engage in many collaborative research efforts in the area of atmospheric science and environmental phenomena. In 2014, SC's Atmospheric Radiation Measurement (ARM) activity provided support for the NASA Integrated Precipitation and Hydrology Experiment (IPHEX). ARM provided an aircraft sensor to measure total condensed water and a ground-based microwave radiometer to measure column water vapor and liquid water for the

IPHEX campaign. These measurements will be used to improve and validate models of cloud and precipitation processes. SC's ARM and Terrestrial Ecosystem Science (TES) activities supported aircraft measurements of atmospheric trace gases in Oklahoma to improve understanding of the influence of atmospheric and terrestrial processes on atmospheric carbon dioxide concentrations. Flights were coordinated with the NASA Tropospheric Emission Sounder for the testing of carbon dioxide retrievals. ARM and TES also provided support in 2014 for ground-based measurements of carbon dioxide in Oklahoma; Darwin, Australia; and Manacapuru, Brazil, as part of the Total Column Carbon Observing Network (TCCON), which will be used to validate NASA's Orbiting Carbon Observatory 2 (OCO-2) satellite. SC's ARM activity includes support for two sites (Southern Great Plains and Barrow, Alaska) that host measurement instrumentation that provide validation of the Cross-track Infrared Sounder and Advanced Microwave Sounder, which will fly on NASA's National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellite and will provide profiles of temperature and moisture. The TES activity also supported nine university awards through the joint-interagency Carbon Cycle Science topic of the 2014 NASA Research Opportunities in Space and Earth Sciences (ROSES) solicitation. SC's Next Generation Ecosystem Experiment (NGEE)–Arctic coupled real-time, ground-based measurements of soil moisture, temperature, carbon dioxide (CO_2), and methane (CH_4) flux while the NASA Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) collected airborne measurements over Barrow, Alaska. SC's NGEE-Arctic scientists also participated in the science definition team for the upcoming NASA Arctic-Boreal Vulnerability Experiment (ABoVE).

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 of concern. SC provides scientific user facilities for the scientific community, including particle accelerators and ion beams for biological and electronic systems radiation studies. NASA Space Radiation Laboratory (NSRL), a leading facility for radiobiology studies in the United States, 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 (RHIC) facility. A recent upgrade mutually beneficial to both NSRL and RHIC, jointly funded by NASA and DOE, was the construction of an Electron Beam Ion Source (EBIS). The newly commissioned EBIS at BNL significantly extends the range of ion species available for both radiological effects research and fundamental nuclear science, advancing the NASA and SC missions. Electronics space radiation effects testing that is necessary for mission assurance occurs at several DOE accelerator facilities, including BNL and the Lawrence Berkeley National Laboratory's 88-inch cyclotron. SC also supports fundamental research on nuclear reactions of astrophysical interest contributing to SC-NASA mutual interests in the knowledge of stellar evolution and the composition of interstellar space. 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 (NE) supports NASA's planetary science and human exploration programs by maintaining the necessary nuclear facilities' infrastructure capabilities to produce and deliver radioisotope power systems (RPSs) and by assisting special-purpose fission power system technology development efforts for Federal user agencies, such as NASA. The RPS infrastructure capabilities, funded by NASA and managed by NE, support NE's production of RPSs for current space mission applications. The Office of Nuclear Energy also conducts research and development for NASA-funded RPS and space reactor power and propulsion systems technology programs.

NE and its predecessors have provided RPSs that have safely enabled deep space exploration and national security missions for over five decades. The RPSs 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 or on the surfaces of other planets. They have proven to be safe, reliable, and maintenance-free in missions to study the moon and all the planets in the solar system except Mercury. In FY 2015, the RPS-powered spacecraft on the Pluto New Horizons mission will give humanity its first up-close view of Pluto.

There are five currently operating spacecraft that utilize RPSs in 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 Radioisotope Thermoelectric Generator (MMRTG) that was designed, built, and delivered by NE. It has completed its primary mission phase and is currently exploring Mount Sharp, in Gale Crater on Mars. Voyagers 1 and 2, each powered by three Multihundred-Watt Radioisotope Generators (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 12 billion miles from Earth, is the farthest humanmade object from Earth and, as of August 2012, the first such object to enter interstellar space. Both spacecraft remain operational and are sending back useful scientific data after over 37 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 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 using a broad range of scientific instruments, and it is expected to continue to operate until at least 2017. The Pluto 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 3 billion miles to study Pluto and its moon, Charon, achieving its closest encounter with Pluto in July 2015.

NE is currently preparing for the next RPS-powered mission, a Mars rover mission to launch in 2020. Like the Curiosity rover, the Mars 2020 rover will be powered by an MMRTG. NE is preparing the nuclear risk assessments to support

environmental and nuclear launch approval processes. With NASA funding support, NE is also making enhancements to the current RPS production infrastructure by upgrading equipment for more robust operations. Although NASA made a budget-driven decision to terminate the Advanced Stirling Radioisotope Generator (ASRG) system development project in FY 2014, NE continues to work with NASA to investigate advances in both thermoelectric and Stirling power-conversion technologies that could result in more efficient and capable RPSs for NASA's long-term exploration goals.

The stockpile of Pu-238 used to power RPS missions to explore the solar system and for other Government applications is limited. NE is working with NASA to re-establish domestic Pu-238 production in order to ensure continued availability of these power systems for future science missions. NASA is fully funding the costs to re-establish this national production capability, a project that began in 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 2014, the project completed qualification of the neptunium-237 target design and initiated testing of chemical processing steps needed to recover Pu-238 from the irradiated targets.

NE has been working closely with NASA to develop a technology that has the potential to significantly advance human exploration capabilities. NASA's Nuclear Cryogenic Propulsion Stage project, commonly known as Nuclear Thermal Propulsion (NTP), utilizes a nuclear reactor to provide nearly double the thrust of conventional chemical engines, potentially reducing transit times to Mars by 50 percent. NE and DOE national laboratories are providing key support in the areas of reactor modeling, as well as fuel development and qualification. In 2014, the project successfully fabricated and heat-treated a graphite composite fuel element. Fabrication of the composite fuel element represents a significant step in re-establishing the fabrication processes used on previous NTP programs.

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.

The biggest news story coming out of SAO in FY 2014 was the detection of B-mode polarization in the cosmic microwave background. This exquisitely precise measurement, accomplished with a telescope located at the South Pole, had two key implications. If confirmed by other teams, it will represent the first direct evidence for cosmic inflation—a hyper-expansion of the universe in the first trillionth of a trillionth of a trillionth of a second. It also represents the first direct image of gravitational waves, which are ripples in the fabric of space-time.

SAO continued to conduct cutting-edge research in the field of exoplanets, or planets orbiting distant stars. In FY 2014, SAO astronomers reported their discovery of the first mega-Earth, a rocky planet weighing 17 times as much as Earth, which theory said could not exist. Researchers also provided new evidence that red dwarf stars would not be good places to look for habitable worlds because of harsh stellar winds that would scour nearby planets.

SAO astronomers detected a mysterious x-ray signal that could be a sign of dark matter. Additionally, they used the MMT telescope[1] to identify the first runaway

1. "MMT" is now simply the name of the telescope; it is no longer an acronym.

star cluster, which has been ejected from its home galaxy at a speed of more than 2 million miles per hour.

SAO scientists also investigate the best methods of science education. In FY 2014, they showed that students grasp the unimaginable emptiness of space more effectively when they use tablet computers such as iPads to explore 3D simulations of the universe, compared to traditional classroom instruction. This finding suggests that iPads (and other tablets) can improve student understanding of challenging scientific concepts like astronomical scale.

NASA's Spitzer Space Telescope continued 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 the NASA Goddard Space Flight Center. SAO scientists, in collaboration with the Spitzer Science Center, continue to play an important role in the operation of IRAC, the data analysis, and the data's use for astronomical observations.

In FY 2014, SAO scientists and their collaborators used the Spitzer Space Telescope to observe the near-Earth asteroid 2011 MD. It is important to know the physical properties of this asteroid because it is one of the candidates for NASA's Asteroid Redirect Mission. This mission will capture an asteroid with a spacecraft and place it in orbit around the moon; later, astronauts will be sent to study it. Spitzer's observations determined that 2011 MD is about 6 meters in diameter and has a very low density, about the same as water. This implies it has a mass of 50–350 metric tons and has the consistency of a pile of rubble.

SAO astronomers also conducted a multi-wavelength study of galaxies with the Hubble Space Telescope and Spitzer. They discovered four amazingly bright galaxies that existed only 500 million years after the Big Bang and, for the first time, measured their abundance of stars and star formation rate. The remarkable brightness of these galaxies will enable deep spectroscopy with the James Webb Space Telescope to determine their nature.

A combination of observations from Spitzer and the Hubble Space Telescope Cosmic Assembly Near-Infrared Deep Extragalactic Legacy Survey was used to discover a galaxy that was rapidly forming stars 700 million years after the Big Bang. The galaxy has a significant abundance of elements heavier than hydrogen

and helium, as well as a surprisingly high star formation rate of about 330 solar masses per year, which is more than 100 times as great as the rate seen in the Milky Way Galaxy. Such a galaxy is unexpected that early in the universe's existence and suggests that the early universe may harbor a larger number of intense sites of star formation than expected.

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 lower-mass galaxies generally ceased their star formation at later epochs.

On July 23, 2014, the Smithsonian celebrated the 15th anniversary of the launch of the Chandra X-ray Observatory aboard Space Shuttle Columbia. Chandra's unique ability to make high-precision x-ray images of cosmic phenomena has established it as one of the most versatile and powerful tools for astrophysical research in the 21st century.

From the brink of space-time around black holes, to the mysterious dark matter that controls the evolution of galaxies, to the outer reaches of the known universe, the Chandra X-ray Observatory is deepening our understanding of the behavior of matter and energy under conditions that cannot be probed on Earth.

Smithsonian Astrophysical Observatory (SAO) scientists and engineers played a vital role—along with partners at NASA, industry, and universities—in the design, development, and building of Chandra. Today, SAO hosts the Chandra X-ray Center, which operates the observatory for NASA, a task that includes managing the satellite, processing the data, and distributing it to scientists around the world for analysis.

In FY 2014, scientists using Chandra made many significant discoveries. Among them was one of the strongest cases yet that the supermassive black hole at the center of the Milky Way is producing a powerful jet of high-energy particles. Another team of scientists used Chandra to take another important step in black hole research: the first direct measurement of the spin of a black hole some 6 billion light-years from Earth. This accomplishment will help astronomers better understand how black holes grow over time.

Also during FY 2014, astronomers studied the details of how star clusters—similar to the one in which our sun formed—come into being. Other researchers used Chandra to study how stars end their lives, including when the most massive ones explode as supernovas and disperse their elements into space for the next generation of stars and planets to incorporate. This ability to study stars from birth to death is just one example of how Chandra continues to be an invaluable asset a decade and a half after it was launched into space.

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.

AIA and Hinode XRT observations formed the basis of new computer models of the sun's magnetic field. These models show how magnetic energy is stored in the corona, along with the conditions that are needed to release the energy quickly in flares and coronal mass ejections.

In FY 2014, the 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 the 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.

NASA's Interface Region Imaging Spectrograph (IRIS) satellite provided a new view of the sun's mysterious chromosphere and transition regions. SAO built the telescope feed and has an active role in IRIS operations, calibration, and science.

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 to view the moon, stars, and planets through a variety of telescopes.

The outreach program in FY 2014 with the greatest public impact addressed these questions: "What is a planet? And does Pluto qualify?" The event and associated in-person audience vote were covered by several hundred media outlets, with unique viewers and readers totaling over 700 million. Another program with significant impact recognized the 50th anniversary of the discovery of the cosmic microwave background. Four leading cosmologists, including one of the Nobel Prize–winning discoverers, offered presentations.

SAO also provided occasional Author's Night programs, as well as Sci-fi Movie Nights that explored the theme "Everything I learned about science, I learned at the movies."

In FY 2014, the Smithsonian National Air and Space Museum (NASM) 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 July, NASM opened the new exhibition "Hawaii By Air," which tells the story of the development of air travel to Hawaii and how air travel transformed the islands. In commemoration of the 10th anniversary of the Mars Exploration Rover landings, NASM presented "Spirit and Opportunity: 10 Years Roving on Mars," an exhibit featuring spectacular images that chronicle the rovers' missions. "Repairing Hubble," an exhibit displaying the Wide-Field Planetary Camera 2 (WFPC2) and Corrective Optics Space Telescope Axial Replacement (COSTAR) instruments formerly aboard the Hubble Space Telescope, was opened in April. At the museum's Steven F. Udvar-Hazy Center, the newly restored World War II dive-bomber, the Curtiss SB2C-5 Helldiver, went on display. This historic aircraft is the first restoration at the Mary Baker Engen Restoration Hangar, where visitors can view expert conservators and restorers at work.

NASM celebrated the fifth anniversary of the Public Observatory Project, now renamed the Phoebe Waterman Haas Public Observatory in honor of the pioneering American astronomer. Through this educational program, the public can view astronomical objects with the observatory's telescope and participate in interactive activities guided by astronomy educators.

In anticipation of New Horizons' encounter with Pluto next year, NASM hosted a lecture presentation called "Exploring Pluto and Its Satellites at the Solar System's Frontier," and the museum is developing an exhibit around a full-scale model of the New Horizons spacecraft. In addition, NASM curator Michael Neufeld published an article on the history of the mission, "First Mission to Pluto: Policy, Politics, Science and Technology in the Origins of New Horizons, 1989–2003."

Staff members in NASM's Center for Earth and Planetary Studies (CEPS) continued to serve on the science teams of several spacecraft missions. 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, and in that capacity, he leads 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 members 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, and Mercury. Research topics included geologic mapping of Mars; comparative planetology; radar imaging of the moon and Mars; Mercury structural studies; and Martian fluvial, aeolian, volcanic, polar, and alluvial features.

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	18	0	1	0
2014 (through September 30, 2014)	19	0	0	0
TOTAL	**1,733**	**157**	**110**	**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
2014*	23	30			2	12			9	4	1			
*(through September 30, 2014)														
TOTAL	**1,485**	**2,997**	**10**	**8**	**86**	**191**	**1**	**1**	**229**	**40**	**7**	**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, 2013–September 30, 2014

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
November 18, 2013 MAVEN 2013-063A Atlas 5-401	Planetary exploration	n/a	Mars Atmosphere and Volatile EvolutioN (MAVEN)
November 20, 2013 STPSAT-3 2013-064A Minotaur 1	Military	491 489 94.1 40.5	U.S. Air Force Space Test Program (STP) Additional payloads 2013-064B-H,[a] 2013-064J-N,[b] 2013-064P-Z,[c] and 2013-064AA-AE[d]
December 3, 2013 SES 8 2013-071A Falcon 9 v1.1	Communications	35,791 35,783 1,436.1 0	First launch of SpaceX's upgraded Falcon 9 rocket from Space Launch Complex 40 (SLC-40) at Cape Canaveral SpaceX's first geostationary transfer orbit mission after successfully restarting the second stage of the launch vehicle
December 6, 2013 NROL 39 (USA 247) 2013-072A Atlas 5-501	Surveillance/Military	n/a	Also known as Topaz, part of the National Reconnaissance Office's Future Imagery Architecture program Additional payloads 2013-072B-N[e]
January 6, 2014 Thaicom 6 2014-002A Falcon 9 v1.1	Communications	35,798 35,776 1,436.1 0.1	
January 9, 2014 Cygnus/Orb 1 2014-003A Antares 120	International Space Station	407 402 92.7 51.6	First of eight commercial cargo resupply missions to the International Space Station under the NASA Commercial Resupply Services (CRS) contract
January 24, 2014 TDRS-L (TDRS 12) 2014-004A Atlas 5-401	Communications	35,805 35,772 1,436.2 6.8	Tracking and Data Relay Satellite (TDRS)
February 21, 2014 GPS 2F-5 (NAVSTAR 69) 2014-008A Delta 4M+4,2	Navigation	20,209 20,155 718.0 54.9	Global Positioning System (GPS) or Navigation System using Timing And Ranging (Navstar)
April 3, 2014 DMSP 5D-3 F19 (USA 249) 2014-015A Atlas 5-401	Military	n/a	Defense Meteorological Satellite Program (DMSP)
April 10, 2014 NROL 67 (USA 250) 2014-020A Atlas 5-541	Surveillance/Military	n/a	
April 18, 2014 CRS-3 Dragon 2014-022A Falcon 9 v1.1	International Space Station	410 398 92.7 51.7	Commercial Resupply Services (CRS) mission to the ISS Additional payloads 2014-022B-F[f]

* U.N. Committee on Space Research

a. Included PHONESAT 2.4, CAPE 2, DRAGONSAT, KYSAT II, TJ3SAT, ORSES, and ORS TECH 1

b. Included SENSE SV1, NPS-SCAT, PROMETHEUS 1–4, PROMETHEUS 1–2, and SENSE SV2

c. Included PROMETHEUS 1–5, PROMETHEUS 1–6, COPPER, ORS TECH 2, HORUS, BLACK KNIGHT, PROMETHEUS 1–7, TRAILBLAZER, PROMETHEUS 1–8, SWAMPSAT, and HO'OPONOPONO 2

d. Included FIREFLY, CHARGERSAT, PROMETHEUS 1-1, VERMONT LUNAR, and PROMETHEUS 1–3

e. Included FIREBIRD A, FIREBIRD B, AEROCUBE 5A, AEROCUBE 5B, ALICE, SNAP-3, MCUBED-2, CUNYSAT-1, IPEX, SMDC ONE 2.4, TACSAT 6, and SMDC ONE 2.3

f. Included SPORESAT, TSAT, ALL STAR/THEIA, PHONESAT 2.5, and KICKSAT

Appendix B (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2013–September 30, 2014

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
May 17, 2014 GPS 2F-6 (Navstar 70) 2014-026A Delta 4M+4,2	Navigation	20,193 20,171 718.0 55.1	
May 22, 2014 NROL 33 (USA 252) 2014-027A Atlas 5-401	Surveillance/Military	n/a	
July 2, 2014 OCO 2 2014-035A Delta 2	Earth Science	703 702 98.8 98.2	Orbiting Carbon Observatory (OCO) 2
July 13, 2014 Cygnus/Orb-2 2014-039A Antares 120	International Space Station	407 386 92.5 51.7	Additional payload 2014-038B (O3B FM7)
July 14, 2014 Orbcomm (FM 103-104, 106-107, 109, 111) 2014-040A-F Falcon 9 v1.1	Communications	729 706 99.1 47.0	Stats specific to Orbcomm FM 109 (2014-040A)
July 28, 2014 GSSAP/ANGELS (USA 253-255) 2014-043A-C Delta 4M+4,2	Military	n/a	2 Geosynchronous Space Situational Awareness Program (GSSAP) satellites Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS) nanosatellite
August 2, 2014 GPS 2F7 (NAVSTAR 71) 2014-045A Atlas 5-401	Navigation	20,191 20,174 718.0 55.0	
August 5, 2014 AsiaSat 8 2014-046A Falcon 9 v1.1	Communications	35,794 35,780 1,436.1 0	Asia Satellite Telecommunications Company (AsiaSat)
August 13, 2014 Worldview 3 2014-048A Atlas 5-401	Earth Science	614 612 97.0 98.0	
September 7, 2014 AsiaSat 6 2014-052A Falcon 9 v1.1	Communications	35,791 35,783 1,436.1 0	
September 17, 2014 CLIO (USA 257) 2014-055A Atlas 5-401	Communications	n/a	
September 21, 2014 CRS-4 Dragon 2014-056A Falcon 9 v1.1	International Space Station	412 403 92.7 51.6	Carried the ISS-Rapid Scatterometer (RapidScat) instrument as a replacement for NASA's QuikScat satellite

Appendix C
HUMAN SPACEFLIGHTS

October 1, 2013–September 30, 2014

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TMA-11M (Expedition 38)	November 7, 2013	Richard Mastracchio Koichi Wakata Mikhail Tyurin	187:22:44	Successful rendezvous with Cygnus/Orb-1. Launched the Olympic Torch Relay for the 2014 Winter Games in Sochi, Russia (returned on Soyuz TMA-09M). Performed the second CubeSat deployment.
Soyuz TMA-12M (Expedition 39)	March 25, 2014	Alexander Skvortsov Oleg Artemyev Steve Swanson	169:5:6	CRS-3 Dragon became the first flight to use the Falcon 9 v1.1 rocket. The High-Definition Earth Viewing (HDEV) investigation installed four commercially available high-definition cameras on the exterior of the space station to stream live video of Earth online. ISS used the new Pre-Determined Debris Avoidance Maneuver capability to move away from space debris.
Soyuz TMA-13M (Expedition 40)	May 28, 2014	Reid Wiseman Maxim Suraev Alexander Gerst	165:7:1	Delivered the ISS-Rapid Scatterometer (ISS-RapidScat) to monitor ocean winds, which reused leftover hardware from the QuikScat scatterometer and demonstrated a unique way to replace an instrument aboard an aging satellite. The Vegetable Production System (Veggie) produced the first salad greens, which may be used to further human habitability in space.
Soyuz TMA-14M (Expedition 41)	September 25, 2014	Barry Wilmore Elena Serova Alexander Samoukutyaev	n/a	The Meteor Composition Determination (Meteor) payload enabled the first space-based observations of meteors entering Earth's atmosphere using high-resolution video and image analysis. First female cosmonaut to visit the ISS.

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
2014	17,647	17,081	10,400	2,839	174	2,087	82	19	461	16	30,320

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 2014 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	6.281	2,079	1,639	3,078	214	214						4,931
1960	6.186	3,242	2,858	3,471	266	266						6,595
1961	6.101	5,881	5,650	4,966	415	415						11,031
1962	6.018	10,983	10,815	7,812	1,198	891	307					19,824
1963	5.957	21,881	21,601	9,234	1,531	1,275	256					32,366
1964	5.885	30,012	29,518	9,410	1,253	1,236	18					40,181
1965	5.814	30,523	29,872	9,151	1,401	1,331	70					40,424
1966	5.714	29,569	28,941	9,651	1,223	1,068	154					39,814
1967	5.593	27,777	27,016	9,308	1,191	1,029	162					37,515
1968	5.428	24,897	24,045	10,432	946	787	152	1	5			35,422
1969	5.248	20,945	20,058	10,564	894	619	105	1	5	164		31,516
1970	5.017	18,795	17,797	8,419	708	517	40	5	5	141		26,924
1971	4.761	15,764	14,764	7,199	771	452	129	10	5	176		22,734
1972	4.532	14,986	13,916	6,376	604	249	140	27	9	178		20,897
1973	4.325	14,731	13,377	7,019	637	234	173	43	9	179		21,034
1974	4.146	12,591	11,439	7,322	655	174	249	37	12	183		19,416
1975	3.871	12,499	11,284	7,324	611	116	248	31	8	208		19,219
1976	3.509	12,457	11,317	6,959	591	81	253	35	14	208		18,866
TQ*	3.281	3,058	2,786	1,509	141	16	72	10	3	39		4,436
1977	3.186	12,164	10,960	7,685	617	70	290	32	19	206		19,261
1978	3.061	12,428	11,090	8,381	692	104	315	31	24	217		20,163
1979	2.868	13,180	11,557	8,706	711	169	281	29	23	209		20,974
1980	2.655	13,911	12,425	10,216	614	106	247	32	37	191		23,254
1981	2.442	13,474	12,190	11,789	572	100	212	29	39	191		24,551
1982	2.225	13,445	12,297	14,857	696	136	323	27	33	177		27,850
1983	2.082	14,310	13,172	18,773	681	81	371	10	42	177		32,626
1984	1.994	14,868	13,672	20,325	787	68	470	6	38	205		34,784
1985	1.926	14,583	13,335	24,587	1,124	65	815	4	29	211		39,046
1986	1.864	14,551	13,354	26,329	889	65	576	4	43	201		40,571
1987	1.822	19,905	17,875	29,679	849	87	507	15	35	204	2	48,403
1988	1.783	16,153	14,834	31,513	1,321	430	627	25	32	205	2	47,668
1989	1.727	18,942	17,436	30,921	967	168	520	29	36	209	5	49,325
1990	1.661	20,467	19,032	25,934	840	131	404	51	42	205	7	45,806
1991	1.603	22,462	20,907	22,726	1,237	402	402	46	42	338	6	44,871
1992	1.548	22,159	20,428	23,251	1,235	345	506	53	45	280	6	44,914
1993	1.511	21,619	19,736	21,310	1,104	249	489	50	38	272	6	42,151
1994	1.476	21,501	19,216	19,429	933	109	460	46	46	265	7	39,579
1995	1.444	20,008	18,114	15,372	1,096	86	508	45	46	401	9	34,582
1996	1.414	19,635	17,775	16,283	1,171	65	667	51	52	326	8	35,229
1997	1.388	19,032	17,294	16,281	1,096	49	622	58	54	305	8	34,671
1998	1.364	18,619	16,809	16,861	1,145	141	593	59	53	291	8	34,815
1999	1.348	18,399	16,790	17,793	1,323	142	775	80	50	270	8	35,906
2000	1.331	18,099	16,662	17,221	1,405	218	765	80	59	275	8	35,288
2001	1.304	18,553	17,346	18,678	1,385	189	752	78	47	302	16	37,408
2002	1.273	18,927	17,658	20,037	1,502	211	820	81	36	339	15	39,197
2003	1.253	19,249	17,991	24,291	1,635	239	813	93	53	422	15	43,918
2004	1.229	18,907	17,607	23,500	1,800	257	916	87	75	450	15	42,907
2005	1.200	19,432	18,276	23,622	1,861	275	968	84	88	432	14	43,758
2006	1.163	19,335	18,337	25,722	1,916	285	1,000	95	98	423	14	45,975
2007	1.127	18,345	17,538	25,254	1,893	225	1,027	98	73	455	14	44,685
2008	1.097	18,775	18,100	27,197	1,862	214	945	99	65	525	14	47,160
2009	1.075	19,102	18,565	28,509	2,007	215	1,158	69	29	521	15	49,081
2010	1.062	19,890	19,362	28,109	2,185	216	1,339	71	28	514	16	49,655
2011	1.053	19,410	18,847	28,678	2,301	241	1,521	70	21	434	16	49,827
2012	1.033	18,357	17,768	27,554	2,664	206	1,938	78	7	419	17	47,987
2013	1.015	17,658	17,120	10,818	2,617	188	1,893	85	20	415	15	30,555
2014	1.000	17,647	17,081	10,400	2,839	174	2,087	82	19	461	16	30,320

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	**2012 actual**	**2013 actual[1]**	**2014 actual**	**2015 est.**	**2012 actual**	**2013 actual**	**2014 actual**	**2015 est.**
NASA[2]	17,203	16,865.2	17,080.5	16,909.5	16,606	16,989	16,558.7	16,392.9
DOD[3,4]	26,677	10,818	10,400	9,600	26,457	10,299	9,900	9,200
DOE	199	185	174	169	158	183	174	30
DOC[5]	1,876	1,864.8	2,087.1	2,247.9	1,074.3	1,130.5	1,167.3	1,257.2
DOI[6]	76	84	82	81	76	81	81	81
USDA	6.7	19.6	19.3	19.2	17.3	17	18.7	18.7
DOT	16	15	16	17	16	15	16	17
NSF[7]	406	409	461	477	489	387	391	417

1. FY 2013 figures incorporate the effect of sequestration.
2. The FY 2015 estimate is based on the prior year's Outlays versus Budget Authority.
3. Does not include Department of Defense (DOD) or Office of the Director of National Intelligence (ODNI) intelligence programs. DOD FY 2014 and FY 2015 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. At the time of preparing this report, DOD submitted estimates as billions of dollars, so the figures are rounded to the nearest hundred million.
5. The Budget Outlays columns reflect dollars "costed" in a fiscal year specific to that same fiscal year's appropriated dollars.
6. The numbers for FY 2014 Actual and Outlays are estimates for both satellite and aerial funding.
7. "Actual" = actual obligations.

Appendix D-3

Federal Aeronautics Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority 2012 actual	2013 actual[1]	2014 actual	2015 est.	Budget Outlays 2012 actual	2013 actual	2014 actual	2015 est.
NASA[2]	570	529.5	566	551.1	584	558.4	538.7	524.5
USDA	36.9	33.1	34.4	25.4	36.8	30.2	32.6	23.8
DOD[3]	14,221	82,730	75,500	66,900	13,509	91,120	75,700	66,200
DOI[4]	27	29	31	31	27	28	30	30
DOT	2,884	2,758	2,744	2,746	3,102	2,990	2,851	2,848

1. FY 2013 figures incorporate the effect of sequestration.
2. The FY 2015 estimate is based on the prior year's Outlays versus Budget Authority.
3. DOD FY 2014 and FY 2015 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. At the time of preparing this report, DOD submitted estimates as billions of dollars, so the figures are rounded to the nearest hundred million.
5. The numbers for FY 2014 Actual and Outlays are estimates for both satellite and aerial funding.

Acronyms

3D-LZ	3D Landing Zone

A

AACUS	Autonomous Airborne Cargo Utility System
ABoVE	Arctic-Boreal Vulnerability Experiment
AC	alternating current
ACCESS	Alternative Fuel Effects on Contrails and Cruise Emissions
ACES	Atomic Clock Ensemble in Space
ACT	Atacama Cosmology Telescope
ACTPol	ACT Polarimeter
ADS-B	Automatic Dependent Surveillance—Broadcast
ADVENT	Adaptive Versatile Engine Technology
AE	Archive Explorer
AEHF	Advanced Extremely High Frequency
AES	Advanced Exploration Systems
AETD	Adaptive Engine Technology Development
AFB	Air Force Base
AFOTEC	Air Force Operational Test and Evaluation Center
AFRL	Air Force Research Lab
AFSC	Air Force Space Command
AFSCN	Air Force Satellite Control Network
AGS	Division of Atmospheric and Geospace Sciences
AHW	Advanced Hypersonic Weapon
AIA	Atmospheric Imaging Assembly
ALASA	Airborne Launch Assist Space Access
ALHAT	Autonomous Landing and Hazard Avoidance Technology
ALI	Advanced Land Imager
ALMA	Atacama Large Millimeter/submillimeter Array
AMC	Additive Manufacturing Consortium
AMISR	Advanced Modular Incoherent-Scatter Radar
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMS	Autonomous Modular Sensor; Alpha Magnetic Spectrometer
ANSI	American National Standards Institute
AO	Arecibo Observatory
APL	Applied Physics Laboratory
ARCD	Active Rotor Components Demonstration
ARES	Aerial Reconfigurable Embedded System
ARM	Asteroid Redirect Mission; Atmospheric Radiation Measurement
ARMD	Aeronautics Research Mission Directorate
ARS	Agricultural Research Service
ARSET	Applied Remote Sensing Training
AS	Atmosphere Section
AS3	Alaska Satellite Facility Antenna
ASB	Agricultural Statistics Board
ASBU	Aviation System Block Upgrade
ASF	Alaska Satellite Facility
ASME	American Society of Mechanical Engineers
ASRG	Advanced Stirling Radioisotope Generator
AST	Office of Commercial Space Transportation; Division of Astronomical Sciences
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer

ASU	Aircraft Sector Understanding
ATD-1	Air Traffic Management Technology Demonstration-1
ATST	Advanced Technology Solar Telescope (now DKIST)
ATTREX	Airborne Tropical TRopopause EXperiment
ATV	Automated Transfer Vehicle
Auto ACAS	Automatic Air Collision Avoidance System
Auto GCAS	Automatic Ground Collision Avoidance System
AUVSI	Association for Unmanned Vehicle Systems International
AVD	Air Vehicle Demonstration
AVHRR	Advanced Very High Resolution Radiometer
AWiFS	Advanced Wide Field Sensor

B

BaPSF	Basic Plasma Science Facility
BDS	BeiDou Navigation Satellite System
BEAM	Bigelow Expandable Activity Module
BIA	Bureau of Indian Affairs
BICEP2	Background Imaging of Cosmic Extragalactic Polarization 2
BIS	Bureau of Industry and Security
BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory
BOR	Bureau of Reclamation

C

C	carbon
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CASIS	Center for the Advancement of Science in Space
CAST	Commercial Aviation Safety Team
CCl_4	carbon tetrachloride
CCAFS	Cape Canaveral Air Force Station
CCiCap	Commercial Crew Integrated Capability
CCL	Commerce Control List
CCMC	Community Coordinated Modeling Center
CCSDS	Consultative Committee for Space Data Systems
CCtCap	Commercial Crew Transportation Capabilities
CDL	Cropland Data Layer
CDP	Cross Deck Pendant
CDR	Critical Design Review
CDRA	Carbon Dioxide Removal Assembly
CDS	Cascade Distillation System
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEPS	Center for Earth and Planetary Studies
CFA	Center for Astrophysics
CFD	computational fluid dynamics
CFIT	controlled flight into terrain
CH_4	methane
CIBER	Cosmic Infrared Background Experiment
CLU	Common Land Unit
CMB	cosmic microwave background
CNES	Centre National d'Études Spatiales
CO_2	carbon dioxide
COCOM	Combatant Commander
COE CST	Center of Excellence for Commercial Space Transportation

CONTRAST	Convective TRansport of Active Species in the Tropics
CONUS	contiguous United States
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COSTAR	Corrective Optics Space Telescope Axial Replacement
CPC	Certification Products Contracts
CPGS	Conventional Prompt Global Strike
CPT	Command Post Terminal
CRS	Commercial Resupply Services
CS	Commercial Service
CSLC	21st Century Space Launch Complex
CTPD	Combat Tempered Platform Demonstration
CYGNSS	Cyclone Global Navigation Satellite System

D

DARPA	Defense Advanced Research Projects Agency
DASI	Degree Angular Scale Interferometer
DEEPWAVE-NZ	Deep-Propagating Gravity Wave Experiment over New Zealand
DFW	Dallas/Fort Worth
DKIST	Daniel K. Inouye Solar Telescope
DLR	German Aerospace Agency
DMC	Disaster Monitoring Constellation
DMS	Defensive Management System
DNN R&D	Office of Defense Nuclear Nonproliferation Research and Development
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
DOT	Department of Transportation
DPLR	Data Parallel Line Relaxation
DSN	Deep Space Network
DSS	Deep Space Station
DTED	digital terrain elevation data
DVE	degraded visual environments

E

EA	Environmental Assessment
EAR	Export Administration Regulations
EAWS	Early Access Web Services
EBIS	Electron Beam Ion Source
ECCN	Export Control Classification Number
ECMWF	European Centre for Medium-Range Weather Forecasts
EELV	Evolved Expendable Launch Vehicle
EFT-1	Exploration Flight Test-1
eHPA	Enhanced High Power Amplifier
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act
ELM	Electromagnetic Levitator
EM-1	Exploration Mission-1
EM-2	Exploration Mission 2
EO-1	Earth Observing-1
EOS	Earth Observing System
EPA	Environmental Protection Agency

EPS	Enhanced Polar System
ER	Eastern Range
ERAU	Embry-Riddle Aeronautical University
ERCDM	Eastern Range Command Destruct Modernization
EROS	Earth Resources Observation and Science
ERS	Earth Remote Sensing
ESA	European Space Agency
ESD	Earth Science Directorate
ET	evapotranspiration
ETM	Enhanced Thematic Mapper
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUV	extreme ultraviolet
eV	electronvolt
EVA	extravehicular activity
EVE	EUV Variability Experiment
EVI	Enhanced Vegetation Index
EVT	Existing Vegetation Type
ExHAM	Exposed Experiment Handrail Attachment Mechanism
EXIS	EUV and X-ray Irradiance Sensor

F

FAA	Federal Aviation Administration
FAB-T	Family of Beyond Line of Sight Terminals
FAS	Foreign Agricultural Service
FCC	Federal Communications Commission
FES	Office of Fusion Energy Sciences
FGS	Fine Guidance Sensor
FGST	Fermi Gamma-ray Space Telescope
FIDAE	La Feria Internacional del Aire y del Espacio
FOC	Full Operational Capability
FONSI	Finding of No Significant Impact
FS	Forestry Service
FSA	Farm Service Agency
FT-2	Flight Test-2
FVL	Future Vertical Lift
FWS	Fish and Wildlife Service

G

G-LiHT	Goddard LiDAR Hyperspectral and Thermal
GaN	gallium nitride
GBD	Global Burst Detector
GCD	Game Changing Development
GDEM2	Global Digital Elevation Map Version 2
GEM	Geospace Environment Modeling
GEMS	General Ensemble biogeochemical Modeling System
GEO	geostationary orbit; Geosynchronous Earth Orbit
GEODSS	Ground-based Electro Optics Deep Space Surveillance
GEOS	Goddard Earth Observing System
GER	Global Exploration Roadmap
GF	Geospace Facilities
GGOT	GPS-Galileo Time Offset

GHG	greenhouse gas
GHz	gigahertz
GIS	Geographic Information System
GLAM	global agricultural monitoring
GMI	GPM Microwave Imager
GNSS	global navigation satellite system
GOES	Geostationary Operational Environmental Satellites
GOES-R	Geostationary Operational Environmental Satellite-R Series
GONG	Global Oscillations Network Group
GPHS	General Purpose Heat Source
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GRC	Glenn Research Center
GS	Geospace Section
GSDO	Ground Systems Development and Operations
GSSAP	Geosynchronous Space Situational Awareness Program
GV	Gulfstream V

H

HAIC	High Altitude Ice Crystals
HDEV	High-Definition Earth Viewing
HEAT	High Elevation Antarctic Terahertz
HEO	Highly Elliptical Orbit
HEOMD	Human Exploration and Operations Mission Directorate
HEP	Office of High Energy Physics
HiRISE	High Resolution Imaging Science Experiment
HIS	Heavy Ion Sensor
HITL	human-in-the-loop
HIWC	High Ice Water Content
HMVS	Hub Mounted Vibration Suppressor
HOGE	hover out of ground effect
HRP	Human Research Program
HST	Hubble Space Telescope
HWB	Hybrid Wing Body

I

IA	Increasingly Autonomous
IADS	Integrated Arrival/Departure/Surface
IBEX	Interstellar Boundary Explorer
ICAO	International Civil Aviation Organization
ICAST	Inter-Center Autonomy Study Team
ICBM	intercontinental ballistic missile
ICESat-2	Ice, Cloud, and Land Elevation Satellite
ICG	International Committee on GNSS
ICNO	IceCube Neutrino Observatory
ICP	increased intracranial pressure
ICV	Integrated Cardiovascular
ID&RR	initial design and risk reduction
IER	Interior Effects Room
IFAR	International Forum for Aviation Research

IFSAR	Interferometric Synthetic Aperture Radar
IMO	International Maritime Organization
INP	Innovative Naval Prototype
InSight	Interior Exploration Using Seismic Investigations, Geodesy and Heat Transport
IOC	Initial Operating Capability
IPHEX	Integrated Precipitation and Hydrology Experiment
IPS	interim polar system
IRAC	Infrared Array Camera
IRIS	Interface Region Imaging Spectrograph
IRS	Indian Remote Sensing
ISECG	International Space Exploration Coordination Group
ISEF	International Space Exploration Forum
ISIM	Integrated Science Instrument Module
ISO	International Organization for Standardization
ISRO	Indian Space Research Organisation
ISRU	in situ resource utilization
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	Japan Aerospace Exploration Agency
JEM	Japanese Experiment Module
JFCC Space	Joint Functional Component Command for Space
JMR	Joint Multi-Role
JMS	Joint Space Operations Center Mission System
JPALS	Joint Precision Approach and Landing System
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSF	Joint Strike Force
JSpOC	Joint Space Operations Center
JUICE	Jupiter Icy Moons Explorer
JWST	James Webb Space Telescope

K

KDP-C	Key Decision Point C
KSC	Kennedy Space Center

L

LADAR	Laser Detection and Ranging
LADEE	Lunar Atmosphere and Dust Environment Explorer
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LANL	Los Alamos National Laboratory
LAPD	Large Plasma Device
LAT	Large Area Telescope
LBFD	Low Boom Flight Demonstration
LDCM	Landsat Data Continuity Mission
LDSD	Low Density Supersonic Decelerator

LEO	low-Earth orbit
lidar	light detection and ranging
LISS	Linear Imaging Self-Scanner
LLCD	Lunar Laser Communication Demonstration
LLNL	Lawrence Livermore National Laboratory
LOX	liquid oxygen
LPD	landing platform/dock
LRO	Lunar Reconnaissance Orbiter
LSC	Legal Subcommittee (United Nations)
LSP	Launch Services Program
LSST	Large Synoptic Survey Telescope
LST	Land Surface Temperature
LTRS	Launch and Test Range System
LTS	Working Group on Long-Term Sustainability of Outer Space Activities (United Nations)
Lunar CATALYST	Lunar Cargo Transportation and Landing by Soft Touchdown
LVC-DE	Live Virtual Constructive-Distributed Environment

M

MACES	Modified Advanced Crew Escape Suit
MAF	Michoud Assembly Facility
MAGIC CARPET	Maritime Augmented Guidance with Integrated Controls for Carrier Approach and Recovery Precision Enabling Technologies
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MAVEN	Mars Atmosphere and Volatile Evolution
MCLAWS	Modernized Control Laws
mcm	million cubic meters
MEDA	Mars Environmental Dynamics Analyzer
MEDLI	Mars Entry, Descent, and Landing Instrumentation
MEN	Modernization Eastern Range Network
MEP	Manufacturing Extension Partnership
MER	Mars Exploration Rover
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MFRF	Multifunction Radio Frequency
MGUE	Military GPS User Equipment
MIT	Massachusetts Institute of Technology
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MMS	Magnetospheric Multiscale
MOA	Memorandum of Agreement
MOBY	Marine Optical Buoy
MOD	Ministry of Defense
MODIS	Moderate Resolution Imaging Spectroradiometer
MOT&E	Multi-Service Operational Test and Evaluation
MOU	Memorandum of Understanding
MOXIE	Mars Oxygen ISRU Experiment
MPS	Mathematics and Physical Sciences
MRI	Magneto-Rotational Instability
MRLC	Multi-Resolution Land Characteristics Consortium
MRO	Mars Reconnaissance Orbiter
MRX	Magnetic Reconnection Experiment
MSAD	Mission Systems Architecture Demonstration
MSFC	Marshall Space Flight Center
MSL	Mars Science Laboratory

MTBS	Monitoring Trends in Burn Severity
MUOS	Mobile User Objective System
MWL GT	Microwave Link Ground Terminal

N

N_2O	nitrous oxide
NAFD	North American Forest Dynamics
NAICS	North American Industry Classification System
NAIP	National Agriculture Imagery Program
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NE	Office of Nuclear Energy
NEA	near-Earth asteroid
NEN	Near Earth Network
NextGen	Next Generation Air Transportation System
NFS	National Forest System
NGA	National Geospatial-Intelligence Agency
NGEE	Next Generation Ecosystem Experiment
NIRCam	Near Infrared Camera
NIRISS	Near Infrared Imager and Slitless Spectrograph
NIRSpec	Near InfraRed Spectrograph
NISP	NSO Integrated Synoptic Program
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Database
NLDAS-2	North American Land Data Assimilation System Version 2
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NOC	National Operations Center
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPS	National Park Service
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRO	National Reconnaissance Office
NSF	National Science Foundation
NSO	National Solar Observatory
NSPO	National Space Organization (Taiwan)
NSRL	NASA Space Radiation Laboratory
NSS	national security space
NSTP	National Space Transportation Policy
NSWP	National Space Weather Program
NTF	National Transonic Facility
NTP	Nuclear Thermal Propulsion
NTSB	National Transportation Safety Board
NuDets	nuclear detonations
NuSTAR	Nuclear Spectroscopic Telescope Array
NWP	numerical weather prediction

O

OCO-2	Orbiting Carbon Observatory 2
ODNI	Office of the Director of National Intelligence
OECD	Organization for Economic Cooperation and Development
OFII	Office of Finance and Insurance Industries
OFN	Obstacle Field Navigation
OGA	Oxygen Generator Assembly; Office of Global Analysis
OLI	Operational Land Imager
OPALS	Optical Payload for Lasercomm Science
OPIR	Overhead Persistent Infrared
OPTIMUS	Open-Architecture Planning and Trajectory Intelligence for Managing Unmanned Systems
ORCA	Ocean Radiometer for Carbon Assessment
ORNL	Oak Ridge National Laboratory
ORS	Operationally Responsive Space
OSC	Orbital Sciences Corporation
OSD	Office of the Secretary of Defense
OSIRIS-REx	Origins Spectral Interpretation Resource Identification Security–Regolith Explorer
OSMRE	Office of Surface Mining Reclamation and Enforcement
OTM	Office of Transportation and Machinery
OVERFLOW	overset grid computational fluid dynamics flow solver

P

PBN	Performance-Based Navigation
PDR	Preliminary Design Review
PDRC	Precision Departure Release Capability
PEO	Program Executive Officer
PIDDP	Planetary Instrument Definition and Development Program
PLR	Division of Polar Programs
PLSS	Portable Life Support System
PNT	Position, Navigation, and Timing
POES	Polar-orbiting Operational Environmental Satellites
POLARBEAR	Polarization of Background Radiation
POTUS	President of the United States
POW	prisoner of war
PPPL	Princeton Plasma Physics Laboratory
PRS	Public Regulated Service
PSD	production, supply, and distribution
Pu	plutonium

R

R&D	research and development
RapidScat	Rapid Scatterometer
RBC	Remote Tracking Station Block Change
RCS	reaction control system
RERP	Reliability Enhancement and Re-engining Program
RF	radio frequency
RFP	Request for Proposals
RGB	red-green-blue
RHIC	Relativistic Heavy Ion Collider
RMA	Risk Management Agency
RNAV	Area Navigation
RO	radio occultation

ROD	Record of Decision
ROSES	Research Opportunities in Space and Earth Sciences
RPS	radioisotope power system
RPT	Rocket Propulsion Test
RSCC	Remote Sensing Coordinating Committee
RSIWG	Remote Sensing Interagency Working Group
RSO	Resident Space Object
RTG	Radioisotope Generator
RTS	Remote Tracking Stations

S

S&P	State and Private Forestry
SAA	Space Act Agreement
SABRS	Space and Atmospheric Burst Reporting System
SAGE	Stratospheric Aerosol and Gas Experiment
SAME	Smoke Aerosol Measurement Experiment
SANS	small-angle neutron scattering
SansEC	sans electric connection
SAO	Smithsonian Astrophysical Observatory
SARDA	Spot and Runway Departure Advisor
SARSAT	Search and Rescue Satellite-Aided Tracking
SATCOM	Satellite Communications
SBIR	Small Business Innovation Research
SBIRS	Space Based Infrared System
SBSS FO	Space Based Space Surveillance Follow-On
SC	Office of Science
SCaN	Space Communications and Navigation
SDO	Solar Dynamics Observatory
SED	Scramjet Engine Demonstrator
SHARAD	Shallow Subsurface Radar
SHINE	Solar, Heliosphere, and INterplanetary Environment
SIA	Satellite Imagery Archive
SIAD	Supersonic Inflatable Decelerator
SLAC	Stanford Linear Accelerator Center
SLAD	Safe Landing Area Determination
SLEP	Service Life Extension Program
SLRS	Spacelift Range System
SLRSC	Spacelift Range System Contract
SLS	Space Launch System
SMAP	Soil Moisture Active-Passive
SMART-NAS	Shadow Mode Assessments Using Realistic Technologies for the National Airspace System
SMAT	Scale Model Acoustic Testing
SMCRA	Surface Mining Control and Reclamation Act of 1977
SMD	Science Mission Directorate
SMDC	Space and Missile Defense Command
SMEs	small- and medium-sized enterprises
SN	Space Network
SNaP	Space and Missile Defense Command Nanosatellite Program
SNL	Sandia National Laboratories
SNSPD	superconducting nanowire single-photon detector
SOC	Space Optical Clock
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOLIS	Synoptic Optical Investigations of the Sun
SpaceX	Space Exploration Technologies Corporation

SPHERES	Synchronized Position Hold, Engage, Reorient Experimental Satellites
SPOT	Satellite Pour l'Observation de la Terre
SPP	Solar Probe Plus
SPT	South Pole Telescope
SPT-SZ	South Pole Telescope–Sunyaev-Zel'dovich
SPUD	Small Polarimeter Upgrade for DASI
SQUID	Superconducting Quantum Interference Device
SSA	Space Situational Awareness
SSC	Stennis Space Center
SSDP	Space Security and Defense Program
SST	Space Surveillance Telescope
SSV	Space Service Volume
STAR	Center for Satellite Applications and Research
STEM	science, technology, engineering, and mathematics
STIM	Space Transportation Infrastructure Matching
STMD	Space Technology Mission Directorate
STP	Space Test Program
STRG	Space Technology Research Grants
STSC	Scientific and Technical Subcommittee (United Nations)
STTR	Small Business Technology Transfer
SUGAR	Subsonic Ultra Green Aircraft Research
Suomi NPP	Suomi National Polar-orbiting Partnership
SUPSALV	supervisor of salvage
SURF	Synchrotron Ultraviolet Radiation Facility
SUVI	Solar Ultraviolet Imager
SVAB	Synthetic Vision Avionics Backbone
SWORDS	Soldier-Warfighter Operationally Responsive Deployer for Space
SWR	Space Weather Research
SWT	Supersonic Wind Tunnel
SZ	Sunyaev-Zel'dovich

T

TALOS	Tactical Autonomous Aerial Logistics System
TBFM	Time Based Flow Management
TCC	Trace Contaminant Control; Tree Canopy Cover
TCCON	Total Column Carbon Observing Network
TCTE	Total solar irradiance Calibration Transfer Experiment
TD	Technology Demonstrator
TDRS	Tracking and Data Relay Satellite
TDRS-L	Tracking and Data Relay Satellite L
TDRSS	Tracking and Data Relay Satellite System
TDS-T	Tactical Departure Scheduling–Terminal
TELS	Threat Emitter Locator System
TES	transition-edge sensor; Terrestrial Ecosystem Science
TESS	Transiting Exoplanet Survey Satellite
TeV	teraelectronvolt
TIA	Technology Investment Agreement
TIM	Total Irradiance Monitor
TM	Thematic Mapper
TOPEX	Topography Experiment
TRACON	Terminal Radar Approach Control Facilities
TRL	technical readiness level; technology readiness level
TRMM	Tropical Rainfall Measuring Mission
TSA	Transportation Security Administration

TSS	Terminal Sequencing and Spacing
TX	Transformer

U

UAS	unmanned aircraft system(s)
UCAR	University Corporation for Atmospheric Research
UCAS-D	Unmanned Combat Air System Demonstrator
UCC	Unified Combatant Commander
UCI	University of California, Irvine
UCLASS	Unmanned Carrier-Launched Airborne Surveillance and Strike
UFO	UHF Follow-On
UHB	Ultra High Bypass
ULA	United Launch Alliance
UN	United Nations
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
USAF	U.S. Air Force
USB	Unified S-Band
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USG	U.S. Government
USGS	U.S. Geological Survey
USML	United States Munitions List
USNDS	U.S. NuDet Detection System
USSTRATCOM	U.S. Strategic Command
UTMB	University of Texas Medical Branch
UV	ultraviolet

V

V&V	verification and validation
VAC	Vertical Assembly Center
VAFB	Vandenberg Air Force Base
VCT	Vegetation Change Tracker
VIIP	Visual Impairment Intracranial Pressure
VIIRS	Visible Infrared Imaging Radiometer Suite
VIPR	Vehicle Integrated Propulsion Research
VTOL	vertical takeoff and landing

W

WAI	Wide Area Imager
WAOB	World Agricultural Outlook Board
WCDMA	Wideband Code Division Multiple Access
WFF	Wallops Flight Facility
WFPC 2	Wide-Field Planetary Camera 2
WGS	Wideband Global SATCOM
WSTF	White Sands Test Facility

X

XRT	X-ray Telescope

Y

Yb	ytterbium

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