Aeronautics and Space Report of the President

Fiscal Year 2017 Activities

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OF THE PRESIDENT

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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, 2016, through September 30, 2017. 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.** Virginia Tech students watch a Black Brant IX sounding rocket take off from NASA's Wallops Flight Facility in Virginia. Credits: NASA/Allison Stancil. **2.** This artist's concept depicts NASA's Mars 2020 rover exploring Mars. Credit: NASA/JPL-Caltech. **3.** This view shows Saturn's northern hemisphere in 2016, as that part of the planet neared its northern hemisphere summer solstice. NASA/JPL-Caltech/Space Science Institute. **4.** NASA astronaut Jack Fischer took this photograph of an American flag in one of the windows of the International Space Station's cupola, a dome-shaped module through which operations on the outside of the Station can be observed and guided. Credit: NASA. **5.** A photo illustration shows how a team of NASA-funded scientists would take to the skies during the August 21, 2017, eclipse, using two of NASA's WB-57 jet planes to chase the shadow of the moon for unparalleled observations of the sun and Mercury. Credits: NASA/Faroe Islands/Southwest Research Institute. **6.** NASA's 18 Earth science missions in space, supported by aircraft, ships, and ground observations, measure aspects of the environment that touch the lives of every person around the world. This visualization shows the NASA fleet in 2017, from low-Earth orbit all the way out to the DSCOVR satellite taking in the million-mile view. Credit: NASA's Goddard Space Flight Center/Matthew R. Radcliff.

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The Re-Establishment of the National Space Council

On June 30, 2017, President Donald Trump signed an Executive Order to reinvigorate the National Space Council for the first time in 24 years and appointed Vice President Mike Pence to serve as the Chair. At the signing ceremony, the President remarked, "Today's announcement sends a clear signal to the world that we are restoring America's proud legacy of leadership in space."

The Council has 13 members: the Vice President as Chair, the Secretary of State, the Secretary of Defense, the Secretary of Commerce, the Secretary of Transportation, the Secretary of Homeland Security, the Director of National Intelligence, the Director of the Office of Management and Budget, the Assistant to the President for National Security Affairs, the Administrator of the National Aeronautics and Space Administration, the Director of the Office of Science and Technology Policy, the Assistant to the President for Homeland Security and Counterterrorism, and the Chairman of the Joint Chiefs of Staff.

President Donald Trump signs an Executive Order to re-establish the National Space Council, alongside members of Congress, NASA, and commercial space companies in the Roosevelt Room of the White House on Friday, June 30, 2017. Also present were Vice President Mike Pence and retired astronauts David Wolf, Alvin Drew, and Buzz Aldrin. Credit: NASA

The Council is tasked with advising and assisting the President regarding national space policy and strategy. The Council was never formally disestablished, but it effectively ceased operation in 1993.

The Council advises and assists the President regarding national space policy and strategy and is directed to review United States Government space policy and develop a strategy for national space activities. The Council also fosters close coordination, cooperation, and technology and information exchange among the civil, national security, and commercial space sectors. Additionally, the Council advises the President on participation in international space activities.

The Council held its first meeting, titled "Leading the Next Frontier: An Event with the National Space Council," on October 5, 2017, at the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Center in Chantilly, Virginia. At the meeting, Vice President Mike Pence outlined the Administration's vision to return American astronauts to the Moon and to build the foundation needed to send Americans to Mars and beyond, remarking, "Today, in the shadow of this history, we pledge to do what America has always done: We will push the boundaries of human knowledge. We will blaze new trails into that great frontier. And we will once again astonish the world as we boldly go to meet our future in the skies and in the stars."

The council heard testimony from expert witnesses representing the civil, commercial, and national security sectors of the space industry.

On December 11, 2017, President Donald Trump signed Space Policy Directive–1, which amended the National Space Policy of 2010 to instruct NASA to "[l]ead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."

National Aeronautics and Space Administration

NASA

Human Exploration and Operations Mission Directorate

Exploration Systems Development

The Exploration Systems Development (ESD) programs—Space Launch System (SLS), Orion, and Ground Systems Development and Operations (GSDO)—are on track to serve as the foundation of U.S. human exploration and will ensure continued U.S. space leadership for decades to come. The systems development, fabrication, assembly, and testing efforts performed today are establishing the foundation for a series of missions that will lead to the moon, Mars, and beyond.

Orion

Orion will serve as the exploration vehicle that will carry the crew to space, provide emergency abort capability, sustain the crew during space travel, and provide safe reentry from deep space return velocities. Orion will launch on NASA's new heavy-lift rocket, the SLS.

The Orion Program made substantial progress in 2017. The Orion Program completed and shipped the European Space Agency (ESA) Service Module (ESM) Structural Test Article (STA) from NASA's Plum Brook Station in Sandusky, Ohio, to Kennedy Space Center (KSC) in Florida. The Program completed a successful hot fire test of the attitude control motor (HT-11) in April 2017 and a successful test of the launch abort system abort qualification motor 1 in June

2017. ESA's ESM Propulsion Qualification Module was installed at NASA's White Sands Test Facility (WSTF) in February, and the first hot fire test of the Reaction Control System thrusters for Orion's ESM was conducted. The Program conducted several successful Orion parachute tests at the U.S. Army Proving Ground in Yuma, Arizona, to qualify the Orion capsule for human flight. Engineers at the Space Power Facility at Plum Brook Station in Sandusky, Ohio, conducted acoustic testing on the ogive panels. The ogive panels protect Orion's crew module from harsh acoustic conditions at launch and in case of an abort. The Exploration Mission–1 (EM-1) Crew Module (CM) and Crew Module Adapter (CMA) production at the KSC Neil Armstrong Operations and Checkout Center has made significant progress; both the CM and the CMA have completed initial power-on. During the initial power-on tests, engineers and technicians connected the vehicle management computers to Orion's power and data units to ensure the systems communicated precisely with one another to accurately route power and functional commands throughout the spacecraft for the duration of a deep space exploration mission. Steady progress is also being made on the EM-1 ESM being manufactured in Bremen, Germany. A NASA and Department of Defense (DOD) team tested procedures for exiting the Orion spacecraft in a variety of scenarios in July in the waters off the coast of Galveston, Texas. In addition, the Orion Program began manufacturing components for the Exploration Mission–2 (EM-2) mission, including the Crew Module forward and aft bulkheads, the Crew Module cone panel, solar cells, and EM-2 motors.

Space Launch System

The Space Launch System (SLS) is an advanced launch vehicle for a new era of exploration beyond Earth's orbit into deep space. SLS, the world's most powerful rocket, will launch astronauts in the Orion spacecraft on missions to the lunar environment and eventually to Mars, while opening new possibilities for other payloads including robotic scientific missions to places like Mars, Saturn, and Jupiter. The SLS Program achieved several important milestones this year. The Program completed the Orion Stage Adapter (OSA)/Interim Cryogenic Propulsion Stage (ICPS)/Launch Vehicle Stage Adapter (LVSA) integrated structural test qualification phase ahead of schedule. The SLS Program completed the EM-1 flight ICPS

and delivered the hardware to the Delta Operations Center at KSC for final testing. In February 2017, an F-3 tornado caused significant damage on the site of the Michoud Assembly Facility (MAF) in Louisiana, where the SLS Program manufactures the major SLS Core Stage elements. After recovering from this event, the Program completed liquid oxygen (LOX) qualification and flight tank Vertical Assembly Center (VAC) welding and the welding of the liquid hydrogen EM-1 flight tank. Completion of the LH2 EM-1 flight tank welding marked the completion of VAC welding for the EM-1 flight. All EM-1 booster separation motors are cast and finalized. The SLS Program completed the Core Stage Pathfinder build—a full-sized replica of the SLS Core Stage, which is used to simulate the Core Stage to test new shipping and handling equipment and procedures. NASA engineers closed a summer of successful hot fire testing for flight controllers on RS-25 engines that will help power the SLS. The 500-second hot fire of a RS-25 engine flight controller unit on the A-1 Test Stand at Stennis Space Center in August marked the fifth and final RS-25 hot fire test. In addition, the SLS Program began manufacturing a number of components for the EM-2 mission, including the EM-2 forward and center-forward booster segments and the EM-2 Core Stage engine section.

Ground Systems Development and Operations

The Ground Systems Development and Operations (GSDO) Program is responsible for overseeing ground systems upgrades and modifications to support the launch of the SLS and Orion spacecraft for EM-1, deep space missions, and NASA's journey to Mars.

At KSC, GSDO completed Vehicle Assembly Building (VAB) platform installation and outfitting. GSDO's renovation of Cape Canaveral Air Force Station (CCAFS) Space Launch Complex (SLC) 39B is progressing well and includes upgrades and modifications to the flame trench and environmental control system and a new flame deflector. GSDO successfully tested Crawler-Transporter 2 (CT-2) upgrades; CT-2 upgrades included new generators, gear assemblies, jacking, equalizing and leveling hydraulic cylinders, roller bearings, and brakes. The Program is progressing with Multi-Payload Processing Facility (MPPF) Verification and Validation; this facility will be used for offline processing and fueling of the Orion spacecraft and Service Module (SM) stack before launch. As of September

2017, the GSDO Program had completed the installation of five sets of umbilicals/attach points on the Mobile Launcher (Orion Service Module Umbilical, Core Stage Intertank Umbilical, Core Stage Forward Skirt Umbilical, Vehicle Support Posts, and Aft Skirt Electrical and Pneumatic Umbilicals), completing more than 70 percent of the umbilical and launch accessory deliveries to the Mobile Launcher from the Launch Equipment Test Facility. The first major integrated operation at CCAFS SLC-39B began in September 2017 with the initial tanking of the liquid oxygen sphere, a giant sphere that can hold about 900,000 gallons of liquid oxygen. Hardware delivered to GSDO this year included a left-hand forward skirt for the SLS solid rocket boosters, service platforms for the SLS booster engines, and the ICPS. Damage to GSDO systems during Hurricane Irma was minimal (limited to some minor damage to the MPPF and some water intrusion on the Mobile Launcher, none of which will significantly impact EM-1 preparations), thanks to the diligence of GSDO personnel ahead of the storm.

Commercial Crew Program

During the fiscal year, the Commercial Crew Program (CCP) partners Boeing and SpaceX continued making technical and programmatic progress in maturing their respective commercial crew transportation systems.

Throughout the year, both partners continued identifying and submitting variances, alternate standards, and hazard reports necessary for NASA's crew transportation system certification efforts.

- Both partners have advanced development and acceptance testing for key subsystems, including qualification and acceptance tests.
- Both partners have completed spacesuit designs and have publicly announced their designs. These suits provide protection to crewmembers during key mission phases.
- Both partners are manufacturing qualification hardware as well as the flight systems used to accomplish International Space Station (ISS) demonstration flights and operational missions.
- Boeing completed modifications to CCAFS SLC-41, their designated commercial crew launch pad.

- Boeing completed several program milestones during fiscal year (FY) 2017, including the Spacecraft Servicing Operational Readiness Review, the Crew Seat Incline Implementation, the Spacecraft Servicing Operational Readiness Review, and the Interim Review of Water/Land Landing Qualification.
- SpaceX completed the activation of CCAFS SLC-39A and has successfully flown multiple successful missions from the pad. SpaceX has designated CCAFS SLC-39A to transport astronauts to the ISS under the Commercial Crew Contract. SpaceX completed several program milestones during FY 2017, including the Spacesuit Qualification Testing Complete milestone; the Environmental Control and Life Support System (ECLSS) Integrated System Test, the Launch Site Operational Readiness Review, and the Validation Propulsion Module Design Review.

Through the CCP, NASA is ensuring that the Agency's commercial partners' crew transportation systems are safe, reliable, and cost-effective. The certification process assesses progress throughout the production and testing of the partners' systems, which include the launch vehicle, the spacecraft, and ground operations.

Collaborations for Commercial Space Capabilities

The objective of the Collaborations for Commercial Space Capabilities (CCSC) is to advance private-sector entrepreneurial space activities. All CCSC partners continue making technical and programmatic progress in maturing their respective commercial space capabilities.

International Space Station

The International Space Station (ISS) continued its focus on research and technology development in such disciplines as biology, human research, biotechnology, Earth science, physical science, and astrophysics during FY 2017. Orbital ATK completed two Commercial Resupply Services (CRS) flights, and SpaceX completed three CRS flights to the ISS. NASA relocated one of the Pressurized Mating Adapters (PMAs) to the forward end of the ISS to allow the ISS to

accommodate future Boeing and SpaceX commercial crew vehicles to dock utilizing the International Docking Adapter. NASA also installed new lithium-ion batteries delivered by the Japanese H-II Transfer Vehicle (HTV) through a combination of robotic operations and extravehicular activities (EVAs).

Five Soyuz crew rotations were accomplished in FY 2017. With the launch of Soyuz 50S on April 20, 2017, the Russian on-orbit crew decreased from three to two. U.S. astronaut Peggy Whitson's stay was extended until after the arrival of Soyuz 51S on July 28, 2017, setting the American record for most days in space and most days by any woman worldwide (665) with 288 days during this mission. In September 2017, the Soyuz 50S crew returned, and with the launch of Soyuz 52S on September 12, the U.S. segment crew increased from three to four. As a result, 2017 crew time spent on utilization far exceeded initial planning and has enabled additional research to be conducted. In 2017, the ISS hosted nearly 400 experiments in collaboration with more than 50 different countries.

Six U.S. EVAs were conducted during FY 2017. A pair of EVAs on January 6 and 13, 2017, successfully installed new lithium-ion batteries to upgrade the power storage system of the ISS. A second pair of EVAs on March 24 and 30, 2017, successfully completed upgrades to an external computer and prepared for the PMA relocation. On May 12, 2017, the U.S. crew conducted the 200th spacewalk in history from the ISS, replacing an external payload avionics box and performing other maintenance tasks. This was followed by an unscheduled EVA on May 23, 2017, to replace a failed external computer that could not be replaced robotically.

Orbital ATK's sixth contracted cargo mission, OA-5 (OA-6 launched in 2016), arrived at the ISS on October 23, 2016, following an October 17, 2016, launch on an upgraded Antares rocket from Wallops Flight Facility, Virginia, and departed from the ISS on November 21, 2016. The Cygnus spacecraft delivered over 5,200 pounds of supplies and science experiments to support Expedition 50, including deployment of four CubeSats after departing the ISS.

Orbital ATK launched its seventh contracted cargo mission, OA-7, to the ISS on April 18, 2017, from CCAFS on a United Launch Alliance (ULA) Atlas V rocket. The Cygnus spacecraft was berthed at the ISS on April 22, 2017, delivering more than 7,600 pounds of science and research, crew supplies, and vehicle hardware, including the Saffire-III combustion experiment, which was activated following Cygnus's

departure from the ISS on June 4, 2017. The spacecraft also deployed four Spire LEMUR-2 CubeSats from the NanoRacks deployer following departure from the ISS.

The HTV-6 cargo mission was launched from the Tanegashima Space Center in Japan on December 9, 2016, and was berthed to the ISS on December 13, 2016. The spacecraft carried more than 9,000 pounds of supplies, water, spare parts, and experiment hardware, including six new lithium-ion batteries and adapter plates to replace the nickel-hydrogen batteries on the ISS.

SpaceX launched its tenth contracted cargo mission, SpX-10, to the ISS on February 19, 2017, from CCAFS SLC-39A, marking the first launch from the site since the last flight of the Space Shuttle Program. The Dragon spacecraft was successfully berthed to the ISS on February 23, 2017, after the initial approach on February 22, 2017, was automatically aborted by an onboard computer when a data error was reported in its navigation system. The problem was traced to an incorrect data value in the spacecraft's Global Positioning System (GPS) and was corrected. The Dragon spacecraft delivered over 5,000 pounds of cargo, including the Stratospheric Aerosol and Gas Experiment III (SAGE III) Earth observation platform, and the U.S. Department of Defense's Space Test Program Houston 5 (STP-H5) package, which included the Raven navigation investigation and the Lightning Imaging Sensor. Dragon departed the ISS and splashed down on March 19, 2017, returning more than 3,600 pounds of NASA cargo and science samples from a variety of technological and biological studies.

SpaceX-11 launched on June 3, 2017, carrying three external payloads—the Roll Out Solar Array (ROSA), the Multi-User System for Earth Sensing (MUSES), and the Neutron star Interior Composition Explorer (NICER)—as well as nearly 4,000 pounds of other supplies and research for the ISS, including an Advanced Plant Habitat to conduct plant bioresearch on the ISS. The mission marked the first reuse of a Dragon spacecraft, which was berthed to the ISS on June 5, 2017, and departed on July 2, 2017, after completing its mission. A constellation of five CubeSats was also carried on the mission, one each from the countries of Japan, Nigeria, Bangladesh, Ghana, and Mongolia. The satellites from Bangladesh, Ghana, and Mongolia were the first in space from each of those countries.

The 12th SpaceX cargo resupply mission, SpaceX-12, was launched on August 14, 2017, and berthed to the ISS on August 16, 2017, carrying more than 6,400 pounds

of cargo, including the ISS Cosmic Ray Energetics and Mass (ISS-CREAM) experiment. The Dragon capsule departed on September 17, 2017, after completing its mission.

Space Life and Physical Sciences Research and Applications

Human Research Program

In 2017, data collection for the NASA Human Research Program (HRP) Twins Study concluded with preliminary results being analyzed across the ten investigator teams; a summary publication is expected in early 2018. For more than a year, identical twin brothers Scott and Mark Kelly participated by providing physiological samples and performing psychological tests. For Scott, samples were collected before, during, and after his one-year ISS mission. While Mark remained on the ground, he also provided identical samples at approximately the same times as his brother provided the in-flight samples. This approach allowed for a more complete and accurate assessment of how genes may be used differently due to environmental factors over time during the year of spaceflight. This comprehensive biological and psychological analysis will allow NASA to better understand the health risks associated with space travel and develop strategies to mitigate these risks.

NASA's Cooperative Agreement with the National Space Biomedical Research Institute (NSBRI) concluded this year. The 20-year agreement was established in 1997 by forward-thinking NASA personnel who envisioned the need for a nongovernmental organization to have a leadership role in bringing top-tier biomedical research, education, and clinical expertise to NASA to solve problems and mitigate risks associated with human space exploration. NSBRI leaves a rich legacy as its program ends, and it validates how great things happen in our Nation when two areas of American preeminence—biomedical research and human space exploration—come together in a collegial and productive mission-focused manner to push the frontier of what is possible.

NASA's Translational Research Institute (TRI), headquartered at Baylor College of Medicine, awarded grants for ten trailblazing research projects in the areas of omics, lymphatic flow, radiation damage resistance, minimally invasive surgical capabilities, and the effects of the microbiome on health during long-duration

spaceflight. The Principal Investigators leading the research studies reside at nine institutions in six states: California, Florida, Kentucky, Massachusetts, North Carolina, and Texas; several are new to the space-related biomedical research community. Three projects are large program grants involving investigators from multiple institutions in different states, all working in a coordinated fashion. NASA's TRI is charged with developing innovative approaches to reduce risks to humans during long-duration exploration missions, including NASA's plans for the exploration of the solar system. Translational research is an interdisciplinary model of research that focuses on rapidly translating fundamental research concepts into practice, thereby generating tangible health outcomes—in this case, for astronauts.

In 2017, the HRP completed delivery of the following for assessment and integration into operations:

- **Hybrid Ultimate Lifting Kit 2** (HULK2) will support the upcoming Next Step Broad Agency Announcement (BAA) Habitat Assessment. HULK2 is a prototype hybrid pneumatic/servomotor-based exercise device for resistive and aerobic training, designed to accommodate long-duration space missions. HULK2 meets aerobic and resistive exercise functional performance requirements needed to maintain crew health for exploration missions, such as those envisioned for the Gateway and Transport habitat concepts, and accomplishes this in an extremely compact footprint.
- **Cognition** is a software tool that assesses real-time crew performance in both terrestrial and spaceflight operations to determine the efficacy of countermeasures designed to mitigate the effects of fatigue, circadian misalignment, and work overload on cognitive functioning.
- **Integrated Medical Model** is a Monte Carlo model using spaceflight medical data and selected terrestrial information to estimate in-flight medical risk to crew given specific resource requirements.
- **Reaction Self-Test** is a self-administered monitoring tool that enables astronauts to detect and measure neurobehavioral changes, which are induced by fatigue and other performance-degrading factors.

Biological and Physical Sciences

Under the management of the Space Life and Physical Sciences Research and Applications Division (SLPSRAD), Biological and Physical Sciences (BPS) at NASA in 2017 initiated a strategy to explicitly align research on two primary thrusts, Enabling Exploration and Pioneering Scientific Discovery. This structure is in keeping with the framework for research prioritization recommended by the National Research Council in its Decadal Survey for Life and Physical Sciences at NASA.

In 2017, SLPSRAD made focused efforts to connect research it sponsors under the theme of Enabling Exploration with organizations responsible for integrating technologies into exploration missions. The Zero Boil-Off Tank experiment, a research project developed by SLPSRAD for operation on the ISS in 2018, was identified by the Space Technology Mission Directorate as "Exploration Critical" in recognition of the value of the data from the experiment for the design of future cryogenic fuel storage facilities in space. The 2017 results of another SLPSRAD project, the Packed Bed Reactor Experiment, are being studied by the Advanced Exploration Systems Division for application to designs of future generations of life-support equipment.

Work in the Space Biology Program in 2017 also made significant progress to enable exploration. Research in the microbiome of space vehicles is just beginning, but it will be important to understand how humans and the microbes that live with and in us will adapt to life on long-duration space missions. In 2017, in the first of a new series of investigations into the microbiome (the microbial ecosystem) aboard the ISS, investigators identified several multi-drug-resistant bacteria, along with two previously unrecognized pathogenic fungi growing on various surfaces aboard the ISS. With the support of the Human Research Program, research on the microbiome of the ISS has been identified as "Exploration Critical." Another 2017 project in Space Biology that was determined to be an "Exploration Critical" investigation on the ISS was Rodent Research–9. NASA researchers are looking to this project, which uses mice to model human physiology, to provide insights into how changes in fluid pressure in the vascular function of the central nervous system might be responsible for changes in visual acuity that have been observed in a number of astronauts on the ISS.

SLPSRAD research in 2017 is part of NASA's commitment to develop the potential of low-Earth orbit (LEO) through pioneering scientific discovery. The continuing success of the ISS partnership hinges on NASA's continuing leadership in space research and development. An example of how SLPSRAD work in 2017 helped maintain the vitality of the ISS partnership is in cold atom research. Working with a team of distinguished physicists that includes three Nobel Laureates, NASA is developing the Cold Atom Laboratory (CAL) at the Jet Propulsion Laboratory for deployment on the ISS in early 2018. In the weightless environment of the ISS, CAL should be able to create the coldest atoms in the observable universe, atoms so cold and nearly motionless that, following the Uncertainty Principle, each atom will be almost observable with the naked eye. Physicists working in German laboratories have been using microgravity for several years now and have been eager to get access to facilities on the ISS. The German Space Agency (DLR) and NASA made substantial progress in 2017 toward an agreement that will see a German-developed follow-on to CAL on the ISS in the early 2020s. In 2017, a joint U.S.-German Science Definition Team was established to define the capabilities and technical objectives for the new facility, called Bose-Einstein Condensate Cold Atom Laboratory, or BECCAL. BECCAL will be an important contribution to the scientific productivity of the ISS for European and American scientists in the next decade of ISS operations.

Scientific discovery is also the pioneering effort for future commercial developments. Throughout the history of science, basic research has created opportunities for commercial application. In 2017, SLPSRAD-sponsored space biology projects in animal physiology, using mice, teamed with commercial investigators sponsored by the management organization for the ISS National Laboratory, the Center for the Advancement of Science in Space (CASIS), to greatly increase the productivity of these resource-intensive experiments. SLPSRAD-sponsored investigations in 2017 enabled commercial experiments to explore many potential new applications for research with rodent models in space. This interaction has led to increasing cooperation between commercial and basic rodent research, as well as the sponsorship by CASIS of a SLPSRAD rodent research investigation on the ISS, because of its potential to shed light on new applications for rodent research in space for pharmaceutical development.

Human Spaceflight Capabilities

By the end of FY 2017, the Rocket Propulsion Test (RPT) Program had safely performed 586 tests. Test time totaled over 205,566 seconds, with more than 18,366 seconds of hot fire testing at various levels of thrust. This represents a 10 percent increase in the number of tests performed and a 35 percent increase in test duration from FY 2016. During this period, the test facilities had seven facility-caused test delays, resulting in 98.8 percent facility readiness, far exceeding the 90 percent RPT Annual Performance Indicator.

In FY 2017, Stennis Space Center (SSC) performed 165 tests for a variety of NASA, other Government, and commercial propulsion systems developers. Test programs included RS-25 in support of the SLS Program, testing of the Aerojet Rocketdyne (AR) RS-68 engine in support of the U.S. Air Force (USAF) and ULA, WSTF testing of ESA's ESM subscale diffuser, testing of Aerojet Rocketdyne AR-1 subscale and full-scale components for the USAF RD-180 replacement effort, subscale and full-scale testing of SpaceX Raptor engine components, and testing of Relativity Space Aeon-1 engine and components.

In 2017, there were several facility preparation activities under way to support multiple Government and commercial development activities, including B-2 test stand repair and restoration activities to support SLS Core Stage testing. Additionally, NASA made investments to modernize and automate the SSC sitewide nitrogen supply system, facility modifications and special test equipment (STE) development in E-1 Cell 1 supporting AR-1 full-scale LOX/refined propellant (Rp) battleship pre-burner testing, and design and demolition activities on A-2 in support of the AR-1 engine system testing.

Other activities at SSC included the buildup of systems in the E-Complex required to support the joint DOD-NASA hydrocarbon boost program and the Aerojet Rocketdyne LOX and refined propellant (Rp) development program. USAF and NASA Advanced Booster Engineering Demonstration and/or Risk Reduction (ABEDRR)/Hydrocarbon Boost development activities, facility modifications, and STE development are under way on E-1 Cell 1, supporting the joint Hydrocarbon Boost testing.

In 2017, Marshall Space Flight Center (MSFC) performed 116 tests for a variety of NASA, other Government, and commercial test programs, which included testing engine components manufactured using advanced technologies and affordable additively manufacturing technologies. In addition, MSFC tested articles using LOX, liquid methane (LCH_4), and new LOX Rp combustion techniques for both Government and commercial test customers. In 2017, MSFC provided test services for Aerojet Rocketdyne, Orbital ATK, Dynetics, and United Launch Alliance.

In 2017, WSTF performed over 250 tests and completed the buildup and preparation of Test Stand (TS) 301 to support testing of the Orion ESA ESM and Test Stand 301A to support the Boeing Crew Space Transportation (CST)–100 crew abort system and SM testing. Following the completion of the buildup activities on TS-301, WSTF performed the first integrated hot fire tests of the ESA ESM. In addition to the two ESM programs, WSTF also provided test support for the Missile Defense Agency (MDA), the USAF Minuteman, and the USAF Peacekeeper demilitarization.

In 2017, WSTF also provided support to the Commercial Crew Program by conducting acceptance-testing of the Boeing CST-100 Launch Abort Engines (LAEs) on TS-301A, Orbital Maneuvering Attitude Control (OMAC) thrusters on TS-401, and Reaction Control System (RCS) thrusters on the reactivated TS-406.

In 2017, Glenn Research Center performed 61 tests. At the Lewis Field location, the Altitude Combustion Stand (ACS) performed 29 tests in support of advanced research and development (R&D) of green-propellant propulsion systems.

The GRC Plum Brook Station (PBS) In Space Propulsion Facility (formerly known as B2) performed 32 hot fire tests in a simulated vacuum and simulated thermal conditions of space. These 32 tests were the first to be performed in the facility in over ten years. The 32 tests were performed over a cumulative 52 hours, during which the test article was also exposed to the simulated space environment. The testing and preparations began for the Moon Express Lander, SpaceX Dragon, and advanced cryogenic fluid management. In 2017, PBS also began preparations for a facility refurbishment that will enable hot fire testing of a 30,000-foot-pound-thrust system for up to 300 seconds (used as a reference; other articles of different thrusts can be tested with varying run times).

Launch Services

During FY 2017, the Launch Services Program (LSP) successfully launched two major science missions and one communications satellite: The Geostationary Operational Environmental Satellite R (GOES-R), the Cyclone Global Navigation Satellite System (CYGNSS), and the Tracking and Data Relay Satellite M (TDRS-M). GOES-R successfully launched on November 19, 2016, aboard an Atlas V rocket, followed by CYGNSS on December 15, 2016, aboard a Pegasus XL rocket. TDRS-M launched on August 18, 2017, also aboard an Atlas V rocket. All three missions launched from CCAFS in Florida. 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 learn more about these and other NASA science missions, see the Science Mission Directorate 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 offering competitive opportunities to U.S. commercial launch providers. In FY 2017, the program acquired launch services for one future science mission and one new-generation polar-orbiting operational environmental satellite: The Surface Water and Ocean Topography (SWOT) and the Joint Polar Satellite System 2 (JPSS-2). The SWOT launch service was awarded to Space Exploration Technologies (SpaceX) of Hawthorne, California. SWOT will launch in April 2021 aboard a Falcon 9 Full Thrust. The JPSS-2 launch service was awarded to United Launch Services (ULS), LLC, of Centennial, Colorado. JPSS-2 will launch in July 2021 aboard an Atlas V rocket. Both missions will launch from Vandenberg Air Force Base in California. JPSS is a collaborative program between the National Oceanic and Atmospheric Administration (NOAA) and NASA.

NASA and LSP continue to partner with several universities and NASA Centers to launch small research satellites through the CubeSat Launch Initiative (CSLI), providing rideshare opportunities for small satellite payloads to fly on upcoming launches when space is available. These partnerships have provided regular educational opportunities for students in science, technology, engineering, and mathematics disciplines, thereby strengthening the Nation's future workforce.

To date, CubeSats have been selected from 38 states across the United States, with 49 missions launched and 46 manifested on NASA, National Reconnaissance Office, U.S. Air Force, and commercial missions. In FY 2017, six CSLI CubeSats were launched.

The Venture Class Launch Services (VCLS) contracts for CubeSat satellites foster a commercial launch market dedicated to flying small-satellite payloads by serving as an alternative to the current rideshare approach, in which one or more CubeSats take advantage of excess payload capacity on a rocket whose primary mission is to launch a larger satellite. Rocket Lab USA has the first VCLS launch scheduled for FY 2018 aboard the Electron launch vehicle. Virgin Galactic will follow with a scheduled launch in FY 2018 aboard the LauncherOne. In addition, the certification effort for ULA's Delta IV Heavy launch vehicle was completed in FY 2017. The Delta IV Heavy launch vehicle is now Category 3 certified by NASA LSP. The Parker Solar Probe mission, which will fly closer to the sun than ever before, is scheduled to launch on the Delta IV Heavy in FY 2018. LSP also continued to support the certification activities of the SpaceX Falcon 9 "Full Thrust" launch vehicle. SpaceX did successfully complete Category 2 certification of the Falcon 9 "Full Thrust" in January 2018, which supports the launch of the NASA Transiting Exoplanet Survey Satellite (TESS) mission in March 2018. The LSP further conducted preliminary activities that would support the eventual certification of the Orbital ATK Antares 230 as well as proposed future launch vehicles such as the ULA Vulcan, the Orbital ATK Next Generation Launcher, and the Blue Origin New Glenn commercial launch vehicles.

Lastly, LSP participated in SpaceX's investigation of the on-pad explosion that occurred on September 1, 2016, at SLC-40 at CCAFS in Florida during propellant loading of the Falcon 9 Full Thrust launch vehicle variant. The vehicle was being prepared for an on-pad engine test when the vehicle explosion occurred. An Accident Investigation Team (AIT) was composed of members from SpaceX, the Federal Aviation Administration (FAA), NASA, the U.S. Air Force, and industry experts. The SpaceX investigation has been completed, and corrective actions are being implemented. While this accident did not occur in preparation for a NASA launch, the Agency wants to understand the incident and any design or procedure changes SpaceX elects to make before committing NASA payloads to fly on future

Falcon 9 vehicles. LSP was a member of the SpaceX AIT and is also conducting its own independent review of the accident.

Advanced Exploration Systems

The Advanced Exploration Systems (AES) Division pioneers 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 2017, the AES Division continued the successful execution of 28 research and technology development activities employing over 400 civil servants spread across all NASA Centers. The activities are grouped into four domains: Habitation Systems, Vehicle Systems, Foundational Technologies, and Robotic Precursors.

Activities in the Habitation Systems domain develop systems to enable the crew to live and work safely in deep space, including beyond-Earth-orbit habitats, life-support systems, radiation protection, fire safety, and logistics reduction.

AES awarded Next Space Technologies for Exploration Partnerships (NextSTEP) contracts to Boeing, Lockheed Martin, Orbital ATK, and Sierra Nevada Corporation to develop prototype deep space habitats for ground testing, and to Nanoracks to study concepts for converting an expended upper stage into a habitat. Building on the successful deployment of the Bigelow Expandable Activity Module (BEAM) on the ISS in 2016, a NextSTEP contract with Bigelow Aerospace to also develop a prototype deep space expandable habitat for ground testing is pending award. These partnerships require the companies to contribute at least 30 percent of their own funding to the efforts.

The Life Support Systems activity launched an Aerosol Sampler to the ISS and returned samples for laboratory analysis. This activity completed assembly of the Spacecraft Atmosphere Monitor development model that will detect hazardous chemicals in the ISS air.

The Radiation Sensors activity launched a Fast Neutron Spectrometer and a Miniature Particle Telescope to monitor the ISS radiation environment. This activity delivered the Hybrid Electronic Radiation Assessor (HERA) flight unit for EM-1.

AES successfully conducted the Saffire-II and Saffire-III fire safety experiments on the Cygnus vehicle to investigate the spread of large-scale fires in microgravity. AES completed the Critical Design Review (CDR) for the next three Saffire experiments that will monitor combustion products and demonstrate postfire cleanup technologies.

The Logistics Reduction activity installed the Radio Frequency Identification (RFID)–Enabled Autonomous Logistics Management (REALM-1) hardware on the ISS and demonstrated end-to-end data transfer from over 3,000 RFID tags to the ground control station. REALM-1 was also used to locate missing items quickly. This activity also completed the CDR for the Universal Waste Management System, which is a compact toilet that will be flown on the ISS and Orion.

Activities in the Vehicle Systems domain develop systems to enable human and robotic exploration vehicles, including advanced in-space propulsion, lander technology, and modular power systems.

AES is developing high-power electric thrusters for the next generation of solar electric propulsion systems via three NextSTEP Advanced Propulsion activities. Ad Astra Rocket Company is developing the Variable Specific Impulse Magnetoplasma Rocket (VASIMR); Aerojet Rocketdyne is developing a nested Hall thruster; and MSNW is developing an Electrodeless Lorentz Force plasma thruster. In the first year of their three-year contracts, the companies assembled their thrusters, upgraded test facilities, and began short-duration tests. The goal is to test the 100-kilowatt thrusters in a vacuum chamber for 100 continuous hours in 2018.

The Lander Technology activity conducted an open-loop flight test of Navigation Doppler Lidar and Lander Vision System on the Masten Space Systems lander to demonstrate technologies for autonomous precision landing.

The Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative is continuing to provide engineering and test support for three companies developing robotic lunar landers: Astrobotic, Moon Express, and Masten Space Systems. In addition, NASA issued a joint Request for Information from the Science Mission Directorate (SMD) and HEOMD to assess the demand for delivering small payloads to the moon using commercial services.

The Orion Ascent Abort flight test vehicle completed its Preliminary Design Review. A mockup of the Orion capsule and an active Launch Abort System will be launched on a booster rocket in 2019 to demonstrate boost phase abort capabilities.

Activities in the Foundational Technologies domain enable more efficient mission and ground operations and those that allow for more Earth independence, including autonomous mission operations, avionics and software, in situ resource utilization, in-space manufacturing, synthetic biology, and communication technologies.

The Avionics and Software activity conducted an integrated test of a reference avionics architecture that uses three voting computers and time-triggered Ethernet to control life support, power, communications, and other subsystems for a deep space habitat.

The In-Space Manufacturing activity issued a Broad Agency Announcement to solicit proposals for a Multi-Material Fabrication Lab on the ISS. This activity completed the CDR for the Refabricator payload that will recycle plastic parts on the ISS and produce feedstock for an integral 3D printer.

The Synthetic Biology Applications activity demonstrated that yeast could be genetically modified to produce a key bio-nutrient. This activity developed a prototype bio-nutrient packet to supplement the crew's diet on long missions.

The Disruption Tolerant Networking (DTN) activity conducted interoperability tests with the Korea Aerospace Research Institute (KARI) in preparation for their Korea Pathfinder Lunar Orbiter mission and demonstrated DTN on the 21-meter antenna at Morehead State University for communicating with CubeSats.

Activities in the Robotic Precursor domain develop robotic missions and payloads to acquire strategic knowledge on potential destinations for human exploration to inform systems development, including prospecting for lunar volatiles, CubeSats launched on EM-1, technology demonstrations on the Mars 2020 mission, and instrument development.

AES continued development of three payloads for the Mars 2020 mission. The Critical Design Reviews for the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) and the Mars Environmental Dynamics Analyzer (MEDA) were completed. The Mars Entry, Descent, and Landing Instrumentation-2 (MEDLI-2) payload completed its Preliminary Design Review. MOXIE will

demonstrate the production of oxygen from the Mars atmosphere; MEDA is a surface weather station; and MEDLI-2 is a suite of temperature and pressure sensors on the Mars 2020 heat shield to validate aerothermal models.

AES plans to launch five CubeSats on EM-1 to fill gaps in our knowledge about space environments and the availability of lunar resources. These activities completed their design and safety reviews and began spacecraft integration. BioSentinel will investigate the effects of deep space radiation on yeast DNA. Lunar Flashlight will search for ice from lunar orbit using lasers to illuminate permanently shadowed lunar craters. Near-Earth Asteroid Scout will use a solar sail to fly by an asteroid. The Lunar Infrared (LunIR) CubeSat is a NextSTEP partnership with Lockheed Martin to fly by the moon and test a new infrared sensor. Lunar IceCube is a NextSTEP partnership with Morehead State University to detect water and other volatiles from lunar orbit using a broadband infrared spectrometer.

NASA signed an agreement with the KARI for hosting NASA instruments on the Korea Pathfinder Lunar Orbiter. AES competitively selected the ShadowCam instrument from Arizona State University to image ice in permanently shadowed lunar craters.

The AES Division is leading the definition of system concepts, requirements, and design standards for a Deep Space Gateway (DSG) concept that will be launched into lunar orbit around 2023. The DSG may consist of a habitat, a solar electric propulsion and power element, logistics capabilities, and an airlock/docking node. Orion will dock with the DSG, and a crew of four will stay onboard for 30 days to gain experience in living and working in deep space and to test critical life-support and logistics management technologies for long missions. In 2029, NASA envisions the launch of a Deep Space Transport (DST) vehicle that can be outfitted at the DSG in preparation for a yearlong shakedown cruise that simulates a human mission to Mars. The DST may consist of a large Mars transit habitat and a hybrid solar electric and chemical propulsion system. After completing the DST shakedown cruise, NASA will be ready to send human missions to the vicinity of Mars.

NASA discontinued the Asteroid Redirect Mission (ARM) in 2017. Key capabilities such as advanced solar electric propulsion continue to be matured for future deep space human and robotic exploration with applicability to the Nation's public- and private-sector space needs.

Leveraging work on a high-power solar electric propulsion spacecraft begun under ARM, NASA issued a Request for Information seeking ideas and readily available information from U.S. industry on their current commercial capabilities, concepts and development approaches, and potential for future commercial applications that support a cost-effective partnership model for possible use in the potential development of a Power and Propulsion Element (PPE) that may become part of the Deep Space Gateway (DSG) concept. NASA also released a NextSTEP BAA solicitation for industry studies of PPE concepts and potential partnership models. These studies are planned for award early in FY 2018.

Space Communications and Navigation

The Space Communications and Navigation (SCaN) Program is responsible for programmatic oversight and management of NASA's space communications and tracking capabilities. Since the launch of first U.S. satellite (Explorer 1) from Cape Canaveral in 1958, these capabilities have been used to provide space communication and navigation (C&N) services to spacecraft and to their rockets. Since 1958, the customer base has expanded from NASA missions to a wide range of external customers (other U.S. and international government agencies and commercial entities) because mission managers recognized the criticality of a robust C&N system for any space mission (e.g., human exploration, robotic spaceflight launches, low-Earth and deep space science, nanosats, and SmallSats). SCaN strives to maintain its C&N infrastructure in a robust operational status. SCaN is also upgrading the infrastructure in response to the customer requirements and demands and because current infrastructure is simply old.

Ongoing operations of NASA's three space communication networks—the Near Earth Network (NEN), the Space Network (SN) Tracking and Data Relay Satellite System (TDRSS), and the Deep Space Network (DSN)—continued their long-standing history of exceeding the Agency requirement of 95 percent proficiency with at least 99 percent proficiency. Astronauts and spacecraft depend on this reliable uplink and downlink of communications for the delivery of commands and essential crew instructions, as well as the retrieval of health and safety information and science data, with delivery of the data to individual mission control centers.

During FY 2017, SCaN networks provided C&N services to 72 missions, including services to human spaceflight. The networks also provided launch and early-orbit telemetry, tracking, and communication (TT&C) services to 23 expendable launch vehicles (ELVs).

SCaN successfully launched the TDRS-M spacecraft on August 18, 2017, to join and sustain the TDRSS. TDRS-M is the final planned TDRSS spacecraft with a spacecraft mission duration of 15 years. Significant progress was made in the SN Ground Sustainment System (SGSS) project in coding, hardware integration, and testing. SCaN continued to address the cost and schedule challenges encountered in this major ground system upgrade activity. The DSN continued to build two new 34-meter antennas at the Madrid Deep Space Communications Complex in Spain. These are part of the DSN Aperture Enhancement Project designed to meet all deep space communication requirements.

SCaN continued to serve as the Agency's Spectrum Manager, with responsibility for representing NASA's spectrum interests and negotiating on its behalf with the White House, Congress, relevant Government agencies and national regulators, and interagency partners in the determination of spectrum allocations. As part of the State Department–led U.S. delegation, SCaN began coordination on Agenda Items on spectrum issues of interest and concern to NASA that will be addressed at the World Radiocommunication Conference 2019.

SCaN serves as the Agency lead in coordinating the development of international space communication standards, which enable cross support and interoperability of systems. This translates into hundreds of millions of dollars in savings for NASA without reducing services and coverage for space missions. The SCaN Data Standard Project remained engaged in the Consultative Committee for Space Data Systems (CCSDS), an international organization chartered in 1982, to provide a forum for the discussion of common problems in the development and operation of space data systems. The CCSDS works closely with the Interagency Operations Advisory Group (IOAG) to ensure that standards are developed in advance of Agency missions. As NASA's representative to the IOAG, SCaN engaged in key discussions related to interoperability and cross support for future moon and Mars missions, mission operations, optical communications, and other key issues. The International Space Exploration Coordination Group (ISECG) requested

this year that the IOAG serve as the international coordination board for space communication–related issues for the ISECG. In FY 2017, SCaN engineers led numerous CCSDS working groups in the completion of many new standards and made substantial progress leading the optical communications working group to charter and develop several new standards for optical communications.

Expanding space communications from the radio frequency to the optical spectrum can increase data rates by an order of magnitude and lower spacecraft burden (mass, power, and volume). Decreased burden enables optical communications to be applied in SmallSat and nanosat applications as well. SCaN is aggressively pursuing making optical communication an operational capability with initial capability from LEO. This fiscal year, SCaN continued building two Optical Ground Stations (OGSes)—OGS-1 at the Jet Propulsion Laboratory in California, and OGS-2 in Hawaii, the U.S. locations with the least interfering cloud coverage. Through participation in the IOAG and the CCSDS, NASA reached agreement with the Japan Aerospace Exploration Agency (JAXA) and Centre National d'Études Spatiales (CNES) on optical communications standards, making interoperability between the participating agencies possible.

NASA directed the continuation of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board through a renewed charter in September 2017, for which SCaN continued in its role as the Executive Director. This Federal Advisory Committee Act (FACA) board includes an august body of PNT experts from within industry and the international community that meets biannually to provide its recommendations on PNT-related issues to the National Space-Based PNT Executive Committee, chaired by the Deputy Directors of Defense and Transportation. On behalf of the Agency, SCaN led the national effort to develop a Space Service Volume (SSV) capacity for the Global Positioning System, which will enable the use of existing GPS signal for beyond-LEO PNT services. Through its efforts with the International Committee on Global Navigation Satellite Systems (GNSS) (ICG), all of the other GNSS providers are now developing SSV capacity for their systems, leading to a much greater reliability and accuracy for beyond-LEO navigation.

Science Mission Directorate

NASA's Science Mission Directorate (SMD) uses the unique vantage point of space, along with assets in the air and on the ground, to seek new knowledge and understanding of Earth, our sun and solar system, and the universe. The four SMD research divisions (Earth Science, Heliophysics, Planetary Science, and Astrophysics), together with the Joint Agency Satellite Division (JASD) and the James Webb Space Telescope (Webb) program office, carry out research that contributes critical knowledge and delivers societal benefits for people around the globe. Science is interconnected; no important question stands alone. In SMD, discoveries in one scientific discipline have a direct route to other areas of study. SMD supports strategic investments in technology to enable new scientific discoveries and shares data and research findings, openly and freely, with the public to improve science, technology, engineering, and mathematics (STEM) education nationwide. The work done in SMD helps to lay the foundation for the robotic and human expeditions of the future. In FY 2017, SMD managed more than 100 space missions and maintained high-altitude balloon, sounding rocket, and airborne research programs, with more than 10,000 scientists around the globe contributing to SMD research.

Earth Science

NASA's Earth Science Division (ESD) seeks to understand our planet as an interconnected system. This system is made up of diverse components—the atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere—that all work together. Yet it is a system that we do not fully understand. The Earth Science program helps to develop a scientific understanding of the changes occurring on our planet on a variety of temporal and spatial scales. A key strategic element is sustained simultaneous observations to unravel the complexity of the global integrated Earth system. The Earth Science program has four major elements: Flight Programs (Earth Systematic Missions and Earth System Science Pathfinder) develop satellite missions; Earth Science Research advances scientific understanding and identifies the focus areas for the next generation of missions; Technology develops new technology and

enables the next generation of effective satellite and airborne instruments; and Applied Sciences advances the effective use of Earth science measurements and scientific understanding by other Federal, state, local, and tribal organizations.

As of September 2017, NASA ESD operated 20 coordinated spaceborne missions, acquiring well-calibrated, global observations with high spatial and high temporal resolution. NASA aircraft- and surface-based instruments calibrate, complement, and enhance interpretation of satellite measurements. The data from these missions, and the products derived from those data, contribute to knowledge and capabilities in a wide range of areas including weather, natural disasters, climate, oceans and water management, and agricultural production. Throughout FY 2017, NASA's fleet of Earth science satellites contributed to our understanding of Earth and directly benefited the lives of people around the globe.

The Global Precipitation Measurement (GPM) core satellite gathered rainfall data on severe storms in the United States and throughout the world, providing data used by forecasters to better understand storm characteristics. Together with data from other U.S. and international satellites, NASA generated products that provided estimates of the rainfall that occurred during severe events. Data from the Atmospheric Infrared Sounder (AIRS) instrument, one of six instruments flying onboard NASA's Aqua satellite, helped improve forecasts by providing three-dimensional maps of clouds, air temperature, and water vapor throughout the atmosphere's weather-making layer.

Following Hurricanes Harvey, Irma, and Maria in August and September 2017, NASA's disaster team worked closely with the Federal Emergency Management Agency (FEMA), the National Guard, and other partners to leverage satellite data to support their decision-making and response efforts. Data from the GPM Core Observatory helped forecasters understand and track the storms as they developed and moved across the United States. NASA partners used GPM data to drive the Global Flood Monitoring System, which produced flood forecasts for all three hurricanes. NASA's Soil Moisture Active Passive (SMAP) satellite provided information about soil moisture relevant to flooding and agricultural impacts. Data from synthetic aperture radar instruments on NASA, European Space Agency, and Japan Aerospace Exploration Agency aircraft and satellites collected high-resolution observations of rivers, floodplains, and critical infrastructure even

through cloudy conditions. NASA was able to use its whole suite of imaging satellites to assist with flood mapping and recovery planning. The NOAA-NASA Suomi National Polar-orbiting Partnership's (Suomi NPP) night lights product even made it possible to locate utility and power outages by identifying areas with a reduction in emitted night lights.

New instruments will further increase our understanding of severe weather phenomena. On December 15, 2016, NASA launched the Cyclone Global Navigation Satellite System (CYGNSS), a science-driven, eight-SmallSat constellation, delivered in a single launch. CYGNSS uses GPS signals reflected by the ocean to determine near-surface wind speed over tropical oceans and inside hurricanes. Scientists will use the data gathered by CYGNSS to help make improvements in hurricane forecasts. On February 19, 2017, the Lightning Imaging Sensor (LIS) and Stratospheric Aerosol and Gas Experiment (SAGE) III instrument were launched to the ISS. Data from LIS are helping improve weather forecasting, climate modeling, and air quality studies. SAGE III is monitoring the condition of the ozone layer, which covers an area in the stratosphere 10 to 30 miles above Earth and protects the planet from the sun's harmful ultraviolet radiation. On May 16, 2017, NASA launched the IceCube mission, a bread loaf–sized satellite that is demonstrating and validating a new 874-gigahertz submillimeter-wave receiver that is helping to advance scientists' understanding of ice clouds—a key property in weather and climate models. Another CubeSat, called Microwave Radiometer Technology Acceleration (MiRaTa), launched in November 2017, carrying ultra-compact instruments capable of measuring temperature and humidity.

In addition to severe weather, NASA collects data and develops products related to a variety of other natural disasters. The Moderate Resolution Imaging Spectroradiometer (MODIS), which flies on both the Aqua and Aura satellites and the Visible Infrared Imaging Radiometer Suite (VIIRS) on Suomi NPP, allowed NASA scientists to quickly determine the exact location of wildfires and monitor their movement. These data are contributing significantly to the tracking of the development of wildfires around the world. MODIS and VIIRS imaging capabilities are also used to track smoke generated by the fires, while its thermal bands make it possible to distinguish active burning areas. The MODIS instrument also is used in combination with VIIRS to identify areas at risk for drought. Scientists

showed that the United States had largely recovered from droughts experienced in recent years but that a number of countries in Africa were now at risk of drought and potentially famine. Scientists combined GPM rainfall observations with data about the ground, including elevation data collected by the Shuttle Topography Mission and forest loss data based on Landsat imagery, to develop a new global map of landslide susceptibility. They hope to use these data to provide situational awareness of landslide hazards to users around the world.

Satellites provide a unique opportunity to understand ice that covers Earth, particularly in remote areas, including the Arctic and Antarctic. Scientists used Landsat 8, along with ESA's Copernicus Sentinel 1 satellites, to track a growing rift in the Antarctic Larson C ice shelf, watching as a massive iceberg broke away in July 2017. The NASA-funded Global Land Ice Velocity Extraction (GoLIVE) project used Landsat 8 data to provide a near-real-time view of every large glacier and ice sheet on Earth. This new product provides critical information to coastal communities that will be most impacted by rising oceans.

NASA's Oceans Melting Greenland (OMG) project uses measurements taken by aircraft and ships to determine the extent to which warm ocean waters are melting glaciers from below. Data from OMG were combined with data from NASA's Operation IceBridge project, which uses aircraft to collect images of Earth's polar ice, to get very accurate measurements of Greenland's melting glaciers. The mission of Operation IceBridge is to bridge the gap between NASA's Ice, Cloud and Land Elevation Satellite (ICESat) missions. The first ICESat mission ended in 2010. ICESat-2, which is scheduled for launch in 2018, will use a laser instrument to measure the height of Earth's surfaces globally. In August, the lasers began several months of testing to ensure they are ready to operate in the harsh environment of space.

Satellites offer the only method to accurately measure solar irradiance, the output of electromagnetic energy from the entire disk of the sun, measured at Earth. This energy sustains the entire Earth system, influencing Earth's surface and air temperatures, among many other effects. NASA will continue a nearly 40-year record of measuring total solar irradiance with the launch of the Total and Spectral Solar Irradiance Sensor (TSIS-1) to the ISS in the first quarter of FY 2018. Closely related is Earth's radiation balance, the difference between the amount of energy

from the sun that reaches Earth and the amount that is reflected and transmitted back into space. The Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat, launched in November 2016, is testing new technologies, including carbon nanotubes that absorb outbound radiation, never before used on an orbiting spacecraft to make this measurement.

NASA missions also make important contributions to studies of the atmosphere. Scientists used observations from NASA's Orbiting Carbon Observatory-2 (OCO-2) to develop a new model of carbon behavior in our atmosphere, showing in detail the complex patterns in which carbon dioxide in the atmosphere increases, decreases, and moves around the globe. Scientists also demonstrated the ability to use OCO-2 data to make satellite-based maps of human emissions of carbon dioxide. The maps depict widespread carbon dioxide around major urban areas, as well as some smaller pockets of high emissions. OCO-2 data helped scientists conclude that impacts of El Niño–related heat and drought in Earth's tropical regions were responsible for the record spike in global carbon dioxide in 2015–16, when Earth experienced the largest annual increases in atmospheric carbon dioxide concentration since measurements began in the 1950s.

Airborne missions also contributed to improved understandings of atmospheric changes. In January 2017, the Atmospheric Carbon and Transport–America (ACT-America) mission returned to the skies over the eastern half of the United States to track the movement of atmospheric carbon and methane with the objective to better understand the sources and sinks of these greenhouse gases. NASA's Atmospheric Tomography (ATom) mission made a 28-day around-the-world journey beginning in January 2017, carrying more than 20 scientific instruments used to measure more than 200 atmospheric gases, including methane and tropospheric ozone, as well as poorly understood particulates like black carbon. In May 2017, NASA flew an airborne campaign called the Carbon Airborne Flux Experiment (CARAFE) in the mid-Atlantic to help scientists better understand the exchange of carbon dioxide and methane between Earth and the atmosphere.

Airborne missions contributed to studies of the ocean, as well. NASA's COral Reef Airborne Laboratory (CORAL) took measurements in Hawaii in February 2017, providing the most extensive and uniform picture to date of coral reef conditions. These measurements will help scientists to steward these fragile ecosystems

through environmental changes. NASA's North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) returned to air and sea in August 2017 to research the declining, or decelerating, phase of the annual cycle of plankton in the North Atlantic. Since plankton form the base of the marine food web and impact the productivity of fisheries, understanding this declining phase is important to forecasting the future of these environments.

NASA's Earth Science Division helps to improve everyday life on Earth, assists in predicting and responding to natural disasters, and improves our understanding of the fundamental nature of our planet. Below are five highlights from FY 2017.

NASA Measures "Dust on Snow" to Help Manage Colorado River Basin Water Supplies

When the snowpack on mountains in Utah and Colorado melts each spring, the water flows into the Colorado River, eventually making its way to some 33 million people across seven western states. For a few of these states, snowfall (and its subsequent melt) provides up to 80 percent of the annual precipitation, which is ultimately used for drinking, farming, recreation, and power generation. NASA worked with local officials to incorporate remote sensing data into melt water forecasts. The research showed that using remote sensing data reduced the error by about 70 percent in some watersheds. Accurately forecasting the amount of meltwater throughout the United States is important. If the actual amount of water is less than predicted, reserves in reservoirs will not be sufficient to meet demand; conversely, if there is more water than predicted, it can lead to damaging floods.

Satellites Eye Winter Crops

Scientists at the U.S. Department of Agriculture (USDA)–Agricultural Research Service, the U.S. Geological Survey (USGS), and the Maryland Department of Agriculture used data and imagery collected by satellites to monitor crop performance, to determine how effective the crops are in protecting the Chesapeake Bay, and to develop strategies that maximize benefits to growers and the environment while minimizing costs. Researchers compared satellite observations with ground-based data collected from collaborating farms to map the performance of winter crops, as well as certain tilling practices that reduce erosion and runoff. They have already identified a few management choices that lead to

more successful crop performance. For instance, planting early—before the first frost—maximizes the amount of nitrogen that crops can absorb. Researchers are now working with NASA's DEVELOP program to create new algorithms that will make finding and interpreting relevant satellite data faster than ever. DEVELOP is a training and development program sponsored by NASA's Earth Science Applied Sciences Program that addresses environmental and public policy issues through interdisciplinary research projects that apply the lens of NASA Earth observations to community concerns around the globe.

Using NASA Satellite Data to Predict Malaria Outbreaks

In the Amazon Rainforest, few animals are as dangerous to humans as mosquitos that transmit malaria, but containing malaria outbreaks is challenging because it is difficult to figure out where people are contracting the disease. To tackle this problem, university researchers have turned to data from NASA's fleet of Earth-observing satellites, which are able to track the types of human and environmental events that typically precede an outbreak. With funding from NASA's Earth Science Applied Sciences Program, they are working in partnership with the Peruvian government to develop a system that uses satellite and other data to help forecast outbreaks at the household level months in advance and prevent them from happening.

Minnesota: Land of the Many-Colored Lakes

When organic matter—leaves, roots, or bark—disintegrates in water, it changes the color of a river or lake. Researchers from the University of Minnesota mapped lake colored dissolved organic matter (CDOM) levels using Landsat 8 imagery and found that levels varied widely across the state. Analyzing the data, they determined that only a minor amount of CDOM was produced in the lakes themselves; most was produced in the watershed and exported into the lake. The researchers noted that learning more about CDOM will help them better understand water treatment problems. Discerning the amount of colored dissolved organic matter that a lake holds is also useful for monitoring how these watersheds may change in the future. That becomes especially important as lakes and rivers become more important as water sources.

Connection Found Between Wildfires and Drought

NASA scientists used satellite records from 2001 to 2014—including data from NASA's Moderate Resolution Imaging Spectroradiometer and the Tropical Rainfall Measurement Mission—to analyze the impact of fires on various water cycle indicators, including soil moisture, precipitation, and vegetation greenness. The data showed that in years that had more than average burning during the dry season, measurements of soil moisture, evaporation and vegetation greenness—all of which help to trigger rain—decreased in the following wet season. The results so far show only a correlation between fires and water-cycle indicators, but the data gathered from the study are now being used to help detect a more direct relationship.

Joint Agency Satellite Division

In addition to its own Earth observation satellites, NASA also develops and launches satellites on behalf of NOAA on a reimbursable basis through the Joint Agency Satellite Division (JASD). Descriptions of these satellite programs can be found in the Department of Commerce chapter of this report.

Heliophysics

Heliophysics is the science of understanding the sun—and how it influences the very nature of space, planets, and the entire solar system. Heliophysics studies key space phenomena and processes at a vast array of scales from particle movements near Earth to explosions on the sun thousands of times bigger than our planet. In turn, this research supports situational awareness to better protect astronauts, satellites, and robotic missions traveling through the solar system.

The sun produces radiation and magnetic energy that can disrupt planets' atmospheres, our satellites, and even life. It produces a magnetic field that extends throughout our solar system and generates a constant stream of solar particles called the solar wind. Events on the sun, such as solar flares and coronal mass ejections (CMEs), send particles and plasma out into the solar system. All of these effects can vary with the sun's 11-year solar cycle. Studying these elements of the space environment helps provide us with the knowledge we need to keep our astronauts

and spacecraft safe. Combined with studies of the magnetic and radiation environment near Earth, it can also help us prepare for the effects of space weather on our communications systems, satellites, and power grids. Heliophysics also provides us with greater insight into the forces that formed and protect the planets in our solar system and in other star systems—key information as NASA searches outside our solar system for habitable planets.

On August 21, 2017, for the first time in 99 years, a total solar eclipse occurred across the entire continental United States. Over a span of almost two hours, 14 states experienced more than two minutes of darkness in the middle of the day, making visible the otherwise hidden solar corona—the sun's atmosphere. NASA Heliophysics played a key role in supporting this event, in terms of both research and communications efforts. NASA funded 11 ground-based and aircraft studies, including six designed to make critical measurements of the corona. NASA and partners also captured observations of the eclipse with 11 spacecraft, three aircraft, and more than 50 high-altitude balloons; additionally, astronauts on board the International Space Station streamed live video of the event on NASA Television. At the midpoint of the live stream, 4.4 million people were watching, making the eclipse the most viewed live-streamed event in the Agency's modern history.

In addition to providing impressive images during the eclipse, NASA's sun-observing spacecraft made important scientific contributions throughout the year. The twin Solar and Terrestrial Relations Observatory (STEREO) satellites, which celebrated ten years in orbit in October 2016, continued to provide comprehensive data that contributed to understanding of how the sun erupts with massive bursts of energy and solar material, such as coronal mass ejections and energetic particles. Combined with images from NASA's Solar Dynamics Observatory (SDO), STEREO data helped to find evidence of Rossby waves on the sun; these waves are analogous to the jet stream or gulf stream on Earth and could potentially help to develop long-term space weather forecasts. The joint ESA-NASA Solar and Heliospheric Observatory (SOHO) found the first evidence of gravity waves in the sun, suggesting that the solar core is rotating once every week, nearly four times faster than the sun's surface and intermediate layers. NASA's Interface Region Imaging Spectrograph (IRIS) mission transitioned to an extended mission phase but continued its study of the sun, collecting data on the temperature and

movement of solar material. NASA also continued work on the Parker Solar Probe, which will be the first spacecraft to fly directly into the sun's atmosphere after it launches in 2018.

Other spacecraft monitored conditions closer to Earth. The Magnetospheric Multiscale (MMS) mission comprises four spacecraft traveling through Earth's magnetic environment. Gathering information on electric and magnetic fields, as well as high-energy particles, they have been charting the dynamic space environment around Earth for over two years. What they are discovering is changing how we understand the magnetic environment protecting our planet. A key discovery MMS revealed was that the abnormal electron motions in the thin layers of electrical current where magnetic reconnection happens allow them to gain additional energy and accelerate the reconnection process. Magnetic reconnection happens across the universe, from the sun to quasars to nuclear reactors, and MMS's discoveries in its Earth-space laboratory help scientists understand the phenomenon in all locations.

After two years of fruitful scientific discoveries, the MMS constellation's orbit was adjusted as planned in the spring of 2017 to bring it into the long region of the magnetosphere trailing behind Earth called the magnetotail. It now passes nearly half the distance to the moon on the dark side of Earth. In this region, magnetic reconnection is thought to be responsible for the auroras seen above the poles. During this phase of the mission, MMS will look at particle and wave interactions and study how the region becomes turbulent during solar storms and how the solar wind can affect magnetic reconnection.

Many key workhorses of the Heliophysics fleet are also continuing to circle Earth. NASA's five-satellite Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission has now spent a decade discovering how mass and energy move through the near-Earth environment in order to determine the physical processes initiating auroras. THEMIS is joined in the near-Earth region by NASA's Van Allen Probes, which study how high-energy particles are accelerated and lost from the Van Allen radiation belts.

The Aeronomy of Ice in the Mesosphere (AIM) mission also recently celebrated 10 years in orbit. Data from AIM helped scientists to understand how and why noctilucent clouds—clouds high in the atmosphere that seem to glow at night—form

in Earth's mesosphere, showing that ice forms around tiny particles that are the remnants of meteors burning up in the atmosphere. AIM has now transitioned to a new phase of science in which it will study atmospheric gravity waves. Also examining the mesosphere, as well as the thermosphere and ionosphere, the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) spacecraft has spent 15 years observing how the upper atmosphere is affected by solar and geomagnetic inputs and tracking the rise of carbon dioxide in this region.

NASA's Heliophysics Division uses a diverse set of spacecraft to study our sun and its interactions with Earth, the solar system, and the interstellar medium, including space weather. This Heliophysics System Observatory collects a vast array of observations to understand the material and energy in space at every scale. Heliophysics missions explore places never before visited: right into the sun's corona, through pockets of intense radiation near Earth, and past the planets into interstellar space. Together, this body of work provides clear information to understand our neighborhood in space and the star we live with—key information as humanity's domain begins to spread farther and farther into our solar system. Some research highlights from FY 2017 are described below.

Scientists Uncover Origins of the Sun's Swirling Spicules

Spicules are wild jets of solar material that burst from the sun's surface, erupting as fast as 60 miles per second and reaching lengths of 6,000 miles before collapsing. As many as ten million of these spicules occur at any given moment, but despite their abundance, scientists did not understand how they formed. A NASA-funded study used observations from NASA's IRIS mission and the Swedish one-meter Solar Telescope in the Canary Islands to peer into the lower layers of the sun's atmosphere. Using these observations and a computer simulation so detailed it took a full year to run on NASA's Pleiades supercomputer, scientists were able to recreate the phenomenon, with simulations matching observations for the first time. Scientists discovered that neutral particles were key to the formation of spicules, allowing magnetic fields to move and rise beyond the sun's surface.

NASA's Van Allen Probes Spot Humanmade Barrier Shrouding Earth

Scientists using data from NASA's Van Allen Probes found that very-low-frequency (VLF) radio communications interact with particles in space, affecting how and where they move. At times, these interactions can create a barrier around Earth against natural high-energy-particle radiation in space. VLF signals are transmitted from ground stations to communicate with submarines deep in the ocean. While these waves are intended for communications below the surface, they also extend out beyond our atmosphere, shrouding Earth in a VLF bubble. The outward extent of the VLF bubble corresponds almost exactly to the inner edge of the Van Allen radiation belts, a layer of charged particles held in place by Earth's magnetic fields. Scientists have suggested that with further study, VLF transmissions may serve as a way to remove excess radiation from the near-Earth environment.

NASA Scientists Demonstrate Technique to Improve Particle Warnings That Protect Astronauts

Our constantly changing sun sometimes erupts with bursts of light, solar material, or ultra-fast energized particles—collectively, these events contribute to space weather. Scientists from NASA and the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, have shown that the warning signs of one type of space weather event, a coronal mass ejection (CME), can be detected tens of minutes earlier than with current forecasting techniques—critical extra time that could help protect astronauts in space. The technique requires tracking CMEs using a ground-based coronagraph, an instrument in which a solid disk blocks the sun's bright face. While space-based coronagraphs have many advantages, images are only returned every 20–30 minutes. Ground-based coronagraphs can only observe the sun in the day during clear weather, but they can return data almost instantly and at a much higher time resolution than satellite instruments. Scientists found that ground-based coronagraphs could provide a new tool in space weather forecasting which, under favorable conditions, could receive data warning of approaching CMEs earlier.

NASA Observations Reshape Basic Plasma Wave Physics

NASA's MMS mission provided observational proof of a 50-year-old theory and reshaped the basic understanding of a type of wave in space known as a kinetic Alfvén wave. MMS's four spacecraft fly in a compact 3D pyramid formation, with just four miles between them, closer than ever achieved before and small enough to fit between two wave peaks. Having multiple spacecraft allowed the scientists to measure precise details about the wave, such as how fast it moved and in what direction it traveled. The observations showed that as kinetic Alfvén waves move through a plasma, electrons traveling at the right speed get trapped in the weak spots of the wave's magnetic field. The new results also showed a much higher rate of trapping than expected, as well as unexpected, small-scale complexities in the wave. These findings are also applicable to nuclear fusion techniques, which rely on minimizing the existence of such waves inside the equipment to trap heat efficiently.

NASA's Cassini, Voyager Missions Suggest New Picture of Sun's Interaction with Galaxy

New data from NASA's Cassini mission, combined with measurements from the two Voyager spacecraft and NASA's Interstellar Boundary Explorer, or IBEX, suggest that our sun and planets are surrounded by a giant, rounded system of magnetic field from the sun—calling into question the alternate view of the solar magnetic fields trailing behind the sun in the shape of a long comet tail. Instead of a prolonged, comet-like tail, this rough bubble-shape of the heliosphere is due in part to the strong interstellar magnetic field—much stronger than what was anticipated in the past. The structure of the heliosphere plays a big role in how particles from interstellar space—called cosmic rays—reach the inner solar system, where Earth and the other planets are. As we continue to gather data from the edges of the heliosphere, these data will help us better understand the interstellar boundary that helps shield the Earth environment from harmful cosmic rays.

Planetary Science

NASA's Planetary Science Division is engaged in one of the oldest of scientific pursuits: the observation and discovery of our solar system's planetary objects. With an exploration strategy based on progressing from flybys, to orbiting, to landing, to roving, and finally to returning samples from planetary bodies, NASA helps to reveal new knowledge of our solar system's content, origin, evolution, and potential for life elsewhere. NASA's Planetary Science Division pushes the limits of spacecraft and robotic engineering design and operations and has sent spacecraft from the innermost planet of our solar system to the very edge of our sun's influence.

FY 2017 saw a dramatic end to NASA's Cassini mission, which was launched nearly 20 years ago. In a phase referred to as the Grand Finale, Cassini undertook a daring set of orbits that involved repeatedly climbing high above Saturn's north pole and flying just outside its narrow F ring. Cassini probed the water-rich plume of the active geysers on the planet's intriguing moon Enceladus, and then it hopped the rings and dove between the planet and innermost ring 22 times before plunging into Saturn's atmosphere. Scientists will continue to analyze the data from the final phase of the mission for some time, but initial findings have produced interesting insights, including promising hints about the structure and composition of the icy rings and high-resolution images of the rings and Saturn's atmosphere. Observations also revealed that the planet's magnetic field has no discernible tilt. This is a surprising observation and means that the true length of Saturn's day is still unknown.

NASA also released some early science results from NASA's Juno mission, which arrived at Jupiter on July 4, 2016. These findings portray the largest planet in our solar system as a complex, gigantic, turbulent world, with Earth-sized polar cyclones; plunging storm systems that travel deep into the heart of the gas giant; and a mammoth, lumpy magnetic field that may indicate it is generated closer to the planet's surface than previously thought. Early data show swirling, Earth-sized storms densely clustered and rubbing together at both poles. They also demonstrated that Jupiter's magnetic field is stronger than models expected. Juno is continuing its flybys of Jupiter and has since imaged many features, including the Great Red Spot. Meanwhile, NASA's partnership in a future European Space

Agency mission to Jupiter and its moons has cleared a key milestone, moving from preliminary instrument design to implementation phase. The JUpiter ICy Moons Explorer (JUICE) is designed to investigate the emergence of habitable worlds around gas giants. JUICE is scheduled to launch in 2022, arriving at Jupiter in October 2029.

NASA has continued to make important new discoveries on Mars as well, part of an ambitious robotic exploration program that both contributes to science and helps lead the way for sending humans to Mars in the 2030s. A comprehensive look at the findings from the first three and a half years of NASA's Curiosity rover mission showed that a long-lasting lake on ancient Mars provided stable environmental conditions that differed significantly from one part of the lake to another, providing multiple opportunities for different types of microbes to survive, similar to many lakes on Earth. In July 2017, Curiosity began a long-anticipated study of an iron-bearing ridge on Mount Sharp. A major appeal of the ridge is an iron-oxide mineral, hematite, which can form under wet conditions and reveal information about ancient environments. Scientists hope to understand the history of hematite and surrounding rock layers.

While Curiosity continued to provide new information about the surface, the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft made new discoveries from above. MAVEN detected electrically charged metal atoms (ions) high in the Martian atmosphere. This is the first time the permanent presence of metal ions has been detected in the ionosphere of a planet other than Earth. The spacecraft also made sophisticated measurements that revealed that the rate of hydrogen escape—and therefore water loss—from the Martian atmosphere varied dramatically, peaking when Mars was at its closest point to the sun and dropping when it was farthest away. These measurements help scientists determine the total amount of water lost over billions of years. Also circling the Red Planet was the Mars Reconnaissance Orbiter (MRO), which completed its 50,000th orbit, providing data that was used to aid in preparations for NASA's next mission to Mars, the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander. Insight will launch in 2018 and study the planet's deep interior.

Elsewhere in the solar system, researchers used data from NASA's Dawn mission to show that Ceres, the largest object in the asteroid belt between Mars and Jupiter,

may have a very weak, transient atmosphere and that this atmosphere appears to be related to the behavior of the sun. Data from NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission, which launched in 2011 and concluded in 2012, was used in two papers published in the journal *Science* in October 2016. These papers provided insights into the huge impacts that dominated the early history of Earth's Moon and other solid worlds, like Earth, Mars, and the satellites of the outer solar system. New analysis of data collected by NASA's New Horizons mission showed evidence of snow and ice features on Pluto that, until now, had been seen only on Earth.

After nearly two and a half years of operations, which included a flyby of Pluto and distant observations of several Kuiper Belt objects, NASA's New Horizons spacecraft went back into hibernation in April 2017. It will awake again for the January 2019 close flyby of a particular Kuiper Belt object known as MU69. Also continuing its journey is NASA's Origins, Spectral Interpretation, Resource Identification, Security–Regolith Explorer (OSIRIS-Rex) mission. OSIRIS-Rex launched in 2016 to visit the asteroid Bennu in 2018. In February 2017, OSIRIS-Rex spent two weeks searching for evidence of Earth-Trojan asteroids—asteroids trapped in gravity wells that precede or follow Earth—but found none, an interesting finding in itself. In September 2017, OSIRIS-Rex captured an image of Earth as it completed its Earth gravity assist maneuver. In addition to providing interesting information, these activities helped the mission team prepare for operations at Bennu.

The Planetary Science Division uses spacecraft to visit planets throughout our solar system, learning about the solar system's origins, evolution, and potential to host life elsewhere. Five FY 2017 research findings are highlighted below.

NASA Missions Provide New Insights into Ocean Worlds in Our Solar System

Two veteran NASA missions provided new details about icy, ocean-bearing moons of Jupiter and Saturn. Cassini scientists announced that hydrogen gas, which could potentially provide a chemical energy source for life, appears to be pouring into the subsurface ocean of Enceladus from hydrothermal activity on the seafloor. With this finding, nearly all of the ingredients for habitability have been shown to exist on Enceladus—a small, icy moon a billion miles farther from the

sun than Earth. In a separate study, Hubble researchers reported observations of Europa from 2016 in which a probable plume of material was seen erupting from the moon's surface at the same location where Hubble had seen evidence of a plume in 2014. Both correspond to the location of an unusually warm region that contains features that appear to be cracks in the moon's icy crust. Researchers speculate that, as with Enceladus, this could be evidence of water erupting from the moon's interior. Both investigations are laying the groundwork for NASA's Europa Clipper mission, which is planned for launch in the 2020s.

Jupiter's Auroras Present a Powerful Mystery

Scientists on NASA's Juno mission have observed massive amounts of energy swirling over Jupiter's polar regions that contribute to the giant planet's powerful auroras, only not in ways the researchers expected. Scientists observed signatures of powerful electric potentials, aligned with Jupiter's magnetic field, that accelerate electrons toward the Jovian atmosphere at energies of up to 400,000 electron-volts—10 to 30 times higher than seen at Earth. Jupiter has the most powerful auroras in the solar system, so the team was not surprised that electric potentials play a role in their generation. However, they are observed only sometimes and are not the source of the most intense auroras, as they are at Earth. Scientists are still working to understand why this may be, but they note that comparing the processes at Jupiter and Earth is incredibly valuable in testing our ideas of how planetary physics works.

Mars Volcano Went Extinct 50 Million Years Ago

New NASA research based on data from NASA's Mars Reconnaissance Orbiter (MRO) revealed that the giant Martian volcano Arsia Mons produced one new lava flow at its summit every one to three million years during the final peak of activity. The last volcanic activity there ceased about 50 million years ago, a very recent event in geological terms. Researchers estimated the ages of flows by mapping the boundaries of lava flows from each of the volcanic vents and tallying all the craters at least 330 feet (100 meters) in diameter. A computer model using these two types of observations revealed details about the volcano's history. A better understanding of when volcanic activity on Mars took place is important because

it helps researchers understand the Red Planet's history and interior structure and may help us understand changes in volcanism on other planets like Earth.

NASA Orbiter Finds New Evidence of Frost on Moon's Surface

Data from NASA's Lunar Reconnaissance Orbiter (LRO) was used to help identify bright areas in craters near the moon's south pole that are cold enough to have frost present on the surface. The icy deposits appear to be patchy and thin, and it is possible that they are mixed in with the surface layer of soil, dust, and small rocks called the regolith. The researchers say they are not seeing expanses of ice similar to a frozen pond or skating rink. Instead, they are seeing signs of surface frost. The findings are consistent with analysis in past studies, which also found evidence of frost near the moon's south pole. The moon's ice could provide resources for human exploration, and a better understanding of how it formed might also help us improve our understanding of the origins of Earth's water.

Comet or Asteroid? Hubble Discovers That a Unique Object Is a Binary

NASA's Hubble Space Telescope helped an international team of astronomers find that an unusual object in the asteroid belt—named 2006 VW239/288P—is, in fact, two asteroids with comet-like features that are orbiting each other. These include a bright halo of material, called a coma, and a long tail of dust. The object is the first known binary asteroid that is also classified as a main-belt comet. Understanding the origin and evolution of this object may provide new insights into the early days of the solar system, for example, helping to understand how water came to a bone-dry Earth billions of years ago. Scientists also hope to understand more about how common such systems are in the asteroid belt.

Astrophysics

The Astrophysics Division seeks to understand the universe and our place in it. Investigations include the creation and evolution of the universe and the formation of planetary systems. Astrophysics includes research on how environments hospitable for life develop and the search for the signature of life on other worlds. Astrophysics undertakes these efforts using three Great Observatories—the

Hubble Space Telescope, the Chandra X-ray Observatory, and the Spitzer Space Telescope—as well as an array of other spacecraft with a variety of capabilities. The Stratospheric Observatory for Infrared Astronomy (SOFIA), an airborne observatory for infrared astronomy, also contributes to astrophysics knowledge, as do high-altitude balloon missions.

Observations made by NASA's Spitzer Space Telescope made news in February 2017, revealing the first known system of seven Earth-size planets around a single star. Three of the planets are firmly located in the habitable zone, the area around the parent star where a rocky planet is most likely to have liquid water. The discovery set a new record for the greatest number of habitable-zone planets found around a single star outside our solar system. All of these seven planets could have liquid water—key to life as we know it—under the right atmospheric conditions, but the chances are highest with the three in the habitable zone. This exoplanet system is called TRAPPIST-1, named for the Transiting Planets and Planetesimals Small Telescope (TRAPPIST) in Chile, which was used to discover the first three planets in the system.

The Hubble Space Telescope continued to make important observations and fuel new discoveries in FY 2017. An observation of a massive disk-shaped galaxy that stopped making stars only a few billion years after the Big Bang forced researchers to reconsider current understandings of how massive galaxies form and evolve. In another study, a deep-sky census assembled from surveys taken by NASA's Hubble Space Telescope and other observatories showed that there are at least ten times more galaxies in the observable universe than previously thought.

Astronomers used NASA's Chandra X-ray Observatory and ESA's X-ray Multi-Mirror (XMM)–Newton x-ray observatory to discover an extremely luminous, variable x-ray source located outside the center of its parent galaxy. Researchers believe the peculiar object could be a wandering black hole that came from a small galaxy falling into a larger one. Another study used all three current Great Observatories, along with two other space telescopes, to produce a highly detailed image of the Crab Nebula spanning the entire breadth of the electromagnetic spectrum, providing a wealth of new detail about this cosmic object.

Other spacecraft made important new findings, as well. A combined analysis of data from NASA's Fermi Gamma-ray Space Telescope and the High Energy

Stereoscopic System (HESS), a ground-based observatory in Namibia, suggests that the center of our Milky Way Galaxy contains a "trap" that concentrates some of the highest-energy cosmic rays, among the fastest particles in the galaxy. NASA's Fermi Gamma-ray Space Telescope also found a signal at the center of the neighboring Andromeda galaxy that could indicate the presence of the mysterious stuff known as dark matter. A team of scientists using observations from NASA's Swift satellite mapped out how and where different wavelengths were produced when a star much like the sun wandered too close to the central black hole of its galaxy.

NASA continues to add new spacecraft with new capabilities. On June 3, 2017, NASA launched the Neutron star Interior Composition Explorer (NICER) mission to the International Space Station to study the densest observable objects in the universe. NICER is the first NASA mission dedicated to the study of pulsars, rapidly spinning dense stellar corpses that appear to pulse at Earth. The first pulsar was discovered just 50 years ago, and scientists still have many questions about the interior of these ultra-dense, fast-spinning, powerful magnetic objects. In August 2017, NICER was joined on the Space Station by the ISS Cosmic Ray Energetics And Mass (ISS-CREAM) experiment, which will examine the cosmic rays that constantly shower Earth. NASA has also continued the construction of the Transiting Exoplanet Survey Satellite (TESS), scheduled for launch in March 2018. TESS will be NASA's next planet-hunting mission, searching for planets orbiting stars outside our solar system, known as exoplanets.

NASA's James Webb Space Telescope, which is managed as a separate program office, continued to make progress toward a spring 2019 launch. The spacecraft underwent rigorous environmental tests, including vibration and acoustic testing that simulate the stresses of a rocket launch, and cryogenic testing simulating the cold environment of space. Webb is much larger than previous space telescopes; its mirror is more than double the diameter of Hubble's, giving it more than six times the collecting area. In addition, Webb will have a significantly larger field of view than the cameras on Hubble, covering more than 15 times the area, and significantly better spatial resolution than is available with the infrared Spitzer Space Telescope. When complete, Webb will be the most powerful space telescope ever built and will contribute to the study of an extremely wide range of astrophysical phenomena: the first stars and galaxies that formed; the atmospheres of nearby

planets outside our solar system, known as exoplanets; and objects within our own solar system.

The Astrophysics Division studies the universe, its origin, and its evolution. Five research findings from FY 2015 are described below.

Cosmic Lenses Support Findings on Accelerated Universe Expansion

The Hubble constant—the rate at which the universe is expanding—is one of the fundamental quantities describing our universe. Astronomers used the Hubble Space Telescope and other telescopes in space and on the ground to observe five galaxies in order to arrive at an independent measurement of the Hubble constant. The new measurement is completely independent of—but in excellent agreement with—other measurements of the Hubble constant in the local universe that used Cepheid variable stars and supernovae as points of reference. However, these values are different from the measurement made by the ESA Planck satellite. While the value for the Hubble constant determined by Planck fits with our current understanding of the cosmos, the values obtained by the different groups of astronomers for the local universe do not. As these measurements become more precise, scientists believe they may represent actual discrepancies that could possibly point toward new physics beyond our current knowledge of the universe.

NASA's Fermi Discovers the Most Extreme Blazars Yet

NASA's Fermi Gamma-ray Space Telescope has identified the farthest gamma-ray blazars, a type of galaxy whose intense emissions are powered by supersized black holes. Light from the most distant object began its journey to us when the universe was 1.4 billion years old, or nearly ten percent of its present age. Previously, the most distant blazars detected by Fermi emitted their light when the universe was about 2.1 billion years old. Scientists are now studying how these huge black holes could have formed in such a young universe and what mechanisms triggered their rapid development. To do so, researchers plan to continue a deep search for additional examples.

Microlensing Study Suggests Most Common Outer Planets Likely Neptune-Mass

A new statistical study of planets found by a technique called gravitational microlensing suggests that Neptune-mass worlds are likely the most common type of planet to form in the icy outer realms of planetary systems. Researchers combined data from the Microlensing Observations in Astrophysics (MOA) group and the Optical Gravitational Lensing Experiment (OGLE) to determine the frequency of planets compared to the mass ratio of the planet and star as well as the distances between them. The results imply that cold Neptune-mass worlds are likely to be the most common types of planets beyond the so-called snow line, the point where water remained frozen during planetary formation.

NASA Study Finds Unexpectedly Primitive Atmosphere Around "Warm Neptune"

A study combining observations from NASA's Hubble and Spitzer space telescopes revealed that the distant planet HAT-P-26b has a primitive atmosphere composed almost entirely of hydrogen and helium. Located about 437 light-years away, HAT-P-26b orbits a star roughly twice as old as the sun. The analysis is one of the most detailed studies to date of a "warm Neptune," or a planet that is Neptune-sized and close to its star. The researchers determined that HAT-P-26b's atmosphere is relatively clear of clouds and has a strong water signature, although the planet is not a water world. This is the best measurement of water to date on an exoplanet of this size.

NASA Scientists Assist LIGO in Third Gravitational Wave Observation

On January 4, 2017, an international group of researchers, which included NASA scientists, used the National Science Foundation's ground-based twin Laser Interferometer Gravitational-Wave Observatory (LIGO) to detect gravitational waves. The third detection of gravitational waves by LIGO, this observation represented energy unleased by the collision of black holes more than three billion years ago. In the future, astronomers will need both ground-based and space-based observatories to take full advantage of the new observational window on the universe offered by gravitational waves. NASA will be partnering with ESA on its recently announced Laser Interferometer Space Antenna (LISA) mission. LISA is a three-spacecraft constellation designed to study gravitational waves.

Cross-Theme Activities

The role of SMD is to enable NASA to achieve its science goals in the context of the national science agenda. Often the breakthrough science required to achieve these goals relies on significant technological innovation—e.g., instruments or platforms with capabilities beyond the current state of the art. SMD's targeted technology investments fill technology gaps, enabling NASA to build the challenging and complex missions that accomplish groundbreaking science. The SMD Chief Technologist works with representatives across all four divisions to survey and assess technology needs across the whole of SMD.

Through its Science Activation program, 27 SMD awardees infuse NASA science expertise and content into the learning environment more effectively and efficiently with learners of all ages. Strengths of the program are 1) providing authentic science-based content and experiences based on identified audience needs and refined by rigorous independent evaluation and 2) leveraging over 200 partners resident in local communities. Volunteer networks, such as the 750 Solar System Ambassadors, are heavily utilized across the country. This program provides a return on the public's investment in NASA by reducing duplication of effort and leveraging resources within and external to NASA.

Aeronautics Research Mission Directorate

NASA's Aeronautics Research Mission Directorate (ARMD) during FY 2017 made important strides toward enabling the most transformative new era of air transportation since the birth of the Jet Age more than a half century ago—an epoch that will see pilotless drones safely integrated into the National Airspace System; commercial supersonic jets quietly moving people and cargo across the country; and the deployment of radical airplane designs that burn less fuel, release fewer emissions, and fly more quietly than the most efficient aircraft flying today.

These goals, and the steps NASA will take to realize them, continue to be subject to mid-course corrections as new research results become available; market conditions change; and valuable input is received from the Agency's government, industry, and academic partners. In fact, NASA Aeronautics during FY 2017

published a new edition of its Strategic Implementation Plan to reflect these constantly moving influences on the ARMD research portfolio. More information is available online at *https://www.nasa.gov/aeroresearch/strategy*.

Of particular note is the progress made toward the New Aviation Horizons initiative, a ten-year plan for conducting transformative aviation research and highlighted by NASA's return to fielding pioneering experimental aircraft, or X-planes. Progress on designing both supersonic and subsonic X-planes was made during FY 2017. At the same time, strong interest from nontraditional aviation companies inspired rapid progress in the area of Unmanned Aircraft Systems (UAS).

NASA's aeronautical innovators were up to the challenge during FY 2017, as indicated by the following program highlights.

Advanced Air Vehicles Program

NASA and Lockheed Martin during FY 2017 conducted the first high-speed wind tunnel tests and completed the preliminary design review for the Quiet Supersonic Transport (QueSST), an initial design for the Low Boom Flight Demonstrator (LBFD) X-plane. Using a nine percent scale model of QueSST, engineers analyzed the design's aerodynamics and propulsion systems by measuring lift, drag, and side forces on the model at different angles. These tests were designed to verify that the aircraft's shape will separate shock waves associated with supersonic flight so they do not coalesce, reducing the annoying sonic booms heard on the ground to a much quieter "thump." The next step is to award a contract to build the large-scale, piloted, single-engine LBFD X-plane. More information is available online at *https://www.nasa.gov/press-release/nasa-wind-tunnel-tests-lockheed-martin-s-x-plane-design-for-a-quieter-supersonic-jet*, *https://www.nasa.gov/press-release/nasa-completes-milestone-toward-quieter-supersonic-x-plane*, and *https://www.nasa.gov/centers/armstrong/feature/70_years_supersonic_flight.html*.

During FY 2017, a series of supersonic test flights demonstrated a technique allowing NASA research pilots to physically see their sonic boom footprint on a map using a cockpit display. The series, which marked the second phase of the Cockpit Interactive Sonic Boom Display Avionics project, or CISBoomDA, continued from the project's first phase, where only a flight test engineer was able to

see the display. The cockpit display shows the location of sonic booms relative to the aircraft's trajectory and altitude and is founded on an algorithm developed in cooperation with industry to produce similar displays with a more predictive element. This method allows a pilot to better keep the loud percussive sounds from disturbing communities on the ground. More information is available online at *https://www.nasa.gov/centers/armstrong/features/cockpit_display_shows_sonic_boom_location.html*.

Throughout FY 2017, engineers conducted wind tunnel testing of a boundary-layer-ingesting (BLI) inlet-fan combination—the first of its kind ever to be tested. This jet engine component, also known as a propulsor, is being examined for BLI's impact on fuel efficiency, and results will be compared with advanced engine designs that airlines are now beginning to use. The new design uses a stronger fan, and the results of the test will be applied to multiple experimental aircraft designs from NASA and its partners in academia and private industry. More information is available online at *https://www.nasa.gov/feature/nasa-runs-first-ever-test-of-new-jet-engine-tech*.

NASA during FY 2017 used crash test dummies to help develop new crashworthiness guidelines for future airplane designs. The dummies were part of two realistic drop tests to obtain data on the airplane's structure and what might happen to its human passengers in the event of an accident. Multiple high-speed video cameras, placed at various locations, recorded the crash and showed how the fuselage section and its occupants fared. NASA researchers are analyzing the data from the cameras and instruments. That information, including any conclusions and recommendations, will be shared with the Federal Aviation Administration (FAA) and deliberated within the FAA's Aviation Rulemaking Advisory Committee. More information is available online at *https://www.nasa.gov/feature/langley/nasa-and-faa-put-dummies-and-baggage-to-the-test-for-airplane-safety*.

During FY 2017, NASA researchers worked on developing a test rig for aircraft designed to take off and land like helicopters but fly like planes. A fully operational Tiltrotor Test Rig (TTR) underwent functional checkout evaluation for the first time in the world's largest wind tunnel, the National Full-Scale Aerodynamics Complex. The tests demonstrated the efficiency of the rotors, helped quantify the relative efficiencies of different configurations, and allowed

researchers to look for ways to improve on the concept. The TTR is expected to handle rotors of up to 26 feet in diameter while reaching speeds of up to 345 miles per hour. More information is available online at *https://www.nasa.gov/ames/feature/unique-tiltrotor-test-rig-to-begin-operational-runs-at-nasa-ames*.

Six organizations joined NASA's Advanced Composites Consortium during FY 2017, bringing the total membership to 13. The Consortium, a public-private partnership, recently completed breakthrough assessments and identified transformative tools and methods for the future of aviation. Such assessments assist U.S. industry in maintaining a competitive advantage in aircraft manufacturing by reducing the time needed to develop and certify composite materials and structures. More information is available online at *https://www.nasa.gov/feature/nasas-advanced-composites-consortium-strengthens*.

Airspace Operations and Safety Program

Milestones for Unmanned Aircraft Systems (UAS) research occurred during FY 2017 as researchers flew four unmanned aircraft at Reno-Stead Airport in Reno, Nevada, in coordination with the FAA and additional industry partners. This series of tests was the first to operate drone flights beyond the visual line of sight of human operators. Other firsts included a demonstration of airspace access for emergency response drones, combined with notification of other UAS operators to clear the area. This test also had the first demonstration of detect-and-alert system capabilities, automated flight deviation alert, and dynamic rerouting capability that allows an unmanned, airborne vehicle to request flight plan changes. More information is available online at *https://www.nasa.gov/feature/ames/nasa-plans-first-beyond-visual-line-of-sight-drone-demonstration-in-nevada*.

Also during FY 2017, NASA and its partners completed the Technology Capability Level 2 (TCL2) National Campaign, featuring use of the most recent version of its UAS Traffic Management (UTM) technologies with live, remotely operated aircraft, or drones, at six FAA sites around the country. The tests involved simulating beyond the pilot's visual line of sight in sparsely populated areas while flying a variety of scenarios, including package deliveries, farmland surveys, search-and-rescue operations, railway inspections, and video surveillance

operations. More information is available online at *https://www.nasa.gov/aero/nasa-completes-latest-drone-traffic-management-flight-campaign*.

A NASA research team completed testing of the Flight Deck Interval Management tool during FY 2017 as part of the Airspace Technology Demonstration–1 project. The cockpit-based air traffic management tool is designed to automatically provide pilots with more precise spacing information and guidance on approaches into busy airports. The FAA, national and international government partners, and representatives from industry observed or participated in the tests. Analysis confirmed that the tool works as expected. More information is available online at *https://www.nasa.gov/aero/flight-tests-of-air-traffic-tool-complete*.

Integrated Aviation Systems Program

NASA continued its UAS integration work during FY 2017, focusing on maturing UAS collision-detection technology and researching safety standards and technology to support the FAA's Next Generation Air Transportation System. NASA project researchers briefed commissioners from the International Civil Aviation Organization and the Radio Technical Commission for Aeronautics (RTCA). The FAA, industry, academia, and other Government agencies also observed the ground cockpit response instrumentation of NASA's remotely piloted Ikhana aircraft during a flight test that demonstrated various intruder-encounter scenarios. More information is available online at *https://www.nasa.gov/centers/armstrong/features/flight_tests-could_lead_to_uas_integration.html*.

During FY 2017, four private companies were awarded contracts to come up with subsonic X-plane configurations that will be quieter, burn less fuel, and release fewer emissions than the most efficient aircraft currently flying. Five X-plane concepts were introduced, including aircraft with lightweight composite structures and new placement for engines to reduce drag, wings blended with the main hull of the fuselage to reduce noise and improve aerodynamic performance, and a truss-braced wing that assists in reducing fuel consumption. NASA has issued a Request for Proposal to allow industry to mature the research on these proposed aircraft designs and identify ways to reduce costs, technological risks, and time required to

complete these concepts. More information is available online at *https://www.nasa.gov/aero/industry-provides-nasa-with-ideas-for-next-x-plane*.

During FY 2017, NASA researchers continued to move closer to readying the X-57 Maxwell for test flights by developing a simulator specifically created for the electric-powered aircraft. The simulator will provide test pilots with a virtual flight experience of flying the X-57 Maxwell and allow them to develop reaction times and maneuvers in the event of an emergency. The simulator and its subsequent tests will be updated as the X-57 design configurations continue to be adjusted for actual flight. More information is available online at *https://www.nasa.gov/centers/armstrong/features/X-57_simulator_prepares_pilots.html*.

A Fiber Optic Sensing System (FOSS) was incorporated in the X-56 Multi-Utility Technology Testbed experimental aircraft during FY 2017. The X-56 is tasked with investigating flexible wings to improve safety, efficiency, and ride quality. Ultimately, the goal for FOSS is to collect information on how aerodynamic forces affect an aircraft in real time, then incorporate those data directly into the aircraft's control system for improved aerodynamic performance. FOSS is also being refined for space launch vehicles to monitor liquid fuel levels, temperatures, and strain on spacecraft. This project is both an Integrated Aviation Systems Program and a Transformative Aeronautics Concepts Program production. More information is available online at *https://www.nasa.gov/centers/armstrong/features/foss_technology_only_limited_by_imagination.html*.

The second series of the Adaptive Compliant Trailing Edge flights, or ACTE II, was conducted during FY 2017. ACTE II is a collaboration between NASA and the U.S. Air Force Research Laboratory to investigate the benefits of using twistable, flexible wing flaps to improve flight efficiency. Milestones included successfully demonstrating the aircraft's ability to fly with a twisted configuration, increasing test speed levels to more accurately represent commercial airliner speeds, and confirming the technology can maintain its stability under these conditions. Researchers collected data on the effects of drag on the materials and configurations at various speeds, altitudes, and weights. Information gathered also allowed the team to analyze changes in fuel burn and efficiency. More information is available online at *https://www.nasa.gov/feature/nasa-flight-tests-advance-research-of-flexible-twistable-wing-flaps-for-improved-aerodynamic*.

FY 2017 was the third year NASA researchers worked on the Advanced Data Acquisition and Telemetry System, or ADATS, to advance the system for the next generation of X-planes. The research included analyzing how ADATS can interact with ground operations while using half the bandwidth of traditional methods in aircraft network and communication, yet still enable precise data collection. Following extensive ground testing, ADATS was recently integrated into a NASA King Air aircraft for a series of three flights. More information online is available at *https://www.nasa.gov/centers/armstrong/features/adats_super_fast_data_transmission.html*.

Transformative Aeronautics Concepts Program

During FY 2017, NASA selected three multidisciplinary research teams from multiple NASA aeronautics centers to prepare solutions that will continue efforts to integrate UAS into the National Airspace System. The studies will explore safe inclusion and certification of autonomous systems through the development of learning algorithms that assist in establishing effective machine decisions, methods to ensure that UAS aircraft are structurally and mechanically fit to fly and protected against damage and hacking, and secure networks capable of accommodating a dense network of drones and other aircraft that fly each day using quantum computing and communication technology. More information is available online at *https://www.nasa.gov/press-release/nasa-selects-three-aeronautics-teams-to-explore-ambitious-ideas*.

Also during FY 2017, NASA selected five university teams to each receive five-year awards to research transformative concepts in aviation as part of the Agency's University Leadership Initiative (ULI). The University of South Carolina; Texas A&M Engineering Experiment Station; the University of Tennessee, Knoxville; Ohio State University; and Arizona State University were the selected university teams. The teams submitted projects that included ideas to improve safety and efficiency of air traffic management in manned and unmanned aircraft, commercial supersonic aircraft design, battery and energy storage, and thermal management, among other concepts. More information is available online at *https://www.nasa.gov/press-release/university-research-teams-to-study-potential-aeronautical-innovations*.

Space Technology Mission Directorate

The Space Technology Mission Directorate (STMD) develops and incorporates transformative space technologies to enable NASA's future missions. STMD has developed a diverse technology portfolio, creating a pipeline to solve the Nation's most difficult challenges in space. Space technology is an investment in our Nation's high-tech economy, spurring innovation and building partnerships across the aerospace sector and beyond.

In FY 2017, STMD made significant progress toward advancing NASA's current and future deep space exploration missions. Presently, STMD has over 750 project activities led by more than 400 companies and over 350 activities led by more than 100 universities. In addition, STMD is partnered with nine other Government agencies or departments as well as four international organizations. In FY 2017, STMD evaluated over 3,400 proposals and funded over 750 new selections, amounting to over $225 million in award investments during the fiscal year. Below are a few of the notable achievements from the year, including major STMD program and project highlights.

Technology Demonstration Missions

Laser Communication Relay Demonstration (LCRD): The LCRD mission proposes to revolutionize the way we send and receive data, video, and other information, using lasers to encode and transmit data at rates 10 to 100 times faster than today's fastest radio-frequency systems, with significantly less mass and power. The LCRD project continues to meet developmental milestones on its way to a flight test in 2019 to demonstrate bidirectional optical communications from geosynchronous orbit, providing critical performance data and operational experience. In FY 2017, the project delivered one of two flight modems, both optical assemblies, controller electronics, and space switching units to the LCRD payload integration and test group for integration of the flight payload on the LCRD Support Assembly. The project is targeting a June 2019 launch readiness date.

Restore-L: The Restore-L mission seeks to launch a robotic spacecraft in 2020 to refuel a U.S. Government satellite in low-Earth orbit, demonstrating a

suite of satellite-servicing technologies and potentially enabling the burgeoning U.S. satellite-servicing industry. The Restore-L project has completed a System Requirements Review (SRR) milestone and has completed Key Decision Point B (KDP-B). KDP-B means the proposed mission architecture is credible and responsive to program requirements and constraints, including resources, as defined in NASA Procedural Requirement 7120.5, "Space Flight Program and Project Management Requirements." It has been working on component-level design, development, testing, and evaluation. The spacecraft bus contract has been awarded, and the spacecraft bus Preliminary Design Review (PDR) has been completed.

Robotic Refueling Mission 3 (RRM3): The RRM3 project became part of the Technology Demonstration Missions portfolio in FY 2017. During the year, the project completed design and assembly on multiple tools, dewars, and payload mechanisms. Component assembly, integration, and testing are under way and will be followed by systems integration and testing prior to delivery for launch. The project is readying for payload delivery to NASA's Kennedy Space Center in December 2017 for launch on a SpaceX Falcon 9 to the International Space Station in 2018.

In-Space Robotic Manufacturing and Assembly: The three projects have completed their first year of base contract performance and have begun their respective option periods of performance. Made In Space, Inc., demonstrated additive manufacturing in a spacelike vacuum and will demonstrate the assembly of additively manufactured parts in the option period. Orbital ATK, Inc., demonstrated assembly and deployment technologies during the base period and will optimize component design during the option period. Space Systems Loral demonstrated an autonomous end-to-end relocation of a mock reflector on a satellite and will focus on a mission concept design during the option period.

Game Changing Development

NICER/SEXTANT: The Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) instrument was launched by a SpaceX Falcon 9 rocket into space on June 3. The instrument was installed as part of the Neutron star Interior Composition Explorer (NICER) hardware aboard the ISS. In July,

SEXTANT calculated its first successful navigation measurement generated in real time by the onboard flight software. The goal of the NICER/SEXTANT mission will be to investigate pulsars and demonstrate real-time, autonomous spacecraft navigation using pulsars as beacons.

Kilopower: In September 2017, The Department of Energy Y-12 National Security Complex completed all quality assurance checks and received approval for packing and shipping of the Kilopower experiment highly enriched uranium (HEU) core to the Nevada National Security Site (NNSS). Following that, the Kilopower project team successfully completed a non-nuclear dry run of the experiment assembly and equipment hardware in NASA's Glenn Research Center hangar before shipping it to the NNSS Device Assembly Facility (DAF). Final assembly at DAF began October 24 with component critical testing scheduled to begin in November 2017 and continue through March 2018.

High Performance Spaceflight Computing: In FY 2017, NASA selected Boeing Company in St. Louis for the High Performance Spaceflight Computing Processor Chiplet contract for the development of prototype Chiplet devices including packaged parts and bare die, a Chiplet behavioral model, Chiplet Evaluation Boards, and System Software. This is a cost-plus-fixed-fee contract with a total contract value of $26.6 million, which includes five options to enhance the capability of the Chiplet, increasing its processing performance, providing additional interfaces, and improving the robustness of the Chiplet packaging. The Chiplet will provide game-changing improvements in computing performance, power efficiency, and flexibility, which will significantly improve the onboard processing capabilities of future NASA and U.S. Air Force space missions.

Bulk Metallic Glass Gears: The Bulk Metallic Glass Gears (BMGG) project successfully fabricated and tested a strain wave gear system at room temperature. The strain wave flexspline without a circular spline operated for 1 million cycles without failure, and a system with the center spline successfully operated for 300,000 cycles without failure. Cold temperature (100 K) testing of this strain wave system at KSC is planned for early FY 2018. Planetary gear components have been received at the NASA Jet Propulsion Laboratory and are being assembled for cold life testing at Kennedy Space Center in FY 2018.

Small Spacecraft Technology Program

The Small Spacecraft Technology Program (SSTP) flight projects made significant accomplishments toward preparing for a planned launch in November 2017. Delta Flight Readiness reviews were held for the Optical Communications and Sensor Demonstration (OCSD) and Integrated Solar Array and Reflectarray Antenna (ISARA) projects in preparation for launch on Orbital ATK's Cygnus spacecraft, which launched from Wallops Flight Facility on November 12. The primary objective of the OCSD mission is to demonstrate optical communications at a rate of up to 1,000 times the current CubeSat communication capability. The ISARA mission will use radio-frequency Ka-band that will surpass the existing baseline CubeSat transmission rate of 9.6 kilobits per second to more than 100 megabits per second. ISARA is the first demonstration of an integrated Ka-band antenna and solar array.

The program awarded Tyvak NanoSatellites, Inc., a contract for up to five Pathfinder Technology Demonstrator (PTD) 6U spacecraft buses. These spacecraft will be utilized to demonstrate enabling space technologies that were developed through various NASA programs, such as Small Business Innovative Research (SBIR) and Tipping Point solicitations. The project has successfully completed Systems Requirements Review (SRR), as well as Delta SRR for potential payloads. The first mission, known as PTD1, is slated for launch in late 2018.

Small Business Innovative Research and Small Business Technology Transfer

NASA awarded 567 contracts for a total of $172.5 million in FY 2017. Specifically, 338 SBIR and 61 Small Business Technology Transfer (STTR) Phase I proposals were selected for award to 277 U.S. small businesses to establish the scientific, technical, and commercial feasibility of each proposed innovation. In addition, 133 SBIR and 19 STTR Phase II awards were selected to further expand upon their Phase I work. The Civilian Commercialization Readiness Pilot Program (CCRPP) awarded 16 contracts in the amount of $9.6 million. Additionally, 38 Phase II Extended/Expanded options were exercised for $10 million, and 48 Phase III awards were made leveraging $7 million in non-SBIR/STTR funding. In FY 2017,

the program published an Economic Impact Report on the NASA SBIR/STTR program, which indicated a $2.74 return for every dollar spent on awards.

Highlights from FY 2017 include the following:

- Robust Analytics in Gambrills, Maryland, received a Phase 2X award for its air traffic management cost assessment, capable of estimating the cost of operating commercial aircraft.
- Through a joint effort funded by NASA and the Department of Defense, Vanilla Aircraft in Falls Church, Virginia, designed a record-breaking UAS to fly long distances without refueling in extremely cold climates.

Flight Opportunities

In FY 2017, the Flight Opportunities program funded flights on two vertical takeoff/vertical lander flight campaigns, three high-altitude balloon flights, and three parabolic campaigns for researchers developing technologies that are of interest to NASA and the commercial space industry. The program flew 17 technology payloads in FY 2017 on 16 flights. One highlight in FY 2017 was the addition of small launch vehicle systems, which had two successful flight tests using 3D additive manufacturing injectors that do not require assembly. Another program success included World View Corporation's high-altitude balloon flight test of a groundbreaking altitude control technology that could enable station-keeping capabilities for longer stratospheric missions, thereby providing lower-cost science missions.

Space Technology Research Grants

Since its inception, Space Technology Research Grants (STRG) has funded exciting space technology research via 525 grants at 106 universities across 43 states and one U.S. territory. In FY 2017, the program made 13 Early Stage Innovations awards, eight Early Career Faculty awards, and 64 NASA Space Technology Research Fellowship awards. New this year, STRG selected and awarded STMD's inaugural Space Technology Research Institutes; these multi-university, multi-disciplinary institutes will strengthen NASA's ties to the academic community

through long-term, sustained investment in research and technology development critical to NASA's future. The Center for Utilization of Biological Engineering in Space, led by the University of California, Berkeley, is advancing research into an integrated, multi-function, multi-organism, bio-manufacturing system to produce fuel, materials, pharmaceuticals, and food in space. The Institute for Ultra-Strong Composites by Computational Design, led by Michigan Technological University, aims to develop and deploy a carbon nanotube–based, ultra-high-strength, lightweight aerospace structural material within five years.

Centennial Challenges

The Centennial Challenges program conducted six competition events in FY 2017 and awarded prize money in each of the competitions, for a total of $1,466,024. This represents the highest percentage of available prize money (62 percent) ever awarded. The program also began the formulation of five new challenges in FY 2017.

- The Space Robotics Challenge (SRC) awarded a total of $255,000 to the Top 20 teams in a qualifying round (February) and a total of $300,000 to three winning teams in the final Virtual Competition (June). The goal of SRC is to advance autonomous perception and manipulation algorithms and software for the Robonaut-5 humanoid robot utilizing a software simulator. This competition received the program's largest team response to date, with 405 pre-registrations from 55 countries.
- The third Cube Quest Ground Tournament was awarded in October 2016, as the top five teams took home a total of $150,000 ($30,000 each). The fourth and final Ground Tournament of the Cube Quest Challenge was conducted in June 2016. The top three teams won a total of $60,000 ($20,000 each) and a secondary payload slot for their CubeSat on the Space Launch System Exploration Mission–1 flight. The purpose of the challenge is to design, build, and launch flight-qualified small satellites capable of advanced operations near and beyond the moon. Teams will move on to compete in the next phases, the Deep Space and Lunar Derbies.

Department of Defense

DOD

Aeronautics Activities

Rotorcraft

The Army continues the process of fleet modernization with divestment of OH-58D Kiowa Warrior aircraft from Air Cavalry Squadrons, replacing them with AH-64 Apaches, and continued AH-64E Apache fielding to active duty units. With its improved engines, increased payload, and enhanced communication and navigation equipment, the AH-64E provides a marked increase in performance, lethality, and joint interoperability over the older AH-64D Apache Longbow. In 2017, AH-64E version 4 retrofits began, providing improved targeting, communications, diagnostics, and logistics support. Future improvements to the AH-64E are provided by the version 6 upgrade, which will begin fielding in 2019.

The Army has also completed the fielding of the UH-60M Blackhawk helicopters to Contiguous United States (CONUS)–based active-duty units. UH-60M fielding continues to Outside of Continental United States (OCONUS) active-duty units and the Army National Guard through FY 2028. With the ongoing fielding, the Army continues the development process for the UH-60V. The UH-60V will offer comparable performance and lift capabilities to the UH-60M, along with a fully digital cockpit, while also providing hard points for hoist attachments in order to become HH-60V MEDVAC aircraft. Furthermore, the UH-60V allows the Army to retain the digital rights for software upgrades, providing the force with the freedom and flexibility to continue improvements for years to come.

The Army contracted with Boeing for the CH-47F Block II Chinook. This update to the Chinook will make the aircraft relevant and ready through at least 2060. The new aircraft will converge the design with the Special Operations MH-47G, allowing the Army to improve sustainability and target operations and sustainment cost drivers.

The U.S. Navy (USN) CH-53K Super Stallion program reached a major milestone as it began low-rate initial production. The first of 194 production aircraft is scheduled to be delivered from Sikorsky Aircraft Corporation in FY 2020. With nearly three times the external lift capacity of the CH-53E and a mission radius of up to 200 nautical miles, the CH-53K has the lift and range to support the future Marine Air Ground Task Force.

The VH-92 Presidential Helicopter Replacement Program reached its first flight milestone in July 2017. Sikorsky Aircraft Corporation has completed two Engineering Development Models that are now supporting flight tests. The program is on track to enter production in FY 2019.

The V-22 Osprey has been in production for several years, with more than 350 aircraft delivered to the U.S. Marine Corps (USMC) and United States Southern Command. This tiltrotor aircraft provides unique capabilities to the warfighter, combining the flexibility of a helicopter with the speed and range of a fixed-wing aircraft. In addition to the wide range of missions that the aircraft can currently support, new capabilities continue to be developed, such as the ability to act as a tanker for aerial refueling. Other upgrades are being completed to enable the aircraft to meet the USN requirements for carrier onboard delivery.

The Navy has delivered 533 of 555 MH-60 helicopters and transitioned all Helicopter Sea Combat and Helicopter Maritime Strike squadrons to the MH-60R/S. Due to high operational demand and evolving warfighter needs, the program has initiated a Structural Life Assessment intended to evaluate requirements for a Structural Life Extension. These efforts will improve mission systems/sensors, recapitalize current MH-60 investments to pace the threat out to 2040, and establish the foundation to rapidly and affordably migrate to the Future Vertical Lift platform.

Navy Fixed-Wing Aircraft

The transition of P-3C to the P-8A continues to progress, with 67 P-8A aircraft delivered to the U.S. Navy and four aircraft delivered to the Royal Australian Air Force under a cooperative agreement. The Navy has transitioned seven of 12 fleet squadrons with the eighth squadron currently in transition. With over 60 percent of the aircraft delivered, the Navy has flown nearly 23,000 sorties and logged over 123,000 flight hours.

The Department of Defense (DOD) continued progress toward the completion of the System Development and Demonstration (SDD) flight testing phase of the F-35 Joint Strike Fighter (JSF) with a target end date of late calendar year (CY) 2017/early CY 2018. Naval Air Station (NAS) Lemoore stood up the first U.S. Navy F-35 Master Jet Base in January. Also in January, the first F-35Bs from Marine Fighter Attack Squadron (VMFA)–121 arrived at Marine Corps Air Station (MCAS) Iwakuni, beginning the squadron's permanent basing at the air station. In July, for the first time, F-35A and F-35B aircraft belonging to the 33rd Fighter Wing and VMFA-221 (respectively) both participated in Red Flag at Nellis Air Force Base (AFB), Nevada. Also in July, the F-35 fleet exceeded 100,000 flight hours. In October, Strike Fighter Squadron (VFA)–125 conducted additional carrier qualification aboard the USS Carl Vinson, to include testing the current helmet-mounted display system. There have been 267 F-35 aircraft delivered to date, with 54 of the 66 planned for this CY already delivered.

The Marine Corps has delivered 53 of 104 KC-130J aircraft, transitioning four active-duty squadrons and one reserve squadron. Harvest Hawk Plus capabilities have been incorporated into six of ten aircraft. The program office has initiated a prototype installation of Block Upgrade 7.0/8.1 and has completed a prototype installation of an interim solution to meet the 2020 mandate for Automatic Dependent Surveillance–Broadcast (ADS-B) Out.

Future Vertical Lift

The Joint Multi-Role Tech Demo (JMR-TD) efforts continue to progress in support of technology development for the Future Vertical Lift. Over the past

12 months, Bell's V-280 Valor made great strides toward flight testing and will conduct its first flight in November 2017. Bell has completed blade production, wing proof loading, and construction of all primary aircraft components. Bell engineers finished the assembly of the airframe and are conducting restrained ground runs and ground-vibration testing. This is the last step prior to flight test. The Sikorsky Boeing (S/B) team's design, the SB>1 Defiant, has successfully completed a ⅓ scale wind tunnel test, fuselage proof loading, fuselage construction, and the building of a fully operational Simulation Lab; they are currently testing their engines on test stands. S/B estimates that their first flight will be in mid–FY 2018. Both Technology Demonstrator original equipment manufacturers have overcome challenges in the manufacturing of new rotor blade technology and continue to progress on their respective aircraft designs. Karem and AVX, although not flying demonstrators, have produced significant technology advancements in tiltrotor technology as well as actuator designs.

Additional efforts within the JMR-TD program include the Mission System Architecture Demonstration. This collaborative industry effort to develop an open system architecture for future platforms across DOD has completed the Architecture Implementation Process Demonstrations (AIPD). AIPD investigated Open Systems Architecture, Model Based System Engineering, and the Architecture Centric Virtual Integration Process and produced detailed reports on each area of interest. The team is currently gearing up for their culminating event, Capstone, which will inform decisions on an Open Systems Approach in future programs.

Improved Turbine Engine Program

The Army is developing the Improved Turbine Engine (ITE), a 3,000-shaft-horsepower engine, designed to replace the current GE 701D engine that powers the AH-64E and UH-60 airframes. In FY 2017, the Army and Joint Staff validated the Capability Development Document in support of a milestone B decision. Milestone B is a Milestone Decision Authority (MDA)–led review at the end of the Technology Maturation and Risk Reduction (TMRR) Phase. Its purpose is to make a recommendation or seek approval to enter the Engineering and Manufacturing

Development (EMD) Phase and is considered the official start of a program. A milestone marks the start or finish of a phase and has defined Entrance and Exit Criteria. This engine will bring new technologies that increase the engine's power and the overall fuel efficiency. This capability will enable the Army to carry required payloads at increased range (Black Hawk missions) and greatly increased endurance (Apache missions) while decreasing the need for logistics resupply of fuel. The ITE will also reduce the cost of ownership by increasing engine design life and overall engine reliability through advanced internal aerodynamics, hybrid ceramic bearings, and improved inlet particle separation. The Army is developing two competing preliminary engine designs to be completed in 2018.

Other Army Aviation Activities

In FY 2017, the Army continued executing the Aviation Restructure Initiative (ARI). The ARI is the Secretary of Defense–approved plan to provide a modernized and ready aviation force while also reducing force structure in response to the Budget Control Act of 2011. This plan has seen the final OH-58D Kiowa Warriors divested from the Army inventory, the continued transitions of the aviation training fleet at Fort Rucker to the Light Utility Helicopter (LUH-72) Lakota aircraft, and the complete transition of both the active and reserve fleet to the CH-47F Chinook cargo helicopter. Finally, based on the recommendations from the National Commission for the Future of the Army, the Army will retain some AH-64Ds within the Army National Guard while increasing the active force structure with an 11th Combat Aviation Brigade. These recommendations will provide Combatant Commanders with flexibility through a strategic reserve in the event of future conflicts.

The Army has begun the process of assisting the Afghan Air Force with the modernization of their rotorcraft fleet, transitioning legacy MI-series helicopters to more modern and capable UH-60 variants. This transition has started with the first delivery of UH-60s complete and is expected to continue through FY 2022. At the conclusion of this modernization process, the Afghan Air Force will possess one of the largest rotorcraft fleets in the world, possessing more helicopters than either Australia or Canada.

Finally, to enhance operations in the National Airspace System, the Army continues to field Ground Based Sense and Avoid (GBSAA) systems. These FAA-approved radar-based systems serve as an alternative compliance method to meeting the FAA's see-and-avoid regulatory requirement. The Army's first GBSAA system was certified for operational use at Fort Hood, Texas, on September 26, 2016, and in FY 2017, the Army fielded three additional locations (Fort Bragg, North Carolina; Fort Campbell, Kentucky; and Fort Riley, Kansas). The Army plans to install its final GBSAA systems at Fort Stewart, Georgia, in support of MQ-1C Gray Eagle operations by December 2017.

Unmanned Aircraft Systems

The Army continues to modernize the MQ-1C Gray Eagle and RQ-7B Shadow UAS in stride with combat operations. The Army fielded its 12th Gray Eagle Company in August and received delivery of the first new Extended Range Gray Eagle, which extends the endurance of the aircraft by more than 50 percent. The Shadow is also undergoing modernization with the fielding of the RQ-7B V2, which includes a new Universal Ground Control Station and the upgrading of existing data links to modern Ku-band Type 1 National Security Agency encryption. The Army will continue to modernize the Shadow V2 to improve reliability, capability, and Manned-Unmanned Teaming (MUMT) through an engine upgrade and an updated mission computer, communications relay, and Mode 5 Transponder. The Shadow is assigned to the Brigade Combat Teams and Special Forces Groups and Combat Aviation Brigades as part of the Apache Helicopter Attack Reconnaissance Squadrons under the Army ARI.

The United States Air Force is executing the RQ-4 Global Hawk Program to provide continuous, high-altitude, long-endurance, all-weather, day/night, wide-area surveillance and reconnaissance capability. The Global Hawk core program is in the final portion of the aircraft production and deployment phase, with an expected completion in FY 2019. In 2017, the program exceeded 200,000 flight hours and shifted focus to planning and executing a series of modernization efforts, including new sensor integration, ground segment modification, operational flight program updates, and ice protection.

The MQ-4C Triton (formerly Broad Area Maritime Surveillance UAS) will develop maritime capable UAS systems for operational deployment by providing persistent maritime Intelligence, Surveillance, and Reconnaissance (ISR) services. Along with the P-8A Poseidon, the Triton UAS is an integral part of the Maritime Patrol and Reconnaissance Force (MPRF) Family of Systems, and it will provide combat information to operational and tactical users such as the Expeditionary Strike Group (ESG), Carrier Strike Group (CSG), and Joint Forces Maritime Component Commander (JFMCC). Developmental testing on the baseline capability was completed in October 2017, and Early Operational Capability (EOC) with two air vehicles is planned for 2018. The upgraded multiple intelligence (Multi-Int) capability is on track to support the maritime Intelligence, Surveillance, Reconnaissance, and Targeting (ISR&T) transition plan in FY 2020.

The MQ-8 Fire Scout UAS program provides real-time and non-real-time ISR data to tactical users without the use of manned aircraft or reliance on limited joint theater or national assets. An MQ-8 system is composed of air vehicles, an Electro-Optical/Infrared (EO/IR) Laser Designator Range Finder payload (one per air vehicle), a Mission Control System (MCS), Tactical Control System software, a Tactical Common Data Link, a UAV Common Automatic Recovery System for automatic takeoffs and landings, and associated spares and support equipment. The MQ-8 launches and recovers vertically and can operate from all suitably equipped air capable ships (SEACS). MQ-8 will eventually support Littoral Combat Ship (LCS) Surface Warfare (SUW) and Mine Countermeasures (MCM) Mission Modules. There are currently 23 MQ-8Bs in service supporting LCS MCM Coastal Battlefield Reconnaissance and Analysis (COBRA) Initial Operational Test and Evaluation (IOT&E). MQ-8Bs are also deployed aboard LCS-4, with deployment work-ups under way aboard LCS-8. MQ-8C deliveries are ongoing, with 30 on contract and 19 delivered to date. MQ-8C IOT&E is currently scheduled to commence in the first quarter of FY 2018.

The MQ-25 program rapidly develops an unmanned capability to embark on CVNs (aircraft carriers with nuclear propulsion) as part of the Carrier Air Wing (CVW) to conduct aerial refueling as a primary mission and provide ISR capability as a secondary mission. MQ-25 extends CVW mission effectiveness range, partially mitigates the current Carrier Strike Group organic ISR shortfall, and

fills the future CVW-tanker gap, mitigating Strike Fighter shortfall and preserving F/A-18E/F fatigue life. MQ-25 will achieve this mission through the use of a carrier-suitable, semi-autonomous Unmanned Air Segment; a Control System and Connectivity Segment; and a Carrier. MQ-25 will be integrated aboard Nimitz- and Ford-class aircraft carriers with a planned Initial Operational Capability (IOC) scheduled for 2028.

The RQ-21A Blackjack provides runway-independent persistent maritime and land-based tactical Reconnaissance, Surveillance, and Target Acquisition (RSTA) data collection, dissemination, and communications relay capabilities to the warfighter. The RQ-21A carries an EO/IR payload with a laser rangefinder and IR pointer. For the United States Marine Corps, the RQ-21A Blackjack provides Marine Expeditionary Force (MEF) and subordinate commands with a dedicated ISR system capable of operating from both L-class ships and remote austere locations ashore delivering intelligence products directly to the tactical commander in real time. For the Navy, the RQ-21A provides persistent RSTA support for tactical maneuver decisions and unit-level force defense/force protection for Navy ships, Marine Corps forces ashore, and Navy Special Warfare Units. IOC was declared by the Marine Corps in the second quarter of FY 2016, and the program is currently in Full Rate Production (FRP).

Airborne Weapons Systems and Missiles

The Army is actively pursuing advanced precision munitions with longer ranges to allow our aircraft to operate outside of the threat weapon system effective range. These precision munitions will make our aircraft more survivable in a peer/near-peer threat environment and help solve the Anti-Access, Area Denial challenge while operating in an enemy integrated air defense system environment. Army Aviation is also developing smaller, more versatile modular missile technology that allows a more scalable and tailorable precision munition for soft/mid-range targets. Tailoring the munition will allow more affordable precision munitions for our UAS. These smaller precision weapons will increase the number of "stowed kills" on the UAS, giving commanders much more flexibility in achieving targeting solutions.

Munition target pairing will also allow the Army to improve specific weapons to overmatch a given target at a reduced cost.

The previous munitions the Army began fielding and/or furthering technology for include the Joint Air-to-Ground Missile (JAGM) and the Advanced Precision Kill Weapon System (APKWS). In 2017, the Army had multiple successful engagements with the APKWS in operational theaters, validating the capability and investments in lighter precision munitions.

JAGM is a multi-mode guidance munition capable of Precision Point (PP) and Fire and Forget (F&F) targeting. The combination of F&F and PP targeting capabilities enables improvements in the use of single-mode laser or radar air-to-ground missiles in adverse weather and against countermeasures while also affording simultaneous engagements on both moving and stationary targets with increased lethality.

Navy Strike Weapons

During FY 2017, the Department of the Navy matured its long-range Cruise Missile Strategy. Key developmental and sustainment tenets of this strategy include support of Tomahawk Land Attack/Block III and Tactical Tomahawk/Block IV (TACTOM) through their anticipated service lives, integration of modernization and obsolescence upgrades to TACTOM during a midlife recertification program (which extends the missile service life an additional 15 years), fielding of the Long-Range Anti-Ship Missile (LRASM) as the Offensive Anti-Surface Warfare/Increment 1 material solution to meet near- to mid-term anti-access Anti-Surface Warfare (ASuW) threats, and development of follow-on Next Generation Strike Capability (NGSC) weapons to address future threats and targets in time to replace or update legacy weapons while bringing next-generation technologies into the Navy's standoff conventional strike capabilities. NGSC includes capabilities for both the air-launched Offensive Anti-Surface Warfare (OASuW)/Increment 2 capabilities to counter long-term anti-surface warfare threats and a surface and subsurface-launched Next Generation Land Attack Weapon (NGLAW) to initially complement, and then replace, legacy land attack cruise missile weapon systems.

In particular, LRASM is pioneering advanced semi-autonomous strike weapon capabilities. In FY 2017, LRASM successfully tested all weapon system capability modes in a complex anti-surface warfare environment. LRASM demonstrated autonomous behaviors against multiple moving ships, culminating in a direct hit on the intended target.

The Advanced Anti-Radiation Guided Missile (AARGM)/Block 1 had formal fleet release in the summer of 2017. AARGM is a cooperative development program with the Italian Air Force to transform the High-Speed Anti-Radiation Missile (HARM) into an affordable, lethal, and flexible time-sensitive strike weapon system for conducting Destruction of Enemy Air Defense missions. AARGM adds multispectral targeting capability and targeting geospecificity to its supersonic fly-out to destroy sophisticated enemy air defenses and expands upon the HARM target set.

Using multi-mode seeker and two-way datalink capabilities, the Joint Small Diameter Bomb II (SDB II) program provides an adverse weather, day-or-night standoff capability against mobile, moving, and fixed targets and enables target prosecution while minimizing collateral damage. During FY 2017, SDB II continued Government confidence tests that had multiple program firsts, including conducting a successful test employment against multiple advanced countermeasures and hitting targets in a cluttered urban environment.

The Advanced Precision Kill Weapon System II continued its high level of reliability and lethality as this weapon has become one of the key weapons in the current fight against the Islamic State (known variously as ISIS and ISIL).

Aviation Survivability Equipment

Aviation Survivability Equipment (ASE) is essential to force protection of aircraft against emerging advanced threats. In 2017, the Army made a concerted effort to modernize the infrastructure for its ASE in order to allow for more rapid and responsive fielding of improved threat detection and defensive countermeasures. The Common Missile Warning System (CMWS) continues to provide the Army's fleet with infrared (IR) threat detection with the primary focus on Man Portable Air Defense Systems (MANPADS). CMWS employs a range of

expendable countermeasures on all platforms, with the addition of the Advanced Threat IR Countermeasure system on CH-47s to defeat incoming MANPADS. Army Aviation will begin receiving production systems of the Common Infrared Countermeasure in the early 2020s. Army Aviation is also developing requirements for the Advanced Threat Detection System (ATDS) designated as the next-generation missile/threat warning system that will significantly increase the array of threats that can be detected and defeated with onboard countermeasure capabilities. ATDS is targeted for fielding in FY 2027 and will also provide greater situational awareness to aircrews against additional threats such as rocket-propelled grenades, anti-tank guided missiles, and unguided ballistic projectiles such as heavy, crew-served machine guns. The Army is also investing in upgraded detection and countermeasures to address Radio Frequency (RF) threats. Radar Warning Receiver upgrades begin at the end of FY 2018 and continue through FY 2022 with the fielding of the Modernized Radar Warning Receiver. Along with advances in detection capabilities, the Army is also advancing its threat defeat capabilities with the development of a family of Advanced Airborne Expendable Countermeasures. Production on an improved counter-RF expendable (chaff) has also commenced and is expected to be fielded to force in 2024. Upgraded chaff and Electronic Countermeasures fielding will coincide with the improved detection initiatives. Essential to the protection of aircraft against emerging threats, Army Aviation will pursue science and technology efforts to develop follow-on systems that are able to detect and defeat a threat system irrespective of its targeting and guidance systems, propulsion means, or warhead type.

Rocket and Missile Propulsion

The Air Force Research Laboratory (AFRL) Rocket Lab at Edwards Air Force Base, California, completed final load trials of AF-M315E for the NASA Green Propellant Infusion Mission (GPIM). This demonstrates the launch team and equipment readiness for launch loading operations. AF-M315E was developed by the AFRL Rocket Lab to be less toxic than traditional chemical fuels like hydrazine, thus requiring fewer handling restrictions and less special equipment. The reduction in handling restrictions and special equipment could shorten launch

processing times, resulting in lowered costs. On track for a 2018 launch, GPIM will demonstrate the practical capabilities of AF-M315E. The new propellant is 45 percent denser than hydrazine, meaning more of it can be stored in containers of the same volume. It has a greater specific impulse (Isp) than hydrazine; this means there is approximately a 50 percent increase in spacecraft maneuvering capability for a given volume. AF-M315E also has a lower freezing point than hydrazine, requiring less spacecraft power to maintain its temperature. Full-scale boost pump component ground testing was completed on the Hydrocarbon Boost Demonstrator program. This is the first component on the program to reach this milestone, which also validated the use of design tools developed under the Upper Stage Engine Technology effort, for the first time, in a liquid-kerosene environment. The first two full-scale pre-burners, a major component of the advanced liquid-oxygen/liquid-kerosene rocket engine, were fabricated. They are scheduled for testing at NASA test facilities early in 2018. The Hydrocarbon Boost Demonstrator pre-burner is being utilized in an Air Force Space and Missile Systems Center (SMC) and NASA thrust chamber combustion stability demonstration project, supporting SMC risk-reduction efforts for a new engine to be used in a future space launch vehicle. The resulting technologies, designs, and test results are being disseminated throughout the industry to enable and support future domestic space launches.

Defense Advanced Research Projects Agency Gremlins Program

The Defense Advanced Research Projects Agency (DARPA) Gremlins program seeks to develop novel air vehicle platforms and capabilities that enable an ability to retrieve and reuse air vehicle assets while airborne. A primary element of Gremlins is to demonstrate limited-life, volley-quantity, air-launched recoverable unmanned platforms to expand options for conducting distributed air operations. A key benefit for this approach is to achieve a lower per-mission cost. In November 2016, the program reported the successful completion of flight testing the full-scale soft capture recovery "bullet" air vehicle outside the turbulent wake of a C-130. The full-scale "bullet" flight test validates aerodynamic stability and provides significant risk reduction to the Gremlins recovery approach for an in-flight capture and retrieval capability. This event marks a first step toward the Gremlins program

goal of flight demonstrations that employ intelligence, surveillance, and reconnaissance and other modular, nonkinetic payloads in a robust, responsive, and affordable manner.

DARPA Aircrew Labor In-Cockpit Automation System Program

The focus of the Aircrew Labor In-Cockpit Automation System (ALIAS) program is to develop a tailorable, drop-in kit that would add high levels of automation to existing aircraft, enabling operations with reduced onboard crew. The program seeks to reduce operator workload, reduce the training burden, augment mission performance, and improve aircraft safety. In February 2017, the program successfully customized and installed ALIAS into a B-737 simulator in just 21 days and demonstrated advanced robotics, voice command, and emergency response capabilities of the system. The advanced robotic capabilities encompassed robotic arm actuation of existing autopilot, transponder, and flight management system controls and more than 20 individual switches and knobs. The testing included complex cockpit instrument interaction, tactile feedback, and an ALIAS-demonstrated ability to read the state of switches and knobs visually. The demonstration also highlighted the integrated speech interaction that commanded ALIAS to execute and compute new routes and waypoints as the robotic arm changed the autopilot-selected heading accordingly. The successful testing validated the high-level automation capability of ALIAS.

Air Force Aeronautics/Aircraft

Low Cost Attritable Aircraft Technologies (LCAAT) is an AFRL effort focused on reducing the cost of building an aircraft airframe by more than a factor of 10. LCAAT will enable a family of limited-function, rapidly produced, low-cost, attritable UAVs to augment manned weapon systems to force a cost imposition effect on near-peer adversaries. The effort completed a successful Critical Design Review in 2017. Flight tests of this low-cost technology will occur in 2018. In addition, the concept was employed at a Red Flag exercise garnering enthusiastic warfighter response.

Four F-16s equipped with Automatic Integrated Collision Avoidance System (ICAS) technology developed by AFRL flew test missions at Edwards AFB in August 2017. This marked the first time that a four-ship Auto ICAS mission has been flown. The primary purpose of these missions was to investigate cooperative and degraded cooperative performance. Having the F-16s fly head-on in formation (two sets of two aircraft flying toward each other) near the ground allows the Air Force to test how well Auto ICAS can protect from ground and air collisions in a congested environment with few "safe" escape options. This is the next extension of the highly successful Automatic Ground Collision Avoidance System (Auto-GCAS) technology developed and transitioned by AFRL. Videos can be found on YouTube of Auto-GCAS saving pilots' lives (eight pilots saved to date). AFRL is exploring several potential transition paths to field Auto ICAS on the F-16 and F-35 fleets.

The AFRL Integrated Vehicle Energy Technology (INVENT) effort developed adaptive, smart aircraft power systems using model-based design. The effort's goal is to integrate hybrid-electric systems to maximize energy efficiency, minimize thermal challenges, and provide power and cooling on demand, based on the duty cycles of individual aircraft systems. The effort recently completed all technical tasks, including the last two of five subsystem tests and two integrated ground demonstrations (IGDs). The testing evaluated the power and thermal architecture concepts, unit technologies, and modeling and simulation development to ultimately enable high-power mission systems on next-generation tactical aircraft through AFRL's Megawatt Tactical Aircraft (MWTA) effort. Testing indicated that the core architectures are sound, applicable unit hardware components can be made available for the integrated designs, and the modeling and simulation tools are suitable for further development required under the MWTA effort.

The MWTA effort completed architecture trade studies on both electrical generation and distribution and thermal management that will enable high-power mission systems on next-generation tactical aircraft. These trade studies have identified the highest-priority units for the program to build and evaluate. On the electrical side, designs of Solid State Electrical Distribution Units (SSEDU) were completed and four builds have been initiated with testing planned to be completed in June 2019. The next electrical hardware to be built will be the combination of generator

with electrical accumulator units or hybrid energy storage modules. On the thermal management side, the highest-risk items are the production of Cold Air From Engines (CAFE), which include the air cycle system. The next priority hardware will involve the distribution of heat sink across the air vehicle systems.

The Affordable Cruise Missile Engine (ACME) is an AFRL effort focused on developing affordable, small turbine engines that can be used on small expendable and/or attritable weapons/UAVs. The propulsion system for a weapon can be a very large portion of its overall cost, impacting how many weapons can be purchased. Many UAVs use commercial off-the-shelf engines, which has encouraged the proliferation of UAVs; however, the increased demand for these UAVs to continue to do more, go farther, and last longer cannot be addressed adequately by these commercial systems. Through the ACME effort, the Air Force is beginning to explore the technologies needed to provide that increased capability in an affordable package. This effort, along with LCAAT, is part of a larger Air Force push to explore low-cost, attritable vehicles.

Honeywell and AFRL have begun a technology transition demonstrator effort to integrate and mature advanced engine technologies into existing and future weapon systems such as the MQ-9 Reaper. Called the TPE331 Improved Performance Technology Engine (IPTE), the new advanced technologies will take Honeywell's existing TPE331 turboprop engine, which has supported everything from modern-day general aviation aircraft to military unmanned systems, and give it 30 percent more power and 15 percent better fuel efficiency while keeping it in the same size and package as the existing engine. With the TPE331 IPTE program, Honeywell's next-generation engine will have the performance and capabilities for continued use in future military missions while finding success and new applications across the commercial industry, such as upgrading twin-engine turboprop aircraft, accelerating performance growth for single-engine platforms, and meeting large-load capacity requirements for agricultural aircraft. The design, development, and testing of the engine will be completed by 2021.

Presidential Aircraft Recapitalization

The Air Force awarded a set of contract modifications to Boeing in August and September 2017 to purchase two commercial 747-8 aircraft and initiate the preliminary design efforts for modification of those aircraft, which will replace the two aging VC-25A (Boeing 747-200) Air Force One aircraft. These contract modifications follow a set of awards in 2016 for risk-reduction activities. The Air Force is also working with Boeing on a contract modification, referred to as the Engineering and Manufacturing Development (EMD) contract modification, which will continue the program through detailed design, aircraft modification, testing, and delivery of two Presidential mission-ready aircraft. The program expects to begin aircraft modifications in 2019 and reach Initial Operational Capability in 2024.

C-5

The C-5 Reliability Enhancement and Re-engining Program (RERP) is a comprehensive modernization effort to improve C-5 reliability, maintainability, and availability. C-5s support NASA by transporting outsized cargo. Upon completion of RERP, the Air Force plans to redesignate 49 C-5Bs, one C-5A, and two C-5Cs as C-5Ms. C-5Ms, when compared to legacy C-5s, have increased range, payload, takeoff thrust, climb performance, and fuel efficiency, as well as an extended service life until at least 2040. All 52 aircraft have been inducted into the program as of January 2017, with the final C-5C and five C-5Bs currently undergoing modification in Marietta, Georgia. The last C-5 RERP modification is contractually scheduled to be completed in April 2018.

Hypersonics

Building upon initial funding from the Small Business Innovative Research (SBIR) program, AFRL awarded a follow-on contract (valued at $11.8 million) to finalize the design and conduct the initial flight test of GOLauncher1 (GO1). GO1 is an air-dropped liquid-propelled rocket designed for routine and affordable hypersonic flight testing of key hypersonic technologies. A wind tunnel test campaign of

GO1 was recently completed using AFRL's wind tunnels at Wright-Patterson AFB. Upcoming testing in December 2017 includes a hot fire test of the GO1 stage at AFRL's Rocket Lab facilities at Edwards AFB and a store separation wind tunnel test in Calspan's transonic tunnel in Buffalo, New York. The first flight test of GO1 is scheduled for spring 2019, when it will cruise at Mach 6. Flight testing is planned to be based out of Cecil Field near Jacksonville, Florida. GO1 will provide much more affordable commercial testing capability available to all parties working on hypersonic technologies and wanting to conduct hypersonic testing. It will become a critical test asset to the Nation.

Space

DARPA Orbit Outlook Program

The objective of the Orbit Outlook program is to engage a set of nontraditional data providers to automatically provide diverse space observation data that support the integrated capabilities of the Space Surveillance Network. The Orbit Outlook technology focuses on demonstrating a capability such that data can be validated post-collection without a full sensor accreditation process. A key component of the Orbit Outlook architecture enables an integrated data repository based on a "world model" in which processing algorithms automatically assign quality measurements and generate high-level products. This new construct of integrating and fusing multiple types of space observations from a wide range of diverse, nontraditional sensors has led to transition opportunities for the warfighter. In October 2016, plans were formalized to enable Orbit Outlook performers to integrate this capability via operations in the National Space Defense Center (NSDC) tasked with the responsibility to improve processes and procedures for ensuring data fusion among DOD; the intelligence community; and interagency, allied, and commercial space entities. Orbit Outlook is one of many key technologies that will enhance U.S. space operations, contribute to operational command and control within DOD, and improve the Nation's ability to protect and defend critical national space infrastructures.

DARPA Space Surveillance Telescope Program

The Space Surveillance Telescope (SST) program incorporates technologies for an advanced ground-based optical system for the detection and tracking of faint objects in deep space with rapid, wide-area, un-cued search capabilities. The program completed a series of wide-field camera development and testing, algorithmic improvements, and procedures necessary to ensure system functionality in a near-sea-level environment less suitable for astrometric operations. In August 2017, an official ceremony to transition the SST from DARPA to U.S. Air Force Space Command was held at the SST site on Atom Peak at White Sands Missile Range. The culmination of the SST activities highlighted the success of the SST program and provided the roadmap for future use by the U.S. Air Force and the relocation of SST to its future site in Western Australia. This accomplishment 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.

Nanosats and SmallSats

The Satellite for High Altitude Radar Calibration (SHARC) is a 6U CubeSat satellite sponsored for launch by the Space and Missiles Systems Center Advanced Systems and Development Directorate Space Test Program. The SHARC mission demonstrated the capability of a CubeSat (a type of miniaturized satellite for space research) to perform critical calibration of the 120 Tri-Service C-Band radars. SHARC provided flight demonstration of three Air Force Research Laboratory Space Vehicles Directorate small business technologies: the MMA Designs, LLC, High Watts per Kilogram (HaWK) deployable solar array; the Blue Canyon Tech, Inc., XACT Attitude Determination and Control System; and the Sierra Nevada Corp. pick-and-place touchless-manufacturing-process solar panel. SHARC was launched to the International Space Station on April 18, 2017, and deployed from the ISS on May 17, 2017; first contact with the satellite occurred within an hour of deployment via a path agnostic communications architecture using the Globalstar commercial satellite network.

The University Nanosat Program (UNP) continued the Nanosat-9 (NS-9) effort. Under NS-9, ten U.S. universities are building small satellites and exploring SmallSat technologies, including propulsion, small-satellite laser communications, advanced radio-frequency communications, and rendezvous and docking, among others. Founded in 1999, the UNP was the first federally funded research program to fund small-satellite projects at universities. The objective of the UNP is to promote and sustain university research and education focused on small satellites and related technologies. The primary outcome of individual projects funded under this program has been the design, fabrication, and functional testing of a small satellite. Secondary objectives are to foster research in enabling technologies for small satellites and the design of experiments that can be performed by small satellites in orbit.

Launch and Range Operations and Spacelift Developments

The Evolved Expendable Launch Vehicle (EELV) program continued to successfully place satellites into orbit during FY 2017. United Launch Alliance (ULA) continued its record of success, with five National Security Space (NSS) launches as of September 30, 2017. A summary of the five EELV NSS launches during FY 2017 follows:

(Launch Date, Launch Vehicle Configuration, Payload)

- December 8, 2016, Delta IV (5,4), Wideband Global SATCOM (Satellite Communications) (WGS)–08
- January 20, 2017, Atlas V (401), Space Based Infrared System (SBIRS) Geostationary (GEO) Flight 3
- March 1, 2017, Atlas V (401), National Reconnaissance Office Launch (NROL)–79
- March 18, 2017, Delta IV (5,4), WGS-09
- September 24, 2017, Atlas V (541), NROL-42

The 45th Space Wing also successfully launched the U.S. Air Force's Orbital Test Vehicle 5 (OTV-5) payload on a SpaceX Falcon 9 launch vehicle on September 7, 2017, from Kennedy Space Center's Launch Complex 39A. Approximately eight minutes after the launch, SpaceX successfully landed the Falcon 9 first-stage

booster on Landing Zone 1 at Cape Canaveral Air Force Station (CCAFS). SpaceX returned to flight on January 14, 2017, after suffering an anomaly at Launch Complex 40 on September 1, 2016, and has successfully launched 13 times this fiscal year, including OTV-5 and NROL-76 on April 30, 2017.

Additionally, Operationally Responsive Space–5 (ORS-5) launched aboard a Minotaur IV on August 26, 2017. This was the first launch of a Minotaur IV from CCAFS.

The GPS III-3 launch services contract was awarded to SpaceX on March 14, 2017. This was the second competitive contract award for NSS launch services planned for EELV Phase 1A. The third competitively awarded NSS launch service for Space Test Program 3 (STP-3) was awarded to United Launch Alliance on June 29, 2017.

The Air Force posted a draft Request for Proposals (RFP) for a Launch Service Agreement (LSA) on March 14, 2017. The Air Force intends to competitively award up to three LSA Other Transactions Authority (OTA) agreements with launch service providers to develop launch system prototypes. These LSAs are the key step to transition from the use of non-allied space launch engines, maintain assured access to space, and introduce sustainable competition for future EELV NSS launch services. The final RFP was released on October 5, 2017.

Range modernization efforts continued in FY 2017 with the following accomplishments:

- The Western-Range Modernization of Network (WMN) contract was awarded as a small business set-aside to upgrade the Western Range mission communications core, addressing obsolescence issues and improving cyber protection. As part of WMN, the contract upgrades the Western Range's communications network from Asynchronous Transfer Mode to IPv6.
- Construction continued on a new Range Communications Facility (RCF) at the Eastern Range. The purpose of the new building is to relocate communications capabilities from the XY building to a new RCF, resolving building degradation, a high risk of flooding, and code noncompliance.

Positioning, Navigation, and Timing

The Global Positioning System (GPS) program celebrated its 22nd anniversary this year of providing uninterrupted Positioning, Navigation, and Timing (PNT) data, free of charge, to users worldwide since July 1995. The success of the GPS program can be reflected in the total number of GPS receivers produced to date, estimated at four billion worldwide. The next block of satellites, GPS III, are nearing completion of development. The first GPS III satellite completed all assembly and factory testing in February 2017 and achieved Availability for Launch (AFL) status in September 2017. GPS III satellites two through ten are in various stages of production. Launch of the first GPS III satellite is projected to occur in 2018.

Satellite Communications

The Advanced Extremely High Frequency (AEHF) is a joint-service satellite communications system that provides global, survivable, secure, protected, and jam-resistant communications for high-priority military ground, sea, and air assets. Three on-orbit AEHF satellites augment the existing Milstar constellation, providing protected satellite communications for strategic users. Three additional AEHF satellites are currently in production, with the next launch forecast to occur in 2018.

The Family of Advanced Beyond-Line-of-Sight Terminals (FAB-T) program will field nuclear-event-survivable terminals capable of communicating with the Milstar and AEHF satellite constellations using jam-resistant, low-probability-of-intercept, and low-probability-of-detection waveforms. On May 19, 2017, FAB-T received Milestone Decision Authority approval to purchase the new Ground Fixed Antenna configuration plus additional airborne terminals with antenna modification kits. In total, 42 Low Rate Initial Production terminals are now on contract. The first production terminal was delivered and installed on the N404 test aircraft at Hanscom AFB in May 2017. The second production terminal, and first of the Ground Fixed configuration, was delivered in June 2017. The first flight test with a production terminal on the N404 test bed aircraft was conducted in July 2017. This test successfully verified the Airborne Command Post Terminal's ability to

1) acquire satellites and maintain a communication link while tracking AEHF and Milstar satellites through standard operational aircraft maneuvers and 2) continue operations while transitioning between satellites and satellite beams.

The Enhanced Polar System (EPS) program now has two hosted payloads on orbit that were launched in FY 2015 and FY 2017. Operational testing is slated for FY 2018, along with initial operational capability shortly thereafter. The EPS will replace the Interim Polar System to ensure that critical protected communications requirements above 65 degrees north latitude are satisfied for joint forces.

The Wideband Global Satellite Communications (SATCOM) (WGS) satellite program consists of ten satellites with nine currently on orbit. WGS 10 is scheduled to launch in 2018. WGS is the DOD SATCOM constellation with the highest capacity and was declared at Full Operational Capability (FOC) with five satellites on May 12, 2014. The WGS system provides up to 3.6 gigabits per second (Gbps) per satellite (13.7 Gbps worldwide as of April 2016) to support various missions of the Unified Combatant Commanders, military services, other DOD agencies, and international partners (Australia, Canada, Denmark, the Netherlands, New Zealand, and Luxembourg). The WGS system is composed of space, control, and terminal segments. The space segment operates in the X-band and Ka-band with flexible connectivity between bands and coverages to support and connect users operating worldwide.

Joint Space Operations Center Mission System Increment 2

The Joint Space Operations Center (JSPOC) Mission System (JMS) provides real-time, integrated Space Situational Awareness (SSA) to allow informed, rapid decision making by the Commander, Joint Functional Component Command-Space, including the ability to plan, direct, coordinate, and control operations of assigned forces. It will allow increased capability, including a User Defined Operational Picture (UDOP), a high-accuracy satellite positional database/catalog, increased capacity for additional space objects, ability to leverage nontraditional sensors/data sources, and automated satellite collision avoidance assessment/prediction services.

JMS Increment 2 is the program of record to replace the aging and sustainment-challenged Space Defense Operations Center, which met its design end of life in 2002. Increment 2 employs agile elements in a net-centric, service-oriented architecture (SOA) to allow

- capabilities to be incrementally deployed in service packs,
- loosely coupled capabilities/applications to enable integration of the latest commercial and Government-developed software and technologies,
- operators to utilize a User Defined Operational Picture via Web start,
- third-party software deployment via a Software Development Kit, and
- the ability to tailor certain content of Service Pack(s) based on warfighter requirements and urgent needs.

The JMS Increment 2 Program Service Pack 9 Development Test (DT) was completed in July 2017, and fielding is planned for early CY 2018. Service Pack 11 development is under way.

Enterprise Space Battle Management Command and Control

DOD has a need to improve both its systems' timeliness and accuracy and its processes for managing multiple simultaneous events to better enable commanders and decision makers to rapidly command and control (C2) space assets throughout the range of operations. Enterprise Space Battle Management Command and Control (ESBMC2) is a command and control software (SW) program. The SW will be able to better integrate multiple streams of SSA, Initial delivery of Indications and Warning (I&W), and counter-space data to provide decision makers with a clearer picture of the contested space environment. The program is specifically designed for the National Space Defense Center and aimed at managing any future space conflicts. ESBMC2 involves multiple lines of effort by Air Force Space Command (AFSPC), the Space and Missile Systems Center (SMC), the Air Force Research Laboratory (AFRL), and the Air Force Rapid Capabilities Office (AFRCO) to quickly provide C2 capabilities across the DOD Enterprise and leverage commercial capabilities to the maximum extent possible. The ESBMC2 program will deliver an automated approach at multiple classification levels to link disparate information across geographically separated operations in order to direct

forces on operationally relevant timelines. It will provide commanders and decision makers with the tools needed to improve timelines and accuracy in commanding and controlling space assets simultaneously. A Request for Information (RFI) for a Broad Agency Announcement (BAA) contract was issued in January 2017 and opened in May 2017. Responses have been received and will allow the ESBMC2 program to start developing initial space BMC2 applications. Multiple RFPs will be going out based on RFI responses received. ESBMC2 lines of effort include

- providing the initial National Space Defense Center (NSDC) infrastructure (through 2019);
- spiral 1: initial delivery of I&W and Course of Action (COA) tools to the NSDC;
- spiral 2: infrastructure Initial Operational Capability (IOC), I&W, COA, sensor tasking using a satellite experiment effort, and multiple operation center collaboration; and
- spiral 3: standup of the Space Operations Development Center (SpODC) for continued training and experimentation with prototypes, as well as improved Spiral 2 tools to meet top requirements.

The Air Force Rapid Capabilities Office will develop enterprise open standards using a consortium and will leverage lessons learned. Spiral 4 will demonstrate space command and control using proven open, scalable, and interoperable systems. The ESBMC2 program will also develop prototypes to address identified capability gaps at space operations centers.

Weather Satellite Follow-on

The Air Force's Weather Satellite Follow-on (WSF)–Microwave (WSF-M) program contributes to a family of space-based environmental monitoring systems that support military operations through remote sensing of weather conditions—such as speed and direction of wind at the ocean's surface and space weather. It also provides real-time data for use in weapons system planning and forecast models.

WSF is a two-phased acquisition approach that launches the ORS-6 technology demonstration in 2018 on a Falcon 9 rideshare and accelerates the WSF-M Objective System launch to 2022. The ORS-6 technology demonstration will mate

the Jet Propulsion Laboratory (JPL) Compact Ocean Wind Vector Radiometer (COWVR) payload to the ORS Modular Space Vehicle bus. The ORS-6 mission is intended to mature the COWVR technology and will provide residual operational capability.

WSF-M is intended to provide a materiel solution that meets Joint Requirements Oversight Council (JROC)–validated requirements for three capability gaps: Gap 3 (Ocean Surface Vector Winds); Gap 8 (Tropical Cyclone Intensity), which requires a microwave sensor; and Gap 11 (Low Earth Orbit Energetic Charged Particles), which requires an in situ energetic particle sensor. The FY 2017 National Defense Authorization Act (NDAA) fenced half of the WSF-M funding and directed the Secretary of the Air Force (SECAF) to develop a plan for the Air Force to transfer acquisition and funding authority for the weather imagery mission to the National Reconnaissance Organization (NRO) in FY 2018. However, the FY 2017 NDAA also allowed SECAF to waive the limitation and transfer plan if the Under Secretary of Defense for Acquisition, Technology and Logistics (USD/AT&L) and the Chairman of the Joint Chiefs of Staff (CJCS) jointly submitted a report to the Congressional Defense Committees stating that the plan to address DOD Requirements for Cloud Characterization and Theater Weather Imagery did not negatively affect the Combatant Commanders. On June 23, 2017, the USD/AT&L submitted the Cloud Characterization and Theater Weather Imagery Plan to the Congressional Defense Committee, and the CJCS certified that the plan did not negatively affect Combatant Commanders on August 3, 2017. The SECAF subsequently signed a waiver memo on October 3, 2017, documenting that the requirements of the FY 2017 NDAA, Sec. 1614, were met.

Space Based Infrared System

The Space Based Infrared System (SBIRS) remains an unblinking eye for ballistic missile warning and defense, battlespace awareness, and technical intelligence for the United States and its allies. SBIRS satellites and ground systems provide operational capability today and will continue to incrementally deliver additional capability to the warfighter in the future. The Air Force is taking projected threats seriously and focusing investments on maturing resilient technology now. An acquisition

strategy is under development for a next-generation Overhead Persistent InfraRed (OPIR) space segment. The strategy is being discussed in pre-decisional forums within the Air Force and seeks to replenish the constellation and address emerging resiliency requirements while addressing a rapidly changing threat environment.

This past year, SBIRS Geosynchronous Earth Orbit (GEO) 4 (the third SBIRS GEO launch) was launched on January 20, 2017. The satellite is fully functional and is proceeding with infrared sensor tuning. It entered operations in September 2017. SBIRS GEO 3 was delivered and entered storage on July 14, 2015, with initial launch capability projected for January 18, 2018. The SBIRS GEO 5 and GEO 6 production contract was awarded on June 24, 2014, using a six-year Efficient Space Procurement (ESP) that provided a cost avoidance of $521 million. The SBIRS GEO 5 and GEO 6 satellites are in production and are meeting cost and schedule objectives. The Space Vehicle Critical Design Review (CDR) occurred on May 2–4, 2017, and the system-level CDR was completed in September 2017.

SBIRS Ground Increment 2 (Block 10) consolidated Defense Support Program (DSP), SBIRS Highly Elliptical Orbit (HEO), and SBIRS GEO operations into a single site in 2017. Block 10.3 (Integrated Tactical Warning/Attack Assessment certification) was delivered in December 2016.

Operationally Responsive Space

ORS was established by Congress to provide assured space power focused on the timely satisfaction of Joint Force Commanders' needs. ORS responds to validated urgent needs, develops an enabler foundation, and provides ORS acquisition. On February 25, 2014, ORS selected an SSA payload to meet validated urgent needs by addressing rapidly evolving threats. ORS-5 was successfully launched on a Minotaur IV from Space Florida's Space Launch Complex-46 at CCAFS on August 26, 2017. The ORS-5 main sensor was uncapped on September 18, 2017, and is successfully performing checkout.

On April 22, 2015, the SECAF directed ORS to help fill weather Gap 3 (Ocean Surface Vector Winds) and Gap 8 (Tropical Cyclone Intensity). The current WSF acquisition strategy proposes launching an ORS technology demonstration, ORS-6, in 2018 and the WSF Objective System in 2022. ORS-6 will inform the WSF

Objective System with a potential to provide a 50 percent cost reduction while also providing a residual operational capability, meeting a subset of WSF requirements.

ORS-7 is a demonstration of the ORS responsive manufacturing assembly line. It will produce two CubeSats for the Coast Guard's search-and-rescue mission. ORS-7 will be integrated into the Department of Homeland Security's Adaptive Space-based Analytics Project and is planned for a rideshare launch in 2018.

On February 7, 2017, the Department of Defense validated the urgent need for an interim capability for weather Gap 1 (cloud characterization) and Gap 2 (theater weather imagery). The ORS Executive Committee approved developing ORS-8 with a planned launch in 2021.

Space Fence

Space Fence provides un-cued surveillance of small objects and satellites primarily in low-Earth orbit (LEO), as well as medium-Earth orbit (MEO) and Geosynchronous Earth Orbit (GEO) (secondary), to provide spaceflight safety, early detection, custody of threats, and awareness to satellite operators in the human spaceflight regime. Space Fence will be the most accurate high-capacity radar in the Space Surveillance Network (SSN) and will provide extensive updates to the space catalogue, increase sensitivity for new object discovery, and deliver optimum orbital coverage, including coverage of much lower inclinations of orbiting objects. Space Fence greatly increases the ability to understand the Space Domain battlespace and inform warfighter decisions. The increased sensitivity, coupled with increased computing capabilities of the Joint Space Operations Center Mission System, improves understanding of the space operating environment and associated threats.

The acquisition strategy implements Better Buying Power—cost, capability, and design trade studies, prototyping, and risk reduction in the System Development and Preliminary Design Review phases. Current efforts are focused on the first site and the operations center, which provide system IOC. The installation and checkout at the operations center is complete, and the construction of the sensor site is near completion. In addition, the radar hardware and software production are near completion. Installation and checkout of the radar components are under

way at the sensor site. The program is on track to achieve IOC in the first quarter of FY 2019.

Geosynchronous Space Situational Awareness Program

The Geosynchronous Space Situational Awareness Program (GSSAP) vehicles will operate in the near-GEO regime and provide the United States with an operational capability to support U.S. Strategic Command's Space Surveillance Operations as a dedicated space-based SSN sensor. The enhanced maneuverability of GSSAP also allows rendezvous and proximity operations to enable on-orbit object characterization and anomaly resolution. Two additional GSSAP space vehicles were launched in August 2016.

Counter-Space

The Counter Communications System (CCS) provides expeditionary, deployable, and reversible counter-space effects applicable across the full spectrum of conflict. CCS denies adversary satellite communications in an area of conflict in ways that include command and control, early warning, and propaganda dissemination. Development was continued in 2017 for the purchase of seven new Counter Communications Systems for the Air National Guard. The preplanned product improvements, which transition the system to Increment 10.2, are on track and progressing well. Three systems have been delivered to date, with remaining deliveries scheduled by end-of year FY 2018.

Space Security and Defense Program

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 non-materiel), leading to a more resilient and enduring National Security Space Enterprise. In FY 2017, SSDP completed efforts resulting in the delivery and implementation of specific cyber and materiel solutions to emergent capability needs. These include the following:

- Developing and accessing protection capabilities, architectures, and requirements across the NSS enterprise.
- Performing technical analyses, studies, and modeling to inform national, DOD, and Intelligence Community (IC) policy for enhancing the U.S. space protection posture.
- Designing and developing tools that provide actionable recommendations to individual programs for increasing system resiliency and informing investment decisions.
- Maturing analytical capability to evaluate resiliency of proposed architectures (both mission-specific and enterprise-wide).
- Developing experiments and exercises to advance space protection Tactics, Techniques and Procedures (TTPs), Concept of Operations (CONOPS), and SSA C2.
- Prototyping C2 and SSA integration solutions to speed information sharing, streamline operations, and shorten decision timelines.
- Refining Space C2 requirements based on National Space Defense Center experiment results, C2 prototypes, and SSA experiments.

Nested Hall Thruster Technology

NASA successfully integrated and demonstrated Nested Hall Thruster (NHT) technology originally developed by AFRL. NASA demonstrated a three-channel system with power up to 102 kilowatts and thrust up to 5.4 newtons. The work leveraged the original AFRL research in two-channel Nested Hall Thrusters, along with many of the original university and industry team members. According to a recent paper to the 35th International Electric Propulsion Conference, "These results demonstrate the capability of Hall thrusters and NHTs for cargo and crew transport applications and show that the X3 represents a significant milestone on the roadmap to Mars."[1]

1 J. Hall, B. Jorns, A. Gallimore, H. Kamhawi, T. Haag, J. Mackey, J. Gilland, and P. Peterson, "High-Power Performance of a 100-kW Class Nested Hall Thruster" (paper presented at the 35th International Electric Propulsion Conference, Electric Rocket Propulsion Society, Atlanta, GA, October 2017), p. 20.

Space Vehicles

AFRL has multiple efforts in collaboration with NASA. AFRL is working with the NASA Safety Center in identifying and evaluating space environment hazards. These hazards will be used to assist NASA in developing a monitoring architecture for human spaceflight beyond Earth orbit. The Air Force will also utilize this developed architecture to conduct spacecraft resiliency assessments to the natural space environment hazards.

AFRL is also conducting research using the NASA Van Allen Probes. The Van Allen Probes are studying the Van Allen Radiation Belts that encapsulate Earth. These radiation belts' harsh nature are important to study and understand as they affect the lifetime of spacecraft. The increased radiation from geomagnetic storms that originate from the sun can cause increased atmospheric drag on and surface and internal charging to a spacecraft, shortening the lifetime of the spacecraft. AFRL is using the data from the NASA Van Allen Probes to model the Van Allen Radiation Belts, providing a more in-depth understanding of the space environment spacecraft will encounter.

Federal Aviation Administration

FAA

The Federal Aviation Administration (FAA) achieved more milestones in its ongoing Next Generation Air Transportation System (NextGen) effort, which is transitioning the National Airspace System (NAS) from analog and ground-based systems to cutting-edge digital and satellite-enabled technologies. The NextGen transformation is fundamentally changing the way we see, navigate, and communicate in the Nation's skies. NextGen seeks to move away from the current system of air traffic control—based on knowing where an aircraft is—to a time-based management system that operates on shared knowledge of where an aircraft will be at any given point in time along its projected trajectory. Using time to manage an aircraft's future position and altitude, known as Trajectory Based Operations (TBO), will increase efficiency and flexibility in the NAS and help achieve the NextGen goals of enhanced safety, reduced delays and cancellations, decreased fuel burn, and lower aircraft exhaust emissions.

NextGen is essential to protecting aviation's contributions to U.S. economic strength. A healthy aviation industry is vital to the Nation's fiscal prosperity, as civil aviation contributes 10.6 million jobs and $1.6 trillion a year to the U.S. economy. Through 2016, NextGen capabilities already deployed have delivered $2.7 billion in benefits to airlines and the traveling public.

Automation

Automation consists of the computer systems that controllers use to manage our Nation's air traffic and are platforms upon which NextGen programs and capabilities are built.

Under the Terminal Automation Modernization and Replacement (TAMR) program, the FAA is replacing the Automated Radar Terminal System in Terminal Radar Approach Control (TRACON) facilities with the state-of-the-art Standard Terminal Automation Replacement System (STARS). TRACONs guide aircraft transitioning to and from high-altitude airspace.

STARS is replacing the automation in our largest TRACONs and is operational at the 11 sites that control 80 percent of U.S. traffic. Nine of those TRACONs are among the ten busiest air traffic facilities in the world. In 2017, the FAA continued to deploy STARS in large, medium, and small TRACONs. STARS enables many NextGen technologies in terminal airspace, such as Automatic Dependent Surveillance–Broadcast (ADS-B), the satellite-based successor to radar, and the advanced terminal sequencing and spacing function for Time Based Flow Management (TBFM).

The TAMR program's success mirrors the FAA's achievement in deploying the En Route Automation Modernization (ERAM) system to all 20 air route traffic control centers in the contiguous United States—a process the FAA completed in 2015. Like STARS, ERAM enables key NextGen capabilities in the facilities that control traffic at cruising altitude, including ADS-B—which is fully integrated—and Data Communications (Data Comm), which supplements voice communications with digital text-based messages exchanged between controllers and pilots.

Data Comm

The FAA received approval to deploy Data Comm departure clearance services at seven more airports after completing installation at 55 airports in 2016, nearly two and a half years ahead of schedule. Data Comm is a priority focus area identified by the NextGen Advisory Committee, a Federal advisory group composed of executives from across the aviation community.

Using Data Comm, controllers select and send departure clearance instructions electronically to the cockpits of equipped aircraft instead of speaking them to pilots over the radio. Air carrier flight dispatchers simultaneously receive the same information, giving all decision makers a shared awareness for faster reactions to changes. Flight crews signal concurrence with the press of a button; instructions can then be automatically loaded into the aircraft's flight management system. This process can be repeated as often as necessary from the gate until the aircraft is ready for takeoff. By providing an air-to-ground data link, this transformational program is a critical component of the FAA's NextGen vision of TBO.

The FAA continued preparing for the next step of adding en route services. Data Comm is expected to save operators more than $10 billion over the 30-year life cycle of the program and the FAA about $1 billion in future operating costs.

ADS-B

Aircraft flying in most controlled airspace must be equipped to transmit their position using ADS-B by January 1, 2020. The Equip 2020 Government-industry working group is striving to eliminate equipage impediments for commercial and general aviation operators. As of September 2017, more than 27,000 general aviation aircraft were equipped with properly functioning ADS-B avionics.

ADS-B uses GPS to determine aircraft position more accurately and with faster updates than radar. Equipping with ADS-B In is optional, but operators who install it experience more benefits. They can see the same traffic picture on their cockpit displays as controllers, which increases safety from improved situational awareness. General aviation operators who equip with ADS-B In also can view graphical weather and flight information delivered to the cockpit at no further cost.

To ease the equipage decision, the FAA offered in September 2016 a $500 rebate to operators of U.S.-registered fixed-wing single-engine piston aircraft that are not equipped with Version 2 of ADS-B Out to defray ADS-B equipment and installation costs. More than 6,700 pilots claimed the offer, which ended one year after its start.

Performance Based Navigation

Performance Based Navigation (PBN) uses satellites and onboard equipment for navigation procedures that are more precise and accurate than using standard avionics and ground-based navigation aids. PBN's name reflects that the types of routes and procedures an aircraft can fly depend on equipment performance level and pilot training.

The FAA publishes more than 9,300 PBN departure, arrival, and approach procedures as well as low- and high-altitude PBN routes. These procedures provide precise flight paths across the United States that are much more direct than the legacy flight paths they replace, which zigzag over ground-based navigation aids. The PBN NAS Navigation Strategy 2016 (available at *http://www.faa.gov/nextgen/media/PBN_NAS_NAV.pdf*) outlines the FAA's plans for moving to a PBN-centric NAS.

PBN's benefits include the following:

- Increased safety through repeatable and predictable flight paths, when accessing airspace near obstacles and terrain, and with vertical guidance for more stable approaches.
- Improved airport and airspace access in all weather conditions.
- Reduced delays at airports and in certain congested airspace by using new parallel routes, newly enabled ingress/egress points around busy terminal areas, and improved flight rerouting capabilities that make better use of closely spaced procedures and airspace.
- Improved efficiency through more direct routes, especially at lower flight altitudes.

PBN's Area Navigation (RNAV) and Required Navigation Performance (RNP) provide environmental benefits through reduced fuel consumption and emissions. For example, since airlines started flying new RNAV approaches into Minneapolis in March 2015, they have saved more than 5.8 million gallons of fuel and prevented more than 57,000 metric tons of carbon dioxide from entering the atmosphere. In Denver, RNP approaches save Southwest, United, and Frontier airlines more than 100 gallons of fuel per flight.

System Wide Information Management

To function smoothly, the NAS relies on users sharing an increasing amount of air traffic management data. System Wide Information Management (SWIM), an advanced technology program, turns NAS data into useful information for aviation stakeholders. The digital data delivery platform provides the foundation for fully implementing many NextGen operational improvements.

Replacing multiple stand-alone computer interfaces that connected point to point, SWIM offers a modern, universally recognized data-exchange format interface through a single connection. The format supports collaboration within the domestic and international aviation communities, and users gain unprecedented access to data products with improved bandwidth and security. SWIM also contributes to the FAA's goal of TBO using time-based traffic management.

SWIM operates through an enterprise service-oriented architecture (SOA) composed of producers, subscribers, and a registry. Producers—in this case, FAA NAS programs—publish data exchanged through the NAS Enterprise Messaging System for registered subscribers. Subscribers can access more than 100 SWIM products, which are categorized as aeronautical, flight and traffic flow, and weather. The FAA and SWIM subscribers—inside and outside the FAA—interact through a registry, where subscribers can search specific criteria to find services.

SWIM's common infrastructure, with connection points at all 20 en route traffic control centers and enterprise SOA, is in place. NAS programs, such as the Traffic Flow Management System and Integrated Terminal Weather System, connect to provide large data sources for subscribers. SWIM also attracts more subscribers interested in accessing the data, the number now reaching 150 and continuing to grow.

In 2017, SWIM continued to develop enhancements to security, customer service, a subscriber-customized data feed, and the SWIM Terminal Data Distribution System.

Decision Support Systems

Air traffic controllers and traffic managers use decision support systems to help solve constraints and optimize traffic flow across the NAS. Integrated Departure/Arrival Capability (IDAC), a component of Time Based Flow Management (TBFM), automates departure demand monitoring and departure slot identification at many busy control towers. It coordinates departure times between airports and provides situational awareness to controllers so they can select from available departure times and plan their operations to meet those times.

Another system progressing is Terminal Flight Data Manager (TFDM). The FAA is completing early implementation of portions of TFDM. The FAA installed Advanced Electronic Flight Strips (AEFS) hardware in September at Charlotte Douglas International Airport in North Carolina to support Airspace Technology Demonstration 2 (ATD-2), a NASA-led project to integrate surface, departure, and arrival activities. AEFS replaces manual tracking with an electronic flight data display so that controllers can stay engaged with traffic at all times.

The ATD-2 team also deployed an Integrated Arrival/Departure/Surface prototype system at the Charlotte air traffic control tower on March 23, 2017. NASA demonstrated the ATD-2 system with live data at its lab at the airport.

In TFDM, AEFS and the ATD-2 prototype tools integrate with other new technologies, such as the IDAC. Together with TBFM, they function to coordinate schedules between the ramp and tower, terminal, and center control facilities to give air traffic managers the tools to better decide how to reduce congestion and increase efficiency.

Interagency Collaboration and UAS

Just as NextGen is transforming the NAS, Unmanned Aircraft Systems (UAS) are bringing unprecedented new opportunities for business and recreation. Enabled by platforms with new technology, the number of UAS pilots in the NAS has grown dramatically. The challenge is to ensure that these new aircraft are integrated with manned aircraft without compromising safety to people and property on the ground or in the air.

The FAA is working with NASA and other Federal and industry partners to safely integrate UAS into the NAS. Since the FAA implemented a new rulemaking to permit small UAS-limited operations in U.S. airspace in August 2016, more than 80,000 individual drones have been registered for various commercial and Government purposes. In June 2017, the FAA established a new aviation rulemaking committee that will help the agency create standards for remotely identifying and tracking unmanned aircraft during operations. Additionally, the FAA published more than 200 facility maps depicting areas and altitudes near airports where UAS may operate safely. The publication marked a key first step as the FAA and industry work together to automate approvals to operate in a specific airspace.

The introduction of UAS affects existing and future aviation requirements from aircraft certification to air traffic management. NASA and the FAA established a UAS Traffic Management Research Transition Team to define and develop requirements and standards that will be necessary for safe and efficient integration of UAS.

Additional information about the FAA Office of NextGen, updates, reports, and other documents can be found at *https://www.faa.gov/NextGen* and on the NextGen Update page at *https://www.faa.gov/NextGen/Update*.

Commercial Space Transportation

In FY 2017, the FAA's Office of Commercial Space Transportation (AST) licensed 18 orbital commercial space launches, including five cargo resupply missions to the International Space Station and the first launch of RocketLab's Electron launch vehicle, from various locations in the United States and one in New Zealand. Additionally, AST issued ten new launch licenses, including a Reusable Launch Operator license to Blue Origin for suborbital launches of its New Shepard launch vehicle, and six National Environmental Policy Act (NEPA)–related environmental documents. AST's safety inspectors conducted 480 inspections to ensure launch and reentry operations did not jeopardize public safety.

In FY 2017, the FAA completed a successful investment analysis readiness decision for the Space Data Integrator (SDI) capability, and it executed the SDI proof of concept in a mission-following mode during 25 launches and reentries. The FAA

is developing an SDI to support launch and reentry operations in a way that will allow the FAA to reduce the amount of airspace required to be closed in advance of a mission, effectively respond to off-nominal scenarios in a more timely manner, and quickly release airspace back to the National Airspace System (NAS) as the mission progresses. This technology is a building block for future technologies that will allow the FAA to move away from accommodating commercial space operations in the NAS to integrating them with other airspace users.

Additional information about the FAA Office of Commercial Space Transportation, regulations, reports, and other documents can be found online at *https://www.faa.gov/about/office_org/headquarters_offices/ast/*.

Department of Commerce

DOC

During FY 2017, the Department of Commerce (DOC) participated in extensive interagency preparations for the first meeting of the Trump administration's National Space Council, which took place on October 5, 2017. In close cooperation with the National Space Council, DOC will advocate for the U.S. commercial space industry to ensure the United States remains the leader in space commerce.

On January 10, 2017, DOC and the State Department updated the U.S. export control regulations applicable to spacecraft and related articles. The revised rules include several notable changes requested by the commercial space industry and advocated by DOC, including increasing the aperture thresholds for control of remote sensing satellites and components, eliminating controls based on whether a spacecraft supports human habitation, redefining several controls based on technical capabilities rather than end use of the spacecraft, removing and replacing confusing criteria concerning integrated propulsion and attitude control, adding thresholds for the controls on electric propulsion systems, and clarifying various ambiguities. The new rules took effect January 15, 2017.

During FY 2017, NOAA continued its efforts to support the development of a viable commercial market for satellite-based weather data. In January 2017, the NOAA Satellite and Information Service (NESDIS) published the final version of its Commercial Space Activities Assessment Process. The document establishes a process by which NESDIS will assess and pursue commercial opportunities to support NOAA's space-based observational information requirements. In summer 2017, NOAA held an industry day and collected public comments on a draft Request for Proposals for the forthcoming Round 2 of its Commercial Weather Data Pilot (CWDP). As a follow-up to the CWDP Round 1 pilot contracts for the

procurement and evaluation of radio occultation data, Round 2 extends the work of the CWDP to incorporate additional operational-like requirements for a second round of radio occultation data procurement and evaluation.

During FY 2017, 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 continued to host the physical offices of the committee as well as the GPS.gov Web site (*https://www.gps.gov*), which it redesigned to improve usability and customer experience.

During FY 2017, DOC participated in various dialogues on satellite navigation and space cooperation with other service providers, including Europe and Japan. DOC continued to work with the European Commission on a proposed waiver of the Federal Communication Commission's (FCC) licensing requirement for Europe's Galileo satellite navigation system. In January 2017, the FCC issued a public notice and solicited comments on this matter. DOC also participated in a series of meetings with the European Union (EU) (led by the State Department) to negotiate possible U.S. access to Galileo's Public Regulated Service (PRS). DOC hosted one of these meetings in Washington in January 2017.

National Oceanic and Atmospheric Administration

In FY 2017, NOAA's satellites remained as critical as ever, monitoring the severe drought and wildfires in the West; hurricanes along the Gulf and East Coasts, as well as in Puerto Rico and the Virgin Islands; and one of the hottest days on record in the American Southwest. Twenty-four-hour global coverage from NOAA's satellites provides scientists and managers with a continuous stream of information used in preparation for events impacting our weather, oceans, and climate. NOAA manages and operates four primary types of environmental satellites: geostationary environmental satellites, polar-orbiting environmental satellites, ocean altimetry satellites, and a deep space satellite for space weather monitoring and forecasting.

NOAA's Geostationary Satellites

Geostationary Operational Environmental Satellite (GOES) satellites 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. GOES imagery and data help meteorologists with forecasting weather in the short term, tracking severe storms, and estimating precipitation for issuing winter storm warnings and spring snow-melt advisories. In FY 2017, GOES-15 flew at 135° west longitude and served as "GOES-West," while GOES-13 flew at 75° west and served as "GOES-East." The newest generation of GOES satellite, GOES-16, was successfully launched at 6:42 p.m. eastern time on November 19, 2016. Declared operational on December 18, 2017, GOES-16 continues 40 years of GOES coverage, as this satellite is more advanced than any other weather satellite of its kind and provides more detailed and accurate data for forecasters.

NOAA's Polar-Orbiting Satellites

NOAA's primary polar-orbiting environmental satellites, Polar-orbiting Operational Environmental Satellites (POES) and Suomi National Polar-orbiting Partnership (Suomi NPP), orbit Earth at an altitude of approximately 517 miles, passing close to both poles and providing 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. All major numerical weather prediction (NWP) centers around the world use this information as the basis of nearly every medium-term weather forecast. The Suomi NPP satellite remained 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), which launched in November 2017.

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) constellation provides precision radio occultation (RO) soundings to

support improved numerical weather prediction model forecasts. The project is a partnership between the National Space Organization (NSPO) of Taiwan and the United States. Over its lifetime, COSMIC has proven to be an extremely cost-effective way to gather an abundance of atmospheric data, including three-dimensional profiles of temperature, humidity, and pressure. Due to the success of the COSMIC program, the follow-on advanced COSMIC-2/FORMOSAT-7 mission is being developed between the American Institute in Taiwan (AIT) and the Taipei Economic and Cultural Representative Office in the United States (TECRO), for which NOAA is AIT's designated representative and NSPO is TECRO's designated representative. During 2017, the teams began preparing the six COSMIC-2/FORMOSAT-7 satellites for launch into an equatorial orbit as part of the U.S. Air Force Space Test Program 2 (STP-2) mission in 2018. The NOAA ground system is ready to support data acquisition, and processing the advanced technology of COSMIC-2/FORMOSAT-7 is expected to improve forecasts of tropical winds.

NOAA's Ocean Altimetry Satellite

Jason-3, an international satellite mission jointly led by NOAA, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), NASA, and the French space agency (Centre National d'Études Spatiales [CNES]), is the fourth in a series of U.S.-European satellite altimeter missions designed to measure the sea surface height variability of the global ocean. Initially, the satellite flew in tandem with its predecessor, Jason-2, 830 miles above Earth's surface, collecting comparable measurements of sea surface height down to the subcentimeter level. Then, in mid-October 2016, Jason-2 was moved so that its ground track now "interleaves" with that of Jason-3. The result is a doubling of the Jason satellites' observations of the ocean. Now, with twice the coverage, the Jason mission is providing more accurate coverage of ocean conditions and will improve the intensity forecasts during the 2017 Atlantic hurricane season.

NOAA's Space Weather Satellites

Launched in February 2015, the Deep Space Climate Observatory (DSCOVR) mission is NOAA's first operational deep space mission. The satellite has become America's primary warning system for solar magnetic storms and solar wind data while giving Earth scientists a unique vantage point for studies of the planet's atmosphere and climate. Without timely and accurate warnings, space weather events, like the geomagnetic storms caused by changes in solar wind, have the potential to disrupt nearly every major public infrastructure system, including power grids, telecommunications, aviation, and GPS. Once fully calibrated and validated, DSCOVR succeeded NASA's Advanced Composition Explorer's (ACE) role in supporting solar wind alerts and warnings from the L1 orbit, the neutral gravity point between Earth and the sun approximately one million miles from Earth.

NOAA's Additional Space-Based Capabilities

NOAA, together with international partners, flew 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. CNES provides sensors that 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 41,000 people worldwide since 1982. NOAA provides space on its polar-orbiting satellites for the French processor and Canadian receiver.

Another capability lies in NOAA's partnership with the Japan Aerospace Exploration Agency (JAXA) on the Advanced Microwave Scanning Radiometer (AMSR). The AMSR2 on board the JAXA Global Change Observation Mission–Water (GCOM-W) satellite is a remote sensing instrument for measuring weak microwave emission from the surface and the atmosphere of Earth. NOAA provides ground data acquisition for GCOM-W in exchange for access to AMSR2 data.

From about 700 kilometers above Earth, AMSR2 provides us with highly accurate measurements of the intensity of microwave emission and scattering. The antenna of AMSR2 rotates once per 1.5 seconds and obtains data over a 1,450-kilometer swath. This conical scan mechanism enables AMSR2 to acquire a set of daytime and nighttime data with more than 99 percent coverage of Earth every two days.

International Activities

In preparation for operationalization of GOES-16 in the GOES East position, NESDIS started the GOES Rebroadcast (GRB) Users Group to aid current users of NOAA's GOES satellite ground receiving stations in the transition to the new generation of ground receiving stations, the GRB stations. The group also promotes the use of other ways to receive GOES-16 data, such as GEONETCast Americas.

The GOES-R team has started the GOES-R International Training Working Group (GITWG). The purpose of the group is to coordinate and organize trainings in North, Central, and South America and the Caribbean on the use of the data from the GOES-R series satellites. The group has developed contacts with other training partner organizations, a process for reviewing training requests, a calendar of trainings planned by other organizations, and a tentative training schedule for 2018.

NOAA continued to expand our collaboration with EUMETSAT with the signing of a Memorandum of Understanding on January 11, 2017, to receive Sentinel-3A data. NOAA contributed to the validation of these datasets by participating on the Sentinel-3 Validation Team and leveraging in situ observations from NOAA's Marine Optical BuoY (MOBY) for Sentinel-3 calibration efforts.

NOAA will evaluate commercial data to demonstrate the quality of the data and its impact on weather forecast models and to inform NOAA's process for ingesting, evaluating, and utilizing commercial data in the future. Based on the findings of recent market research and Federal Acquisition Regulation processes (e.g., Requests for Information), NOAA has selected GNSS radio occultation (GNSS-RO) as the most suitable data type for the CWDP.

National Institute of Standards and Technology

In FY 2017, the National Institute of Standards and Technology (NIST) continued to provide the aerospace industry, academia, and Federal agencies with the research, standards, products, services, and guidance needed to advance the President's aeronautics and space agenda. These wide-ranging NIST outputs are grouped into four main categories: 1) measurements to support aerospace manufacturing, 2) measurements to support the aerospace industry and space exploration, 3) technology developments to support the aerospace industry and space exploration, and 4) calibrations of satellite sensors.

NIST Measurements to Support Aerospace Manufacturing

In FY 2017, NIST used measurement expertise in mass, force, networking, and other areas to partner with Boeing, Honeywell Aerospace, Lockheed Martin, Northrop Grumman, General Electric Aviation, Rolls-Royce, United Technologies Aerospace, Spirit Aerospace, and others in addressing the measurement needs of aerospace manufacturing companies. To meet these needs, NIST

- identified technical issues and requirements definitions for industrial wireless networking, cybersecurity in manufacturing environments, and prognostics for manufacturing systems;
- engaged with the FAA, DOD, and NASA to identify proposed approaches for qualification and certification of additive manufacturing materials, processes, and parts;
- collaborated with members of the Additive Manufacturing Consortium (AMC) and with manufacturers of aerospace components to conduct round-robin testing and determine the mechanical properties of parts made from Inconel 625 aerospace alloy;
- contributed as expert panel member for 2017 industry workshop titled "Realizing Gas Turbine Performance Goals Through Advanced Manufacturing" to address the advances, challenges, and certification issues associated with additive manufacturing for advanced gas turbines used in aircraft, aerospace, and power generation;

- researched the processing of materials during additive manufacturing to enable the attainment of consistent, homogeneous, and optimal properties in additive manufactured parts;
- discussed technology advancements and new standards relevant to aircraft manufacturing and sustainment at the 2017 Aircraft Airworthiness and Sustainment (AA&S) Conference; and
- performed measurements to enable new capabilities for collaborative robotics.

In the first three quarters of FY 2017, the NIST Manufacturing Extension Partnership (MEP) engaged in 167 projects with 110 individual manufacturing companies designated with an aerospace North American Industry Classification System number (NAICS 3364). The MEP post-project, follow-up survey of aerospace NAICS companies revealed that MEP services resulted in the creation or retention of 3,929 aerospace jobs, over $235 million in new and retained sales, over $137 million in new investment, and $104 million in cost savings.

NIST Measurements to Support the Aerospace Industry and Space Exploration

In FY 2017, NIST supported the aerospace industry and relevant Government agencies across various programs by providing measurements, calibration services, and research traceable to international standards, where NIST

- worked with DOD and Boeing to develop calibration methodologies and facilities for laser-scanner systems used for the accurate dimensional measurements of aircraft components;
- worked with the U.S. Air Force to modify existing laser tracker documentary standards to include NIST-developed field test procedures to reduce the cost of utilizing laser trackers;
- provided air-speed measurement calibrations of anemometers used at airports, on aircraft, and in wind tunnels;
- prepared a new release of the online NIST Atomic Spectra Database, used by astrophysicists and astronomers for the calibration of equipment searching for exoplanets;

- utilized the NIST Van de Graaff accelerator with SolAero Technologies Corporation to "space qualify" solar cells by irradiating them with the equivalent number of electrons that the cells would experience in several decades of Earth orbit; NIST and NASA's Goddard Space Flight Center (GSFC) also used high-energy electron beam radiation to test components destined for the Interstellar Mapping Probe (IMAP), Europa Deep Geophysical Explorer (EDGE), and Europa Clipper missions;
- tested the performance of a micro-cryocooler system developed at the Jet Propulsion Laboratory (JPL) for the Mapping Imaging Spectrometer for Europa (MISE) mission in a high-energy radiation environment;
- started a new effort to revise the U.S. Coordinate Measuring Machine (CMM) documentary standard to meet the needs of Boeing and other large precision component manufacturers; Boeing metrologists have requested that NIST revise the current U.S. standard to incorporate testing procedures for larger CMMs, which are becoming more frequently utilized in the aerospace industry;
- continued to support NASA in the development of its MaterialsLab microgravity materials science program for materials experiments aboard the International Space Station; for more information, see *https://www.nasa.gov/mission_pages/station/research/news/materialslab*; and
- presented the NASA-NIST MaterialsLab collaboration to the National Academies Division on Engineering and Physical Sciences Boards for Aeronautics and Space Studies' "Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA" project, April 18, 2017 (see *http://www8.nationalacademies.org/cp/meetingview.aspx?MeetingID=9265&MeetingNo=3)*.

NIST, members of the aerospace field (Thermacore, Marshall Space Flight Center, and the Air Force Academy), and members of academia (the University of Tennessee, the University of Missouri, and Michigan Technology University) used unique NIST neutron facility resources to perform measurements on several aerospace-related systems, including cryogenic liquid propellants critical for understanding long-term microgravity storage of cryogens, and proton-exchange membrane fuel cells.

NIST Technology Developments to Support the Aerospace Industry and Space Exploration

In FY 2017, NIST collaborated with NASA and NASA-related entities such as GSFC; JPL; the Space Science Laboratory; and Sensor Sciences, LLC, on a diverse set of projects for developing detectors used in space applications. To reach project goals, NIST

- designed and fabricated nanotextured gallium nitride (GaN) and GaN nanowires to serve as photo-cathode films for space-based photodetection;
- created superconducting nanowire single-photon detectors (SNSPDs) optimized for ultraviolet light detection at 370 nanometers;
- generated superconducting transition-edge sensor (TES) polarimeters to provide the most-sensitive measurements of cosmic microwave background (CMB) polarization to date and for incorporation into the balloon-borne instrument SPIDER;
- fabricated NIST-developed Microwave Kinetic Inductance Detectors (MKIDs) to measure electromagnetic signals from millimeter waves to x-rays and for deployment in the Balloon-borne Large-Aperture Submillimeter Telescope–The Next Generation (BLAST-TNG);
- disseminated Superconducting Quantum Interference Devices (SQUIDs) and SQUID-based multiplexers to multiple researchers and used the related detector expertise to develop magnetic micro-calorimeters; and
- developed precision microchannel plate detectors using novel cross-strip anode readouts, relevant for neutron imaging and in x-ray telescopes that peer into space.

Also in FY 2017, NIST supported the European Space Agency's Atomic Clock Ensemble in Space (ACES) and Space Optical Clock (SOC) programs by continuing preparations to host a Microwave Link Ground Terminal and participating in microwave link time and frequency transfers.

NIST worked with GSFC by using NIST-developed infrared interferometry methods to characterize and certify critical imaging parts of NASA's Wide Field Infrared Survey Telescope (WFIRST), which was designed to investigate the distribution and evolution of dark energy and dark matter in the universe.

NIST collaborated with the University of Texas at Austin on a NASA-funded project to improve the performance of immersed silicon diffraction gratings for a new generation of compact satellite-based spectrometers used in the analysis of remote stars, interstellar gases, and extrasolar planets.

NIST partnered with the University of Colorado Laboratory for Atmospheric and Space Physics (LASP) and NASA to develop and fabricate a Carbon Nanotube Electrical Substitution Radiometer (CNT ESR) for the Compact Solar Irradiance Monitor (CSIM) instrument (scheduled for launch in June 2018) and the Carbon Absolute Electrical Substitution Radiometer (CAESR) for a future CubeSat mission.

NIST collaborated with the Air Force Services Division (SVD) to transfer frequency comb technology from NIST to the Air Force for incorporation into their next-generation compact optical clock. NIST also collaborated with the Air Force Laboratory and their contractors to transfer the technique of comb-based optical time-frequency transfer that could be potentially used in the future to provide optical cross-links for the next-generation GPS satellite system.

NIST Calibrations of Satellite Sensors

In FY 2017, NIST continued to provide calibration measurements, services, and support for multiple space-related programs. The satellite systems relied on unique measurement expertise, where NIST

- provided calibration support for sensors within the satellite missions JPSS and GOES-R, with NIST transferring its calibration technology to GSFC and LASP;
- utilized the NIST Synchrotron Ultraviolet Radiation Facility (SURF) III to support the calibration of the Extreme Ultraviolet (EUV) Variability Experiment (EVE) aboard NASA's Solar Dynamics Observatory; the EUV and X-ray Irradiance Sensor (EXIS) for NOAA's GOES-S, -T, and -U satellite missions; and the Miniature X-ray Solar Spectrometer (MinXSS) nanosatellite;

- performed measurements of the amount of light from the moon and sun to enable the moon to serve as a calibration source for satellite sensors while in Earth orbit;
- calibrated MOBY, which is in turn used in the calibration of satellite sensors for ocean-color measurements, and worked with NOAA to improve measurement variability and uncertainty as part of the MOBY Refresh effort;
- utilized the NIST-developed Missile Defense Transfer Radiometer (MDXR) to perform calibrations for infrared remote sensors used by the Missile Defense Agency;
- calibrated optical apertures for the NASA Total and Spectral Solar Irradiance Sensor (TSIS), which is used aboard the ISS to measure solar power per unit area that reaches Earth; and
- continued to develop versions of the NIST Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) facility, which provides tunable, powerful, and uniform irradiance to calibrate satellite sensors, with both GSFC and LASP.

International Trade Administration

Industry and Trade Policy

The Office of Transportation and Machinery (OTM) continues to pursue multiple paths to promote exports of products and services that support the Next Generation Air Transportation System (NextGen). OTM created and published an online NextGen Solutions Vendors Guide to help foreign customers identify U.S. companies who can provide products that meet the requirements of the International Civil Aviation Organization's (ICAO) Aviation System Block Upgrade (ASBU) technology roadmaps. The Guide currently is being transferred to the Salesforce platform, which will enable a more customer-friendly interface and provide end-to-end tracking and communication between vendors, customers, and relevant International Trade Administration (ITA) staff.

OTM participates in the World Air Traffic Management (ATM) Congress in Madrid, Spain, and has worked with the Federal Aviation Administration (FAA), industry, and the Air Traffic Control Association (ATCA) to emphasize U.S. technical capabilities to the global audience that attends. The Congress represents an opportunity to learn about the specific air navigation procurement needs of specific countries, to counsel individual companies on NextGen-related prospects as well as the Department of Commerce services, and to recruit participants for the NextGen Solutions Vendors Guide and potential applicants to the Industry Trade Advisory Committee on Aerospace Equipment (ITAC 1). OTM has been working with ATCA to more fully engage Commerce resources. To that end, ATCA applied for and received trade fair certification for the 2018 World ATM Congress.

Additionally, OTM worked with the FAA, the Transportation Security Administration (TSA), and the State Department in preparation for the 39th ICAO Assembly in September 2016, providing the ITA perspective on aviation safety, aviation security, air-navigation policy and procurement, and the economics of air transportation. ICAO had formally endorsed the ASBU roadmaps at the previous Assembly. OTM also supported the visit by Fang Liu, the Director General of ICAO, to meet with Assistant Secretary Jadotte and promote ICAO's No Country Left Behind initiative.

OTM also participated in the Association for Unmanned Vehicle Systems International (AUVSI) XPONENTIAL 2017 Conference to engage with Government, academic, and industry stakeholders within the UAS community, to learn more about the projected market for UAS, to hear about the latest roadmaps for the technology, and to recruit participants for the ITAC 1. Specifically, OTM cultivated contacts with various state business development offices at XPONENTIAL 2017, with particular emphasis on the regions represented in the FAA's six UAS test sites. Moreover, OTM visited the FAA UAS test sites in New York and Texas to evaluate both sites in terms of export potential of the local industry as well as the attractiveness of the regions for foreign investors. As well, OTM organized a UAS industry roundtable in November 2016 to inform stakeholders of Commerce equities in UAS (such as participation in the interagency UAS Executive Committee) and provide a forum for industry to discuss challenges the UAS sector currently faces.

OTM continued to implement 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 MOA includes an addendum detailing a virtual research partnership program in which ERAU-Worldwide students will research topics suggested by ITA.

Throughout the year, OTM organized and led four meetings of ITAC 1. The committee provides advice to the Secretary of Commerce and U.S. Trade Representative on aerospace-related trade policy issues.

ITA continues to support the Office of the U.S. Trade Representative on issues relating to the enforcement of U.S. rights under the World Trade Organization concerning trade in civil aircraft. In particular, OTM provided support in 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. Industry feedback and available data on the usage of the latest version of the ASU, which was finalized in 2011, suggest that the agreement is working as intended, although financing levels declined significantly due to unrelated disruptions in both U.S. and European export credit support for aircraft exports. As a member of the U.S. delegation, ITA helped ensure that the interests of industry were addressed as the 2011 ASU was negotiated and continues to monitor implementation. ITA also provided advice on the importance of Export-Import (Ex-Im) Bank programs to the aerospace industry and its supply chain.

ITA and NOAA continued their active participation in the implementation of the current National Space Policies, which include industrial base and

competitiveness issues. ITA's OTM actively participated in the implementation of several actions that were identified in the June 2010 National Space Policy, which revised and updated several aspects of the previous policies. In order to ensure that commercial interests continue to be adequately addressed, OTM and NOAA continued to ensure that all of the policies' implementation actions will improve U.S. industry's competitiveness, stimulate the American economy, increase exports, and create U.S. jobs.

NOAA, ITA, and the Bureau of Industry and Security (BIS) supported the inaugural meeting and activities of the reconstituted National Space Council. Secretary Wilbur Ross participated in the meeting.

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

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

In June 2017, ITA organized and supported the Commerce Department's participation in the Paris Air Show and arranged senior-level meetings for the Assistant Secretary for Industry and Analysis with foreign government and industry officials as well as U.S. industry executives. ITA/OTM met with numerous U.S. and foreign government and industry officials to discuss ongoing policy issues impacting the competitiveness of U.S. industry.

Industry and Trade Promotion

ITA's Global Aerospace & Defense Team recorded approximately 547 Written Impact Narratives (WINs) in FY 2017. A WIN is a new organizational metric that showcases ITA's contribution to a company's success. These include ITA- and particularly Commercial Service (CS) personnel–impacted deals with small- and medium-sized companies, as well as larger corporations such as Bell Helicopter, Boeing, General Dynamics, Lockheed Martin, and United Technologies Corporation.

The Global Team held over 1,541 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 Avalon Air Show, the Paris Air Show, the International Defense Exhibition (IDEX), the Aircraft Interior Show, and the Japan Air Show, among others.

Bureau of Industry and Security

BIS continued to support the U.S. Munitions List/Commerce Control List efforts as they relate to spacecraft. During this fiscal year, BIS worked with industry and the interagency Space Working Group on identifying changes to the current regulations on spacecraft and related items. Updates to the regulations covering controls on certain remote sensing satellites, integrated propulsion, and plasma thrusters became final in January 2017. These updates were several years in the making and are greatly appreciated by industry. In particular, the changes to add certain remote sensing satellites and satellite thrusters to the regulations helped level the playing field for U.S. industry to compete with foreign industry in remote sensing. BIS also participated in the Transportation Technical Advisory Committee discussions, which include aerospace-related topics.

Department of the Interior

DOI

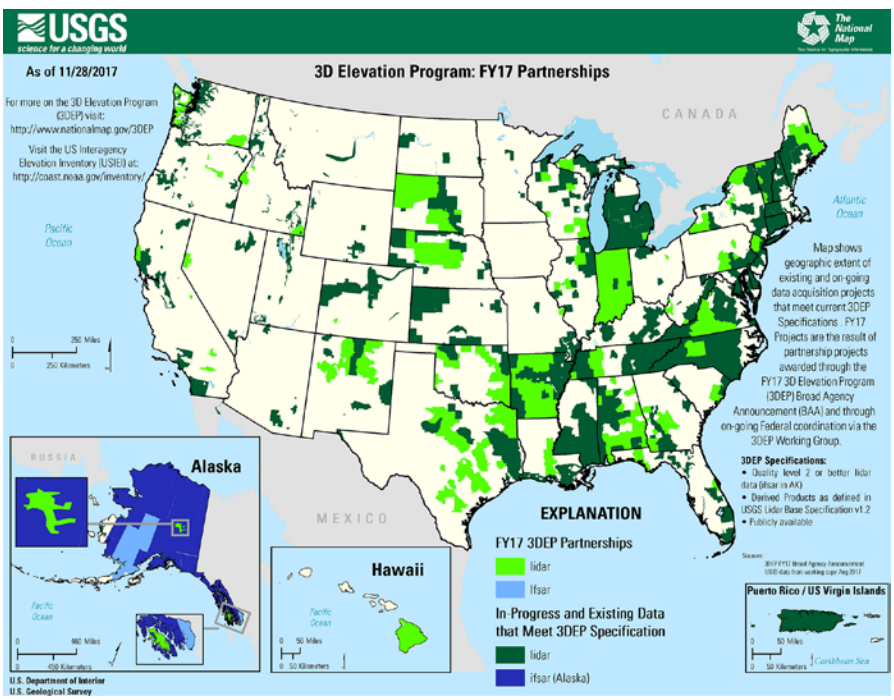
Remotely sensed data and derived information contribute significantly to mission-critical work across the Department of the Interior (DOI). This DOI section highlights a sample of DOI remote sensing applications and illustrates a range of technology, platforms, and specialized sensors employed.

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. Landsat represents the world's longest continuously acquired collection of space-based moderate-resolution land remote sensing data, and the entire archive became available for download at no charge in December 2008. The USGS also distributes aerial photography through the National Map and archives and distributes historical aerial photography, light detection and ranging (lidar) data, declassified imagery, 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, such as mineral resource development; monitoring the health of U.S. and global ecosystems; land-use change; emergency response; and assessments of natural hazards such as fires, hurricanes, earthquakes, droughts, and floods.

3D Elevation Program Status

On behalf of the broad partner and user community, the USGS is managing the 3D Elevation Program (3DEP) with the goal to complete nationwide coverage of light detection and ranging (lidar) data in CONUS and the territories and Interferometric Synthetic Aperture Radar (IfSAR) data in Alaska by 2023. Investments in the program continue to grow under the leadership of the interagency 3DEP Executive Forum and Working Group, which respectively coordinate the strategic direction and operational implementation of the program through the participation of 16 Federal agencies. At the end of FY 2017, 37 percent of the Nation had 3DEP-quality data available or in work. 3DEP is based on the National Enhanced Elevation Assessment to provide a return on investment of 5:1 and to conservatively provide new benefits of $690 million per year with the potential to generate $13 billion per year in new benefits through applications that span the economy. 3DEP data support a broad range of nationally significant applications, including flood risk management, infrastructure construction and management, critical minerals exploration, landslides and other hazards mitigation and response, and more.



This map shows the 3D Elevation Program's FY 2017 Partnerships.

Alaska Interferometric Synthetic Aperture Radar Elevation Data Status

The USGS is leading efforts to coordinate with other Federal agency partners and the state of Alaska to acquire new Alaska elevation data statewide using remote sensing techniques. Under its Geospatial Products and Services Contract (GPSC), the USGS is contracting with vendors to acquire five-meter-resolution elevation data using IfSAR sensors flown on aircraft. Deliveries include a Digital Terrain Model (DTM) representing the bare earth, a Digital Surface Model (DSM) representing the tops of vegetation and structures, and an orthorectified radar intensity image (ORI). The new data are replacing decades-old 60-meter-resolution elevation data that have known vertical and horizontal errors. By the end of 2017, 92 percent of statewide IfSAR coverage was available or in work. Some of the Alaska IfSAR coverage, specifically over the National Petroleum Reserve–Alaska (NPRA), was collected under slightly different specifications prior to the current effort, which began in 2010. The USGS hopes to complete IfSAR collection by 2020, including an update of the legacy NPRA data. IfSAR data are being used in a wide variety of mapping, resource management, and human safety applications. A recent literature search discovered dozens of scientific journal articles that cite the use of the new data. The new elevation data also serve as a foundational layer for new USGS US Topo digital topographic maps that are being generated statewide for Alaska as the new elevation data become available. These Alaska mapping efforts are coordinated through the Alaska Mapping Executive Committee (AMEC), an executive body cochaired by the Department of the Interior and the Department of Defense. AMEC members represent a large number of Federal agencies and the state. Alaska IfSAR elevation data can be downloaded through the USGS National Map data download service at *https://viewer.nationalmap.gov/basic/*.

Automated Identification and Mapping of Minerals and Vegetation

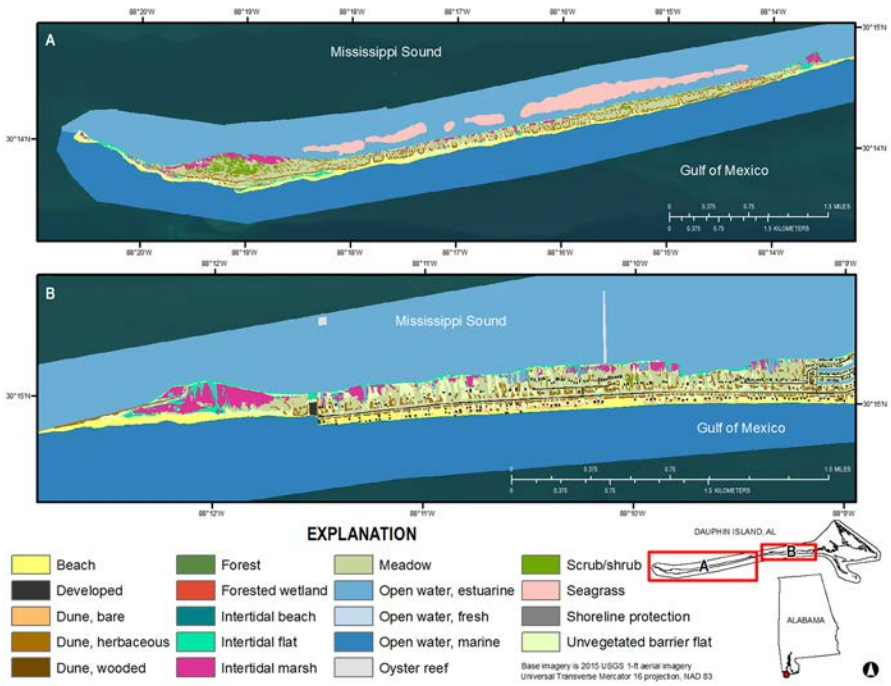
An algorithm for the automated analysis of multispectral remote sensing data acquired by the Landsat 8 Operational Land Imager (OLI) sensor has been developed that can efficiently identify surface occurrences of iron sulfate minerals. The algorithm combines thresholded band ratio results into displayed mineral and

vegetation groups using Boolean algebra. New analysis logic has been implemented to exploit the coastal aerosol band in Landsat 8 OLI data and identify concentrations of iron sulfate minerals that may indicate the presence of near-surface pyrite that can be a potential nonpoint source of acid rock drainage. Using this technique in areas adjacent to and down gradient of known sources of pyrite produced maps of zoned iron sulfate minerals that show high correlation with occurrences of jarosite-bearing mineral assemblages mapped using airborne imaging spectrometer data and supporting field verification surveys. Mapping the occurrence of iron sulfate minerals (after pyrite) in exposed hydrothermally altered rocks can provide an important indicator of the genetic environment of the alteration and associated mineral deposit type, particularly for advanced argillic alteration. Highly pyritic exposures of quartz-sericite-pyrite (QSP, or phyllic) alteration can be readily identified and differentiated from argillically altered rocks that are low in pyrite. The automated analysis methodology will be published in a USGS Scientific Investigations Report and is being employed to rapidly and cost-effectively generate maps of large regions of the United States in support of USGS mineral resource and mineral-environmental assessments.

The maps generated from the analysis of Landsat 8 data are most effective when used in conjunction with mineral maps derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data analysis in which diagnostic minerals associated with several types of hydrothermal alteration can be identified. ASTER-derived maps of surface minerals and green vegetation covering the western United States were published recently in a USGS Data Release: *https://doi.org/10.5066/F7CR5RK7.*

Barrier Island Habitat Mapping

Barrier islands are dynamic environments due to their position at the land-sea interface. Storms, waves, tides, currents, and relative sea-level rise are powerful forces that shape barrier island geomorphology and habitats (for example, beach, dune, marsh, and forest). Hurricane Katrina in 2005 and the Deep Water Horizon oil spill in 2010 are two major events that have impacted habitats and natural resources on Dauphin Island, Alabama. The latter event prompted a collaborative



This habitat map for the western two-thirds of Dauphin Island, Alabama, is from 2015.

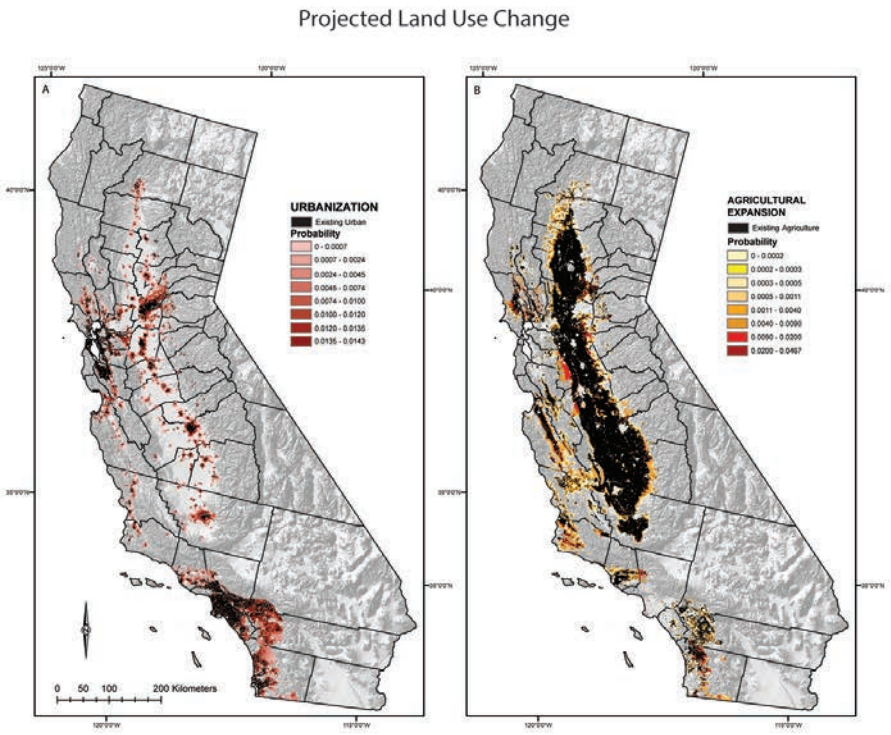
project funded by the National Fish and Wildlife Federation that involves efforts by the state of Alabama, the USGS, and the U.S. Army Corps of Engineers to evaluate the feasibility of various restoration alternatives and how specific alternatives might increase the resiliency and sustainability of Dauphin Island (*http://www.nfwf.org/gulf/Documents/al-dauphin-assessment-14.pdf*).

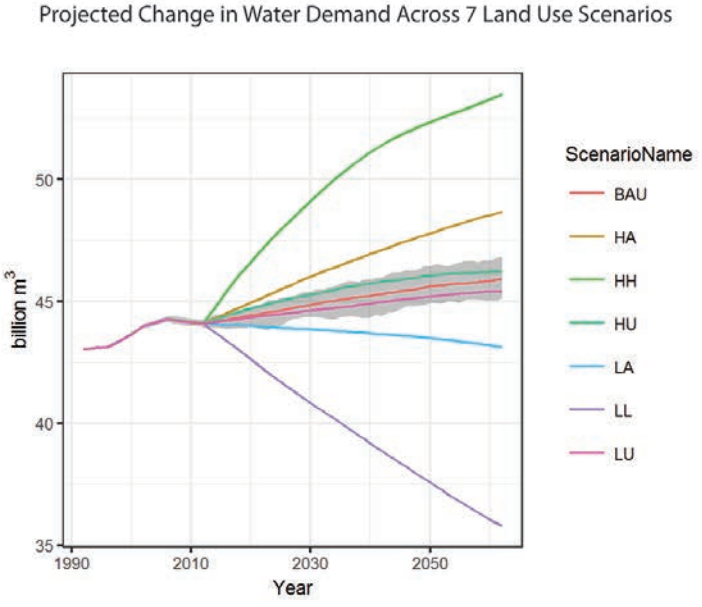
In order to understand the feasibility and sustainability of various restoration scenarios, it is important to understand current conditions on Dauphin Island. To accomplish this, researchers at the USGS Wetland and Aquatic Research Center produced a detailed map of barrier island habitats on Dauphin Island by using object-based image analyses trained with a suite of environmental variables. These include tide data, topography, surface elevation, 1-foot aerial imagery, road data, salinity data, and lidar data that incorporate elevation uncertainty by using Monte Carlo simulation to estimate probability surfaces for intertidal areas and areas above extreme storm water levels. As part of this effort, we also conducted a survey of land-cover types, vegetation community, and elevations from mid-November 2015 to mid-December 2015 along randomly placed transects at seven sites throughout

the eastern half of the island. These products provide baseline data regarding the ecological and general geomorphological attributes of the area, which can be compared with observations from other dates for tracking changes over time. For more information, visit *https://pubs.er.usgs.gov/publication/ofr20171083*.

California's Water-Use Future Based on Scenarios of Land-Use Change

California's water-use future is fraught with uncertainty, given growing demand and highly variable interannual water supplies. A broad suite of spatially explicit future land-use scenarios and their associated county-level water-use demand projected out to 2062 will be modeled using a state-and-transition simulation modeling approach. Scenarios have been developed by sampling from a 20-year record of historical (1992–2012) aerial photography data to generate low/high change scenarios for urbanization and agriculture as well as "lowest of the low" and "highest of the high" anthropogenic use. Current results indicate the greatest increased water demand in the highest-of-the-high land-use scenario at 9.4 billion cubic meters (Bm^3), high agricultural expansion (+4.6 Bm^3), and high urbanization (+2.1 Bm^3) scenarios. Decreased water demand was projected in the lowest-of-the-low scenario (–8.3 Bm^3) and decreased 0.8 Bm^3 in the low-agriculture scenario. Results show that agricultural land-use decisions will likely drive future water demand more than increasing municipal and industrial uses, yet improved efficiencies across all sectors could lead to potential water use savings. Results provide water managers with information on diverging land-use and water-use futures, based on historical, observed land-change trends and water-use histories. For more information, see *https://geography.wr.usgs.gov/LUCC/mediterranean_california_land_change_and_water_use_projections.php*.





Top panels: Mapped land-use projections (expressed as probabilities of conversion) for Mediterranean California for expansion of urban (left) and agricultural (right) areas are modeled for 2012–62 using 40 Monte Carlo iterations for each of the following land-use scenarios: 1) Business As Usual (BAU), 2) High Agriculture (HA), 3) Highest of the High (HH), 4) High Urban (HU), 5) Low Agriculture (LA), 6) Lowest of the Low (LL), and 7) Low Urban (LU). Mapped values represent a cumulative transition probability across all scenarios. Bottom panel: Projected change in land-use-related water demand is expressed in billions of cubic meters (Bm^3) for each scenario, with variability across the 40 Monte Carlo simulations shown in gray for the BAU scenario.

Global 30-Meter Cropland Extent Map for 2015

Climate variability and ballooning populations are putting unprecedented pressure on agricultural croplands and their water use, which are vital for ensuring global food and water security in the 21st century. In this context, there is a need to produce consistent and accurate global food security support-analysis data (GFSAD) at fine spatial resolution that are generated routinely (e.g., every year). Hence, the overarching goal of this project was to produce GFSAD models, maps, and monitoring tools using machine learning algorithms (MLAs) on cloud computing platforms with the ability to handle multi-sensor remotely sensed big data, leading to a comprehensive set of cropland, crop water-use, crop productivity, and crop water productivity products that ensure food security for all people globally. The outcome resulted in the first global 30-meter cropland extent product (*https://croplands.org/app/map*) derived using Landsat 8 16-day time-series data for the nominal year 2015. Overall accuracies in about 100 segments of the world were consistently higher than 90 percent, with producer's accuracies typically higher than 85 percent and user's accuracies typically higher than 80 percent. The study estimated global net cropland area (GNCA) of 1.872 billion hectares (about 12.6 percent of Earth's land area). Four countries—India, the United States, China, and Russia—together had 35 percent of GNCA. The methods described in this study produced 30-meter derived cropland areas for each country of the world as well as for subnational regions such as provinces, districts, and counties and were compared with the national agricultural statistics compiled by the United Nations Food and Agriculture Organization (UN FAO) and others. For more information, visit *https://croplands.org/app/map*.

Hyperspectral Microscopy of Harmful Algal Blooms

Cyanobacterial blooms in eutrophic inland waters are a worldwide concern. Simple and fast detection methods would greatly aid water managers in issuing proper warnings for harmful algae. Blooms are exacerbated by high nutrient inputs and warmer waters, and they have been appearing with increasing frequency in water bodies used for drinking water supply or recreation, a problem that will

likely worsen as the climate warms. Cyanobacterial blooms are a nuisance for their unsightly surface scums and the production of taste-and-odor compounds, and some strains of cyanobacteria produce toxins that are hazardous to human and animal health. Remote sensing has been used to detect cyanobacterial blooms, but few studies have distinguished between genera of cyanobacteria. Because some genera are more likely to be toxic than others, this is a useful distinction. In this study, hyperspectral imaging reflectance microscopy was used to examine cyanobacteria from Upper Klamath Lake, Oregon, at high spatial and spectral resolution to determine if two genera found commonly in the lake, *Aphanizomenon flos-aquae* and *Microcystis* sp., can be separated spectrally. Of the analytical methods applied, a spectral shape algorithm applied to the derivative was found to be most successful in classifying genera in microscope scenes. For more information, visit *https://egsc.usgs.gov/PDS_HSImicro.html*.

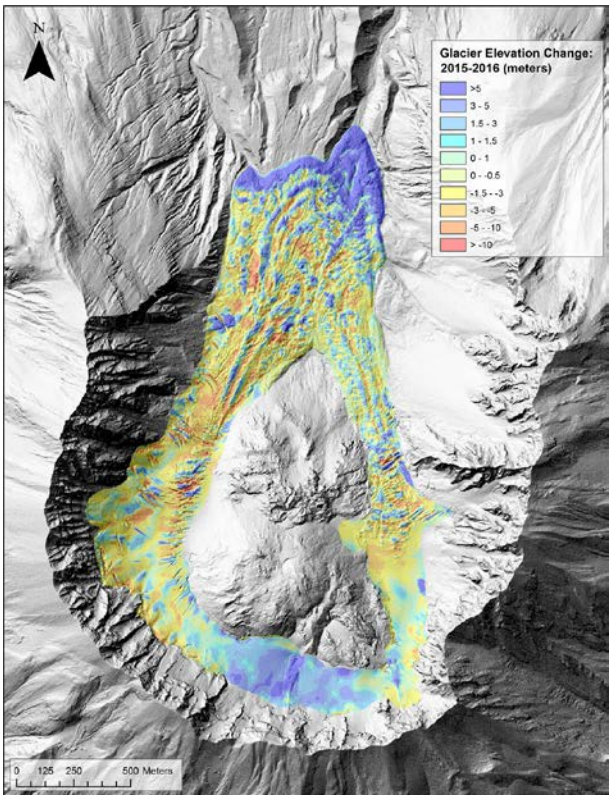
National Land Cover Database Design Completed

The USGS, working in partnership with the Federal interagency Multi-Resolution Land Characteristics (MRLC) Consortium, is developing the National Land Cover Database (NLCD) 2016. NLCD serves as the definitive Landsat-based, 30-meter-pixel-resolution land-cover database for the Nation. NLCD 2016 will feature new products of labeled land-cover and fractional-cover products of urban imperviousness, tree canopy, shrub canopy, grass canopy, and bare ground. In addition, previous NLCD labeled land-cover releases from 2001, 2006, and 2011 will be reharmonized with NLCD 2016 to ensure that all products are spatially coherent and consistent among all four epochs for accurate capture of land-cover change across time. NLCD 2016 will represent the most accurate and detailed NLCD products ever delivered. NLCD data are being used in a wide variety of applications, including hazard mitigation, resource management, and human safety applications. A recent literature search discovered hundreds of scientific journal articles that cite the use of the previous NLCD data.

For more information on NLCD and to download NLCD data, including shrub and grassland products, visit *http://www.mrlc.gov/*.

Monitoring Changes to Crater Glacier at Mount St. Helens

The USGS Cascades Volcano Observatory utilizes oblique and vertical aerial photography to monitor topographic changes at the Mount St. Helens volcano. Annual photogrammetry surveys are conducted to create high-resolution (0.5–1-meter) digital elevation models (DEMs) to monitor and measure changes within the crater that include setting and slumping of the 2004–08 lava dome, erosion of the crater walls, and advancement and volume change of Crater Glacier. Lava that erupted during the 2004–08 eruption severely deformed Crater Glacier, splitting it in two and pushing each arm northward until they joined again on the north side of the 1980–86 lava dome. Following the eruption, the glacier has continued to advance north each year. The glacier continues to gain volume, although at a decreasing rate from previous years. Elevation increase is most prominent in the south and at the toe of the glacier in the north. Elevation loss (thinning) and deep crevassing is most prominent in the glacier arms.



This image shows Crater Glacier elevation change from 2015 to 2016 measured by differencing high-resolution DEMs created with photogrammetry.

Rapid Estimation of Snowpack Water Content

Record high precipitation over the winter of 2016–17 across the central and northern Sierra Nevada of California and Nevada resulted in flooding across the region. Silver Lake, a 3-square-kilometer lake surrounded by industrial and residential development in Reno, Nevada, began to experience a substantial rise in water level in March, requiring a rapid response from the Reno emergency management services. In late March, the USGS collaborated with the city of Reno and Washoe County emergency management services to produce a rapid assessment of stored snow water equivalent and potential runoff for the Lemmon Creek drainage above Silver Lake. The Lemmon Creek drainage was ungauged and uninstrumented, and no high-resolution snow-free DEM was available for use in a lidar-differencing approach for estimation of snow-cover height. Wind redistribution of snow cover and differences in incoming solar radiation resulted in variations in snow depth of up to 5 meters over short distances, complicating efforts to conduct a traditional snow survey to estimate stored snow water equivalent. On March 28, teams conducted a specialized snow survey optimized for estimation of snow depth using Landsat-derived mean annual snow-cover duration for 1984–2015 from the Landsat Snow Covered Area Science Data Product. Mean annual snow-cover duration calculated using Landsat data showed a strong correlation with measured snow depth, allowing spatially distributed snow depth to be estimated using the combination of measured snow depth values and mean annual snow-cover duration. Modeled snow depth was converted to snow water equivalent using density observations from the field and then constrained to pixels where snow cover was mapped from a WorldView-2 image acquired within 24 hours of the snow survey. The spatially distributed model of stored snow water equivalent was then used to provide an estimate of the anticipated rise in lake level for Silver Lake, allowing the city and county to take precautionary measures to prevent the lake from spilling over into structures adjacent to the lake. For more information, visit *https://nevada.usgs.gov/water/Flood2017/lemmonvalley.html*.

Remote Sensing Support for DOI Burn Area Emergency Response Teams

Since 2003, the USGS Earth Resources Observation and Science (EROS) Center and the U.S. Forest Service (USFS) Remote Sensing Applications Center (RSAC) have jointly provided satellite-derived burn severity mapping products to meet the requirements of DOI and USFS Burn Area Emergency Response (BAER) teams. BAER teams are mandated to quickly (within two weeks) evaluate the effects of wildland fires and develop mitigation plans to safeguard valuable natural resources, protect human life and property, and promote landscape recovery. Derived from Landsat images, the soil burn severity map is a major resource used by the BAER teams to develop postfire hazard-mitigation prescriptions. Additionally, burn severity maps are provided to USGS Landslide Hazards staff to support ongoing debris flow modeling and prediction analyses associated with wildland fires.

The USGS EROS rapidly processes Landsat and other satellite imagery, enabling the timely generation of map products for large wildland fires on DOI-managed lands, generally less than two days after fire containment. These map products allow the BAER teams to better understand the patterns of burn severity and make more precise mitigation recommendations. Since 2003 and through the 2016 fire season, the USGS and USFS have mapped 1,759 wildfires representing 48.8 million burned acres in support of BAER and local DOI and USFS land managers.

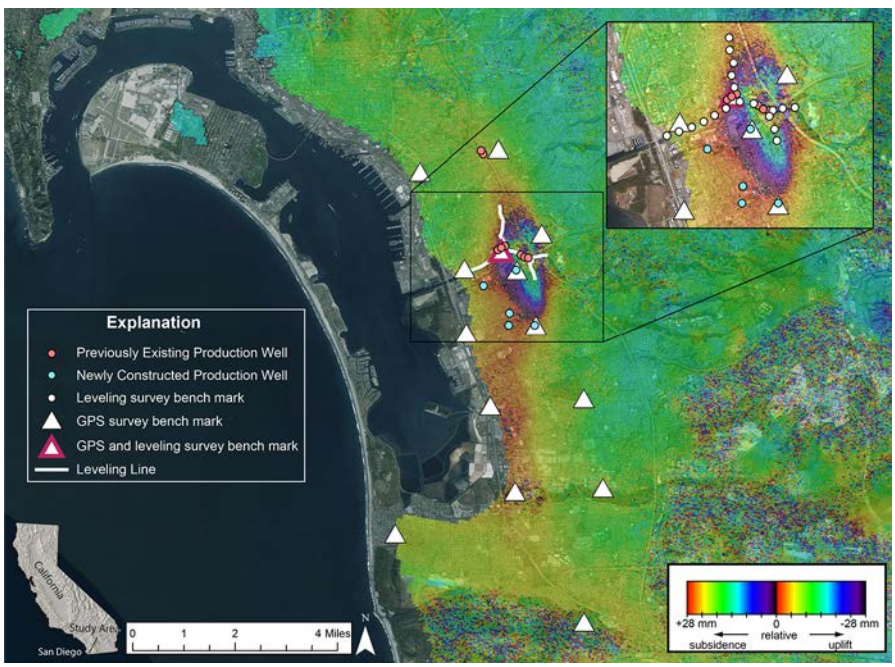
In 2017, wildland fire activity on DOI-managed lands is expected to be extensive. By early June, the USGS EROS had responded to seven DOI requests for burn area mapping support, including the large 152,515-acre West Mims fire located in the U.S. Fish and Wildlife Service Okefenokee National Wildlife Refuge (Georgia/Florida). For more information, visit *http://eros.usgs.gov/landscape-dynamics/fire-science*.

Tracking Land Subsidence

Multiple agencies in the San Diego area have the responsibility to effectively manage the water supply in this arid, urban, densely populated, coastal basin in Southern California. Recently, five additional groundwater production wells were constructed to increase the water supply; the new wells are scheduled to begin

pumping in 2017. California's Sustainable Groundwater Management Act of 2014 (SGMA) provides a framework to comprehensively measure and manage groundwater. SGMA empowers local agencies to assess hydrologic conditions that can cause "undesirable results," which include land subsidence resulting from compaction of unconsolidated aquifer systems caused by groundwater extraction. Therefore, as part of the overall water-management strategy, changes in land-surface elevation need to be regularly monitored to assess whether and where land subsidence may be occurring.

The USGS, in cooperation with the city of San Diego and the Sweetwater Authority, designed GPS and leveling networks using existing and newly constructed benchmarks to measure land-surface elevation changes at regional and local scales that may occur as a result of groundwater production. As part of a suite of considerations, satellite-based Interferometric Synthetic Aperture Radar (IfSAR) measurements showing deformation caused by previously existing production wells were used to help guide the network design. A static GPS survey of



Shown are production wells, GPS and leveling survey locations, and an interferogram spanning June 1, 1998, to June 5, 2000, of the San Diego area, California. This interferogram indicates that about 35 millimeters of subsidence occurred near two previously existing production well clusters. Interferograms were used to help design terrestrial-based subsidence monitoring networks to track subsidence in the greater San Diego area.

14 benchmarks was combined with a first-order leveling survey of 20 benchmarks to obtain high-precision elevations to serve as baseline conditions for which to compare results of future surveys. The surveys will be augmented with IfSAR methods to provide spatially detailed maps of changes in land-surface elevations before and after the newly constructed wells begin producing groundwater, and to guide spatial and temporal logistics of future GPS and leveling surveys. This information will be useful to San Diego and the Sweetwater Authority in complying with SGMA while expanding water supplies. For more information, see *https://ca.water.usgs.gov/sandiego/*.

Users, Uses, and Value of Landsat Imagery

Social scientists at the USGS Social and Economic Analysis (SEA) Branch of the Fort Collins Science Center in Colorado are leading a long-term study to help assess the uses and value of Landsat imagery. A series of surveys provides longitudinal data on how the users and uses of the imagery are changing over time in response to changes in the provision of the imagery. This analysis allows economists to explore the value and benefits of the imagery to a community of users. Multiple case studies focusing on the use and benefits of Landsat imagery in water, agriculture, forestry, and private-sector technological applications have been completed. These case studies provide context and depth, which complement the more quantitative survey data. In 2017, a report containing case studies on the use of Landsat in agriculture was published (*https://pubs.er.usgs.gov/publication/ofr20171034*). A Landsat user survey was also developed to assess current and future requirements, which will be used in the development of future Landsat satellites.

Wolf Movements and Pack Spacing in the High Arctic

The USGS is now partnering with Utah State University (USU) and the Department of the Environment in Nunavut (DEN) to investigate wolves' (*Canis lupus*) movements and spacing in the high Arctic. This follows the USGS five-year study (summers 1986–2010) of the behavior of wolves habituated to humans on Ellesmere Island in northern Canada. Biologists from USU and DEN have

been putting GPS collars on wolves on Ellesmere to study movements and spacing behavior year-round. The data are sent via satellite to Web sites used by all three agencies. Data have been obtained on wolf packs of up to 20 animals, and based on clusters of locations indicating lack of movement for one to two days, summer investigation of those sites have yielded information about prey killed, most often musk oxen (*Ovibos muschatus*). Some dispersal and other unusual travels of over 250 kilometers have been observed, and information about wolf movements during the long period of 24-hour darkness over winter has been documented. These data are useful to agencies for understanding the habitats that wolves and their prey use, including their movements and their behavior in areas where coal and mineral exploration is being considered or is being carried out.

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 monitor and manage fish and wildlife populations, habitats, waters, wetlands, and landscapes. The FWS utilizes acoustic geographic positioning systems and 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, as well as thermal, radar, sonar, and lidar imagery. This time and geospatial system of imagery and location is used to map habitats, find invasive plants, determine flight paths of birds and bats, conduct fish and wildlife inventories, watch over refuge lands, and monitor trust species.

Aerial Migratory Bird Surveys Using Integrated Thermal/Visible Camera Imagery

Wildlife management agencies in North America have a long history of using aircraft to monitor population abundance of ducks, geese, swans, and other migratory birds. While low-level, ocular surveys have been very successful and cost-efficient, they subject agency personnel to substantial risk. Ocular surveys,

involving multiple air crews and observers, must include methods to minimize or estimate important biases such as detection, misclassification, flock-size estimation, and sample area determination. The integration of airborne remote sensing as a primary data collection tool is of interest as a means of enhancing crew safety and reducing or standardizing survey biases. In 2016, FWS Region 3 partnered with a diverse team from Federal, university, and nongovernmental organizations to begin determining whether low-level ocular surveys of long-tailed ducks in Lake Michigan could be replaced with a photo survey alternative. A camera and direct georeferencing system consisting of an 80-megapixel metric grade aerial visible camera with a 70-millimeter lens, a mid-wave (three to five micrometers) cryo-cooled InSb thermal camera with a 50-millimeter lens, and an Applanix Inertial Navigation System was mounted in an FWS Region 3 Partenavia aircraft and used to conduct photo surveys at a variety of altitudes ranging from 61 to 600 meters above the water surface. Images were selected based on quality, annotated based on content (species, age, and sex of waterfowl, along with behavior), and used to train a deep Convolutional Neural Network (CNN) and a baseline (off-the-shelf) machine vision algorithm to recognize birds in four categories.

Results were extremely promising: the imagery collected was of high quality, making it easy to annotate many birds into the sex and behavior categories that the algorithms needed to recognize. Both the baseline machine vision and the CNN algorithms were successful at identifying most categories of long-tailed ducks, especially birds sitting on the water (81 percent and 89 percent identified, respectively). The CNN deep learning approach was more successful at identifying birds overall (63 percent versus 40 percent), especially in flight (55 percent versus 1 percent). With the advances in airborne remote sensing technology and the rapid development in the field of artificial intelligence, the operational use of photo documentation and deep learning object recognition methods to survey pelagic waterbirds in systems as large as the Great Lakes is within reach.

This thermal and visible long-tailed duck imagery was collected during an experimental aerial pelagic survey of Lake Michigan in 2016. The top photos are mosaicked images with a close-up of visible and thermal signatures. The lower photos are a close-up of test images annotated with long-tailed duck sex/behavior categories.

Alternative Fuel Models to Estimate Fire Behavior Patterns

Wildland fires are an important natural disturbance in semidesert grasslands, but they can pose a threat to natural resource values and private property. Predicting the spread and intensity of fires allows for the prioritization of areas to mitigate fuels and reduce fire hazard. Fire behavior models for grasslands fundamentally depend on topography, fire weather, and presumed fuel-bed conditions. National fuel model data products are available through Landscape Fire and Resource Management Planning Tools (LANDFIRE). LANDFIRE fuel models for the semidesert grasslands in Arizona typically assume low flammability of desert grasslands because of low to moderate fuel loads and connectivity. However, invasive plant dominance and increased fuel load on more productive sites suggest that alternative fuel models or adjustments are needed to accurately estimate grassland fire behavior over large landscapes. For this study, FWS scientists compared fire behavior model outputs developed from a conventional LANDFIRE standard fuel model with custom-derived fuel models developed from extensive vegetation plots, fine-fuel data, and high-resolution satellite data in Buenos Aires National Wildlife Refuge (BANWR) in southern Arizona.

To develop a custom fuel model, ground-based surveys were conducted to collect plant species composition, structure, and herbaceous plant biomass (fine fuels) for 446 20-meter × 50-meter vegetation plots between 2012 and 2015. These data were coupled with seasonal WorldView-3 imagery (2015) and Landsat 8 imagery (2014, 2015) from September (peak green) and November (senesced/dormant vegetation) in Random Forest (RF) and regression tree classifications to develop inputs needed for fuel models, including a plant life-form–based land cover map; fine fuels biomass (kilograms per hectare); and percent tree, woody, herbaceous, and bare-ground cover. Finally, the custom fuel model was created using the derived geospatial products in a multiple-criteria evaluation, which assigns fire characteristics to a specific fuel type as part of the 40 Scott and Burgan Fire Behavior Fuel Model types.

Researchers developed a comparison of fire risk using LANDFIRE 2014 fuel models and the derived 2015 custom fuel model for 20 random ignitions throughout the refuge. The custom-derived 2015 model predicts a more continuous fuel bed

with higher biomass leading to a much higher risk of fire spread and hazard with 1,766 hectares burning versus 61 hectares ($p<.001$). Fuel intensity was also higher using the 2015 custom fuel model. After a comparison of predicted fire intensity to fire severity classes for six fires occurring on the refuge in the last ten years, the magnitude of severity of burn for the custom-derived 2015 fuel model more closely matched what is detected in the normalized burn ratio of prefire and postfire imagery. Fire behavior estimated from custom-derived models also better represented conventional knowledge of fire activity on the refuge during 90th percentile fire weather conditions. Wildfires commonly burn between several hundred to a few thousand hectares during May and July each year. This indicates that the FWS custom model provides a more accurate estimate for semidesert fuel types and can be used by fire managers to more strategically target fuel reduction efforts to help mitigate hazardous conditions.

Improving Models of Animal Density Using Land-Surface Phenology and Cluster Data

Models of animal density commonly use coarse land-cover categories that homogenize vegetation attributes, thereby limiting specificity of results. Alternatively, models including land-surface phenology (LSP) metrics derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery capture continuous data describing plant growth and senescence. LSP metrics may better discriminate between the vegetation conditions influencing species habitat and distribution. Additionally, applications modeling animal density often use clusters (i.e., groups of individuals) but omit differences in cluster sizes. Ignoring how cluster size varies with landscape characteristics risks misrepresenting the spatial distribution of a species's density.

Using lesser prairie-chickens (LEPC; *Tympanuchus pallidicinctus*) as an example, FWS researchers integrated the spatial distributions of cluster density and cluster size with LSP metrics to better predict their density in Texas. The team modeled LEPC cluster density using hierarchical distance sampling and cluster size with zero-truncated generalized linear modeling. Variables included land-cover categories, LSP metrics, human infrastructure, and topography. Models incorporating

LSP metrics received the most support and identified conservation areas that land-cover models missed in the northern portion of the Texas Panhandle. Cluster density correlated with LSP metrics, road density, oil and gas well density, topography, and grassland-to-shrubland ratio. Cluster size correlated with topography and LSP metrics. Omitting the spatial distribution of cluster size underestimated LEPC density.

This approach generates geospatial predictions for prioritizing LEPC protection and habitat restoration and evaluating impacts from development or phenological change. This study demonstrates the utility of integrating LSP metrics, cluster density, and cluster size for predicting species density across large and heterogeneous landscapes, and the results have been accepted for publication in the journal *Remote Sensing of Environment*.

Water Dynamics at the Bear River Migratory Bird Refuge

The Bear River Migratory Bird Refuge, located west of Brigham City, Utah, where the Bear River terminates into the Great Salt Lake, is a critically important feeding, resting, and breeding area for many species of migratory water birds. Established by Congress in 1928 to help conserve and protect the once vast, productive marshes on the Bear River delta, the refuge today faces many challenges, including excess nutrients and sedimentation, invasive plants, and altered hydrology. Refuge staff members are currently drafting a habitat management plan that will provide management direction into the future.

To support ongoing planning efforts, understanding past hydrologic characteristics and patterns (i.e., when water is present on the landscape and how it is managed) is important, especially on a deltaic system such as Bear River. To better understand past water management, FWS scientists used the long-term Landsat archive to search for appropriate images that document the extent of water in spring (early to mid-May) and summer (August) for the 26-year time period 1990 through 2016. While usable Landsat 5 data existed back to 1984, the refuge was completely submerged from 1984 to 1988, when the Great Salt Lake reached record levels before receding to more normal elevations. (Note: 2012 was not included due to lack of suitable Landsat 7 images during the time periods of interest.)

Images were located using the U.S. Geological Survey (USGS) LandsatLook Viewer Web application. Upon review, suitable images were downloaded and areas of open water were extracted using band-specific criteria within ArcMap software. Individual raster grids by year showing areas of open water were combined into one composite image for spring and summer showing water availability. Various map products and summary statistics were compiled to help refuge staff better visualize which areas within the refuge (and surrounding landscape) are consistently wet (or dry) over this time period. Water frequency is one component of hydrology being correlated with measures of wetland productivity and use by water birds. In addition, water frequency data are also being used to understand ecological drivers directly related to the extent and spread of invasive plants (principally *Phragmites australis*) on the refuge. By understanding these relationships, refuge staff members are better positioned to make informed decisions now and into the future.

Waterfowl and Shorebird Habitat on Agricultural Lands

The western U.S. Gulf of Mexico coast provides important habitat for migrating waterfowl and shorebirds. The Gulf Coast Joint Venture (GCJV) uses bioenergetic models (i.e., models that incorporate species-specific population objectives, temporal residency, energy demand of birds, and foraging values of habitats) to translate fall-winter waterfowl population targets and summer-fall shorebird population targets into habitat objectives for this important region. These objectives are expected to represent landscape conditions needed to support desired population levels. GCJV scientists, in collaboration with geographers at the USGS Wetland and Aquatic Research Center, use remote sensing to conduct annual periodic assessments of waterfowl and shorebird habitat on flooded agricultural lands and moist-soil impoundments within the GCJV region. The assessments are conducted several times per year during important migration periods for each of these two bird guilds. Spectral indices derived from Landsat imagery, including the land-surface water index, the modified normalized water index, the enhanced normalized difference vegetation index, and the normalized difference built-up index, are used to classify bird habitats.

Assessments have been conducted for 2005 to the present and are used to help determine if regional habitat objectives are being met, while also providing insights into inter-annual and intra-annual variation in habitat. In addition, these data are used to assist with planning and assessment of conservation delivery practices. For example, the GCJV uses waterfowl habitat assessments to measure the contribution of the Texas Prairie Wetlands Project, a partnership that works with private landowners to restore, enhance, and create shallow-water wetlands, to the overall regional waterfowl habitat abundance.

National Park Service

The National Park Service (NPS) has a substantial 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 across the Nation. 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; a monumental task given that the agency has responsibility for over 30 million acres. These data are particularly critical for NPS activities in Alaska because of its remote and vast expanses of public land and the fact that the Arctic is warming rapidly in response to climate change. The NPS takes advantage of the free Landsat archive to quantify decadal changes in glacier ice cover and document land-cover change in national park units. NPS has been the DOI sponsoring agency to map all large wildland and prescribed fires as part of the DOI Monitoring Trends in Burn Severity project, using the Landsat archive. GPS supports field data collection, navigation, and search-and-rescue operations conducted by the agency.

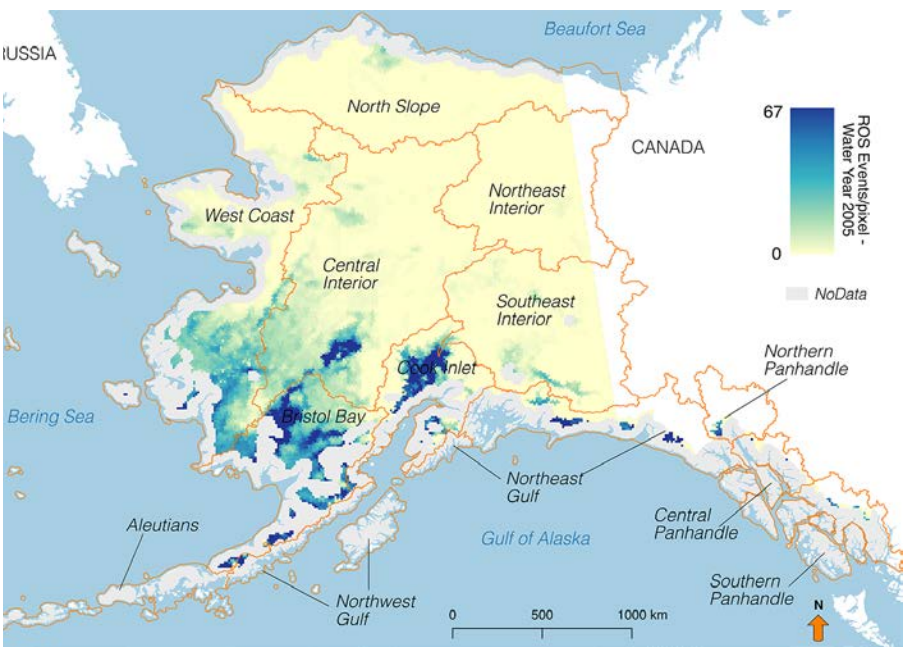
Detecting Snow Wetness and Icing

Snow wetness and icing can affect ecosystem processes at multiple spatial and temporal scales including hydrology, carbon cycling, wildlife movement, and human transportation. Snow wetness occurs when the cold content of part or all of the snowpack is less than the positive energy fluxes from radiative, sensible, or

latent heat transfer. Icing events normally occur daily in the spring and summer and less predictably following wintertime rain on snow or warm weather. In the future, the frequency and extent of wet snow followed by icing events is predicted to increase, particularly in the high latitudes, due to the effects of amplified temperatures on rain-to-snow transition gradients.

Snowmelt and icing processes result in marked changes to snowpack processes, such as snowmelt, surface albedo, and energy balance. Changes in the surface structure of the snowpack are visible using optical remote sensing, and changes in the relative content and distribution of water, air, and ice in the snowpack are detectable using passive microwave remote sensing. This project aims to develop products showing the spatial and temporal distribution of snow wetness and icing events using satellite data products derived from both optical and passive microwave satellite records.

To detect snow wetness and icing, NPS researchers used brightness temperature measurements derived from vertical and horizontal polarizations at 19 and 37 gigahertz from the Advanced Microwave Scanning Radiometer (AMSR-E and



The southwestern and south-central regions of Alaska show the greatest occurrence of rain on snow events for the 2005 water year (October 1, 2004–September 30, 2005).

AMSR-E 2) passive microwave satellites, which are downscaled to 6 kilometers. Unlike optical measurements, passive microwave retrievals are not susceptible to cloud cover or the polar darkness of high-latitude winters and can produce daily measurements of snow properties. Combining these products with finer-resolution optical snow-cover data will provide a more complete picture of snow processes in Alaska and may allow us to address important management questions regarding wildlife mortality and regional transportation.

Forest Structure Patterns Across Crater Lake National Park from Lidar Data

In 2010, a team of researchers at the University of Washington worked with the NPS to analyze the canopy structure across Crater Lake National Park using lidar data. The data were used to identify individual trees, and the results were classified into openings (no canopy cover greater than two meters) and clumps of trees in the height ranges of 2–8, 8–16, 16–32, and greater than 32 meters. These strata were further used to identify and map canopy structural classes across the park, and the distribution of these classes was compared with patterns of climate and topography.

The results show that stands are most complex in terms of the number of openings, tree clumps, and tree cluster peaks when the area in openings is approximately 20–40 percent. Stands were least complex when openings were less than ten percent or greater than 50 percent of the area. None of the structure classes were uniquely associated with any particular forest zone. Conversely, all forest zones had mixtures of structure classes, with one to three structure classes typically dominant. The lower and more mesic zones (mesic low, mesic mid, and Sierra Mixed) were dominated by the tall structure classes (11, 12 in the figure) with significant proportions of their area in the mid-height class (21).

Forest zones that represent harsher climate extremes (subalpine, lodgepole pine, ponderosa pine, and East Cascades Mixed) were dominated by mixtures of the mid to shorter height and more open structure classes (31, 32, 41, 42, 51 in the figure). Only the mesic high forest zone included substantial area across a wide range of structure classes, which may represent its large area that includes a wider range of ecotones than the other forest zones. Monitoring these stands allows for a better understanding of how climate impacts forest community structure at Crater Lake.

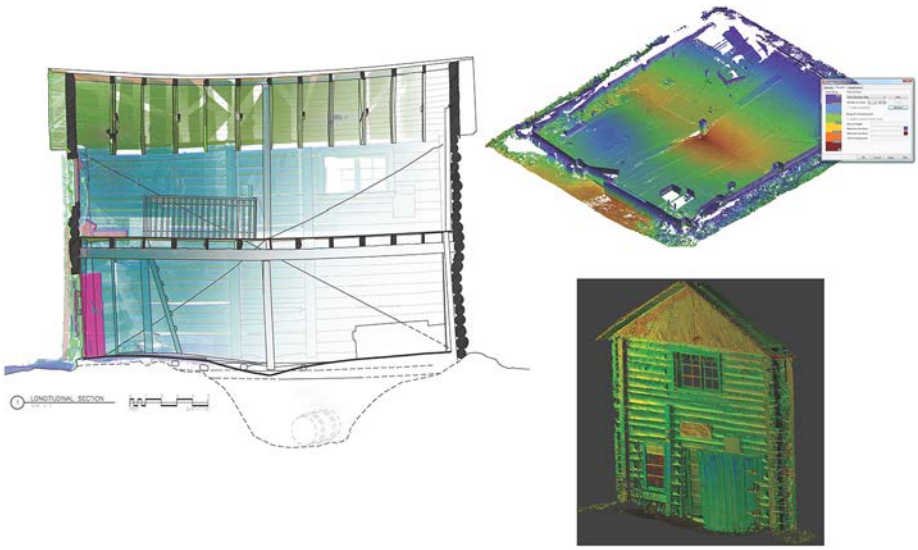
Historic American Buildings Survey Documentation of Historic Kantishna Roadhouse at Denali National Park

In spring 2017, Denali National Park consulted with the Alaska Regional Office (AKRO) to develop a project for the documentation of the aging Kantishna Roadhouse, a building located near the end of the Denali Park Road in Denali National Park. The goal of the project was to obtain measurements using a terrestrial laser scanner in order to facilitate the production of Historic American Buildings Survey (HABS) drawings that capture the existing condition of the structure. The Kantishna Roadhouse is considered eligible as a contributing structure to the Old Eureka/Kantishna Historic District.

High-definition laser scanning was conducted on the interior and exterior of the two-story log structure, which measures approximately 26 by 22 feet. Weather reports of inbound snowfall resulted in compressing available field time to one day. The speed of the terrestrial laser scanner (a Trimble TX8) allowed for one surveyor to acquire 16 scan positions, utilizing a combination of spherical and paper targets to facilitate registration.

Structural deficiencies due to deteriorating wall logs and a settling foundation are visible to the naked eye when on-site, but larger trends become visible in the processed point cloud dataset. The section shows the general slope of the building to the west (left) and the resulting failure in some structural members. Using different classification and visualization tools, the point cloud can be cleaned and cropped to isolate specific areas of interest, such as the deflection in the floor, or severity of deterioration for individual logs.

A set of architectural line drawings will be produced from the dataset and sent to the Library of Congress for inclusion in the HABS/Historic American Engineering Record (HAER)/Historic American Landscapes Survey (HALS) Collection of the Prints and Photographs Division. These collections document achievements in architecture, engineering, and landscape design in the United States and its territories through a comprehensive range of building types, engineering technologies, and landscapes. The collection can be found at *https://www.loc.gov/collections/historic-american-buildings-landscapes-and-engineering-records/*. Preserving and documenting the Kantishna Roadhouse as a noteworthy structure of the Eureka/

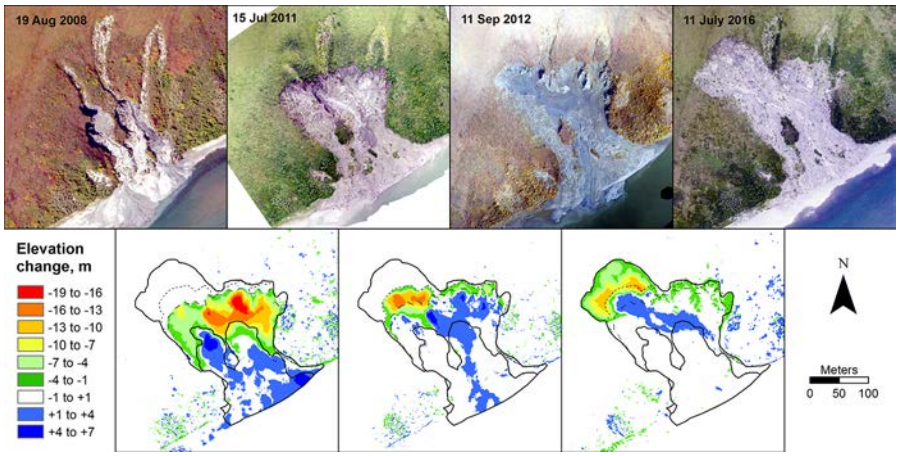


Shown above are (clockwise from left) a longitudinal section through point cloud with an overlay of the line drawing, point cloud isolating the ground floor and its deflection using a colorized elevation ramp, and point cloud showing the west elevation of the Kantishna Roadhouse.

Kantishna Historic District will offer historic insight for Denali National Park long after the building is gone.

Monitoring Permafrost Thaw Slumps

The NPS Arctic Inventory and Monitoring Network (ARCN) is using 35-millimeter aerial photography to monitor the growth of permafrost thaw slumps in the five national parks of northern Alaska. These slumps can grow for a decade or longer and shed large amounts of sediment into nearby rivers and lakes. ARCN scientists have obtained overlapping, oblique, and vertical digital aerial photographs of 15 slumps taken from a helicopter or fixed-wing aircraft between 2008 and 2016. Each slump is represented by between four and seven photographs captured on an annual basis. These photographs were analyzed with structure-from-motion software to produce digital elevation models and orthophotographs of the slumps. Between 2013 and 2016, ARCN researchers obtained accurate camera coordinates that allowed georeferencing of the digital models. These coordinates help to analyze slump growth metrics, such as rates of scarp migration, subsidence, volume loss in relation to weather, and slump morphology. Comparison of 3D



The upper row shows orthophotographs of a slump on the Noatak River in northern Alaska (latitude 67.957°, longitude 161.085°) from four different years. The lower row shows elevation change maps between the photograph dates.

models between years has revealed subsidence of nearly 20 meters and long-term scarp retreat rates of up to 30 meters per year on some slumps. For more information, see *http://science.nature.nps.gov/im/units/arcn/vitalsign.cfm?vsid=9*.

Bureau of Land Management

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

Dam Breach Monitoring

The BLM National Operations Center (NOC) has partnered with the BLM Arizona State Office and the Safford Field Office to document and measure the

The graphics shown here identify imagery acquired at different periods over the HX Dam. Figures A and B are WorldView-2 and -3 high-resolution multispectral imagery collected prior to and after the original dam failure, in 2014 and 2015, respectively. Figure C is WorldView-1 panchromatic imagery acquired in June 2016, following additional structural damages due to flooding. Figure D is WorldView-3 high-resolution multispectral imagery acquired in November 2016, during dam-breach remediation efforts.

impacts of the HX Dam failure, which occurred in June 2014. This is a multi-year effort, which has comprised the use of both Unmanned Aerial Systems (UAS) and spaceborne imaging systems. Original efforts focused on the use of UAS and WorldView imaging systems for the identification of structural impacts and environmental effects following the earthen dam's failure. Sentinel-2, WorldView-1, and WorldView-3 imagery was employed to detect increased structural damage to the dam and sediment flow due to heavy rainfall in late 2016. These images were also used to monitor subsequent dam-breach remediation efforts on the ground. This project has demonstrated the value and importance of leveraging multitemporal imagery for resource monitoring and management.

Indian Sunset Mine Verification Pilot

The BLM NOC regularly assists field offices with photogrammetric and remote sensing projects involving UAS in a variety of natural-resource management applications. The NOC is currently providing subject matter expertise to the Royal Gorge Field Office (RGFO) in Cañon City, Colorado, as part of an ongoing pilot

project leveraging the use of multi-scale remotely sensed data for mine production verification (PV). The current PV model is labor-intensive, includes extensive field work, and is cost-prohibitive, which results in a less-than-optimal number of mine operations being verified. Working in conjunction with the NOC, the RGFO purchased high-resolution imagery of the Indian Sunset Mine site near Westcliffe, Colorado, from Leptron Unmanned Aircraft Services, LLC. The imagery captured the mine site areas of interest undergoing mineral extraction, as well as the product piles of aggregate material to be verified. NOC personnel then applied a rigorous photogrammetric workflow to measure both the volume of material removed from the site and the volume of the product piles. PV monitoring using UAS provides comparable results to ground-based surveys, saving time and money.

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 data, multispectral aerial imagery, and sonar data are used to generate maps of topography, vegetation, and river channel bathymetry, which guide restoration activities.

Estimates of Evapotranspiration and Evaporation

The Colorado River is the principal source of water for agriculture and riparian vegetation in Arizona, southern California, and southern Nevada. To account for water use by each state or individual and to verify lands fallowed for conservation programs and other water management needs, the BOR routinely monitors more than 3.5 million acres of agriculture and riparian vegetation along the Lower Colorado River, from Hoover Dam south to the international border with Mexico. Multispectral satellite and aerial images are analyzed in combination with other spatial data in a Geographic Information Systems (GIS) environment to generate information regarding crop and riparian types, acreages, and water-use estimates.

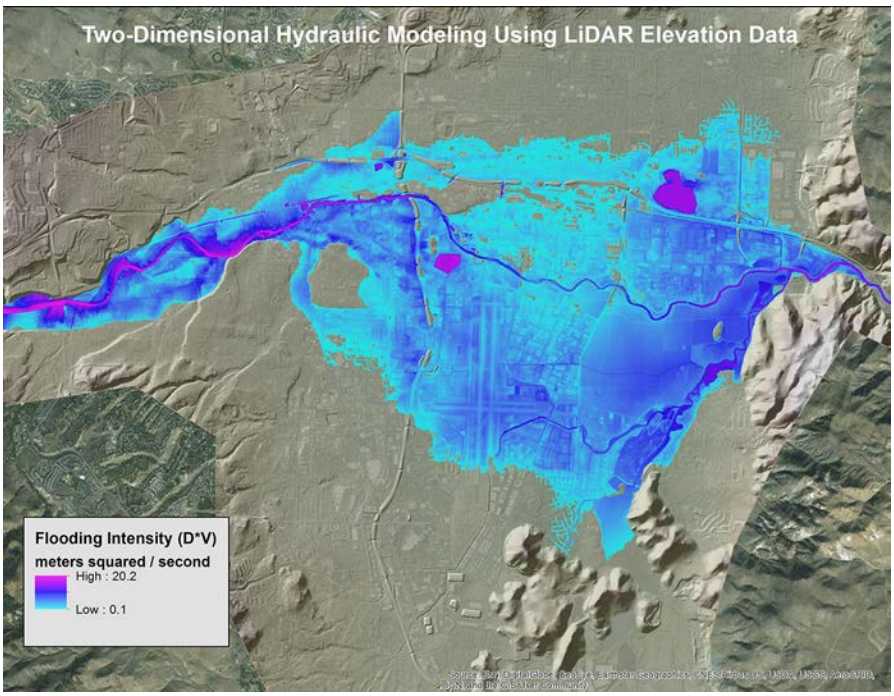
The BOR completed a major update to the riparian vegetation database utilizing high-resolution multispectral National Agriculture Imagery Program (NAIP) imagery and an object-oriented-based classification scheme resulting in revised vegetation types and crown closure.

These data and information assist 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. This program is an example of implementing remote sensing–based methodologies to routinely meet the BOR's water management needs. For more information, visit *http://www.usbr.gov/lc/region/g4000/wtracct.html*.

Hydraulic Modeling for Dam Safety and Emergency Management Applications

The BOR uses lidar and other remote sensing–based elevation data as a basis for hydraulic modeling of dam failure and operational release flood flows. This work involves the implementation of both one-dimensional and two-dimensional hydraulic models and relies heavily on an interfacing with Esri's ArcGIS software. Hydraulic modeling employs the use of the Danish Hydraulic Institute's MIKE models. Applications of this technology include emergency management and dam safety risk analysis.

The graphic shows potential flooding modeled in an urbanized area due to uncontrolled dam releases. The two-dimensional hydraulic modeling is based on lidar terrain data obtained from the local municipality via a cost-sharing program, which substantially reduces data acquisition costs. Flood flows are presented in a raster format that depicts maximum flooding intensity represented as the product of maximum depth and velocity (DV).



This image shows flooding in an urbanized area due to uncontrolled dam releases.

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 activities in FY 2017 related primarily to commercial communications satellites and Earth observation satellites, as well as experimental satellites.

The FCC took a number of significant actions in rulemaking proceedings in FY 2017. Several of these actions related to nongeostationary satellite systems designed for communications in the fixed-satellite service, including in some cases to provide broadband Internet access. On September 26, 2017, the FCC modified the rules applicable to these systems. Among the major changes are the following:

- Modifying the FCC's frequency allocations in the Ka-band to allow additional commercial fixed-satellite service operations.
- Adopting technical limits for nongeostationary satellite systems to enable the sharing of radio frequencies with terrestrial stations and geostationary satellite systems.
- Revising rules that apply to the sharing of spectrum among nongeostationary satellite systems.
- Modifying FCC rules to reduce the percentage of total satellites in a system that must be constructed, launched, and deployed within a specific number of years.

- Eliminating international coverage requirements for nongeostationary fixed-satellite service systems to allow for more flexibility in the design of satellite systems.

On April 21, 2017, the FCC adopted rules to limit radio-frequency interference into the 17/24-gigahertz Broadcasting Satellite Service, which can provide video and other services to consumers. On May 19, 2017, the FCC proposed to update the rules applicable to earth stations in motion (ESIMS), which are earth stations located aboard ships, aircraft, and vehicles. Under the proposal, additional frequency bands would be made available for use by these types of earth stations.

The FCC acted in FY 2017 to facilitate the development of new communication services:

- On December 22, 2016, the FCC adopted rule changes that would allow GlobalStar, Inc., to operate a low-power, terrestrial-based network using the radio-frequency spectrum licensed to it for mobile satellite service in the 2.4-gigahertz frequency range. The FCC subsequently modified Globalstar's licenses to allow implementation of the terrestrial network.
- On January 18, 2017, the FCC authorized Higher Ground LLC to operate terminals embedded in smartphones, which will communicate with several geostationary satellites. These terminals are designed to provide consumer-based text messaging and other communications and to operate in the C-band.
- On June 22, 2017, the Commission issued a ruling outlining the conditions under which WorldVu Satellites Limited (doing business as OneWeb) can obtain a license for earth stations in the United States for use with its nongeostationary satellite system, which will operate under the authority of the United Kingdom. The system will consist of up to 720 satellites, operating at an approximate altitude of 1,200 kilometers and utilizing frequencies in the Ku- and Ka-bands. This large constellation of nongeostationary satellites is designed to provide high-speed broadband connectivity across the United States and throughout the world.

In FY 2017, the FCC authorized a number of commercial communication satellite deployments and operations. These authorizations included the following:

- **October 5, 2016:** To Intelsat License LLC, to construct, deploy, and operate a C- and Ku-band satellite to be located at the longitude 34.5° west orbit location.
- **December 7, 2016:** To SES Americom, Inc., to construct, deploy, and operate a Ku- and Ka-band satellite to be located at the longitude 104.95° west orbit location. The portion of the satellite operating in the C-band was authorized separately and will operate under the authority of the United Kingdom (Gibraltar).
- **June 8, 2017:** To Intelsat License LLC, to construct, deploy, and operate a C-, Ku-, and Ka-band satellite to be located at the longitude 18° west orbit location.

During FY 2017, the FCC granted authority to Spire Global, Inc., and Terra Bella Technologies Inc. to deploy and operate nongeostationary small satellites in low-Earth orbit, primarily for remote sensing activities. Specifically:

- **October 14, 2016:** To Spire Global, Inc., for up to 28 satellites to be deployed at orbital altitudes at or below 650 kilometers.
- **April 7, 2017:** To Spire Global, Inc., for an additional four satellites to be deployed at orbital altitudes at or below 500 kilometers.
- **May 18, 2017:** To Spire Global, Inc., for an additional 24 satellites to be deployed at orbital altitudes at or below 600 kilometers.
- **June 28, 2017:** To Terra Bella Technologies Inc., for up to six satellites to be deployed at orbital altitudes between 400 kilometers and 630 kilometers.
- **July 13, 2017:** To Spire Global, Inc., for an additional 72 satellites to be deployed at orbital altitudes at or below 600 kilometers.

In addition to these commercial operations, the FCC continued to grant applications for experimental operations by nongovernmental small satellites. Many of the experimental grants by the FCC for small-satellite operations were to universities and institutions conducting research and developing new spacecraft technologies. The satellites' missions included testing new equipment, including spacecraft propulsion technologies, for use on satellites, as well as measuring the orbital debris

environment, observing space weather and taking atmospheric measurements, demonstrating communications, and developing CubeSat positioning capabilities. Other experimental licenses granted in FY 2017 included grants to test prototype telecommunications satellites and a grant to Iridium Satellite LLC for testing of mobile earth terminals for the global maritime distress and safety service.

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 25, 2016:** The FCC granted special temporary authority to Spaceflight, Inc., to communicate for 12 hours or less with a nongeostationary spacecraft deployer known as SHERPA. The grant was revised and reissued on December 7, 2016, to reflect changes in the planned operations. The mission was subsequently cancelled.
- **April 25, 2017:** The FCC granted special temporary authority to EchoStar Satellite Operating Corporation for 30 days for its EchoStar 8 satellite to operate outside of its previously assigned longitude 77° west orbital location due to a satellite anomaly.
- **April 27, 2017:** The FCC granted special temporary authority to EchoStar Satellite Operating Corporation for 30 days to move its EchoStar 8 satellite to a disposal orbit.
- **June 19, 2017:** The FCC granted special temporary authority to SES Americom, Inc., for 30 days for its AMC-9 space station to operate outside of its previously assigned longitude 83° west orbital location due to a satellite anomaly. The FCC extended this grant of special temporary authority on July 20, 2017; August 23, 2017; and September 20, 2017.
- **June 22, 2017:** The FCC granted special temporary authority to RBC Signals LLC for 60 days for its earth station located in Deadhorse, Alaska, to communicate with the Red Diamond, Green Diamond, and Blue Diamond small nongeostationary satellites operating under the authority of the United Kingdom. On September 11, 2017, the FCC extended this grant of special temporary authority for 180 days.

The FCC also added non-U.S.-licensed space stations to its permitted list to allow these space stations to provide domestic and international satellite service to U.S. earth stations that have routine technical parameters.

- **December 7, 2016:** The FCC added SES Satellites (Gibraltar) Ltd.'s planned SES-11 satellite to the permitted list, operating under the authority of the United Kingdom (Gibraltar) and using the C-band at the longitude 104.95° west orbit location. This satellite will also operate in the Ku- and Ka-bands under the United States license granted to SES Americom, Inc., on the same date.
- **February 9, 2017:** The FCC added SES DTH do Brasil Ltda's planned SES-14 satellite to the permitted list, operating under the authority of the Netherlands and Brazil and using the C- and Ku-bands at the longitude 47.5° west orbit location.
- **April 6, 2017:** The FCC added HISPASAT, S.A.'s planned HISPASAT 30W-6 satellite to the permitted list, operating under the authority of Spain and using the C- and Ku-bands at the longitude 30° west orbit location.
- **April 25, 2017:** The FCC added ABS Global, Ltd.'s ABS-3A satellite to the permitted list, operating under the authority of the Russian Federation/Intersputnik and Papua New Guinea and using the C- and Ku-bands at the longitude 3° west orbit location.

In addition, the FCC took action on the following requests for non-U.S.-licensed space stations to provide service in the United States on a nonroutine basis:

- **October 5, 2016:** The FCC granted the application of ViaSat, Inc., to access the United States market using its planned VIASAT-79W satellite, operating under the authority of the United Kingdom and using the Ka-band at the longitude 79° west orbit location.
- **October 5, 2016:** The FCC granted the application of ViaSat, Inc., to access the United States market using its planned VIASAT-133W satellite, operating under the authority of the United Kingdom and using the Ka-band at the longitude 132.9° west orbit location. ViaSat, Inc., subsequently declined that grant at the deadline for submitting a required performance bond.

- **October 5, 2016:** The FCC granted the application of Spectrum Five LLC to access the United States market using its planned BSSNET2A-111W satellite, operating under the authority of the Netherlands in the 17/24-gigahertz Broadcasting Satellite Service at the longitude 110.9° west orbit location. Spectrum Five LLC subsequently declined that grant at the extended deadline for submitting a required performance bond.
- **October 5, 2016:** The FCC granted the application of Spectrum Five LLC to access the United States market using its planned BSSNET2A-115W satellite, operating under the authority of the Netherlands in the 17/24-gigahertz Broadcasting Satellite Service at the longitude 115° west orbit location. Spectrum Five LLC subsequently declined that grant at the extended deadline for submitting a required performance bond.
- **October 25, 2016:** The FCC granted the application of ViaSat, Inc., to access the United States market using its planned VIASAT-109W satellite, operating under the authority of the United Kingdom and using the Ka-band at the longitude 109.1° west orbit location.
- **December 14, 2016:** The FCC granted the request of SES Satellites (Gibraltar) Ltd. for a modification of its grant of market access to the United States using its planned SES-15 satellite, to add operations in the L-band at the longitude 129.15° west orbit location. SES-15's operations in the L-band will provide support to the Federal Aviation Administration's Wide Area Augmentation System for air navigation.
- **March 2, 2017:** The FCC granted the application of Spectrum Five LLC to access the United States market using its planned BSSNET2A-95W satellite, operating under the authority of the Netherlands in the 17/24-gigahertz Broadcasting Satellite Service at the longitude 95.15° west orbit location. Spectrum Five LLC subsequently declined that grant at the deadline for submitting a required performance bond.
- **July 6, 2017:** The FCC granted the application of ViaSat, Inc., to access the United States market using its planned VIASAT-RDBS2 satellite, operating under the authority of the Netherlands in the 17/24-gigahertz Broadcasting Satellite Service at the longitude 110.9° west orbit location.

ViaSat, Inc., subsequently declined that grant at the deadline for submitting a required performance bond.

- **July 6, 2017:** The FCC granted the application of ViaSat, Inc., to access the United States market using its planned VIASAT-RDBS1 satellite, operating under the authority of the Netherlands in the 17/24-gigahertz Broadcasting Satellite Service at the longitude 115° west orbit location. ViaSat, Inc., subsequently declined that grant at the deadline for submitting a required performance bond.
- **July 13, 2017:** The FCC granted the application of Spectrum Five LLC to access the United States market using its planned BSSNET2A-95W satellite, operating under the authority of the Netherlands in the 17/24-gigahertz Broadcasting Satellite Service at the longitude 95.15° west orbit location. Spectrum Five LLC again subsequently declined that grant at the deadline for submitting a required performance bond.
- **September 7, 2017:** The FCC granted the request of SES DTH do Brasil Ltda for a modification to its grant of market access to the United States to include data transmissions from the NASA-commissioned Global-Scale Observations of the Limb and Disk instrument that will conduct imaging of Earth's atmosphere from the planned SES-14 satellite at the longitude 47.5° west orbit location.

U.S. Department of Agriculture

USDA

Agencies within the U.S. Department of Agriculture (USDA) utilize a diverse set of remote sensing and related technology to support their missions, ranging from ground-based data collection validated with GPS to global crop assessments using medium-resolution satellite imagery. Specifications in USDA image acquisition contracts, including the National Agriculture Imagery Program (NAIP), continued to result in heavy reliance on piloted aircraft–based imagery collection.

Farm Service Agency

The Farm Service Agency (FSA) administers farm commodity, credit, conservation, disaster, and loan programs as laid out by Congress through a network of Federal, state, and county offices. Land-based information has always played a fundamental role in daily operations and administration of those programs. FSA's core geospatial dataset, the Common Land Unit (CLU), is a dynamically updated, nationally consistent digital dataset representing farm and field boundaries. This dataset is integrated with nongeospatial data in a common enterprise system. FSA uses geospatial data, including the CLU, to record producer-reported crop plantings and to support conservation-, commodity-, and agriculture-based lending programs.

Using FSA's public-facing application, FSAfarm+, producers had Web access to their stored FSA data, such as the CLU data, related farm data, and other producer information, associated with their operations. Other producer information would include address, contact information, and participation demographics. This

functionality allowed producers to view, export, and print maps and farm records data from their home through a public-facing Web portal. It also provided the opportunity for producers to electronically export their farm CLU field boundaries and share them with other agencies or crop insurance companies and other third parties that offer assistance with precision agriculture-related activities.

FSA administers a number of disaster recovery programs, including Emergency Loan and Emergency Conservation Programs. Remotely sensed data, such as Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Wide Field Sensor (AWiFS), and other high-resolution aerial and satellite imagery collected as a result of interagency coordination, are examples of imagery sources used as assessment tools to help oversee these programs.

FSA continued to manage NAIP, the largest aerial acquisition program in the civilian part of the Federal Government and a primary source of imagery for the USDA. The program leverages partnership funds from other Federal entities to acquire imagery during the growing season over the contiguous United States. In 2017, NAIP acquired over 1.7 million square miles of four-band (natural-color and near-infrared) imagery in 26 states at a cost of $16.3 million. Data from 24 states were acquired at 1-meter resolution, and data from two states were acquired with a partner "buy-up option" at 60-centimeter resolution. 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.

FSA has acquired imagery for agricultural purposes since the late 1930s. To more effectively maintain this historical archive, FSA began a historical scanning project in 2013. The project has six operators using 13 DSW700 photogrammetric long-roll film scanners. At the end of FY 2017, the agency had digitally scanned almost two million historical images.

Foreign Agriculture Service

The Foreign Agricultural Service's (FAS) Office of Global Analysis (FAS/OGA) serves as a major source of objective and reliable global agricultural production information to the USDA's monthly World Agricultural Supply and Demand

Estimates (WASDE) report, the primary source of the USDA's global commodity outlook. The monthly WASDE report provides public access to information affecting world food security and is crucial to decisions affecting U.S. agriculture, trade policy, and food aid. FAS/OGA uses satellite imagery at regional, national, and subnational scales to operationally monitor and analyze monthly changes in global crop production. FAS archives and displays global monthly crop production, supply, and distribution (PSD) data from the USDA's WASDE report on the FAS PSD Online Web site (*http://apps.fas.usda.gov/psdonline/psdhome.aspx*).

Over this past year, the International Production Assessment Division (IPAD) operated the remote sensing program at FAS/OGA. IPAD is an operational user of remotely sensed imagery and processed multiple U.S. and international sources of global imagery and satellite-derived weather information. Landsat 7 and Landsat 8 served as the primary satellites used by FAS/OGA/IPAD for mapping crop area and crop type for numerous countries worldwide, whereas NASA's MODIS sensor, on board the Aqua and Terra satellites, is used by IPAD to monitor crop conditions and relative crop yields. The USDA-NASA Global Agricultural Monitoring (GLAM) Web system displayed and archived historical MODIS-Terra (i.e., 2000–present) and MODIS-Aqua (i.e., 2002–present) imagery, and the GLAM Web interface easily allowed public users to analyze and compare current crop conditions with past years' crop conditions (*http://glam1.gsfc.nasa.gov/*). FAS plans to utilize the Visible Infrared Imaging Radiometer Suite (VIIRS) as a bridge to Earth Observing System (EOS) MODIS. FAS worked on processes to supplement Landsat imagery with Sentinel-2 imagery.

FAS/OGA also maintained several public global agricultural datasets by processing, archiving, and displaying on the Web a variety of satellite imagery products. The FAS/OGA Crop Explorer Web system allows the user to monitor, analyze, and display rainfall, temperature, soil moisture, and vegetation conditions by utilizing satellite imagery from NASA's Global Precipitation Measurement (GPM), NOAA's Polar-orbiting Operational Environmental Satellites (POES), ESA's Proba-V, and satellite-derived weather information from the U.S. Air Force's 557th Weather Wing. In addition, the Global Reservoir and Lake Monitor (G-REALM) monitored and displayed reservoir and lake water heights by utilizing satellite radar altimeter

data from NASA's Ocean Topography Experiment (TOPEX)/Poseidon, Jason-1, and Jason-2 satellites. For more information, see *https://ipad.fas.usda.gov/cropexplorer/*.

FAS/OGA is part of the early adopter program for Soil Moisture Active Passive (SMAP). FAS/OGA hopes to enhance the USDA's global crop production monitoring system using SMAP soil moisture products. As an operational user, FAS relies on the Agricultural Research Service (ARS) and NASA researchers to provide the process to ingest SMAP products and (hopefully) future products that will combine radar imagery with the SMAP passive radiometer.

FAS/OGA managed the USDA's Satellite Imagery Archive (SIA) program and displayed all moderate-resolution satellite imagery archived via SIA's Archive Explorer (AE). In 2000, the USDA's Remote Sensing Coordinating Committee (RSCC) established the SIA program, which is chaired by the USDA's Remote Sensing Advisor. During 2017, the USDA/FAS purchased satellite imagery with 22-meter spatial resolution from the Deimos-1 and UK-DMC2 satellites and archived it via SIA's AE. The USDA's National Agricultural Statistics Service used the Deimos-1 and UK-DMC2 satellite imagery covering the lower 48 U.S. states to map crop type for the 2017 United States crop season and to monitor crop damage caused by natural disasters such as drought, fires, diseases, or insects. FAS/OGA/SIA provided funding to USGS/EROS to process Indian Space Research Organisation (ISRO) AWiFS and LIS imagery. The ISRO imagery is now available for operational use through the USGS's EarthExplorer Web site, *https://earthexplorer.usgs.gov/*.

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 encompasses partnerships with states, tribes, and other Federal agencies to address forestry and natural resource issues; administration and management of 154 national forests and 20 national grasslands collectively known as National Forest System (NFS) lands, totaling 193 million acres; and 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.

In FY 2017, 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 accomplishments included the following:

- Collected comprehensive EOS, MODIS, and Suomi NPP VIIRS direct-broadcast data and Landsat 8 Operational Land Imager (OLI) data via the USGS's Earth Resources Observation Systems (EROS) for the United States and Canada. Provided operational processing and dissemination of near-real-time fire mapping and geospatial data products to fire managers and the general public, including all science-sanctioned fire-detection algorithms for MODIS (1 kilometer), VIIRS (750 meters and 375 meters) and Landsat (30 meters). (*https://fsapps.nwcg.gov/afm/*)
- 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, including land, atmospheric, and ocean science processing algorithms for EOS and Suomi NPP sensors, to support evolving resource management and operational information needs. (*https://fsapps.nwcg.gov/directreadout/*)
- Continued operational processing and analysis of MODIS and Landsat imagery for systematic detection of damage and changing health conditions in Federal, state, and private forested lands throughout the continental United States. Monitoring data products provide early warning information to Forest Health Protection staff about forest areas potentially affected by pests/pathogens and support targeted monitoring and suppression activities. Also initiated efforts to leverage operational VIIRS imagery for comprehensive forest monitoring and ensure future continuity with current MODIS-based monitoring approaches. (*http://foresthealth.fs.usda.gov/portal/Flex/FDM?dL=0*)
- Utilized MODIS imagery to conduct coarse-level forest damage assessments for large geographic areas of the continental United States and Puerto Rico in the immediate aftermath of several 2017 hurricane events

(Harvey, Irma, and Maria). This strategic information supports the agency in targeting areas for fuels management activities and/or areas where higher-resolution forest damage assessments are required.

- Continued to maintain and 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 maintain and 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 coordination with NASA Ames Research Center to upgrade Autonomous Modular Sensor (AMS) electronics and sensor components and further develop the AMS firmware and software for onboard processing system capabilities and user interface to support operational integration flights on USFS aircraft. Initiated an interagency agreement with NASA Ames to support continued work toward the goal of having AMS at an operational readiness status in CY 2018.
- Continued coordination with NASA Goddard Space Flight Center on testing and evaluation of the Multi-Angle Implementation of Atmospheric Correction (MAIAC) for MODIS and other MODIS and VIIRS science-processing algorithms to support low-latency land and atmospheric remote sensing applications.
- Operationally applied Landsat 7 Enhanced Thematic Mapper (ETM) and Landsat 8 OLI imagery to respond to 142 requests to map the location, extent, and severity of large wildfires amounting to more than 2.1 million acres in FY 2017. These rapid-response products support postfire emergency stabilization/hazard-mitigation activities conducted by Forest Service Burned Area Emergency Response (BAER) teams. (*http://www.fs.fed.us/eng/rsac/baer*)
- Operationally applied Landsat 7 ETM and Landsat 8 OLI imagery to respond to map and estimate postfire basal area loss and canopy cover loss for 147 large wildfires totaling nearly 2.1 million acres in FY 2017. These

products support forest restoration planning management activities and efficient use of resources to support those activities. (*http://www.fs.fed.us/postfirevegcondition*)

- Continued to operationally apply Landsat 4/5 Thematic Mapper (TM), Landsat 7 ETM and Landsat 8 OLI 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 2017 include the completion of 20,340 historical fires (about 155 million burned acres) spanning 1984 to 2015. (*http://www.mtbs.gov*)
- Coordinated with the University of Maryland, NASA, and the USGS under the auspices of a NASA Research Opportunities in Space and Earth Sciences (ROSES) A35 Wildfires Project to execute a Landsat 8 active fire detection algorithm, refine as needed, and provide output products to support USFS operational fire support activities.
- Continued technology transfer activities between the USFS and Ames Research Center regarding Unmanned Aircraft Systems (UAS) 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*). Effort also includes transfer and implementation of relevant NASA-developed technologies to support manned and unmanned airborne remote sensing activities in the USFS.
- Used imagery from Landsat 5 TM and from Landsat 8 OLI and NAIP to initiate, complete, and update mid-level vegetation-mapping products for national forest lands and adjacent land areas throughout the country.
- After successful completion of Tree Canopy Cover (TCC) data in FY 2016 for the continental United States, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands using imagery from Landsat 5 and Landsat 8 OLI and NAIP as part of the Multi-Resolution Land Characteristics (MRLC) Consortium National Land Cover Database (NLCD) 2011, initiated production on NLCD TCC 2016.

- Leveraged the Landsat TM/ETM/OLI time-series stacks, together with NAIP imagery and plot data, to detect, map, and monitor forest land-cover change from the mid-1980s to the present in the watersheds of the Great Lakes. Remote sensing analysts conducted activities using cloud remote sensing processing/analysis technologies and automated change-detection capabilities within the 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 in the northeast and western United States, which the USFS, Natural Resources Conservation Service (NRCS), and other agencies apply to resource management, planning, and decision making. (*http://www.fs.fed.us/eng/rsac/programs/teui/about.html*)
- Continued progression toward a comprehensive and consistent land-cover/land-use monitoring system, the Landscape Change Monitoring System (LCMS), for the continental United States. LCMS utilizes Landsat TM/ETM/OLI time-series stacks to detect and monitor land-cover/land-use change from the mid-1980s to the present across all administrative ownerships. This effort is being conducted in collaboration with several Federal and academic partners. (*http://larse.forestry.oregonstate.edu/lcms-landscape-change-monitoring-system* and *http://landsat.gsfc.nasa.gov/?p=10868*)
- Continued to develop and refine standards and practices for integrating light detection and ranging (lidar) into forest and resource management (e.g., defining acquisition specifications, assessing data quality, conducting analysis/modeling procedures for forest parameters, etc.). Continued to expand USFS involvement in the USGS 3D Elevation Program to ensure consistent acquisition specifications and to minimize redundant collections by partnering with other state and Federal entities on data acquisitions.

Use of Positioning, Navigation, and Timing Signals from Space

- The Forest Service utilizes signals broadcast from the GPS constellation of satellites to provide Positioning, Navigation, and Timing (PNT)

services that support the Forest Service mission "To sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations." The Forest Service actively supports the National Coordination Office for Positioning, Navigation and Timing, which provides interagency coordination, consensus development, and issue resolution in support of the GPS system.

Elevation Data

- The Forest Service participates in the USGS 3D Elevation Program (3DEP) to acquire high-quality 3D elevation data. (*https://nationalmap.gov/3DEP/*)
- Elevation data are essential to a broad range of applications, including design, implementation, and management of natural resources conservation practices; engineering; forest resources management; wildlife and habitat management; determination of highly erodible lands; flood risk management; resource assessment; water supply and quality; and other business uses.

National Agriculture Imagery Program

- The Forest Service is a cost-share partner in the National Agriculture Imagery Program (NAIP). NAIP collects orthoimagery during peak vegetation periods throughout the United States. NAIP has been supported by the Forest Service and other cost-share partners since the program's inception in 2003. NAIP orthoimagery is used extensively within the Forest Service for a variety of business needs. NAIP is collected on a two- to three-year cycle for the Contiguous United States (CONUS).

National Agricultural Statistics Service

The National Agricultural Statistics Service (NASS) used remote sensing data to construct and sample area frames for agricultural statistical surveys, to estimate

crop area and yield, and to provide geospatial data products for decision support for assessing the flooding from Hurricanes Harvey and Irma; NASS also continued contributing to a NASA science grant on a flood disaster–based crop loss assessment system. Additionally, NASS published papers describing the development of crop-specific area frame stratifications based on geospatial crop frequency and cultivation data layers, using a mobile mapping instrument to modernize field survey data collection and cost reduction–leveraging geospatial technologies, as well as the impact of pixel buffering on ground reference data for land-cover classification.

NASS used Landsat imagery, digital NAIP orthophoto quadrangles, and other remotely sensed inputs for the contiguous United States and Puerto Rico to select the yearly area-based samples for the June Agricultural Survey and the 2017 Census of Agriculture Survey. In addition, NASS is currently updating a new area-based sampling frame for Texas.

NASS continued to utilize a new geospatial Cropland Data Layer (CDL)–based automated stratification method for area-sampling frame operations, resulting in nine updated state area frames built at reduced cost with improved objectivity and efficiency, as well as a 29 percent improvement in 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), Landsat 8, Sentinel-2, and Resourcesat-2 imagery to produce crop acreage estimates for crops at the state and county levels during the 2017 crop year. Acreage estimates were created for all market-sensitive crops and states. 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. The primary satellite imagery inputs were from the Foreign Agricultural Service's Satellite Imagery Archive, which provided growing-season coverage with DMC imagery through a cooperative partnership while utilizing growing-season Landsat 8 imagery. In addition, NASS distributed the CDL for 48 states to stakeholders for the previous 2016 crop season via the USDA Geospatial Data Gateway and the CropScape data visualization portal at *https://nassgeodata.gmu.edu/CropScape*.

Geospatial decision-support products were provided for rapid-response assessments of flooding and potential crop losses following Hurricanes Harvey and Irma. The products included crop and pasture land inundated areas, estimated precipitation totals, CDL crop area maps, and wind swaths or surface winds overlaid onto crop areas identified from the CDL product in Texas, Louisiana, and Florida. A synthetic aperture radar satellite named Sentinel-1 was used to provide a see-through-the-clouds opportunity for the first time to capture real-time storm inundation over crop and pasture lands, providing flooding assessments and sharing critical data for both USDA and FEMA usage.

NASS utilized NASA MODIS Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) 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.

NASS is developing a Decision Support System called AgroClimate in collaboration with researchers from the University of Florida and the University of Nebraska to improve yield forecasts using crop indicators obtained during critical stages of the crop's growing season. A study is being conducted that focuses on the evaluation of the potential use of satellite data, crop simulation models, and/or mathematical models to develop critical crop indicators. Research objectives include 1) the determination of corn and soybean phenological critical stages; 2) how critical stages can be predicted or identified using remote sensing, mathematical models (i.e., crop simulation models), and/or a combination of these techniques; 3) how to retrieve and relate information about soil moisture, spectral reflectance, and other available products during critical stages; and 4) how to develop metrics at critical stages or critical crop indicators to improve corn and soybean yield forecasts.

The Web-based national vegetation condition geospatial portal VegScape (*https://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 monitoring the ongoing California

drought, providing monthly growing-season CDL-based fallowed land estimates for California water resource stakeholders.

NASS is continuing to collaborate with George Mason University, the USDA Risk Management Agency, and the University of Colorado in developing a remote sensing–based flood disaster crop loss assessment system from a NASA research grant titled "A Remote-Sensing-Based Flood Crop Loss Assessment Service System (RF-CLASS) for Supporting USDA Crop Statistics and Insurance Decision Making." The proposed system will provide the capability of flood disaster crop acreage loss and crop yield loss assessments using NASA remote sensing data and science results.

Natural Resources Conservation Service

NRCS helps America's farmers, ranchers, and forest landowners conserve the Nation's soil, water, air, and other natural resources. To fulfill this mission, NRCS assesses, acquires, develops, interprets, analyzes, and delivers natural-resource data and information to enable knowledge-based natural-resource planning and decision making at all landscape levels. Various types of geospatial systems, data, and information are crucial to the successful delivery of NRCS services.

Orthoimagery, elevation data, and Global Positioning Systems are essential geospatial data integrated into NRCS program applications, service centers, state offices, and national centers. Since the 1930s, NRCS (formerly the Soil Conservation Service) has used aerial photography and orthoimagery for conservation and soil survey purposes. Today, NRCS offices use geospatial data on a daily basis to support conservation programs.

NRCS coordinates acquisitions of orthoimagery and digital elevation data with other Federal and state agencies through interagency committees like the National Digital Orthoimagery Program (NDOP) and the National Digital Elevation Program (NDEP). Participation in NDOP and NDEP assists NRCS in maximizing geospatial investments and avoiding duplication of acquisitions for orthoimagery and digital elevation datasets.

Aerial Imagery

The Rural Development Act of 1972, Section 302, directed the Secretary of Agriculture to put in place a land inventory and monitoring program that would, among other things, study and survey damage from soil erosion and sedimentation; floodplain identification and use; land-use change; and potential environmental damages resulting from the misuse of soil, water, and related natural resources. This program, which became the National Resources Inventory (NRI), results in the publication of a land inventory report at not less than five-year intervals on the condition of the Nation's soil, water, and related natural resources. In FY 2017, NRCS used the USDA Small Area Aerial Photography Contract to acquire high-resolution aerial photography (4-inch ground-resolving distance) and scans of over 70,714 confidential statistical sites used to collect natural-resource data for the annual NRI program in CONUS. The NRCS also contracted for aerial photography over 472 NRI sites in Puerto Rico and the U.S. Virgin Islands and 346 sites in Hawaii. NRCS continues to use natural-color negative film for these collections. Despite the known advantages of direct digital imagery, film continues to be the least costly method to acquire imagery for the NRI. The scanned film imagery is georeferenced and interpreted at one of NRCS's three Remote Sensing Labs. The resulting data are sent to the Center for Survey Statistics and Methodology at Iowa State University for statistical analysis. For more information, see *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/*.

Through the Agricultural Conservation Easement Program (ACEP), NRCS holds title or enforcement rights to over 17,500 easements, providing protection to more than 3.4 million acres nationally. Annual monitoring of these easements is critical to ensuring that the objectives of each easement program are being met on the enrolled lands. Additionally, NRCS is required to report the condition of its easements as part of its annual financial accountability reporting. The NRCS uses high-resolution imagery to assist in the monitoring activities. In FY 2017, NRCS used the USDA Small Area Aerial Photography Contract to acquire imagery and monitor restoration efforts on each property enrolled. The collection was divided into 1) 24,679 high-resolution natural-color negative film aerial photos and 2) 582,161 acres of direct digital, 15-centimeter-resolution, four-band, orthorectified

imagery in Alabama, Arkansas, Illinois, Indiana, Kentucky, North Carolina, New Hampshire, Virginia, and West Virginia. For more information, see *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/.*

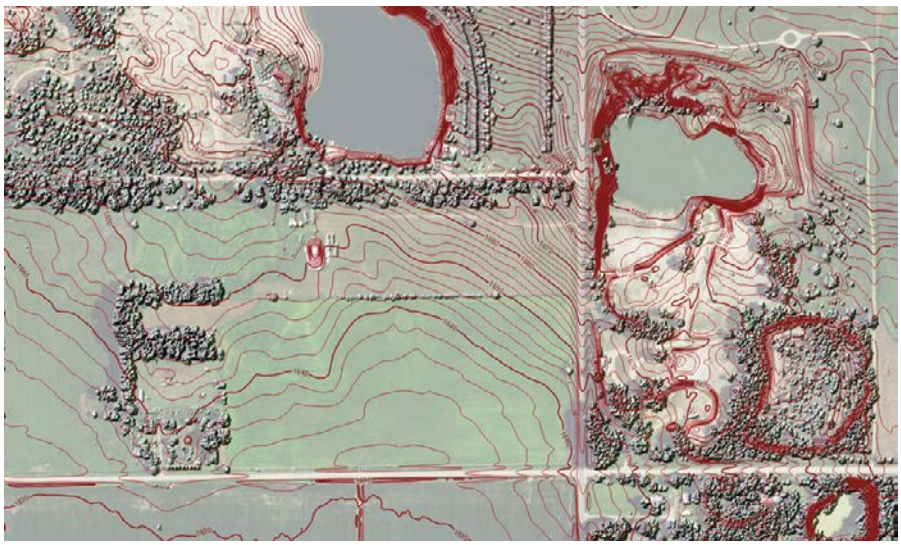
The NRCS is a cost-share partner in the National Agriculture Imagery Program (NAIP). NAIP collects orthoimagery during peak vegetation periods throughout the United States. NAIP has been supported by NRCS since the program's inception in 2003. NAIP orthoimagery is used extensively within NRCS. NAIP orthoimagery is delivered to NRCS at a one-meter or higher ground resolution and with four multispectral bands (Natural Color and Color Infrared [CIR]). NRCS makes use of NAIP in many programs, such as the Web Soil Survey (*https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm*) and Conservation Planning (*https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/*), and it makes the data available for download in the USDA Geospatial Data Gateway (*https://gdg.sc.egov.usda.gov/*). NAIP is collected on a two- to three-year cycle for CONUS. NAIP collects data from all areas of the United States, including agricultural land, public lands (Federal, state, and local) and urban areas.

Satellite Imagery

NRCS provides assistance in all 50 states and the U.S. territories, including Puerto Rico, the U.S. Virgin Islands, Guam, the Northern Mariana Islands, American Samoa, and Pacific island trusts. Acquisition of imagery in non-CONUS areas is challenging because of remoteness and weather. NRCS uses satellite imagery from the DigitalGlobe EnhancedView Web Hosting Service (*https://evwhs.digitalglobe.com*) and purchases imagery from commercial sources for areas such as these and over restricted airspace. DigitalGlobe imagery is also used for pre- and post-event disaster response and in cases were other imagery is outdated.

Elevation

NRCS has national requirements for high-quality elevation data, and the agency has a national strategy to acquire, integrate, and deliver high-quality digital elevation data that meets the agency's geospatial requirements. High-quality digital



This image shows custom contours and first-return raster elevation data from lidar over NAIP imagery in Madison County, Nebraska. (Source: USDA NRCS and USDA FSA)

elevation data support the agency's business activities by improving employee effectiveness and efficiency in providing assistance to our customers.

NRCS participates in the USGS 3D Elevation Program (3DEP) to acquire high-quality 3D elevation data. For more information, visit *https://nationalmap.gov/3DEP/*.

Elevation data are essential to a broad range of applications, including design, implementation, and management of natural resources conservation practices; agriculture; precision farming; engineering; forest resources management; wildlife and habitat management; determination of highly erodible lands; flood risk management; resource assessment; water supply and quality; and other business uses.

Use of Positioning, Navigation, and Timing Signals from Space

NRCS utilizes signals broadcast from the GPS constellation of satellites to provide Positioning, Navigation, and Timing (PNT) services that support the NRCS mission of "Helping People Help the Land."

Employees of NRCS, located in over 2,000 Field Service Centers across the country, performed the following activities while using GPS PNT services in FY 2017:

- NRCS technical specialists and contractors used GPS as an aid for collection of NRI information in 49 states on over 3,500 sample sites. Global

Positioning System receivers were used to navigate across varying landscape types to locate the sample sites. Accurate navigation to sample sites was essential for statistically valid data collection. Results of the data collection were analyzed and archived pending production of information products such as "Invasive Plant Species on Pasturelands" (*https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1303413.pdf*, November 2016) and "NRI Rangeland Resource Assessment" (*https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/rangepasture/range/?cid=stelprdb1068409*, June 2014).

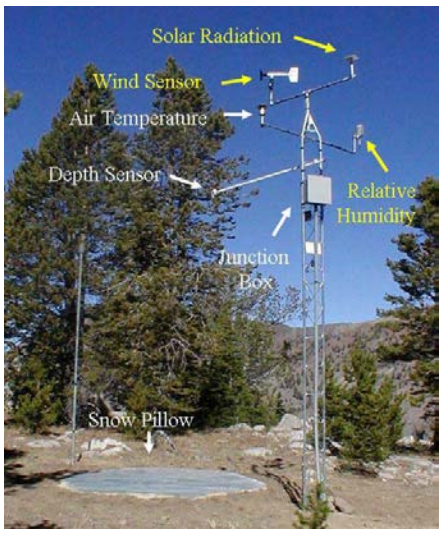
A team of NRCS employees collects data along a transect tape. GPS was used to navigate to the origin of the sample site. (Source: Courtesy of USDA NRCS)

- Iowa NRCS technical specialists used GPS to collect monitoring information for easements enrolled in the ACEP. The ACEP provides financial and technical assistance to help conserve agricultural lands and wetlands and their related benefits. Iowa NRCS employees visited 1,561 easements

Waterfowl land at an NRCS agricultural easement. (Source: Courtesy of USDA NRCS)

in FY 2017. Periodic on-ground monitoring was used to assess performance of the easements and to ensure that the easements conformed to the terms of easement contracts. Contract surveyors used survey-grade GPS equipment to establish boundaries of new agricultural easements.

- NRCS soil scientists used GPS to routinely navigate to soil sampling sites to conduct follow-up investigation and to provide soil survey technical services to farm and ranch operators.
- The NRCS Water and Climate Center utilized GPS to map locations of instrumentation and provide timing to telemetry signals. Coordination and delivery of data from 869 Snow Survey Telemetry (SNOTEL) and 219 Soil Climate (SCANS) stations require nanosecond precision that timing signals from GPS provide. The Water Climate Center also utilized the NOAA Geostationary Operational Environmental Satellite (GOES) network to provide telemetry services for remote monitoring sites.



Pictured is a typical SNOTEL monitoring station. (Source: Courtesy of USDA NRCS)

- A core NRCS activity, conservation planning, utilizes GPS to mark the positions of resource concerns. Conservation planners transfer resource concern position information from GPS receivers to a USDA Enterprise Geographic Information System (GIS) application called Conservation Planning Toolkit. Planners use the Toolkit to prepare conservation and alternative plan maps that are used by farm and ranch owner/operators to choose conservation practices that address the identified resource concerns. In FY 2017, NRCS conservation planners prepared over 95,000 plans, with GPS providing positional data about resource concerns in most of the plans. NRCS planners also used GPS to verify measurements for contract cost-sharing payments.

- NRCS engineers utilized GPS to perform detailed topographic surveys of farms to support conservation planning. Additional GPS surveying was performed to design and layout conservation practices that managed or controlled the flow of water across the landscape. Many NRCS contractors utilized GPS through all phases of conservation practice and structural construction projects.
- NRCS Remote Sensing Labs utilized thousands of photo images acquired by private aerial contractors for NRI and ACEP monitoring. The aerial contractors utilized GPS for flight path navigation and initial registration of the photos that were used in agency GIS and remote sensing applications.
- The Texas NRCS state office prepared an application that utilized an employee's smartphone and GPS to mark and comment on Hurricane Harvey damage. Texas NRCS employees located areas with damage, obtained a GPS position of the location, and entered notations regarding the scope and effect of the damage. Each location was uploaded to a real-time Web map for analysis in the Texas NRCS State Office. For more information, see "NRCS Develops New Web App to Expedite Agency Response to Harvey" (*https://www.usda.gov/media/blog/2017/09/20/nrcs-develops-new-web-app-expedite-agency-response-harvey*, September 20, 2017).

These images show a damaged grain storage facility and a cow crossing a flooded field. (Source: Courtesy of USDA NRCS)

Risk Management Agency

The USDA's Risk Management Agency (RMA), created in 1996, serves America's agricultural producers through effective, market-based risk management tools to strengthen the economic stability of agricultural producers and rural communities. RMA manages the Federal Crop Insurance Corporation (FCIC) to provide innovative crop insurance products to America's farmers and ranchers. Geospatial systems and data, including space-based remote sensing systems, have played a fundamental role in RMA's program delivery, particularly in program compliance and oversight.

RMA uses remote sensing data, such as Landsat, DMC, MODIS, and high-resolution aerial and satellite imagery. These data are often collected as a result of USDA interagency coordination. RMA often partners with scientists and researchers to develop products to meet agency business needs, including Oregon State University's PRISM Climate Group, George Mason University and USDA NASS on developing an agricultural flood-loss estimation system, and Tarleton State University's Center for Agribusiness Excellence (CAE) on integrating MODIS data for enhancing program integrity models.

RMA staff are active participants in Science Teams, such as the USGS-NASA Landsat Science Team and the USDA Soil Moisture Working Group that focuses on the use of data from the NASA SMAP mission. As an operational user of remote sensing products, RMA's participation in these work groups provides insight to scientists in developing applications that benefit crop insurance delivery and oversight, as well as farmers and ranchers across America.

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, Physics, Atmospheric and Geospace Sciences, and Polar Programs, the NSF sponsored a broad base of observational, theoretical, and laboratory research aimed at understanding the states of matter and physical processes in the universe. Areas of research ranged from the most distant reaches of the universe and the earliest moments of its existence to nearby stars and planets—including our own sun and planetary system—as well as Earth's atmosphere and space environment.

Division of Astronomical Sciences

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 with state-of-the-art instrumentation and observing capabilities 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.

During FY 2017, AST, in partnership with the European Union, Canada, Japan, the Republic of Korea, and Taiwan, continued science operations of the Atacama Large Millimeter/Submillimeter Array (ALMA), an interferometric array located near San Pedro de Atacama, Chile. ALMA received over 1,600 observing proposals, the most for any observatory on the ground or in space. New capabilities offered to the community included simultaneous observations with arrays of 12-meter- and seven-meter-diameter antennas, observations with antenna separations of up to 16 kilometers, and observations at a frequency of 183 gigahertz. ALMA continues to provide unique insights across a broad range of topics, including planets and planet formation, proto-stellar and debris disks, low- and high-mass star formation, stellar evolution, normal galaxies, galactic centers, and galaxy formation and evolution.

Construction of the NSF's Daniel K. Inouye Solar Telescope (DKIST) continued through FY 2017. DKIST is the result of a collaboration of scientists from more than 20 institutions representing a broad segment of the U.S. solar physics community, and it had previously earned the strong recommendation of the National Research Council of the National Academy of Sciences. When completed in 2020, 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. The baseline cost for the DKIST project is $344.13 million. The project is approximately 78 percent complete and is both on budget and on schedule. Construction is currently focused on the telescope mount assembly (TMA), which consists of the Coudé rotator platform and the telescope mount itself. The Coudé rotator was completed in FY 2017 and has undergone site acceptance testing (SAT). The telescope mount is nearly completed and will begin SAT in FY 2018.

The National Solar Observatory (NSO) is the lead organization for construction of DKIST. NSO will also operate the facility under a ten-year cooperative agreement. Funding for DKIST operations is in the fourth year of a five-year ramp to a steady-state level of approximately $16.5 million per year by FY 2019. NSO is currently building a new Data Center at its headquarters in Boulder, Colorado. This Data Center will process the 10–12 terabytes of data per day expected from DKIST.

The importance of the potential impacts of space weather on the Nation's critical infrastructure has raised the level of awareness of space weather within the Federal Government. Personnel from MPS-AST, along with colleagues from the Directorate for Geosciences' Division of Atmospheric and Geospace Sciences (GEO-AGS), participated in the National Science and Technology Council's (NSTC) Space Weather Operations, Research, and Mitigation (SWORM) multi-agency task force. The NSTC tasked SWORM with developing a National Space Weather Strategy (NSWS) and an associated National Space Weather Action Plan (NSWAP). In October 2016, the President signed an executive order to coordinate and spur space weather preparedness, thus continuing the activities of the SWORM task force. This increased level of awareness of space weather has resulted in focused attention concerning the data products provided by NSO's Global Oscillations Network Group (GONG) facility. GONG provides detailed synoptic solar data crucial to operational space weather forecasting. In FY 2016, the NSF received a one-time increase of $2.5 million to refurbish GONG and make it operationally robust. Refurbishment activities for GONG continued through FY 2017. Operations of the GONG facility are jointly funded through a five-year Interagency Agreement between the NSF and the National Oceanic and Atmospheric Administration.

Construction of the Large Synoptic Survey Telescope (LSST) project continued in FY 2017, with realized risks remaining well within the originally assigned cost and schedule contingencies. With construction nearly halfway over, there has been a major replan of the work required for the data management system and some use of schedule contingency for weather-related and complexity-related delays, but "first light" is on schedule for 2020. After two years of commissioning to tune all of the complex interrelated operating systems, full science observing will start on October 1, 2022. In LSST's planned ten-year prime mission, imaging the entire accessible sky many hundreds of times, the multicolor survey will populate a science-ready database of unprecedented size, enabling breakthrough research in dark energy and dark matter, in galactic structure, and in solar system astronomy. The relentless, repeated observations will also open up the time domain and revolutionize the study of transient events. The Federal partners, the NSF and the Department of Energy (DOE), expect this survey to generate 30–40 terabytes of data every night,

night after night, throughout its operational life. DOE is funding the camera in a project led by the SLAC National Accelerator Laboratory. The NSF is funding the telescope, building, site, network and software pipelining, and data management systems that allow specialized access separately for research and for education and public outreach. Private, non-Federal funding provided long-lead-time items and technology development essential for mitigating early risks. The NSF and DOE will support installation and commissioning together. Operations support has been requested from both agencies and will be augmented by negotiated non-Federal and international contributions.

In FY 2017, AST's Mid-Scale Innovations Program (MSIP) supported nine programs, with five-year project costs in the range of $3–10 million. They include the Cosmic Large Angular Scale Survey (CLASS), a pair of telescopes being built at 5,200 meters (17,000 feet) on Cerro Toco near the ALMA site on the Atacama Plateau in Chile, designed to measure so-called "B-mode" polarization of the cosmic microwave background (CMB, the radiation at microwave wavelengths that is a remnant of the Big Bang); TolTech, a 3,000-pixel millimeter-wavelength camera for observing our galaxy and distant dusty galaxies, to be installed on the Large Millimeter Telescope in Mexico; the Hydrogen Epoch of Reionization Array (HERA), for construction of 240 14-meter-diameter low-frequency radio telescopes in the Karoo Desert of South Africa, to observe the 21-centimeter emission signal of neutral hydrogen from the Epoch of Reionization in the early universe; and the Subaru Measurement of Images and Redshifts (SuMIRE), a camera and observing program developed by Princeton for use on the Japanese telescope Subaru on Mauna Kea in Hawaii to conduct a very deep optical survey of distant galaxies.

Other MSIP programs in FY 2017 included the Zwicky Transient Facility (ZTF), a telescope/camera combination at Mount Palomar in California dedicated to high-cadence optical surveys and a pathfinder for the LSST; the Atacama Cosmology Telescope (ACT), a six-meter-diameter millimeter-wave telescope; and POLARBEAR, a 3.5-meter-diameter millimeter telescope. The last two are both, like CLASS, sited on Cerro Toco and are designed to measure minute variations in the intensity and polarization of the CMB. POLARBEAR is funded in partnership with the Simons Foundation. Also ongoing is an award for the Event Horizon Telescope (EHT), designed to measure, at extremely high resolution, radio

emissions originating from the near environs of the black hole at the center of the Milky Way. The EHT had an observing run in FY 2017 that included ALMA, which substantially increases the sensitivity of the experiment.

MSIP also provided the U.S. astronomical community with observing time at the Center for High Angular Resolution Astronomy (CHARA) optical interferometer on Mount Wilson in California and at the Las Cumbres Observatory, a network of 18 optical telescopes at eight sites around the world working together as a single instrument.

Division of Physics

The Division of Physics (PHY) continued to operate its Laser Interferometer Gravitational-Wave Observatory (LIGO), which in FY 2017 announced the third and fourth gravitational wave detections from merging black holes. The fourth detection was the first to be made using both the two LIGO observatories, in Hanford, Washington, and Livingston, Louisiana, plus the VIRGO observatory in Santo Stefano a Macerata, Cascina, Italy. VIRGO is a collaboration among six European countries; the two countries mainly responsible for the construction of the facility are Italy and France. The characteristic signal of a merging black hole system was seen simultaneously at all three sites.

Complementing LIGO, the Division of Physics, in partnership with AST, continued its funding of a Physics Frontiers Center for the study of gravitational radiation, called the North American Nanohertz Observatory for Gravitational Waves (NANOGrav). NANOGrav uses large radio telescopes to study the arriving clocklike signals from over 50 rapidly spinning pulsars to search for deviations in the timing that could indicate the passage of a single gravitational wave through our galaxy or the presence of a stochastic background of many gravitational wave sources throughout the universe. A typical source of gravitational waves for NANOGrav would be a black hole pair with millions of times the mass of the sun, in contrast to LIGO's tens of times, and the wave itself would have a period of several years.

For a description of the IceCube Neutrino Observatory, partially supported by PHY, see the Office of Polar Programs section below.

Division of Atmospheric and Geospace Sciences

During FY 2017, the Space Weather Operations, Research, and Mitigation (SWORM) subcommittee began its formal work as a new subcommittee of the Committee on Environment, Natural Resources, and Sustainability (CENRS) of the President's National Science and Technology Council (NSTC). The Space Weather Action plan, managed by the SWORM subcommittee, encourages the NSF to support fundamental research linked to societal needs for space weather information and to work with other agencies specifically "to develop models, observation systems, technologies, and approaches that inform and enhance national preparedness for the effects of space weather events." The NSF is fulfilling this through its science programs in the Directorate for Geosciences (GEO), the Directorate for Mathematical and Physical Sciences (MPS), and the Directorate of Geosciences program Prediction and Resilience against Extreme Events (PREEVENTS). Additional support comes through the NSF's multi-directorate Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) program and through interagency collaborations such as the joint sponsoring of the Community Coordinated Modeling Center located at NASA's Goddard Space Flight Center and the NSF-DOE plasma partnership.

The NSF, through GEO and MPS participation, remained active in SWORM activities. In the past year, the Space Weather Benchmark document received public comment and was reviewed and approved by the subcommittee and is under review by the NSTC. The next phase of the benchmarks is now under way. NSF/AGS has a leading role in this phase, which is centered on garnering worldwide community guidance on the necessary science to improve the initial benchmarks. NSF/AGS is also leading an action (Goal 5.5.1) to identify space weather research priorities. The second phase of this effort, in which scientific community input will be obtained, is now under way. The NSF was also active in Goal 6—International Collaboration—through the funding of the highly successful International Space Weather Initiative Workshop, which was held at Boston College in August 2017; it had over 150 participants from 50 countries.

The Geospace Section (GS) within AGS supported a wide variety of research programs in space science in FY 2017. 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 2017 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. As part of the PREEVENTS program, two awards were made, with approximately $4 million in funding that included support for the development of space weather models capable of handling extreme space weather events.

The NSF funded approximately $2.5 million in awards to support activities during the Great American Eclipse, which took place on August 21, 2017. It crossed the contiguous United States with totality visible in 14 states, creating a unique opportunity for instruments to be tested and measurements to be made. The NSF supported studies on the effects of the eclipse on Earth's upper atmosphere and the first-ever infrared measurements of the lower solar corona from an aircraft.

The Geospace Section runs the Faculty Development in Space Sciences (FDSS) Program to ensure the health and vitality of solar and space sciences within university teaching faculties; it offers five-year awards for the creation of new tenure-track faculty positions within the intellectual disciplines that compose the space sciences. In FY 2017, the GS continued to support the hires resulting from the most recent competition.

In FY 2017, the GS continued to support its program for CubeSat-based small-satellite science missions for geospace and atmospheric research and education. During FY 2017, two projects continued to operate successfully in space and one new mission was launched. The analysis of high-quality observations from many of the previous missions continued to deliver scientific findings and results throughout FY 2017. Development efforts also continued on another six projects for future CubeSat launches that will add new capabilities and breadth to the overall CubeSat program.

In FY 2017, the GS continued to support the satellite-based Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE),

which is now in its second implementation phase, AMPERE-II. AMPERE utilized the 66 networked satellites of the existing Iridium constellation to create a new facility for collecting geomagnetic field data. The AMPERE facility continued to provide the first-ever global 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 eruptions interact with Earth's magnetosphere. Such storms can cause major disruptions of power and communications systems on the ground. During FY 2017, the data collection for AMPERE continued, and the addition of new data and software updates to the AMPERE data server facility made the data freely available to researchers.

Research facilities remained as the key component of GS efforts. The Geospace Facilities program in FY 2017 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 2017, observations made by the Advanced Modular Incoherent-Scatter Radar (AMISR) at Poker Flat, Alaska, examined the ionospheric effects of auroral particle precipitation in three dimensions. These observations provided a wealth of data particularly useful to researchers interested in validating space weather models. A second AMISR system has been operating at Resolute Bay in Nunavut, Canada, since 2009. AMISR 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.

The GS solar physics community was supported by a Major Research Instrumentation award to the Mees Solar Telescope in Hawaii. This award is to develop instrumentation for measuring the magnetic field of the sun and is synergistic with AST's DKIST project (described above).

In FY 2017, the AGS's 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, designed and built the COSMIC six-satellite constellation, which launched on April 14, 2006, with the support and assistance of the U.S. Air Force's Space Test Program. 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's Met Office, the Meteorological Service of Canada, Taiwan's Central Weather Bureau, and others. All of these centers have reported that RO data had a significant positive impact on numerical weather forecasts. In ionospheric studies, COSMIC RO data accelerated the development of physical models for space weather prediction by providing dense, accurate, and global electron-density measurements used for model testing and initialization, including the response of the global ionosphere to the impact of solar storms.

During FY 2017, the number of COSMIC satellites still reporting (beyond the expected three-year lifespan) dropped from four to one and produced between 250 and 700 occultations per day. The reduction in COSMIC coverage has been somewhat mitigated through the use of missions of opportunity including the Korean Kompsat5 satellite, and UCAR is working with NOAA to obtain these data in near-real time. Approximately 90 percent of real-time processed COSMIC data are available for the users and operational weather forecasting centers within three hours. COSMIC 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. UCAR also reprocessed data to provide consistent records for the duration of the mission and produced post-processed and reprocessed data from several GPS radio occultation (GPSRO) missions of opportunity. The NSF and NASA are jointly funding the COSMIC mission for the duration of its expected lifespan.

The NSF continued to collaborate with NOAA, USAF, Taiwan, and UCAR to ensure the success of the follow-on COSMIC-2 mission. COSMIC-2 now consists of a six-satellite constellation to be launched into low-inclination orbits to provide dense coverage of the tropics (a second polar constellation was planned but has now been cancelled).

Office of Polar Programs

For FY 2017, the primary activities of the Office of Polar Programs (OPP) 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 South Pole Telescope (SPT); the battery of five small-aperture (25-centimeter) telescopes called the Small Polarimeter Upgrade for Degree Angular Scale Interferometer (SPUD) array; and another, stand-alone Background Imaging of Cosmic Extragalactic Polarization (BICEP3) telescope—a wide-field cryogenic refractor with a 55-centimeter aperture and fast optics that achieves an order of magnitude increase in throughput. The High Elevation Antarctic Terahertz (HEAT) robotic telescope, deployed since 2011 at the highest point of the Eastern Antarctic Plateau (Ridge A), has completed successful operation through 2017; it will be removed and shipped back to the home institution in January 2018. Scientific data collected through the lifetime of this project have been analyzed for publication, and all observational data will be shared with the scientific community.

The SPT continued observations with the new, third-generation receiver SPT-3G, which has wide-field optics to measure the CMB polarization at high sensitivity. Both the SPT and BICEP research groups are currently focusing on measurements of the CMB polarization anisotropy. They target measurements of the *B*-mode polarization where primordial gravitational waves have their imprint, as well as on the *B*-mode signal caused by the gravitational lensing of the intrinsic CMB's *E*-mode polarization signal. Polarization measurements on smaller angular scales measured with the SPT are being used to increase the precision of the CMB-lensing determination of projected mass maps of the sky.

The ongoing cosmological research with the SPT program consists of three parts: 1) scientific analysis and public release of data products from the completed SPT-SZE (a large survey for galaxy clusters detected by the Sunyaev-Zel'dovich Effect) and the SPTpol (CMB polarization) surveys; 2) ongoing observations with SPT-3G, including the data analysis and public release of data products; and 3) after data taking is complete, a final year for analysis and full survey data release. The SPT-3G camera has three observing bands (centered at 95, 150, and 220 gigahertz)

and represents a fundamental step forward in CMB polarization measurements. Recent SPT results from measurements of degree-scale anisotropies in the CMB have spectacularly confirmed predictions of the Hot Big Bang cosmological model and made precise measurements of many cosmological parameters.

Recent scientific results from the BICEP Collaboration include deep multi-frequency (95-, 150-, and 220-gigahertz) maps of degree-scale *B*-mode polarization that measure gravitational lensing and foregrounds to unprecedented precision. This project also produced the deepest-ever maps of CMB polarization, now at four different frequencies, or colors, of light: 95-, 150-, 220-, and 230-gigahertz. A new receiver was deployed and has started making maps at 270 gigahertz as well; these higher frequencies are particularly valuable for separating galactic dust from CMB polarization signals. The constraints that BICEP telescopes have produced on primordial gravitational waves continue to improve, leading the way in probing models of inflation that operate near grand-unified theory (GUT) energy scales. In the past year, the BICEP group published the most sensitive constraints yet on cosmological variation in the speed of light for left- and right-handed photons, which would be visible as subtle rotations of CMB polarization.

The IceCube Neutrino Observatory (ICNO, jointly operated at the South Pole by the NSF's Office of Polar Programs and Division of Physics) has now collected data for almost seven years of operation from a complete array of 86 strings of optical photodetectors deployed in the ice under the South Pole Station in Antarctica at depths between 1.4 and 2.4 kilometers. The ICNO Collaboration, upon analyzing more than a million neutrino-induced events and hundreds of billions of cosmic-ray muons, has detected through FY 2017 more than 130 high-energy cosmic neutrinos.

The ICNO has produced the world's best limit on the flux of cosmogenic neutrinos, which places very strong constraints on the sources of ultra-high-energy cosmic rays. The petaelectronvolt (PeV) neutrinos observed by IceCube have a thousand times the energy of the highest-energy neutrinos produced with Earthbound accelerators and a billion times the energy of the neutrinos detected from supernova SN1987 in the Large Magellanic Cloud, the only neutrinos that had been detected on Earth from outside the solar system prior to IceCube's breakthrough. However,

the most surprising property of these cosmic neutrinos is their large flux rather than their high energy or their origination outside our galaxy.

The ICNO's DeepCore subdetector extends measurements of the neutrino flux from 100 teraelectronvolts (TeV) down to below 10 gigaelectronvolts (GeV). At these energies, DeepCore observes atmospheric neutrino oscillations and performs searches for sterile neutrinos with a precision compatible with and comparable to those of the dedicated oscillation experiments, such as Main Injector Neutrino Oscillation Search (MINOS), T2K, or Super-Kamiokande. In FY 2017, the IceCube Collaboration presented a new measurement of the neutrino oscillation parameters that, for the first time, is competitive with the best measurements to date by the T2K neutrino experiment. Understanding neutrino oscillations at higher energies tests systematic uncertainties and also places constraints on different new physics models in the neutrino sector. These are the first "pixels" of the first picture of the distant neutrino universe, an example of how IceCube is opening doors to a new era in particle astrophysics.

The NSF's Office of Polar Programs also supports NASA's Long Duration Balloon Program in the Antarctic. McMurdo Station provides the necessary logistics for astrophysics payload assembly and final testing and then helps launch the balloons and support payload recovery after the flights in various regions of the Antarctic continent.

Department of State

DOS

The Department of State (DOS) carries out diplomatic and public diplomacy efforts to strengthen understanding of, and support for, U.S. national space policies and programs and to encourage the foreign use of U.S. space capabilities, systems, and services. State supports U.S. civil space activities through the negotiation of bilateral and multilateral agreements with partner countries and leads U.S. participation in numerous international space and technological activities and international organizations.

In FY 2017, State's Office of Space and Advanced Technology within the Bureau of Oceans and International Environmental and Scientific Affairs (OES/SAT) continued its long-standing efforts to lead the U.S. delegation to the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) and supported its Legal Subcommittee (LSC) and Scientific and Technical Subcommittee (STSC). State also continued to lead the participation of both U.S. Government and private-industry participation in the Working Group on Long-Term Sustainability of Outer Space Activities (LTS) and continued its contribution to the developing of the seven thematic priorities and agenda for the 50th anniversary of the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE+50) planned for 2018. Additionally, DOS continued co-leading an action team to develop a plan of activities to be approved in 2018, highlighting the importance of international cooperation in global space exploration efforts.

DOS continued to promote space weather as an important foreign policy topic across the U.S. Government and in our discussions with foreign partners, noting the potential for global impacts from an extreme event. OES/SAT actively participated in the National Science and Technology Council's Space Weather

Operations, Research, and Mitigation (SWORM) subcommittee and cochaired the working group tasked with coordinating international issues and activities. State further included space weather as an agenda item for bilateral space policy dialogues with the European Union, China, Korea, Japan, and Thailand.

Under the auspices of COPUOS, DOS, NASA, and NOAA represented the United States at the UN Expert Group on Space Weather meeting held in Vienna on April 27 and 28. The Expert Group is addressing UNISPACE+50 Thematic Priority IV on developing an international framework for space weather services. At this meeting, the group reviewed LTS guidelines specific to space weather, with a focus on mapping each guideline to ongoing/planned activities by member states, intergovernmental organizations, and nongovernmental organizations.

Outcomes from this meeting fed into the "United Nations/United States Workshop on the International Space Weather Initiative" held in Boston from July 31 to August 4. State worked with NASA, NOAA, and the UN Office of Outer Space Affairs (UNOOSA) to organize a high-level session during the first 1.5 days focused on developing an international framework for space weather. OES/SAT spoke on our efforts to raise awareness for space weather through diplomatic outreach in Washington and among our international partners. UNOOSA considers the workshop, and particularly the high-level session, as one of their "Flagship Events" in the lead-up to the UNISPACE+50 Conference.

As part of our diplomatic outreach, OES/SAT co-organized a second "Space Weather as a Global Challenge" event on May 18, 2017 (see *https://www.state.gov/e/oes/sat/space_weather/*). Hosted by the Embassy of Italy in Washington, DC, the event highlighted the importance of addressing the threat of space weather and provided updates on progress made toward implementing the U.S. National Space Weather Strategy and Action Plan and advances in addressing the threat of space weather made in Italy, Europe, and beyond. The dialogue was opened with welcoming remarks from H. E. Armando Varricchio, Ambassador of Italy to the United States of America; Professor Roberto Battiston, President of the Italian Space Agency; and Dr. Jonathan Margolis, Acting Deputy Assistant Secretary for Science, Space, and Health at the U.S. Department of State. The agenda and subsequent roundtable discussions included representatives of government, research,

and private-sector organizations from the United States, Italy, Germany, Japan, and Russia.

DOS hosted the fourth meeting of the U.S.-Japan Comprehensive Dialogue on Space on May 16, 2017, to continue the strong and shared commitment of two of the world's most advanced spacefaring nations to enhance further bilateral space cooperation and to cooperate closely with the international community toward ensuring the continuous, safe, and stable use of outer space for current and future generations. The meeting was cochaired by representatives from the Executive Office of the President's National Security Council and Office of Science and Technology Policy (OSTP) for the United States and by representatives from the Ministry of Foreign Affairs and the National Space Policy Secretariat, Cabinet Office, for Japan. The Department of State serves as the U.S. Executive Secretariat for the Comprehensive Dialogue. State also hosted and chaired the Seventh U.S.-Japan Civil Space Dialogue and the 11th U.S.-Japan GPS Cooperation Plenary Meeting on May 15, 2017. Outcomes from all three meetings were released as a Media Note (see *https://www.state.gov/r/pa/prs/ps/2017/05/270946.htm*).

The Department of State and NASA continued to work with Japan, the European Union, and other planning countries in preparation for the Second International Space Exploration Forum (ISEF2), to be held in Tokyo, Japan, on March 3, 2018. ISEF2 is an important step in defining an ambitious vision for the next phase of human expansion beyond low-Earth orbit, involving commercial and international partners and including a return to the moon for long-term exploration and utilization, as well as missions to Mars and beyond.

OES/SAT recently led State Department participation in producing the National Near-Earth Object (NEO) Preparedness Strategy (NNPS), which outlines how the U.S. Government would respond to a threat of a "killer asteroid" on a potential collision course with Earth. The office engages at COPUOS via the International Asteroid Warning Network (IAWN), which serves as a clearinghouse for the receipt, acknowledgment, and processing of NEO observations worldwide, having registered upward of 20 million observations from 39 countries. The office also engages at the Space Mission Planning Advisory Group (SMPAG), which helps coordinate an international response to a NEO threat through the exchange of information, the development of options for collaborative research and space

mission opportunities, and mitigation planning activities. OES/SAT supported the development of these international advisory bodies and is also engaged in promoting international communication plans and protocols to assist governments in the analysis of impact consequences and in the planning of mitigation responses at COPUOS.

In November 2016, State led the U.S. delegation to the 11th meeting of the International Committee on GNSS (ICG) in Sochi, Russia. This meeting brought together approximately 200 experts and government officials representing more than 15 countries and organizations to discuss GNSS service provision and use in a multilateral forum. The four working groups of the ICG include 1) Systems Signals and Services; 2) Enhancement of GNSS Services Performance; 3) Information Dissemination and Capacity Building; and 4) Reference Frames, Timing, and Applications. All four working groups met and developed nine new recommendations that were adopted by the full ICG, with a focus on improving GNSS compatibility and interoperability as well as improving outreach to the user community.

Working-level discussions with the EU on GNSS also continued in FY 2017 through working groups formed by the 2004 U.S.-EU GPS-Galileo Cooperation Agreement, administered for the U.S. by OES/SAT. The working group on next-generation GNSS applications, including aviation applications, met in October 2016 and April 2017. Three new subgroups have been established under this working group: 1) Service Evolution, 2) Resiliency, and 3) Service Provision Coordination. The working group on trade and civil applications also met in December 2016. The United States has also begun discussions with the EU on possible cooperation on the Galileo encrypted Public Regulated Service, with an emphasis on increased resiliency.

OES/SAT continued to lead productive bilateral meetings in FY 2017 with China, noting that the Subgroup on Compatibility and Interoperability met in El Segundo, California, in June 2017 to discuss GNSS signals with respect to compatibility and interoperability between GPS and BeiDou. Another informal bilateral meeting took place in September 2017 in Portland, Oregon, on the margins of the U.S. Institute of Navigation's GNSS+ 2016 Conference.

In October 2016, State hosted a delegation from China for the Second Bilateral U.S.-China Civil Space Dialogue, highlighting the importance of transparent, safe,

and responsible exploration and use of outer space for peaceful purposes by China and all spacefaring nations. The agenda included discussions related to Earth and space science cooperation and space exploration, as well as a follow-up on the spaceflight safety discussions that took place in the Expert Workshop on Satellite Collision Avoidance and Orbital Debris Mitigation that was held in June 2016.

In September 2017, OES/SAT also led the United States in a Civil Space Dialogue with the Government of Thailand. The discussions focused on the two nations' respective space policies and diplomatic activities, as well as important space applications such as Earth observation, GNSS, and civil Maritime Domain Awareness.

In the area of Earth observations, DOS promoted international cooperation through both bilateral and multilateral processes.

Our noteworthy bilateral collaboration with the European Union is focused on their Copernicus program. Thanks to the October 16, 2015, U.S.-EU Cooperation Arrangement on Copernicus Earth Observation Data, the United States continues to access data and information from the European constellation of Sentinel satellites. During the busy 2017 Atlantic hurricane season (the first time that three Category 4 hurricanes have made landfall in the United States and its territories in one season), the Department of Homeland Security (DHS) and FEMA accessed timely inundation maps derived from Europe's Synthetic Aperture Radar satellites, including Sentinel 1a and 1b, as well as CosmoSkyMed. The U.S.-EU partnership is guided through a mechanism known as the Copernicus Coordination Group (CCG), with participation on the U.S. side from the Department of State, NASA, DOC/NOAA, and DOI/USGS, and on the European side by the European Commission, the European Space Agency (ESA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

The two primary multilateral organizations of direct relevance to Earth observation cooperation are the Group on Earth Observation (GEO) and its space element, the Committee on Earth Observation Satellites (CEOS). OES/SAT participated in the U.S.-hosted 14th Plenary Session of GEO in Washington, DC, as well as the 31st CEOS Plenary meeting in Rapid City, South Dakota, October 18–19, 2017. The United States is a founding member of both organizations. GEO today has more than 105 member governments, while CEOS has more than 60

member space agencies operating over 150 Earth-observing satellites. Continued active U.S. engagement in both groups reaffirms its commitment to international collaboration and promotion of U.S. science and technology leadership in space, as called for in the National Space Policy.

After many years of negotiation, the Department welcomed the Framework Agreement between the Government of the United States of America and the Government of the Republic of Korea for Cooperation in Aeronautics and the Exploration and Use of Airspace and Outer Space for Civil and Peaceful Purposes, signed at Seoul on April 27, 2016, entering into force on November 3, 2016.

Department of Energy

DOE

The Department of Energy (DOE) participates in the national effort to further U.S. interests in space. Organizations within DOE that provide this capability are the National Nuclear Security Administration (NNSA) Office of Defense Programs; the NNSA Office of Safety, Infrastructure, and Operations; the NNSA Office of Counterterrorism and Counterproliferation; the NNSA Office of Defense Nuclear Nonproliferation Research and Development (DNN R&D); the DOE Office of Science (SC); and the DOE Office of Nuclear Energy (NE).

National Nuclear Security Administration

The NNSA and NASA have established and maintain a strong, collaborative, scientific, and operational partnership. NNSA's engagements in support of NASA's mission are summarized below.

NNSA Office of Defense Programs

Planetary Defense: NNSA has participated in the Detecting and Mitigating the Impact of Earth-bound Near-Earth objects (DAMIEN) initiative, which has developed a National Strategy and Action Plan for the mitigation and emergency response preparedness planning from the threat of Near-Earth Objects (NEO). The DAMIEN initiative is cochaired by the White House Office of Science and Technology Policy (OSTP) and NASA. In addition to the DAMIEN initiative, there is an interagency agreement between NNSA and NASA in place for analyzing asteroids and planetary defense scenarios. NASA provides expertise in the

characterization of Potentially Hazardous Asteroids (PHA), and NNSA provides the analysis of options for the most effective ways to mitigate the risk that they pose to our planet. This NNSA-NASA interagency agreement provides the analysis that satisfies actions associated with two strategic goals of the DAMIEN National Strategy by

- characterizing the PHA target sets, defining mission requirements, and identifying capability gaps;
- examining the effects of either a kinetic impactor and/or a nuclear detonation, either at the surface or at a standoff distance from a model asteroid, using simulation from petascale computers at the National Laboratories;
- defining additional development and system engineering requirements addressing technical gaps such as arming, fusing, and firing of a deflection device;
- participating in Planetary Defense tabletop exercises and technical interchange meetings; and
- advising on risk-assessment analysis and the effectiveness of mitigation approaches.

Strategic Partnership Projects: NNSA supports Strategic Partnership Projects, funded by NASA, with the following capabilities:

- Providing metrology support with calibration on standards and measuring test equipment supporting metrology areas at NASA White Sands Test Facility.
- Monitoring satellite visible-light sensor data for bolide occurrences worldwide and generate reports detailing bolide parameters.
- Modeling asteroid entry, airburst, and surface impact effects.
- Enabling joint exploration of sounding rocket technologies at NASA's test ranges.

Radioisotope Power System Production for NASA: Radioisotope Power Systems (RPSs) from Los Alamos National Laboratory (LANL) have powered NASA's Cassini spacecraft, New Horizons spacecraft, and Mars Science Laboratory. LANL will produce fuel clads to provide enough energy to power the MARS 2020 mission and three additional Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs) for a possible 2025 mission.

NNSA Office of Safety, Infrastructure, and Operations

Small Fission Power Systems: NASA employs NNSA assets to develop and test a prototypic reactor and power system to enable NASA to execute a deep space exploration mission. A technology demonstration, referred to as Kilowatt Reactor Using Stirling TechnologY (KRUSTY), provides expertise from LANL, the Y-12 National Security Complex, and the Nevada National Security Site to build and test a full-scale flight-prototypic nuclear reactor by the end of 2018. This partnership will help determine whether the reactor design is suitable for flight development. NNSA will retain the fissile material, which will be available to perform a variety of radiation test object experiments and to complete planned nuclear data measurements for nuclear criticality safety benchmarking purposes.

NNSA Office of Counterterrorism and Counterproliferation

Major Radiological Space (MRS) Launch: NNSA employs Office of Counterterrorism and Counterproliferation assets to support the preparation for and execution of the MRS launch at Kennedy Space Center (KSC).

- During the preparation phase, NASA employs NNSA assets to conduct training, drills, and exercises with the state, tribal, and local emergency management organizations and agencies to validate the ability to manage the consequences of a launch anomaly that may result in an uncontrolled release of radiological materials into the atmosphere and surrounding environment.
- During the execution phase, NASA stages NNSA personnel and equipment in the vicinity of the launch site to be prepared to respond immediately in the unlikely event of a launch anomaly. NNSA personnel would be assigned to the KSC Radiation Control Center (RADCC) to provide real-time data assessment and coordinate with the NNSA Consequence Management Home Team should an NNSA-led Federal Radiological Monitoring and Assessment Center (FRMAC) be established following a launch anomaly.

NASA's Environmental Continuous Air Monitors: NASA has agreed to loan their Environmental Continuous Air Monitors (ECAMS) to NNSA for use in support of NNSA's nuclear incident response mission when those devices are not being used for mission launch support. These devices are being upgraded to provide real-time associated data telemetry systems and will be interoperable with NNSA's existing data telemetry capability.

Ocean Wave Monitoring: NNSA has provided aviation and technical support to NASA JPL's Doppler Scatterometer (DopplerScatt) Instrument Incubator Project (IIP) to monitor ocean wave currents pursuant to an interagency agreement between NNSA and the NASA Earth Science Technology Office located at GSFC.

NNSA Office of Defense Nuclear Nonproliferation

NNSA builds the Nation's operational sensors to monitor the entire planet from space in order to detect and report surface, atmospheric, or space nuclear detonations. NNSA provides much of the Nation's capability to detect, report, locate, and identify nuclear explosions using orbiting satellites. NNSA 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. Nuclear Detonation Detection System (USNDS).

Since the 1960s, beginning with the Vela satellite program, 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. This fiscal year, NNSA continued full-scale production and delivery of sensor payloads as needed to meet national security requirements. To ensure that the technologies and capabilities developed for the program support stakeholder needs, NNSA actively engaged in intergovernmental working groups to reduce duplication of effort, refine user requirements, and improve the quality of relevant technologies across funding agencies.

The NNSA weapons laboratories—specifically Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), and Lawrence Livermore National Laboratory (LLNL)—supply the science, technology, and engineering required for USNDS. LANL and SNL lead the production of sensor-laden payloads, and

LLNL contributes to the end-to-end modeling of USNDS. These laboratories have a unique and comprehensive understanding of nuclear weapons, as well as the observables associated with nuclear detonations and the propagation of signals to sensors. Moreover, these laboratories have extensive capabilities in the design, construction, calibration, deployment, and operation of satellite-based instruments, along with detailed modeling and analysis. To support continuous global monitoring, the operations communities routinely receive analysis, insights, and computer codes based on this research.

Two payload suites built at the NNSA laboratories accomplish the nuclear detonation reporting mission: the Global Burst Detector (GBD) and the Space and Atmospheric Burst Reporting System (SABRS). The GBD is hosted on all GPS satellites, and SABRS is carried on satellite hosts in geosynchronous orbit. In order to maintain a vital capability to design and implement these systems, NNSA supported demonstration-validation payloads both 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.

DOE Office of Science

In FY 2017, the Office of Science (SC) supported several activities that contribute to a broad range of space interests. These activities included SC fundamental research that is of mutual interest to the NASA mission, NASA researchers, SC program offices, and SC-sponsored scientists; 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 frontier plasma science research that contributes to SC-NASA mutual interests in the knowledge of heliospheric and astrophysical systems. Some of the research supported by SC's Office of Fusion Energy Sciences (FES) enables the development of a comprehensive understanding of heliospheric and astrophysical magnetized plasma processes, including magnetic reconnection, particle energization, and turbulent cascade processes in the solar corona and Earth's magnetosphere; magneto rotational instability in generating turbulence in accretion disks; and dynamo processes creating planetary/galactic magnetic field

structures. Specific examples of FES-supported activities in FY 2017 include 1) 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; 2) the Magnetic Reconnection Experiment (MRX) at the Princeton Plasma Physics Laboratory (PPPL), which permits laboratory studies of magnetic reconnection and particle energization processes in the solar corona and Earth's magnetosphere; 3) the Big Red Plasma Ball (BRB) and Madison Symmetric Torus (MST) experiments at the Wisconsin Plasma Physics Laboratory (WiPPL) at the University of Wisconsin, Madison, which allow comprehensive experiments, isolating the key effects of magnetic reconnection, dynamo, turbulence, and particle energization processes with high fidelity; 4) the Max-Planck-Princeton Center for Plasma Physics, established in 2012 in partnership with the Max Planck Society in Germany, which specifically explores the application of plasma science to solar and astrophysical problems and their connections to fusion science; and (5) the DIII-D Frontier Science campaign initiated in 2017 to conduct basic plasma science experiments as well as space plasma–relevant experiments, including Whistler wave interactions with collisionless electrons, as well as flux rope structures in magnetic reconnection on the DIII-D National Fusion Facility at General Atomics in San Diego, which is the largest magnetic fusion facility in the United States.

In addition, FES sponsored unmagnetized plasma research, such as the properties of plasmas created by hypervelocity impacts, and the properties of warm dense matter similar to that found in planetary cores. In 2015, FES sponsored a series of community research opportunities workshops to identify compelling scientific challenges at the frontiers of plasma physics, with workshop reports delivered in 2016. Attention was paid to opportunities in the next decade. Plasma science governing space weather, an area of broad mutual interest to NASA and FES, and laboratory-based FES intermediate-scale plasma science facilities, providing reconnection data to complement the NASA Magnetospheric Multiscale (MMS) mission, were highlighted. Furthering the study of laboratory plasmas for growing our understanding of astrophysical plasma phenomena was also a focus.

SC also funds the development of experimental techniques and instrumentation for use on NASA space missions to study fundamental physics and 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 is a particle physics experiment supported by DOE and international partners, who designed and built the AMS-02 detector and associated systems. Launched on Space Shuttle Endeavour on the Space Transportation System (STS) mission STS-134 in May 2011 and mounted on the International Space Station (ISS), AMS searches for various types of unusual matter in the cosmos through its exquisite accuracy in the measurement of cosmic rays. AMS science goals include a search for evidence of dark matter and cosmic domains of antimatter, as well as for novel features in cosmic-ray spectra. A Memorandum of Understanding (MOU) signed between DOE and NASA defined NASA's responsibilities to include provision of power, data handling, and other services on the ISS, while DOE's responsibilities include experimental operations and data analysis. Currently, more than 100 billion cosmic-ray events have been collected. Recent results include the ratio of the antiproton-to-proton flux, with the ratio's rigidity not explained by current models. 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 for high-energy acceleration mechanisms generated by supermassive black holes and supernovae and to search for dark matter. It does a complete survey of the entire sky in high-energy gamma rays every three hours and enables searches for transient phenomena over a wide range of timescales. SC managed the LAT fabrication and now operates the LAT Instrument Science Operations Center. In 2017, the FGST/LAT collaboration published results, showing that the gamma-ray emission of the M-31 (Andromeda) Galaxy is concentrated with its center. Results are expected in 2018 on limits on the evaporation of primordial black holes and on the source of the high-energy gamma-ray excess in the inner Milky Way.

SC also made crucial contributions to the European Space Agency–NASA Planck Cosmic Microwave Background (CMB) mission. Planck measures the CMB, which allows studies of the inflationary epoch in the early universe, as well as dark energy, dark matter, and neutrino properties. A Memorandum of Agreement (MOA) signed by NASA and DOE provided dedicated DOE National Energy Research Supercomputing Center (NERSC) computing resources for the Planck mission.

SC and NASA also engaged in many collaborative research efforts in the areas of atmospheric science and terrestrial ecology. In FY 2017, SC's Atmospheric Radiation Measurement (ARM) Climate Research Facility activity supported the Land-Atmosphere Feedback Experiment (LAFE), a collaboration between DOE, NASA, NOAA, and the German Federal Ministry of Education and Research. The experiment deployed several state-of-the-art scanning lidar and remote sensing systems to Oklahoma to collect a dataset for studying feedback processes between the land surface and the atmosphere. ARM also supported special scanning strategies of the Scanning ARM Cloud Radar at its Oliktok Point, Alaska, site during overpasses of the NASA CloudSat satellite. Availability of matched ARM and CloudSat radar profiles will allow for intercomparisons and validation activities that could lead to improved remote sensing results from both ground-based and satellite cloud radars. ARM also collaborated with NASA on studies of biomass burning aerosol in the Southern Atlantic. ARM's mobile facility was deployed to Ascension Island to take ground-based remote sensing measurements of cloud and aerosol properties, while a NASA aircraft took in situ measurements of cloud and aerosol properties in the region during a related campaign. Finally, ARM continues to support efforts to validate spaceborne satellite instruments.

ARM provided support for ground-based measurements of carbon dioxide in Oklahoma as part of the Total Column Carbon Observing Network (TCCON); these measurements are being used to validate NASA's Orbiting Carbon Observatory-2 (OCO-2) satellite. SC's ARM activity also included support for the launch of dedicated radiosonde observations during satellite overpasses at three sites (Southern Great Plains, Oklahoma; Graciosa Island, Azores; and Barrow, Alaska) to obtain profiles of temperature and moisture for the validation of algorithms for the Cross-track Infrared Sounder and Advanced Technology Microwave Sounder on NASA's Suomi National Polar-orbiting Partnership satellite and future Joint Polar Satellite System satellites.

The Terrestrial Ecosystem Science (TES) manages the Next Generation Ecosystem Experiment (NGEE)–Arctic and is working with the NASA Arctic-Boreal Vulnerability Experiment (ABoVE) study to couple real-time ground-based and airborne-based measurements of soil moisture, temperature, carbon dioxide (CO_2), and methane (CH_4) flux over Barrow and Council, Alaska. An MOA to

leverage the complementary expertise between these two activities has been developed which provides generation of high-resolution lidar and elevation data products, as well as including representatives on each project's science team to provide coordination of data and modeling efforts. NASA Goddard's Lidar, Hyperspectral and Thermal (G-LiHT) airborne imager is being used to characterize tropical forest dynamics across a range of edaphic, climatic, and land-use gradients in Puerto Rico to support SC's NGEE-Tropics activity. The AmeriFlux Network, supported by SC's TES activity, is collaborating with NASA's ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) by providing real-time ground validations and joint data products. Through interagency agreements, SC's Atmospheric System Research (ASR) activity also supported collaboration with NASA scientists on studies using ARM and NASA observations to investigate aerosol and cloud processes and their role in Earth's energy balance.

SC has been working with NASA in a couple of areas to help support NASA's mission interests in radiation effects and astrophysics. In addition, the office provides user facilities for the scientific community, including particle accelerators and ion beams for biological and electronic systems radiation studies, as well as nuclear astrophysics. The 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), which are also produced to deliver into SC's Relativistic Heavy Ion Collider (RHIC) facility. An upgrade mutually beneficial to both NSRL and RHIC, and jointly funded by NASA and DOE, was the construction of an Electron Beam Ion Source (EBIS). The EBIS at BNL significantly expanded 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, which 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.

DOE Office of Nuclear Energy

The Office of Nuclear Energy supports NASA's planetary science and human exploration programs by maintaining capabilities to develop, produce, and deliver radioisotope power systems (RPSs) for space mission applications. The RPS capabilities are funded by NASA and managed by NE. 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 reliably operate for decades under the harsh conditions encountered in deep space or on the surfaces of other planets.

In FY 2017, NE continued its support for Mars 2020, the next RPS-powered mission scheduled for launch in July 2020. This support included fuel processing at the Los Alamos National Laboratory (LANL) and preparation of analyses and assessment to support launch certification activities. The Idaho National Laboratory continues preparations to assemble graphite impact shells with fueled clads received from LANL to support Mars 2020. They are also proceeding to train and qualify personnel and initiating formal readiness activities to support launch activities at Kennedy Space Center.

With NASA funding support, NE continued to invest in RPS capabilities and associated infrastructure to ensure availability for future missions. NE supported NASA through technical expertise, procurement coordination, and planning as they continued to investigate advances in both thermoelectric and dynamic power-conversion technologies that could result in more efficient and capable RPSs for their long-term exploration goals.

NE also continued working with NASA to increase domestic Pu-238 production to ensure that supplies are available for future missions. The Oak Ridge National Laboratory (ORNL) completed building and irradiating targets for tests to demonstrate production of new Pu-238. ORNL completed processing the third set of irradiated targets containing newly generated Pu-238. Chemical processing took place within heavily shielded hot cell facilities at ORNL. The efforts yielded about 250 grams of new plutonium oxide for use in heat sources. The newly produced domestic Pu-238 material was blended with existing inventory and was inserted

into the fuel inventory for the Mars 2020 mission to demonstrate the Pu-238 production cycle. ORNL also purchased new equipment designed to automate the target fabrication process and begin to scale up the processes to produce 1.5 kilograms per year.

Additionally, NE and DOE national laboratories provided technical support to NASA for fission technologies, specifically Nuclear Thermal Propulsion (NTP) system development. In FY 2017, technical advice and support regarding nuclear design alternatives were provided.

Smithsonian Institution

The Smithsonian Institution continued to contribute to national aerospace goals through a variety of activities in FY 2017. The Smithsonian Astrophysical Observatory (SAO) and the Harvard College Observatory jointly form the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. Through this organization, more than 300 scientists engage in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education during the year. The Smithsonian National Air and Space Museum (NASM) and the Smithsonian National Museum of Natural History (NMNH) in Washington, DC, also contributed to reaching national aerospace goals through research and education activities.

The most widely reported news story for SAO in FY 2017, published in *Nature Astronomy*, was the discovery of a supermassive black hole that has ripped apart a star and has been gorging on the remains for almost a decade—more than ten times longer than any other observed episode of stellar death by a black hole. SAO astronomers made this discovery in a relatively small galaxy using NASA's Chandra X-ray Observatory along with two other astronomical satellites. SAO controls science and flight operations for the Chandra X-ray Center from its location in Cambridge, Massachusetts. Among other popular CfA news stories was the discovery of an Earth-sized exoplanet in its habitable zone, which was featured in the *New York Times*.

The Chandra X-ray Observatory (a NASA "Great Observatory") is an orbiting telescope designed for precision x-ray astronomy for which SAO played a key design and development role. SAO also runs the Operations Control Center in Cambridge. Chandra, with its unrivaled ability to obtain high-resolution x-ray images, plays a pivotal role in the exploration of the universe, enabling astronomers

to investigate phenomena as diverse as comets, black holes, supernova remnants, galaxy clusters, dark matter, and dark energy. Chandra operates at high efficiency, carrying out observations for teams from all over the world with a high productivity rate; the teams average about 450 publications per year. In 2017, Chandra discoveries included obtaining the most sensitive image yet of the seeds of supermassive black holes in the distant universe only a few billion years after the Big Bang, discovering a mysterious flash of x-rays from what may have been a gamma-ray burst in a distant galaxy, finding a star orbiting a black hole every 30 minutes, and revealing that stars like the sun experience an unexpectedly sharp drop in their x-ray emission after their youth, with dramatic consequences for their planets.

NASA's Spitzer Space Telescope, now in its 14th year of operation and more than 235,000 kilometers away from Earth, has 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 (with Giovanni Fazio as Principal Investigator) and was constructed at NASA's Goddard Space Flight Center. The IRAC camera has been the only instrument operating since Spitzer ran out of cryogens in May 2009. In 2017, IRAC discoveries included the remarkable star TRAPPIST-1 with seven planets orbiting it, a new iceball planet with the mass of Earth that was discovered when its gravity (acting as a lens) reimaged a distant star, and a massive star that died and was reborn as a black hole. SAO scientists using Spitzer recently completed a Near-Earth Object (NEO) Survey on over 1,000 objects, resulting in estimations of their sizes and reflectivities (albedos). SAO astronomers used Spitzer to study the cloud layers on the exoplanet WASP-43b, measure the massive dust-rich shell of a supernova remnant, study the stupendous jet—it is almost half a million light-years long—in a distant quasar, and observe the coma of a comet that shows evidence of processed organic material.

The Solar Dynamics Observatory provides better-than-HD-quality images of the sun's surface and outer atmosphere, measuring physical conditions that help determine the "space weather" around Earth. SAO is a major partner in the Atmospheric Imaging Assembly (AIA)—a group of four telescopes that photograph the sun in ten different wavelength bands, or colors, once every 12 seconds, producing the most spectacular images ever recorded of the active surface of the sun.

NASA's Interface Region Imaging Spectrograph (IRIS) satellite offers a unique 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. IRIS is providing information on particle acceleration in hot coronal loops, providing better understanding of the physical processes in solar flares. During 2017, SAO scientists continued their involvement in other solar satellites, including Hinode and the Deep Space Climate Observer, as well as development activities of new solar probe instruments, including the Solar Wind Electrons Alphas and Protons (SWEAP) Faraday Cup experiment on the Solar Probe Plus mission (which will fly to within ten solar radii of the sun) and the Hi-C II and Marshall Grazing Incidence X-ray Spectrograph (MaGIXS) rockets (which will observe the solar corona while pushing the limits of spatial resolution and x-ray spectral coverage, respectively).

SAO took advantage of the 2017 total solar eclipse with a unique project, the Airborne Infrared Spectrometer (AIR-Spec) for Solar Eclipse Observations. Flying with a team of SAO astronomers, this Gulfstream aircraft flew at 50,000 feet over Kentucky during totality to take detailed measurements of the sun's outer atmosphere, the corona, at infrared wavelengths.

FY 2017 marked continued progress for the Giant Magellan Telescope (GMT), on which the SAO is a team leader. The GMT is a facility for optical and infrared observations that will combine seven huge mirrors to create the world's largest telescope. It will address key questions in cosmology, astrophysics, and the study of planets outside our solar system. Three of the seven eight-meter-diameter mirror segments have now been fabricated, and one has been polished and prepared for shipment to the site in Chile. Meanwhile construction at the site is under way; work on essential infrastructure—roads, power, water, sanitation, communications, and a worker's residence—is complete.

The Event Horizon Telescope (EHT) is a developing facility that unites telescopes around the world to study the event horizon of the supermassive black hole at the center of the Milky Way. In 2017, the EHT team used the Submillimeter Array (SMA, jointly built and operated by the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics), together with eight other facilities around the world, to examine the black hole and activity going on around it. SAO scientists also combined SMA observations

of flaring of the black hole (produced as the black hole accretes material) with simultaneous measurements taken by the Chandra and Spitzer space telescopes. In separate research, SAO scientists used the SMA to study for the first time the large region of our galaxy to probe an unexpected outburst in a newly forming star, thought to be due to accretion, and to analyze the structures of galaxies in the very early universe.

The Tropospheric Emissions: Monitoring Pollution (TEMPO) mission made excellent progress in 2017 and is nearing completion of the instrument construction, with launch scheduled in 2019. The mission will study the constituents of the atmosphere in more detail and precision than ever before, compiling a new dataset of atmospheric chemistry as measured from space. TEMPO will be the first space-based instrument to monitor major air pollutants across the North American continent every daylight hour at high spatial resolution.

NASA selected SAO's Arcus mission to compete in a final down-select for the next Medium-Class Explorer (MIDEX) mission. Arcus is a high-resolution x-ray grating spectrometer telescope mission. SAO is a team member of a second competing MIDEX selection: SPHEREx, a telescope that will conduct four all-sky infrared spectral surveys of the sky.

The SAO Eclipse Soundscapes project used sound to bring the 2017 total eclipse experience to the blind and visually impaired community. With audio descriptions of the eclipse delivered in real time and an interactive "Rumble Map," it allowed users to hear and feel the physical qualities of the eclipse, bringing this astronomical event to a larger, more diverse audience. Eclipse Soundscapes partnered with the National Park Service, Brigham Young University, and citizen scientists. The SAO Eclipse App was a free mobile app that calculated a user's view of the eclipse with an interactive map, providing a virtual view in an eclipse simulator, as well as a live NASA stream of the eclipse as it traveled across the continental United States. At the same time, users learned about solar research at the SAO. The MicroObservatory is a robotic network of telescopes operated by the CfA for research and public outreach purposes. During the eclipse, MicroObservatory facilities in Massachusetts and Arizona observed the eclipse from above and below the path of totality. Science education specialists engaged users by creating

eclipse animations and calculating the distance of the moon by comparing the two image sets.

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. Observatory Night talks also reach worldwide audiences via YouTube.

"The Dynamic Sun," an exhibit conceived, designed, and built by SAO researchers, features a giant seven- by six-foot video wall intended to create a visceral impact and show visitors how an ever-changing sun affects Earth. The "Dynamic Sun" at NASM in Washington, DC, continues to be seen by millions of visitors each year.

In FY 2017, NASM continued to educate and inspire the public through exhibits, research, and education programs, including discovery stations, lecture series, family educational events, publications, STEM Webcasts, and intern training. NASM was a center of activity for the historic August 21 solar eclipse, providing free eclipse glasses and safe solar telescope viewing, as well as a variety of educational activities. The eclipse was also broadcast live online from NASM's Phoebe Waterman Haas Public Observatory.

In September, NASM's "STEM in 30" program presented a live downlink from the International Space Station (ISS). Astronaut Randy Bresnik spoke with students at the museum, and the live broadcast was viewed in classrooms across the country. This event is part of a larger NASA-NASM collaboration that provides educational materials for teachers.

The exhibition "Artist Soldiers: Artistic Expression in the First World War" marked the 100th anniversary of the U.S. entry into World War I. This moving exhibition presents works of individual soldiers immersed in war. At the museum's Steven F. Udvar-Hazy Center, the exhibition "Clouds in a Bag: The Evelyn Way Kendall Ballooning and Early Aviation Collection" showcased artifacts and art from the time when humans first took to the skies in balloons. Also on display at the Udvar-Hazy Center was the suit worn by Alan Eustace when he broke the world record for the highest-altitude free-fall jump, skydiving from 135,890 feet.

Museum staff worked in 2017 to prepare the Apollo 11 Command Module Columbia for a four-city tour that began in October. Columbia will tour as part of the exhibition "Destination Moon: The Apollo 11 Mission." A 3D interactive unit created using high-resolution digital scans will allow visitors to explore this iconic symbol of the Space Age inside and out.

Staff members in NASM's Center for Earth and Planetary Studies (CEPS) continued to participate on the science teams of several spacecraft missions. Dr. John Grant 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. In addition, he is Cochair of the Mars 2020 Landing Site Steering Committee. CEPS staff are also on the science teams for the Mars Science Laboratory (MSL), the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on Mars Express, both the High Resolution Imaging Science Experiment (HiRISE) and Shallow Subsurface Radar (SHARAD) instruments on the Mars Reconnaissance Orbiter (MRO), the radar sounder on ESA's JUICE, the Lunar Reconnaissance Orbiter (LRO), MESSENGER, and the Europa Mission. CEPS continued its active research program in planetary and terrestrial geology and geophysics with research on such topics as comparative planetology; Martian fluvial, aeolian, impact, and volcanic features; tectonic studies of Mercury and Enceladus; and radar studies of the moon, Mercury, Venus, and Mars.

The Smithsonian National Museum of Natural History continued, through the Department of Mineral Sciences and the Offices of Education and Exhibits, its mission of education, research, and curation related to space exploration.

Approximately one million people per year visit the Moon, Meteorites and Solar System Gallery of the Geology, Gems and Meteorites Hall, where they can see one of the finest displays of meteorites anywhere in the world, ranging from presolar diamonds separated from the Allende meteorite; to the carbonate-bearing Allan Hills 84001 meteorite, which spurred the debate about past microbial life on Mars; to impactites, including a square-meter section of the K-T boundary layer (the K-T marks the point between the Cretaceous and Tertiary periods).

The collections of the Division of Meteorites continue to grow, including through the acquisition of a portion of the "Black Beauty" meteorite shower that

samples ancient regolith on Mars. Notably, the Smithsonian's partnership with the NSF and NASA in the U.S. Antarctic Meteorite Program surpassed 25,000 individual meteorites collected in Antarctica, including samples from Mars, the moon, and numerous poorly known asteroids. Provided free of charge to qualified scientists, these samples help scientists address fundamental questions about the origin and evolution of our solar system.

Scientists in the Department of Mineral Sciences remain engaged in the study of meteorites and asteroids to unravel their origin in the early solar nebula, their evolution on asteroids, the differentiation of asteroids in the early history of the solar system, and the geologic evolution of Mars. NMNH scientists remain actively engaged in spacecraft missions, with Tim McCoy serving as Co-Investigator on the OSIRIS-REx mission and Psyche missions and having just completed working on the MESSENGER mission. OSIRIS-REx will visit asteroid Bennu and return samples to Earth for study. McCoy is leading efforts to map the geology of the asteroid and will study the mineralogy and origin of the samples when they return to Earth in 2023. He will lead efforts to exhibit a sample of Bennu at NMNH. The Psyche mission, which was selected as one of the newest Discovery missions this year, will visit the asteroid of the same name, which is a 200-kilometer-diameter asteroid thought to be composed of metallic iron, akin to our own metallic core. McCoy will lead efforts to study the role of oxidation and reduction in the formation of this asteroid. Dr. Catherine Corrigan is a Co-Investigator on a proposal for NASA's latest call for missions in the New Frontiers Program, where she joins a team proposing to return material from the surface of a comet.

Public outreach beyond the exhibit continues to be a focus of our efforts, with numerous "Scientist Is In" presentations in the *Q?rius* learning center at NMNH and outreach efforts beyond the National Mall, including digital outreach through NMNH's Web site and Dr. Corrigan's appearance on the NPR podcast *Undiscovered*.

Appendices

Appendix A-1

U.S. Government Spacecraft Record

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

Calendar Year	Earth Orbit[a]		Earth Escape	
	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	22	1	0	0
2015	12	1	1	0
2016	27	3	2	0
2017*	20	1	0	0
* (through September 30, 2017)				
TOTAL	**1,795**	**163**	**113**	**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 United States.

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[d]	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[e]	19	29			3	14			7	3				1
2014[e]	22	31			4	16			10	4	1			
2015	13	16			3	9			8	4		1		
2016	29	25			5	32			14	8	1		1	
2017*	20	13			4	8			9	5				
*(through September 30, 2017)														
TOTAL	**1,550**	**3,060**	**10**	**8**	**100**	**250**	**1**	**1**	**262**	**58**	**8**	**4**	**2**	**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.
d. Since 2008, the ESA statistics include the Soyuz launches from Guiana Space Centre.
e. The data published in the FY 2014 report reflect incorrect totals and have been adjusted.

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

October 1, 2016–September 30, 2017

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
October 17, 2016 Cygnus CRS OA-5 2016-062A Antares 230	International Space Station	ISS	Cargo Resupply
November 11, 2016 WorldView 4 2016-067A Atlas 5-401	Earth observation	504 496 94.61 51.64	Operated by DigitalGlobe
November 19, 2016 GOES-R 2016-071A Atlas 5-541	Earth observation	35,792 35,782 1,436.1 0.0	U.S. National Oceanic and Atmospheric Administration meteorological satellite Also called GOES 16
December 7, 2016 WGS 8 (USA 272) 2016-075A Delta 4M+5,4	Military/Communications	N/A	Department of Defense
December 15, 2016 CYGNSS 2016-078A-H Pegasus XL	Earth observation	536 513 95.1 35.0	Weather satellite developed and operated by the Southwest Research Institute (SwRI), University of Michigan, and NASA's Science Mission Directorate Cyclone Global Navigation Satellite System (CYGNSS) Constellation of eight microsatellite observatories
December 18, 2016 Echostar 19/Jupiter 2 2016-079A Atlas 5-431	Communications	35,793 35,781 1,436.1 0.0	Broadband internet satellite operated by Hughes Network Systems
January 14, 2017 Iridium Next 1-10 2017-003D A-H, JK Falcon 9 v1.2	Communications	780 776 100.4 86.4	Operated by Iridium Communications, Inc. Ten satellites
January 21, 2017 SBIRS GEO 3/ US-273 2017-004A Atlas 5-401	Military/Communications	N/A	U.S. Air Force
February 19, 2017 Dragon/CRS-10 2017-009A Falcon 9 v1.2	International Space Station	ISS	Cargo resupply
March 1, 2017 NROL 79/USA 274 2017-011B Atlas 5-401	Surveillance/Military	N/A	U.S. National Reconnaissance Office Also known as Naval Ocean Surveillance System (NOSS) 3
March 16, 2017 Echostar 23 2017-014A Falcon 9 v1.2	Communications	35,796 35,778 1,436.1 0.0	Television broadcast satellite operated by Hughes Network Systems
March 19, 2017 WGS 9 2017-016A Delta 4M+5,4	Military/Communications	N/A	U.S. Air Force
March 30, 2017 SES 10 2017-017A Falcon 9 v1.2	Communications	35,798 35,775 1,436.1 0.01	Designed and built by Airbus Defence and Space for SES S.A.

* U.N. Committee on Space Research

Appendix B (cont.)

SUCCESSFUL LAUNCHES TO ORBIT ON U.S. VEHICLES

October 1, 2016–September 30, 2017

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
April 18, 2017 Dragon/Cygnus OA-7 2017-019A Atlas 5-401	International Space Station	ISS	Cargo resupply
May 1, 2017 NROL 76 2017-022A Falcon 9 v1.2	Surveillance/Military	N/A	U.S. National Reconnaissance Office
May 15, 2017 Inmarsat 5 F4 2017-025A Falcon 9 v1.2	Communications	35,602 35,595 1,426.49 0.04	Operated by Inmarsat, PLC, for mobile satellite broadband support
June 3, 2017 Dragon 6/CRS-11 2017-030A Falcon 9 v1.2	International Space Station	ISS	Cargo resupply
June 23, 2017 BulgariaSat 1 2017-038A Falcon 9 v1.2	Communications	35,798 35,776 1,436.1 0.0	Operated by Bulsatcom
June 25, 2017 Iridium Next 11-20 2017-039A-H, JK Falcon 9 v1.2	Communications	627 606 97.03 85.61	Operated by Iridium Communications, Inc. Ten satellites
July 5, 2017 Intelsat 35e 2017-041A Falcon 9 v1.2	Communications	35,797 35,778 1,436.1 0.02	Designed and built by Boeing for Intelsat, S.A.
August 14, 2017 CRS-12 2017-045A Falcon 9 v1.2	International Space Station	ISS	Cargo resupply Last of 12 resupply missions under Commercial Resupply Services contract
August 18, 2017 TDRS-M 2017-047A Atlas 5-401	Communications	35,821 35,751 1,436.1 6.9	Tracking and Data Relay Satellite M (TDRS-M), part of NASA's Space Network Also called TDRS-13
August 24, 2017 Formosat 5 2017-049A Falcon 9 v1.2	Earth observation	729.9 716.6 99.25 98.3	Earth remote sensing satellite that was built and operated by the National Space Organisation of the Republic of China (Taiwan)
August 26, 2017 ORS 5 2017-050A Minotaur 4	Surveillance/Military	N/A	Also called Sensorsat, used by U.S. Air Force for space situational awareness (SSA) or space surveillance—monitoring other satellites in orbit
September 7, 2017 OTV-5 2017-052A Falcon 9 v1.2	Military	N/A	X-37B mission carrying the Air Force Research Laboratory (AFRL) Advanced Structurally Embedded Thermal Spreader (ASETS-11) to test experimental electronics and oscillating heat pipes
September 24, 2017 NROL 42 (USA 278) 2017-056A Atlas 5-541	Surveillance/Military	N/A	U.S. National Reconnaissance Office

Appendix C
HUMAN SPACEFLIGHTS

October 1, 2016–September 30, 2017

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz MS-02 (Expedition 49)	October 19, 2016	Shane Kimbrough Andrei Borisenko Sergey Ryzhikov	173:03:16	Orbital ATK's Cygnus CRS OA-05 docked to the ISS on October 23, 2016
Soyuz MS-03 (Expedition 50)	November 17, 2016	Oleg Novitsky Thomas Pesquet Peggy Whitson	196:17:49	Peggy Whitson set NASA record for cumulative time in space: 665 days Installed adapter plates for six new lithium-ion batteries Japan Aerospace Exploration Agency's HTV-6 docked to the ISS on December 13, 2016 SpaceX CRS-10 docked to the ISS on February 23, 2017
Soyuz MS-04 (Expedition 51)	April 20, 2017	Fyodor Yurchikhin Jack Fischer	135:18:08	Crew conducted 200th ISS spacewalk on May 12, 2017 Orbital ATK's CRS-7 docked to the ISS on April 22, 2017 Installed a protective shield on the Pressurized Mating Adapter-3 SpaceX CRS-11 docked to the ISS on June 5, 2017
Soyuz MS-05 (Expedition 52)	July 28, 2017	Sergei Ryazanski Randy Bresnik Paolo Nespoli	N/A	Manually deployed five nanosatellites SpaceX CRS-12 docked to the ISS on August 16, 2017
Soyuz MS-06 (Expedition 53)	September 12, 2017	Alexander Misurkin Mark Vande Hei Joseph Acaba	N/A	Replaced a Latching End Effector (LEE) on the Station's robotic arm, Canadarm2 Installed a camera system on the LEE

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[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	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
2015	18,010	17,359	10,325	3,010	182	2,223	83	19	485	18	30,694
2016	19,285	18,645	6,967	3,159	178	2,346	87	19	508	22	28,771
2017	19,653	18,993	10,316	2,995	172	2,214	85	20	480	24	32,304

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.
b. 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 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.
c. DOE has recalculated its space expenditures since 1998.
d. 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 2017 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	6.591	2,181	1,720	3,229	224	224						5,174
1960	6.500	3,406	3,003	3,646	279	279						6,929
1961	6.411	6,181	5,937	5,219	436	436						11,592
1962	6.347	11,583	11,405	8,238	1,263	939	324					20,906
1963	6.269	23,027	22,732	9,717	1,611	1,342	270					34,061
1964	6.194	31,588	31,068	9,904	1,319	1,301	19					42,291
1965	6.087	31,958	31,276	9,581	1,467	1,394	73					42,324
1966	5.959	30,837	30,182	10,065	1,275	1,114	161					41,522
1967	5.782	28,715	27,929	9,622	1,232	1,064	168					38,782
1968	5.591	25,646	24,768	10,746	974	811	157	1	6			36,487
1969	5.345	21,333	20,430	10,760	911	631	107	1	5	167		32,101
1970	5.072	19,000	17,991	8,511	715	522	41	5	5	142		27,217
1971	4.828	15,984	14,971	7,299	782	459	130	10	5	178		23,052
1972	4.609	15,243	14,155	6,485	615	254	143	28	9	182		21,256
1973	4.417	15,044	13,661	7,169	651	239	177	44	9	183		21,481
1974	4.125	12,529	11,382	7,285	652	173	248	37	12	182		19,320
1975	3.738	12,071	10,897	7,073	590	112	239	30	7	201		18,560
1976	3.496	12,410	11,274	6,932	588	80	252	35	14	207		18,795
TQ*	3.394	3,163	2,882	1,561	146	17	75	10	3	41		4,589
1977	3.261	12,451	11,218	7,866	631	72	297	33	20	210		19,715
1978	3.056	12,407	11,072	8,367	691	104	315	31	24	217		20,129
1979	2.828	12,999	11,398	8,587	701	167	277	28	23	206		20,686
1980	2.602	13,634	12,177	10,012	601	104	242	31	36	188		22,791
1981	2.370	13,077	11,830	11,442	555	97	206	28	38	186		23,827
1982	2.218	13,403	12,258	14,811	693	135	322	27	33	177		27,763
1983	2.124	14,604	13,442	19,159	695	83	378	11	42	181		33,296
1984	2.052	15,303	14,072	20,919	810	70	484	6	39	211		35,800
1985	1.986	15,040	13,753	25,357	1,159	68	840	4	30	218		40,269
1986	1.942	15,159	13,912	27,428	926	68	600	4	45	209		42,266
1987	1.899	20,746	18,630	30,934	885	91	528	15	36	212	2	50,449
1988	1.840	16,671	15,310	32,524	1,363	443	648	26	33	212	2	49,197
1989	1.769	19,407	17,864	31,680	991	172	533	30	37	214	5	50,535
1990	1.708	21,044	19,569	26,665	863	135	415	53	43	211	7	47,097
1991	1.649	23,114	21,514	23,386	1,273	414	414	48	43	348	7	46,173
1992	1.610	23,046	21,246	24,182	1,284	359	526	55	47	291	6	46,712
1993	1.572	22,500	20,541	22,179	1,149	259	509	52	39	283	6	43,869
1994	1.539	22,420	20,038	20,259	973	114	480	48	48	276	8	41,270
1995	1.507	20,875	18,900	16,038	1,143	90	530	47	48	419	9	36,081
1996	1.479	20,537	18,592	17,032	1,224	68	698	53	55	341	9	36,848
1997	1.454	19,927	18,107	17,046	1,148	51	651	61	57	319	9	36,301
1998	1.436	19,597	17,691	17,746	1,205	148	625	62	56	307	9	36,642
1999	1.418	19,358	17,665	18,720	1,392	149	815	84	52	284	9	37,778
2000	1.389	18,891	17,391	17,975	1,466	228	799	83	61	287	8	36,832
2001	1.357	19,303	18,047	19,433	1,441	197	783	81	49	315	16	38,921
2002	1.335	19,847	18,516	21,011	1,575	222	860	85	37	355	16	41,103
2003	1.310	20,125	18,810	25,396	1,709	250	850	97	55	441	16	45,915
2004	1.278	19,658	18,307	24,433	1,871	267	952	91	78	468	15	44,611
2005	1.239	20,074	18,879	24,402	1,922	284	1,000	87	90	446	15	45,203
2006	1.200	19,952	18,922	26,542	1,977	294	1,032	98	101	437	14	47,441
2007	1.169	19,029	18,192	26,196	1,963	234	1,066	102	76	472	14	46,351
2008	1.145	19,595	18,891	28,384	1,944	223	987	103	68	548	15	49,219
2009	1.132	20,114	19,548	30,019	2,114	226	1,220	72	30	549	16	51,681
2010	1.122	21,004	20,447	29,684	2,307	228	1,415	75	30	543	17	52,438
2011	1.099	20,264	19,677	29,941	2,403	252	1,588	73	21	453	16	52,020
2012	1.080	19,189	18,574	28,802	2,785	215	2,025	82	7	438	17	50,161
2013	1.062	18,469	17,906	10,818	2,737	196	1,980	89	21	434	16	32,129
2014	1.043	17,647	17,081	10,400	2,839	174	2,087	82	19	461	16	31,613
2015	1.031	18,010	17,359	10,325	3,010	182	2,223	83	19	485	18	30,694
2016	1.018	19,285	18,645	6,967	3,159	178	2,346	87	19	508	22	28,771
2017	1.000	19,653	18,993	10,316	2,995	172	2,214	85	20	480	24	32,304

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.
b. 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 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.
c. DOE has recalculated its space expenditures since 1998.
d. 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)

Federal Agencies	Budget Authority 2015 actual	2016 actual	2017 actual	2018 est.	Budget Outlays 2015 actual	2016 actual	2017 actual	2018 est.
NASA[1]	17,359	18,645	18,993.3	18,468.2	17,697.4	18,225	18,074	18,820
DOD[2, 3]	10,325	9,655	10,136	11,390	10,854	10,300	10,400	10,500
DOE[4]	182	178	172	169	198	180	173	170
DOC[5]	2,223.1	2,346	2,214	1,833	1,300.3	2,053	1,938	1,833
DOI[6]	82.2	71.2	85.4	83.6	82	71.1	85	83.5
USDA[7]	18.9	18.5	20.1	14.3	17.3	17.1	18.4	14.1
DOT	17.6	21.8	24.2	26.3	17.6	21.8	24.2	26.3
NSF[8]	485.2	507.5	480.1	483.9	444.6	382.6	352.7	459.1

1. The FY 2018 estimate is based on the prior year's Outlays versus Budget Authority. FY 2018 Enacted Funding Levels were not available at the time this report was requested. The FY 2018 Budget Authority Estimate is based on the 2018 President's Budget Request.
2. Does not include DOD or Office of the Director of National Intelligence (ODNI) intelligence programs. DOD FY 2015, FY 2016, and FY 2017 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.
3. At the time of preparing this report, DOD submitted estimates as billions of dollars, so the figures are rounded to the nearest hundred million.
4. In prior years, the High Energy Physics program also reported Ground- and Underground-Based Astrophysics Projects. These projects and the associated funding are no longer included, starting in the FY 2009 report.
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 2015 Actual and Outlays are estimates for both satellite and aerial funding.
7. At the time of preparing this report, the USDA submitted FY 2017 estimates, not actuals.
8. "Actual" = actual obligations.

Appendix D-3

Federal Aeronautics Activities Budget

(in millions of dollars by fiscal year)

	Budget Authority				Budget Outlays			
Federal Agencies	**2015 actual**	**2016 actual**	**2017 actual**	**2018 est.**	**2015 actual**	**2016 actual**	**2017 actual**	**2018 est.**
NASA[1]	651	640	660	624	578.3	609	629	622
USDA[2, 3]	26.7	37.3	38.6	44.2	32.6	36.6	70.7	30.1
DOD[4, 5]	50,800	50,550	53,440	49,900	32,422	33,351	33,213	32,630
DOI[6]	25	30.4	35	34.7	25.2	29.5	35.1	26.3
DOT	2,741.8	3,004.9	3,014.9	2,995.1	2,761.1	2,733.9	2,674.9	3,105.9

1. The FY 2018 estimate is based on the prior year's Outlays versus Budget Authority.
2. At the time of preparing this report, the USDA submitted estimates, not actuals.
3. FY 2017 is the first time the National Resources Conservation Service (NRCS) is reporting state expenditures for this report. FY 2017 Outlays represent national lidar initiatives, where NRCS spent $3 million and state offices spent another $33 million.
4. DOD FY 2015, FY 2016, and FY 2017 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.
5. At the time of preparing this report, DOD submitted estimates as billions of dollars, so the figures are rounded to the nearest hundred million.
6. The numbers for FY 2015 Actual and Outlays are estimates for both satellite and aerial funding.

Appendix E-1

Executive Order 13803 of June 30, 2017

Reviving the National Space Council

By the authority vested in me as President by the Constitution and the laws of the United States of America, and in order to provide a coordinated process for developing and monitoring the implementation of national space policy and strategy, it is hereby ordered as follows:

Section 1. Purpose. The National Space Council (Council) was established by Title V of Public Law 100-685 and Executive Order 12675 of April 20, 1989 (Establishing the National Space Council). The Council was tasked with advising and assisting the President regarding national space policy and strategy. The Council was never formally disestablished, but it effectively ceased operation in 1993. This order revives the Council and provides additional details regarding its duties and responsibilities.

Sec. 2. Revival and Composition of the National Space Council.

(a) The Council is hereby revived and shall resume operations.

(b) The Council shall be composed of the following members:

(i) The Vice President, who shall be Chair of the Council;

(ii) The Secretary of State;

(iii) The Secretary of Defense;

(iv) The Secretary of Commerce;

(v) The Secretary of Transportation;

(vi) The Secretary of Homeland Security;

(vii) The Director of National Intelligence;

(viii) The Director of the Office of Management and Budget;

(ix) The Assistant to the President for National Security Affairs;

(x) The Administrator of the National Aeronautics and Space Administration;

(xi) The Director of the Office of Science and Technology Policy;

(xii) The Assistant to the President for Homeland Security and Counterterrorism;

(xiii) The Chairman of the Joint Chiefs of Staff; and

(xiv) The heads of other executive departments and agencies (agencies) and other senior officials within the Executive Office of the President, as determined by the Chair.

Sec. 3. Functions of the Council.

(a) The Council shall advise and assist the President regarding national space policy and strategy, and perform such other duties as the President may, from time to time, prescribe.

(b) In particular, the Council is directed to:

(i) review United States Government space policy, including long-range goals, and develop a strategy for national space activities;

(ii) develop recommendations for the President on space policy and space-related issues;

(iii) monitor and coordinate implementation of the objectives of the President's national space policy and strategy;

(iv) foster close coordination, cooperation, and technology and information exchange among the civil, national security, and commercial space sectors;

(v) advise on participation in international space activities conducted by the United States Government; and

(vi) facilitate the resolution of differences concerning major space and space-related policy matters.

(c) The Council shall meet at least annually.

(d) The revival and operation of the Council shall not interfere with the existing lines of authority in or responsibilities of any agencies.

(e) The Council shall have a staff, headed by a civilian Executive Secretary appointed by the President.

Sec. 4. Responsibilities of the Chair.

(a) The Chair shall serve as the President's principal advisor on national space policy and strategy.

(b) The Chair shall, in consultation with the members of the Council, establish procedures for the Council and establish the agenda for Council activities.

(c) The Chair shall report to the President quarterly on the Council's activities and recommendations. The Chair shall advise the Council, as appropriate, regarding the President's directions with respect to the Council's activities and national space policy and strategy.

(d) The Chair may recommend to the President candidates for the position of Executive Secretary.

(e) The Chair, or upon the Chair's direction, the Executive Secretary, may invite the heads of other agencies, other senior officials in the Executive Office of the President, or other Federal employees to participate in Council meetings.

(f) The Chair shall authorize the establishment of committees of the Council, including an executive committee, and of working groups, composed of senior designees of the Council members and of other Federal officials invited to participate in Council meetings, as he deems necessary or appropriate for the efficient conduct of Council functions.

Sec. 5. National Space Policy and Strategy Planning Process.

(a) Each agency represented on the Council shall provide such information to the Chair regarding its current and planned space activities as the Chair shall request.

(b) The head of each agency that conducts space-related activities shall, to the extent permitted by law, conform such activities to the President's national space policy and strategy.

(c) On space policy and strategy matters relating primarily to national security, the Council shall coordinate with the National Security Council (NSC) to create policies and procedures for the Council that respect the responsibilities and authorities of the NSC under existing law.

Sec. 6. Users' Advisory Group.

(a) The Council shall convene a Users' Advisory Group (Group) pursuant to Public Law 101-611, section 121, composed of non-Federal representatives of industries and other persons involved in aeronautical and space activities.

(b) Members of the Group shall serve without any compensation for their work for the Group. Members of the Group, while engaged in the work of the Group, may be allowed travel expenses, including per diem in lieu of subsistence, to the extent permitted by law for persons serving intermittently in Government service (5 U.S.C. 5701-5707), consistent with the availability of funds.

(c) The Group shall report directly to the Council and shall provide advice or work product solely to the Council.

Sec. 7. Administrative Provisions.

(a) To aid in the performance of the functions of the Council:

(i) The Office of Administration in the Executive Office of the President shall provide the Council with administrative support on a reimbursable basis; and

(ii) Legal advice to the Council itself with respect to its work and functions shall be provided exclusively by the Office of the Counsel to the President.

(b) To the extent practicable and permitted by law, including the Economy Act, and within existing appropriations, agencies serving on the Council and interagency councils and committees that affect space policy or strategy shall make resources, including, but not limited to, personnel, office support, and printing, available to the Council as reasonably requested by the Chair or, upon the Chair's direction, the Executive Secretary.

(c) Agencies shall cooperate with the Council and provide such information and advice to the Council as it may reasonably request, to the extent permitted by law.

Sec. 8. Report.

Within 1 year of the date of this order, and annually thereafter, the Council shall submit a report to the President setting forth its assessment of, and recommendations for, the space policy and strategy of the United States Government.

Sec. 9. General Provisions.

(a) This order supersedes Executive Order 12675 of April 20, 1989 (Establishing the National Space Council). To the extent this order is inconsistent with any provision of any earlier Executive Order or Presidential Memorandum, this order shall control.

(b) If any provision of this order or the application of such provision is held to be invalid, the remainder of this order and other dissimilar applications of such provision shall not be affected.

(c) This order is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person.

(d) Nothing in this order shall be construed to impair or otherwise affect:

(i) the authority granted by law to an executive department or agency, or the head thereof; or

(ii) the functions of the Director of the Office of Management and Budget relating to budgetary, administrative, or legislative proposals.

(e) This order shall be implemented consistent with applicable law and subject to the availability of appropriations.

Donald J. Trump

The White House,

June 30, 2017

Appendix E-2

Remarks by the President Signing an Executive Order on the National Space Council

Roosevelt Room

THE PRESIDENT: Thank you, very much. You don't mind if I do that? Get rid of it. (Laughter.)

Thank you very much to our great Vice President and also for the fantastic job that Mike has been doing.

The future of American space leadership—we're going to lead again. It's been a long time. It's over 25 years, and we're opening up, and we are going to be leading again like we've never led before.

We're a nation of pioneers, and the next great American frontier is space. And we never completed—we started, but we never completed. We stopped. But now we start again. And we have tremendous spirit, and we're going to have tremendous spirit from the private sector—maybe in particular from the private sector.

I'd like to extend a special welcome to an American hero who've I've known actually for a long time, Buzz Aldrin, who is with us today. (Applause.) Known him a long time. Thank you also to Astronauts Benjamin Drew and David Wolf and former NASA Flight Director Gene Kranz for being with us and for working with us on exactly what we're doing today. Thank you all very much. We appreciate it. Thank you, thank you, thank you. (Applause.)

We're also joined by our great Secretary of Commerce, Wilbur Ross, who spent the morning negotiating trade deals with South Korea. And as you know, that trade deal is coming due, and it actually came due a couple of weeks ago. And I think we're going to make a good deal, right?

SECRETARY ROSS: We've made some progress.

THE PRESIDENT: I think so. That's what the word is. And good for both countries.

Also distinguished members of Congress are with us, and leaders of several of America's great aerospace companies.

Today, we're taking a crucial step to secure America's future in space by reviving the National Space Council after it was—has been dormant almost 25 years if you can believe it.

During the campaign, Vice President Pence promised that our administration—because Mike is very much into space—would revive the National Space Council, and with this executive order, we're keeping that promise. Feel very strongly about it. I've felt strongly about it for a long time. I used to say before doing what I did—I used to say, what happened? Why aren't we moving forward?

Today's announcement sends a clear signal to the world that we are restoring America's proud legacy of leadership in space.

Our Vice President cares very deeply about space policy, and for good reason—space exploration is not only essential to our character as a nation, but also our economy and our great nation's security.

Our travels beyond the Earth propel scientific discoveries that improve our lives in countless ways here, right here, at home: powering vast new industry, spurring incredible new technology, and providing the space security we need to protect the American people. And security is going to be a very big factor with respect to space and space exploration. At some point in the future, we're going to look back and say how did we do it without space?

The Vice President will serve as the council's chair. Several representatives of my administration will join him including the Secretaries of State, Defense, Commerce, Transportation, and Homeland Security; the Chairman of the great—I'll tell you, he's doing a fantastic job, always working, always fighting, and winning—winning big against ISIS, that I can tell you, seeing what's happening there—the Chairman of the Joint Chiefs of Staff, the National Security Advisor, NASA, and the Director of National Intelligence.

The council will also draw the expertise of other White House offices as well as insights from scientists, innovators, and business leaders from across the country. Many business leaders that want to be a big part of this. I think the privatization of certain aspects is going to play a very crucial role, don't you think? They are truly into it. This coordination will be accomplished through an advisory group that is being convened by today's executive order, which I'll be signing in a minute.

The National Space Council will be a central hub guiding space policy within the administration. And I will draw on it for advice and information and recommendations for action. And the Vice President, myself, and a few others are going to pick some private people to be on the board. I will say that's not easy because everybody wants to be on this board. People that you wouldn't have believed loved what we're doing so much they want to—some of the most successful people in the world want to be on this board.

The human soul yearns for discovery. By unlocking the mysteries of the universe, we unlock truths within ourselves. That's true. Our journey into space will not only make us stronger and more prosperous, but will unite us behind grand ambitions and bring us all closer together. Wouldn't that be nice? Can you believe that space is going to do that? I thought politics would do that. (Laughter.) Well, we'll have to rely on space instead.

Every launch into the skies is another step forward toward a future where our differences seem small against the vast expanse of our common humanity. Sometimes you have to view things from a distance in order to see the real truth. It is America's destiny to be at the forefront of humanity's eternal quest for knowledge and to be the leader amongst nations on our adventure into the great unknown. And I could say the great and very beautiful unknown. Nothing more beautiful.

With the actions we are launching today, America will think big once again. Important words: Think big. We haven't been thinking so big for a long time, but we're thinking big again as a county. We will inspire millions of children to carry on this proud tradition of American space leadership—and they're excited—and to never stop wondering, hoping, and dreaming about what lies beyond the stars.

So, I just want to tell you that we are now going to sign an executive order, and this is going to launch a whole new chapter for our great country. And people are very excited about it and I can tell you, I'm very excited about it. Thank you all very much. (Applause.)

(The order is signed.)

COLONEL ALDRIN: Infinity and beyond. (Laughter.)

THE PRESIDENT: This is infinity here. It could be infinity. We don't really don't know. But it could be. It has to be something—but it could be infinity, right?

Okay. (Applause.)

END

Acronyms

3DEP	3D Elevation Program

A

AA&S	Aircraft Airworthiness and Sustainment
AARGM	Advanced Anti-Radiation Guided Missile
ABEDRR	Advanced Booster Engineering Demonstration and/or Risk Reduction
ABoVE	Arctic-Boreal Vulnerability Experiment
ACE	Advanced Composition Explorer
ACEP	Agricultural Conservation Easement Program
ACES	Atomic Clock Ensemble in Space
ACME	Affordable Cruise Missile Engine
ACS	Altitude Combustion Stand
ACT	Atacama Cosmology Telescope
ACT-America	Atmospheric Carbon and Transport–America
ACTE	Adaptive Compliant Trailing Edge
ADATS	Advanced Data Acquisition and Telemetry System
ADS-B	Automatic Dependent Surveillance–Broadcast
AE	Archive Explorer
AEFS	Advanced Electronic Flight Strips
AEHF	Advanced Extremely High Frequency
AES	Advanced Exploration Systems
AFB	Air Force Base
AFL	Availability for Launch
AFRCO	Air Force Rapid Capabilities Office
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
AGS	Atmospheric and Geospace Science Division
AIA	Atmospheric Imaging Assembly
AIM	Aeronomy of Ice in the Mesosphere
AIPD	Architecture Implementation Process Demonstrations
AIRS	Atmospheric Infrared Sounder
AIR-SPEC	Airborne Infrared Spectrometer
AIT	Accident Investigation Team; American Institute in Taiwan
AKRO	Alaska Regional Office
ALIAS	Aircrew Labor In-Cockpit Automation System
ALMA	Atacama Large Millimeter/Submillimeter Array
AMC	Additive Manufacturing Consortium
AMEC	Alaska Mapping Executive Committee
AMISR	Advanced Modular Incoherent-Scatter Radar
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMS	Autonomous Modular Sensor; Alpha Magnetic Spectrometer
AMSR	Advanced Microwave Scanning Radiometer
AO	Arecibo Observatory
APKWS	Advanced Precision Kill Weapon System
AR	Aerojet Rocketdyne
ARCN	Arctic Inventory and Monitoring Network
ARI	Aviation Restructure Initiative
ARM	Asteroid Redirect Mission; Atmospheric Radiation Measurement

ARMD	Aeronautics Research Mission Directorate
ARS	Agricultural Research Service
AS	Atmosphere Section
ASB	Agricultural Statistics Board
ASBU	Aviation System Block Upgrade
ASE	Aviation Survivability Equipment
ASETS	Advanced Structurally Embedded Thermal Spreader
ASR	Atmospheric System Research
AST	Division of Astronomical Sciences; Office of Commercial Space Transportation
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASU	Group on the Sector Understanding on Export Credits for Civil Aircraft (the "Aircraft Sector Understanding")
ASuW	Anti-Surface Warfare
ATCA	Air Traffic Control Association
ATD-2	Airspace Technology Demonstration 2
ATDS	Advanced Threat Detection System
ATM	Air Traffic Management
ATom	Atmospheric Tomography
Auto-GCAS	Autonomous Ground Collision Avoidance System
AUVSI	Association for Unmanned Vehicle Systems International
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer–Next Generation
AWiFS	Advanced Wide Field Sensor

B

BAA	Broad Agency Announcement
BAER	Burn Area Emergency Response
BANWR	Buenos Aires National Wildlife Refuge
BaPSF	Basic Plasma Science Facility
BAU	Business As Usual
BEAM	Bigelow Expandable Activity Module
BECCAL	Bose-Einstein Condensate Cold Atom Laboratory
BICEP3	Background Imaging of Cosmic Extragalactic Polarization
BIS	Bureau of Industry and Security
BLAST-TNG	Balloon-borne Large-Aperture Submillimeter Telescope–The Next Generation
BLI	boundary-layer-ingesting
BLM	Bureau of Land Management
Bm^3	billion cubic meters
BMC2	Battle Management Command and Control
BMGG	Bulk Metallic Glass Gears
BNL	Brookhaven National Laboratory
BOR	Bureau of Reclamation
BPS	Biological and Physical Sciences
BRB	Big Red Plasma Ball

C

C&N	communication and navigation
C2	command and control
CAE	Center for Agribusiness Excellence
CAESR	Carbon Absolute Electrical Substitution Radiometer
CAFE	Cold Air From Engines
CAL	Cold Atom Laboratory
CARAFE	Carbon Airborne Flux Experiment

CASIS	Center for the Advancement of Science in Space
CCAFS	Cape Canaveral Air Force Station
CCG	Copernicus Coordination Group
CCP	Commercial Crew Program
CCRPP	Civilian Commercialization Readiness Pilot Program
CCS	Counter Communications System
CCSC	Collaborations for Commercial Space Capabilities
CCSDS	Consultative Committee for Space Data Systems
CDL	Cropland Data Layer
CDOM	colored dissolved organic matter
CDR	Critical Design Review
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CENRS	Committee on Environment, Natural Resources, and Sustainability
CEOS	Committee on Earth Observation Satellites
CEPS	Center for Earth and Planetary Studies
CfA	Center for Astrophysics
CHARA	Center for High Angular Resolution Astronomy
CIR	Color Infrared
CISBoomDA	Cockpit Interactive Sonic Boom Display Avionics
CJCS	Chairman of the Joint Chiefs of Staff
CLASS	Cosmic Large Angular Scale Survey
CLU	Common Land Unit
CM	Crew Module
CMA	Crew Module Adapter
CMB	cosmic microwave background
CME	coronal mass ejection
CMM	Coordinate Measuring Machine
CMWS	Common Missile Warning System
CNES	Centre National d'Études Spatiales
CNN	Convolutional Neural Network
CNT ESR	Carbon Nano-tube Electrical Substitution Radiometer
COA	Course of Action
COBRA	Coastal Battlefield Reconnaissance and Analysis
CONOPS	Concept of Operations
CONUS	Contiguous United States
COPUOS	Committee on the Peaceful Uses of Outer Space
CORAL	COral Reef Airborne Laboratory
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COSPAR	U.N. Committee on Space Research
COSPAS-SARSAT	Search and Rescue Satellite-Aided Tracking
COWVR	Compact Ocean Wind Vector Radiometer
CRISP	Critical Resilient Interdependent Infrastructure Systems and Processes
CRS	Commercial Resupply Services
CS	Commercial Service
CSG	Carrier Strike Group
CSIM	Compact Solar Irradiance Monitor
CSJWG	Civil Space Joint Working Group
CSLI	CubeSat Launch Initiative
CST	Crew Space Transportation
CT-2	Crawler-Transporter 2
CVN	aircraft carrier with nuclear propulsion
CVW	Carrier Air Wing
CWDP	Commercial Weather Data Pilot
CY	calendar year
CYGNSS	Cyclone Global Navigation Satellite System

D

DAF	Device Assembly Facility
DAMIEN	Detecting and Mitigating the Impact of Earth-bound Near-Earth objects
DARPA	Defense Advanced Research Projects Agency
Data Comm	Data Communications
DEM	digital elevation model
DEN	Department of the Environment in Nunavut
DHS	Department of Homeland Security
DKIST	Daniel K. Inouye Solar Telescope
DLR	German Space Agency
DMC	Disaster Monitoring Constellation
DNN R&D	Defense Nuclear Nonproliferation Research and Development
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DopplerScat	Doppler Scatterometer
DOS	Department of State
DSCOVR	Deep Space Climate Observatory
DSG	Deep Space Gateway
DSM	Digital Surface Model
DSN	Deep Space Network
DSP	Defense Support Program
DST	Deep Space Transport
DT	Development Test
DTM	Digital Terrain Model
DTN	Disruption Tolerant Networking
DV	depth and velocity

E

EBIS	Electron Beam Ion Source
ECAMS	Environmental Continuous Air Monitors
ECLSS	Environmental Control and Life Support System
ECMWF	European Centre for Medium-Range Weather Forecasts
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EDGE	Europa Deep Geophysical Explorer
EELV	Evolved Expendable Launch Vehicle
EHT	Event Horizon Telescope
ELV	expendable launch vehicle
EM-1	Exploration Mission–1
EM-2	Exploration Mission–2
EMD	Engineering and Manufacturing Development
EOC	Early Operational Capability
EO/IR	Electro-Optical/Infrared
EOS	Earth Observing System
EPS	Enhanced Polar System
ERAM	En Route Automation Modernization
ERAU	Embry-Riddle Aeronautical University
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESBMC2	Enterprise Space Battle Management Command and Control
ESD	Earth Science Division; Exploration Systems Development
ESG	Expeditionary Strike Group

ESIMS	earth stations in motion
ESM	ESA Service Module
ESP	Efficient Space Procurement
ETM	Enhanced Thematic Mapper
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUV	Extreme Ultraviolet
EVA	extravehicular activity
EVE	Extreme Ultraviolet Variability Experiment
Ex-Im	Export-Import
EXIS	EUV and X-ray Irradiance Sensor

F

F&F	Fire and Forget
FAA	Federal Aviation Administration
FAB-T	Family of Advanced Beyond-Line-of-Sight Terminals
FACA	Federal Advisory Committee Act
FAS	Foreign Agricultural Service
FAS/OGA	Foreign Agricultural Service Office of Global Analysis
FCC	Federal Communication Commission
FCIC	Federal Crop Insurance Corporation
FDSS	Faculty Development in Space Sciences
FEMA	Federal Emergency Management Agency
FES	Office of Fusion Energy Sciences
FGST	Fermi Gamma-ray Space Telescope
FOC	Full Operational Capability
FOSS	Fiber Optic Sensing System
FRMAC	Federal Radiological Monitoring and Assessment Center
FRP	Full Rate Production
FSA	Farm Service Agency
FWS	Fish and Wildlife Service
FY	fiscal year

G

GaN	gallium nitride
GBD	Global Burst Detector
Gbps	gigabits per second
GBSAA	Ground Based Sense and Avoid
GCJV	Gulf Coast Joint Venture
GCOM-W	Global Change Observation Mission–Water
GEM	Geospace Environment Modeling
GEO	Geostationary; Geosynchronous Earth Orbit; Group on Earth Observation
GEO-AGS	Directorate for Geosciences' Division of Atmospheric and Geospace Sciences
GeV	gigaelectronvolt
GF	Geospace Facilities
GFSAD	global food security support-analysis data
GIS	Geographic Information Systems
GITWG	GOES-R International Training Working Group
GLAM	Global Agricultural Monitoring
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal
GMT	Giant Magellan Telescope
GNCA	global net cropland area
GNSS	Global Navigation Satellite Systems

GNSS-RO	GNSS radio occultation
GO1	GOLauncher1
GOES	Geostationary Operational Environmental Satellite
GOES-R	Geostationary Operational Environmental Satellite R
GoLIVE	Global Land Ice Velocity Extraction
GONG	Global Oscillations Network Group
GPIM	Green Propellant Infusion Mission
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GPSC	Geospatial Products and Services Contract
GPSRO	GPS radio occultation
GRAIL	Gravity Recovery and Interior Laboratory
GRB	GOES Rebroadcast
G-REALM	Global Reservoir and Lake Monitor
GS	Geospace Section
GSDO	Ground Systems Development and Operations
GSFC	Goddard Space Flight Center
GSSAP	Geosynchronous Space Situational Awareness Program
GUT	grand-unified theory

H

HA	High Agriculture
HABS	Historic American Buildings Survey
HAER	Historic American Engineering Record
HALS	Historic American Landscapes Survey
HARM	High-Speed Anti-Radiation Missile
HaWK	High Watts per Kilogram
HEAT	High Elevation Antarctic Terahertz
HEO	Highly Elliptical Orbit
HERA	Hybrid Electronic Radiation Assessor; Hydrogen Epoch of Reionization Array
HESS	High Energy Stereoscopic System
HEU	highly enriched uranium
HH	Highest of the High
HiRISE	High Resolution Imaging Science Experiment
HRP	Human Research Program
HTV	H-II Transfer Vehicle
HU	High Urban
HULK2	Hybrid Ultimate Lifting Kit 2

I

I&W	Initial delivery of Indications and Warning
IAWN	International Asteroid Warning Network
IBEX	Interstellar Boundary Explorer
IC	Intelligence Community
ICAO	International Civil Aviation Organization
ICAS	Auto Integrated Collision Avoidance System
ICESat	Ice, Cloud and Land Elevation Satellite
ICG	International Committee on Global Navigation Satellite Systems
ICNO	IceCube Neutrino Observatory
ICPS	Interim Cryogenic Propulsion Stage
IDAC	Integrated Departure/Arrival Capability
IDEX	International Defense Exhibition
IfSAR	Interferometric Synthetic Aperture Radar

IGD	integrated ground demonstration
IIP	Instrument Incubator Project
IMAP	Interstellar Mapping Probe
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
INVENT	Integrated Vehicle Energy Technology
IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
IPAD	International Production Assessment Division
IPTE	Improved Performance Technology Engine
IR	infrared
IRAC	Infrared Array Camera
IRIS	Interface Region Imaging Spectrograph
ISARA	Integrated Solar Array and Reflectarray Antenna
ISECG	International Space Exploration Coordination Group
ISEF	Second International Space Exploration Forum
ISIL, ISIS	Islamic State
Isp	specific impulse
ISR	Intelligence, Surveillance, and Reconnaissance
ISR&T	Intelligence, Surveillance, Reconnaissance, and Targeting
ISRO	Indian Space Research Organisation
ISS	International Space Station
ISS-CREAM	ISS Cosmic Ray Energetics and Mass
ITA	International Trade Administration
ITAC 1	Industry Trade Advisory Committee on Aerospace Equipment
ITE	Improved Turbine Engine

J

JAGM	Joint Air-to-Ground Missile
JASD	Joint Agency Satellite Division
JAXA	Japan Aerospace Exploration Agency
JFMCC	Joint Forces Maritime Component Commander
JMR-TD	Joint Multi-Role Tech Demo
JMS	Joint Space Operations Center Mission System
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JPSS-2	Joint Polar Satellite System 2
JROC	Joint Requirements Oversight Council
JSF	Joint Strike Fighter
JSPOC	Joint Space Operations Center
JUICE	JUpiter ICy Moons Explorer

K

KARI	Korea Aerospace Research Institute
KDP	Key Decision Point
KRUSTY	Kilowatt Reactor Using Stirling TechnologY
KSC	Kennedy Space Center

L

LA	Low Agriculture
LAE	Launch Abort Engine
LAFE	Land Atmosphere Feedback Experiment

LANDFIRE	Landscape Fire and Resource Management Planning Tools
LANL	Los Alamos National Laboratory
LAPD	Large Plasma Device
LASP	Laboratory for Atmospheric and Space Physics
LAT	Large Area Telescope
LBFD	Low Boom Flight Demonstrator
LCAAT	Low Cost Attritable Aircraft Technologies
LCMS	Landscape Change Monitoring System
LCRD	Laser Communication Relay Demonstration
LCS	Littoral Combat Ship
LEE	Latching End Effector
LEO	low-Earth orbit
LEPC	lesser prairie-chicken
lidar	light detection and ranging
LIGO	Laser Interferometer Gravitational-Wave Observatory
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LL	Lowest of the Low
LLNL	Lawrence Livermore National Laboratory
LOX	liquid oxygen
LRASM	Long-Range Anti-Ship Missile
LRO	Lunar Reconnaissance Orbiter
LSA	Launch Service Agreement
LSC	Legal Subcommittee
LSP	Launch Services Program; land-surface phenology
LSST	Large Synoptic Survey Telescope
LST	Land Surface Temperature
LTS	Working Group on Long-Term Sustainability of Outer Space Activities
LU	Low Urban
Lunar CATALYST	Lunar Cargo Transportation and Landing by Soft Touchdown
LunIR	Lunar Infrared
LVSA	Launch Vehicle Stage Adapter

M

M31	Andromeda Galaxy
MAF	Michoud Assembly Facility
MaGIXS	Marshall Grazing Incidence X-ray Spectrograph
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MANPADS	Man Portable Air Defense Systems
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MAVEN	Mars Atmosphere and Volatile Evolution
MCAS	Marine Corps Air Station
MCM	Mine Countermeasures
MCS	Mission Control System
MDA	Missile Defense Agency; Milestone Decision Authority
MDXR	Missile Defense Transfer Radiometer
MEDA	Mars Environmental Dynamics Analyzer
MEDLI-2	Mars Entry, Descent, and Landing Instrumentation-2
MEF	Marine Expeditionary Force
MEO	medium-Earth orbit
MEP	Manufacturing Extension Partnership
MER	Mars Exploration Rover
MIDEX	Medium-Class Explorer
MINOS	Main Injector Neutrino Oscillation Search

MinXSS	Miniature X-ray Solar Spectrometer
MiRaTa	Microwave Radiometer Technology Acceleration
MISE	Mapping Imaging Spectrometer for Europa
MKID	Microwave Kinetic Inductance Detector
MLA	machine learning algorithm
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MMS	Magnetospheric Multiscale
MOA	Microlensing Observations in Astrophysics; Memorandum of Agreement
MOBY	Marine Optical BuoY
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
MOXIE	Mars Oxygen In-Situ Resource Utilization Experiment
MPPF	Multi-Payload Processing Facility
MPRF	Maritime Patrol and Reconnaissance Force
MPS	Directorate for Mathematics and Physical Sciences
MRLC	Multi-Resolution Land Characteristics
MRO	Mars Reconnaissance Orbiter
MRS	Major Radiological Space
MRX	Magnetic Reconnection Experiment
MSFC	Marshall Space Flight Center
MSIP	Mid-Scale Innovations Program
MSL	Mars Science Laboratory
MST	Madison Symmetric Torus
MTBS	Monitoring Trends in Burn Severity
Multi-Int	multiple intelligence
MUMT	Manned-Unmanned Teaming
MUSES	Multi-User System for Earth Sensing
MWTA	Megawatt Tactical Aircraft

N

NAAMES	North Atlantic Aerosols and Marine Ecosystems Study
NAICS	North American Industry Classification System
NAIP	National Agriculture Imagery Program
NANOGrav	North American Nanohertz Observatory for Gravitational Waves
NAS	Naval Air Station; 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
NDAA	National Defense Authorization Act
NDEP	National Digital Elevation Program
NDOP	National Digital Orthoimagery Program
NDVI	Normalized Difference Vegetation Index
NE	Office of Nuclear Energy
NEN	Near Earth Network
NEO	Near-Earth Object
NEPA	National Environmental Policy Act
NERSC	National Energy Research Supercomputing Center
NESDIS	NOAA Satellite and Information Service
NextGen	Next Generation Air Transportation System
NextSTEP	Next Space Technologies for Exploration Partnerships
NFS	National Forest System
NGEE	Next Generation Ecosystem Experiment

NGLAW	Next Generation Land Attack Weapon
NGSC	Next Generation Strike Capability
NHT	Nested Hall Thruster
NICER	Neutron star Interior Composition Explorer
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Database
NMNH	National Museum of Natural History
NNPS	National NEO Preparedness Strategy
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NOC	National Operations Center
NOSS	Naval Ocean Surveillance System
NPRA	National Petroleum Reserve–Alaska
NPS	National Park Service
NRAO	National Radio Astronomy Observatory
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NRO	National Reconnaissance Organization
NROL	National Reconnaissance Office Launch
NS-9	Nanosat-9
NSBRI	National Space Biomedical Research Institute
NSDC	National Space Defense Center
NSF	National Science Foundation
NSO	National Solar Observatory
NSPO	National Space Organization
NSRL	NASA Space Radiation Laboratory
NSS	National Security Space
NSTC	National Science and Technology Council
NSWAP	National Space Weather Action Plan
NSWS	National Space Weather Strategy
NTP	Nuclear Thermal Propulsion
NWP	numerical weather prediction

O

OASuW	Offensive Anti-Surface Warfare
OCO-2	Orbiting Carbon Observatory-2
OCONUS	Outside of Continental United States
OCSD	Optical Communications and Sensor Demonstration
ODNI	Office of the Director of National Intelligence
OECD	Organization for Economic Cooperation and Development
OES/SAT	Bureau of Oceans and International Environmental and Scientific Affairs/Office of Space and Advanced Technology
OFII	Office of Finance and Insurance Industries
OGLE	Optical Gravitational Lensing Experiment
OGS	Optical Ground Station
OLI	Operational Land Imager
OMAC	Orbital Maneuvering Attitude Control
OMG	Oceans Melting Greenland
OOSA	Office of Outer Space Affairs
OPIR	Overhead Persistent InfraRed
OPP	Office of Polar Programs

ORI	orthorectified radar intensity image
ORNL	Oak Ridge National Laboratory
ORS	Operationally Responsive Space
OSA	Orion Stage Adapter
OSIRIS-Rex	Origins, Spectral Interpretation, Resource Identification, Security–Regolith Explorer
OTA	Other Transactions Authority
OTM	Office of Transportation and Machinery
OTV-5	Orbital Test Vehicle 5

P

PBN	Performance Based Navigation
PBS	Plum Brook Station
PD/NSC-25	Presidential Directive/National Security Council-25
PDR	Preliminary Design Review
PESEP	Professional Engineer and Scientist Exchange Program
PeV	petaelectronvolt
PHA	Potentially Hazardous Asteroid
PHY	Division of Physics
PMA	Pressurized Mating Adapter
PNT	Positioning, Navigation, and Timing
POES	Polar-orbiting Operational Environmental Satellites
PP	Precision Point
PPE	Power and Propulsion Element
PPPL	Princeton Plasma Physics Laboratory
PREEVENTS	Prediction and Resilience against Extreme Events
PRS	Public Regulated Service
PSD	production, supply, and distribution
PTD	Pathfinder Technology Demonstrator
Pu	plutonium
PV	production verification

Q

QSP	quartz-sericite-pyrite
QueSST	Quiet Supersonic Transport

R

R&D	research and development
RADCC	Radiation Control Center
RAVAN	Radiometer Assessment using Vertically Aligned Nanotubes
RCF	Range Communications Facility
RCS	Reaction Control System
REALM-1	Radio Frequency Identification–Enabled Autonomous Logistics Management
RERP	Reliability Enhancement and Re-engining Program
RF	Radio Frequency; Random Forest
RF-CLASS	Remote-Sensing-Based Flood Crop Loss Assessment Service System
RFI	Request for Information
RFID	Radio Frequency Identification
RFP	Request for Proposals
RGFO	Royal Gorge Field Office
RHIC	Relativistic Heavy Ion Collider
RMA	Risk Management Agency
RNAV	Area Navigation

RNP	Required Navigation Performance
RO	radio occultation
ROSA	Roll Out Solar Array
ROSES	Research Opportunities in Space and Earth Sciences
Rp	refined propellant
RPS	Radioisotope Power System
RPT	Rocket Propulsion Test
RRM3	Robotic Refueling Mission 3
RSAC	Remote Sensing Applications Center
RSCC	Remote Sensing Coordinating Committee
RSIWG	Remote Sensing Interagency Working Group
RSP	radioisotope power system
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RTCA	Radio Technical Commission for Aeronautics

S

SABRS	Space and Atmospheric Burst Reporting System
SAGE	Stratospheric Aerosol and Gas Experiment
SAO	Smithsonian Astrophysical Observatory
SAT	site acceptance testing
SATCOM	Satellite Communications
S/B	Sikorsky Boeing
SBIR	Small Business Innovative Research
SBIRS	Space Based Infrared System
SC	Office of Science
SCaN	Space Communications and Navigation
SCANS	Soil Climate
SDB II	Small Diameter Bomb II
SDD	System Development and Demonstration
SDI	Space Data Integrator
SDO	Solar Dynamics Observatory
SEA	Social and Economic Analysis
SEACS	suitably equipped air capable ships
SECAF	Secretary of the Air Force
SEXTANT	Station Explorer for X-ray Timing and Navigation Technology
SGMA	Sustainable Groundwater Management Act
SGSS	SN Ground Sustainment System
SHARAD	Shallow Subsurface Radar
SHARC	Satellite for High Altitude Radar Calibration
SHINE	Solar, Heliosphere, and INterplanetary Environment
SIA	Satellite Imagery Archive
SIRCUS	Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources
SLC	Space Launch Complex
SLPSRAD	Space Life and Physical Sciences Research and Applications Division
SLS	Space Launch System
SM	Service Module
SMA	Submillimeter Array
SMAP	Soil Moisture Active Passive
SMC	Space and Missile Systems Center
SMD	Science Mission Directorate
SMPAG	Space Mission Planning Advisory Group
SN	Space Network
SNL	Sandia National Laboratories
SNOTEL	Snow Survey Telemetry

SNSPD	superconducting nanowire single-photon detector
SOA	service-oriented architecture
SOC	Space Optical Clock
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SpaceX	Space Exploration Technologies
SpODC	Space Operations Development Center
SPT	South Pole Telescope
SPT-3G	South Pole Telescope third generation
SPTpol	South Pole Telescope CMB polarization
SPT-SZE	South Pole Telescope–Sunyaev-Zel'dovich Effect
SPUD	Small Polarimeter Upgrade for Degree Angular Scale Interferometer
SQUID	Superconducting Quantum Interference Device
SRC	Space Robotics Challenge
SRR	System Requirements Review
SSA	Space Situational Awareness
SSC	Stennis Space Center
SSDP	Space Security and Defense Program
SSEDU	Solid State Electrical Distribution Units
SSN	Space Surveillance Network
SST	Space Surveillance Telescope
SSTI	Small Spacecraft Technology Initiative
SSTP	Small Spacecraft Technology Program
SSV	Space Service Volume
STA	Structural Test Article
STARS	Standard Terminal Automation Replacement System
STE	structural test equipment
STEM	science, technology, engineering, and mathematics
STEREO	Solar and Terrestrial Relations Observatory
STMD	Space Technology Mission Directorate
STP	Space Test Program
STP-H5	Space Test Program Houston 5
STRG	Space Technology Research Grants
STS	Space Transportation System
STSC	Scientific and Technical Subcommittee
STTR	Small Business Technology Transfer
SuMIRE	Subaru Measurement of Images and Redshifts
Suomi NPP	Suomi National Polar-orbiting Partnership
SURF	Synchrotron Ultraviolet Radiation Facility
SUW	Surface Warfare
SVD	Services Division
SW	software
SWEAP	Solar Wind Electrons Alphas and Protons
SWIM	System Wide Information Management
SWORM	Space Weather Operations, Research, and Mitigation
SWOT	Surface Water and Ocean Topography
SWR	Space Weather Research
SwRI	Southwest Research Institute

T

TACTOM	Tactical Tomahawk/Block IV
TAMR	Terminal Automation Modernization and Replacement
TBFM	Time Based Flow Management
TBO	Trajectory Based Operations

TCC	Tree Canopy Cover
TCCON	Total Column Carbon Observing Network
TCL2	Technology Capability Level 2
TDRS-M	Tracking and Data Relay Satellite M
TDRSS	Tracking and Data Relay Satellite System
TECRO	Taipei Economic and Cultural Representative Office in the United States
TEMPO	Tropospheric Emissions: Monitoring Pollution
TES	transition-edge sensor; Terrestrial Ecosystem Science
TESS	Transiting Exoplanet Survey Satellite
TeV	teraelectronvolt
TFDM	Terminal Flight Data Manager
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TM	Thematic Mapper
TMA	telescope mount assembly
TMRR	Technology Maturation and Risk Reduction
TOPEX	Ocean Topography Experiment
TRACON	Terminal Radar Approach Control
TRAPPIST	Transiting Planets and Planetesimals Small Telescope
TRI	Translational Research Institute
TRL	Technology Readiness Level
TS	Test Stand
TSA	Transportation Security Administration
TSIS	Total and Spectral Solar Irradiance Sensor
TT&C	telemetry, tracking, and communication
TTPs	Tactics, Techniques and Procedures
TTR	Tiltrotor Test Rig

U

UAS	Unmanned Aerial Systems; Unmanned Aircraft Systems
UCAR	University Corporation for Atmospheric Research
UDOP	User Defined Operational Picture
ULA	United Launch Alliance
ULI	University Leadership Initiative
ULS	United Launch Services
UN FAO	United Nations Food and Agriculture Organization
UNISPACE+50	United Nations Conference on the Exploration and Peaceful Uses of Outer Space
UNP	University Nanosat Program
USAF	U.S. Air Force
USD/AT&L	Under Secretary of Defense for Acquisition, Technology and Logistics
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USMC	U.S. Marine Corps
USN	U.S. Navy
USNDS	U.S. Nuclear Detonation Detection System
USU	Utah State University
UTM	UAS Traffic Management

V

VAB	Vehicle Assembly Building
VAC	Vertical Assembly Center
VASIMR	Variable Specific Impulse Magnetoplasma Rocket

VCLS	Venture Class Launch Services
VFA	Strike Fighter Squadron
VIIRS	Visible Infrared Imaging Radiometer Suite
VLF	very-low-frequency
VMFA	Marine Fighter Attack Squadron

W

WASDE	World Agricultural Supply and Demand Estimates
Webb	James Webb Space Telescope
WFIRST	Wide Field Infrared Survey Telescope
WGS	Wideband Global SATCOM
WIN	Written Impact Narrative
WiPPL	Wisconsin Plasma Physics Laboratory
WMN	Western-Range Modernization of Network
WSF	Weather Satellite Follow-on
WSF-M	WSF-Microwave
WSTF	White Sands Test Facility

X

XMM	X-ray Multi-Mirror
X-planes	experimental aircraft

Z

ZTF	Zwicky Transient Facility

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