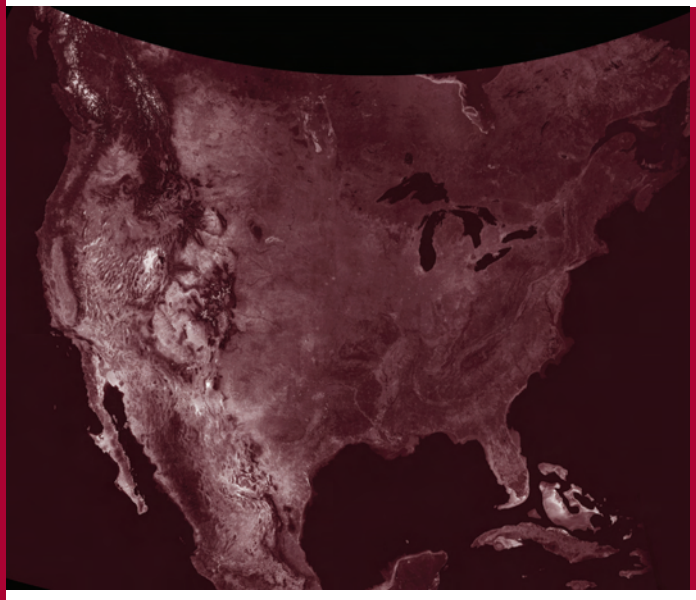
Aeronautics and Space Report of the President



Fiscal Year 2005 Activities

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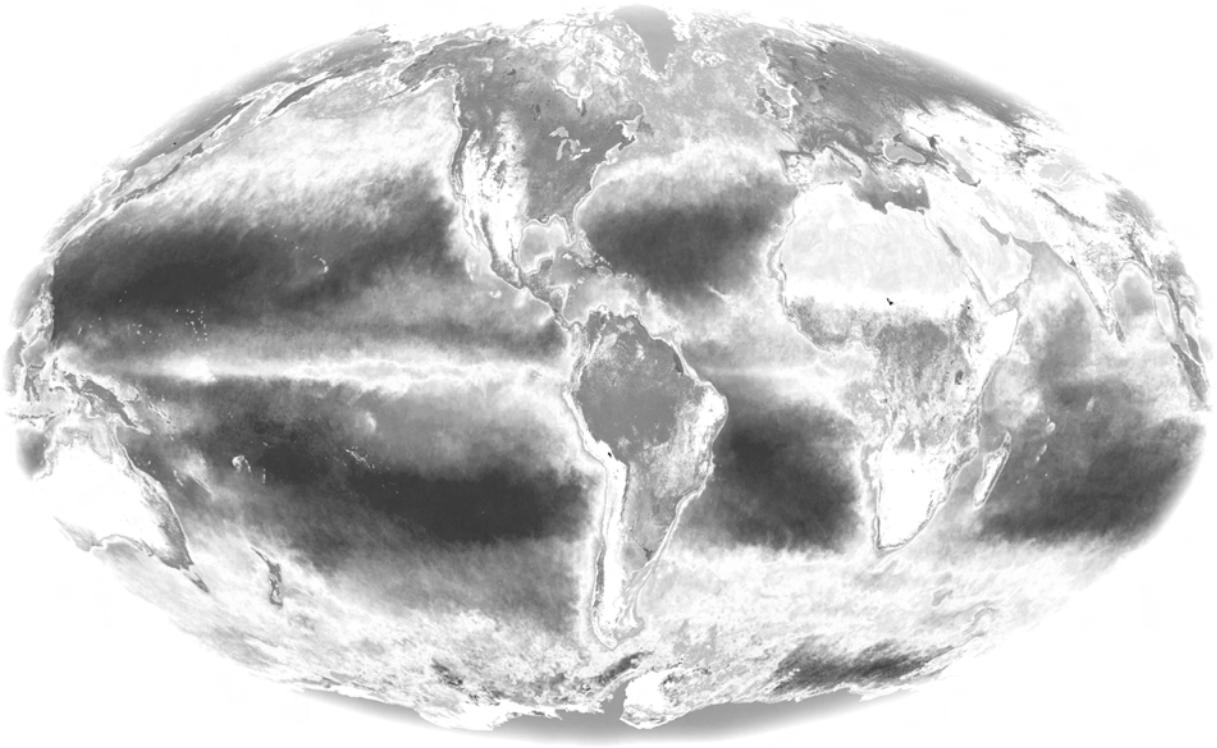


Fiscal Year 2005 Activities

The National Aeronautics and Space Act of 1958 directed the annual Aeronautics and Space Report to include a "comprehensive description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities during the preceding calendar year." In recent years, the reports have been prepared on a fiscal-year basis, consistent with the budgetary period now used in programs of the Federal Government. This year's report covers activities that took place from October 1, 2004, through September 30, 2005.

Table of Contents

National Aeronautics and Space Administration

NASA

NASA completed a successful year of milestones and discoveries in 2005 as the Agency began to implement the Vision for Space Exploration (VSE), America's long-term plan for returning astronauts to the Moon and to prepare for voyages to Mars and other destinations in the solar system. The year included returning the Space Shuttle to flight, the announcement of plans for America's next generation of spacecraft, numerous achievements in aeronautics, and dramatic discoveries in Earth science and space science.

Exploration Systems Mission Directorate

The goal of NASA's Exploration Program is to conduct a series of human space expeditions of increasing scope. These expeditions are expected to follow an evolutionary pathway, starting in low-Earth orbit (LEO) with missions supporting the International Space Station (ISS) and expanding to encompass the Moon, Mars, and other destinations. The knowledge, technology, operational experience, and systems developed during each stage of this program are expected to provide the foundation for more extensive exploration activities as the Exploration Program matures. As part of this evolutionary philosophy, the initial steps along this path are designed to leverage flight-proven technologies and techniques of earlier human exploration efforts, including the ISS, Space Shuttle, and Apollo programs.

The Exploration Systems Mission Directorate engaged numerous experts in the public and private sector to perform studies to identify launch vehicle requirements for crew and cargo to support the nation's Vision for Space Exploration. These preliminary studies looked at over sixty-three launch vehicle options and assessed

each of the architectures against numerous figures of merit, such as crew safety, mission success, cost, performance, schedule, and extensibility.

The NASA Administrator, Dr. Michael Griffin, then commissioned an internal study of the exploration architecture. The Exploration Systems Architecture Study (ESAS) was staffed by members of ESMD along with other exploration and technology experts from NASA Centers and Headquarters. The results of the ESAS included recommendations for exploration mission requirements, technology needs, and schedule. The mission requirements serve as the basis for the design, development, and production of the exploration systems necessary to achieve the VSE.

Based on the ESAS recommendations, the NASA Administrator instituted changes that have impacted the allocation of and plans for ESMD investments. The research and technology portfolio was reduced, with focus placed upon the near-term requirements for lunar missions. The acquisition approach for the Constellation Systems Program was revised to accelerate and more clearly define the government's requirements, as well as to increase the proportion of design, development, and integration work to be performed by the government. In lieu of industry trade studies and a longer competitive phase for selection of the Crew Exploration Vehicle (CEV) contractor, NASA has taken the lead in both defining its needs for industry and accelerating the timeframe for down-selection of the CEV contract. These revisions were made in an effort to address Congressional and Administration requests for initial CEV capability earlier than 2014 while prioritizing NASA investments to address funding constraints. ESMD modified its strategy, plans, and organization to implement and achieve the VSE in the years to come.

Management Approach

Since its inception in January 2004, ESMD has made communication and active involvement with industry an essential part of its plans for achieving the nation's VSE. Through extensive discussions and competitive acquisition opportunities (industry days, draft solicitations, draft requirements, and workshops), the private sector has provided invaluable contributions. ESMD also engaged industry and the international community by conducting the forums "Space Exploration Conference" and "International Workshop on Space Exploration." These meetings

included plenary discussions, technical sessions, and informal informational exchanges between NASA, industry, and the global space exploration community.

In addition to evolving its strategy and creating an organizational structure and management team to implement the VSE, ESMD continued to make other noteworthy accomplishments. The sections below highlight key elements of ESMD scope, structure, and accomplishments.

Constellation Systems – Scope & Structure:

- The Constellation Systems Program Office, which is responsible for overall development of Constellation Systems, was moved from NASA Headquarters (HQ) to Johnson Space Center (JSC). JSC also manages the CEV, Space Suit Development, Mission Operations Systems, and Commercial Crew/Cargo projects. Marshall Spaceflight Center (MSFC) manages the Crew Launch Vehicle (CLV) and Heavy Lift Launch Vehicle (HLLV), while Kennedy Space Center (KSC) develops Ground Operations Systems. Glenn Research Center (GRC) provides risk reduction and advanced technology development for a new liquid oxygen/methane rocket engine. Langley Research Center (LaRC) provides an unpressurized cargo carrier, while Ames Research Center (ARC) provides Thermal Protection System research. NASA Centers will also have responsibility for overall Systems Engineering and Integration (SE&I).
- HQ manages purchases of ISS Crew/Cargo services from International Partners. NASA transferred ISS Crew/Cargo from the Space Operations Mission Directorate (SOMD) to the ESMD to ensure sound resource allocation between International Partner purchases, commercial services, and NASA-developed systems. NASA's preferred path to meeting its needs to transport human-related cargo or crew to and from the ISS is through cost-effective U.S. commercial space transportation service providers.

Constellation Systems – Accomplishments:

- NASA contracted with two industry teams to complete phase 1 engineering studies for the CEV. These two industry teams (led by Northrop Grumman and Lockheed Martin) are vying for the CEV

contract. The phased down-select is proceeding as planned, with selection planned for FY 2006.

- NASA issued engineering study contracts to two Shuttle contractors to study evolution of the Shuttle design for the CLV.
- NASA completed the major CLV acquisition strategies.
- ESMD released a draft solicitation for Commercial Crew/Cargo transportation services.

Advanced Capabilities – Scope & Structure:

As part of the process of refocusing the Agency's work to support the VSE, ESMD significantly restructured the technology programs to align their content with the new technology priorities for lunar exploration identified by the ESAS. An overview of the changes in scope and priorities is provided below.

- The focus changed to near-term development of technologies needed to support the CEV and the CLV, such as a propulsion system that uses methane and oxygen propellants, and the heat shield that protects the vehicle during atmospheric entry.
- A majority of the research and development directed to future Mars missions was deferred.
- The ESAS reprioritized the human systems research and technology portfolio required to support the new exploration architecture.
- The Prometheus Nuclear Systems and Technology (PNST) Program was restructured to support the timely development of the new CEV and to reflect Agency near-term technology development priorities for lunar exploration. A decision was made to terminate all advanced nuclear electric propulsion technology and nuclear reactor power flight systems efforts, including all Jupiter Icy Moon Orbiter (JIMO) activities. NASA initiated a research and technology effort focused on key, high priority, long-lead nuclear systems and technology issues.
- The research and technology development required to support the VSE, including development of robotic precursor missions for lunar exploration, resides under the guidance of ESMD's Advanced

Capabilities Division. ESMD assigned management of the Advanced Capability programs and projects to the NASA Centers.

- The Robotic Lunar Exploration Program (RLEP) was transferred to ESMD from the Science Mission Directorate (SMD).
- ESMD transferred RLEP management responsibility from GSFC to ARC. Lunar Reconnaissance Orbiter (LRO) project management remains at GSFC. MSFC gained management responsibility for the new RLEP-2 project. NASA LaRC manages the Exploration Technology Development Program and JSC manages the Human Research Program. PNST Program management resides with ESMD Headquarters with participation by GRC and MSFC.

Advanced Capabilities – Accomplishments:

- ESMD competitively selected the instruments and completed the Systems Requirements Review (SRR) for the LRO mission, in addition to establishing the initial requirements for a second RLEP mission.
- ESMD conducted the first two prize competitions in the Centennial Challenges Program to demonstrate technologies applicable to space elevators.
- After completion of a successful review, the Fluids and Combustion Facility (FCF) was shipped to KSC where it will be flown to the ISS.
- NASA's Human Research Facility (HRF-2) was flown to the ISS where it will enhance human research aboard the ISS.
- ESMD continued to engage with private industry in the transfer and infusion of technology. Through the NASA Centers, the Agency entered into over eighty-five partnership agreements infusing innovative technology into NASA programs and over 220 licensing agreements and fifty partnership agreements transferring NASA-developed technology to the U.S. industrial sector.

Space Operations Mission Directorate

Since the release of the Columbia Accident Investigation Board (CAIB) final report on August 26, 2003, NASA employees and contractors invested approximately 3.5 million engineering hours of testing, analysis, development, and

processing to prepare Discovery for its flight on STS-114. With the goal of eliminating, reducing, controlling, and mitigating potential hazards and risks in all critical areas of the Space Shuttle system, Shuttle engineers made over 116 individual hardware modifications. All improvements were vetted through a rigorous and multilayered review process. The Return to Flight Task Group subjected the fifteen CAIB Return to Flight recommendations to further independent assessment. The Task Group's findings provided the NASA leadership with an important alternative opinion throughout the Return to Flight process and during the STS-114 launch review. NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond outlined the path that NASA took to respond to the Board's recommendations and safely return the Space Shuttle to flight. The Implementation Plan was updated periodically to reflect NASA's continuing progress and to provide detailed cost estimates of the Return to Flight process. NASA released the tenth revision to the Implementation Plan on June 3, 2005, and issued a pre-launch addendum on July 7, 2005.

The launch of Space Shuttle Discovery on July 26, 2005, followed by its safe return on August 9, 2005, represented important milestones in validating the improvements made to the Space Shuttle system during Return to Flight—critical first steps in executing the VSE. STS-114 also put the Space Shuttle and ISS programs in a position to resume ISS assembly flights in 2006. Discovery and its crew delivered over 15,000 pounds of hardware and supplies to the ISS, conducted three spacewalks to restore three of the Station's four Control Moment Gyroscopes and complete other installation activities outside the ISS, and brought over 7,200 pounds of expended hardware and unneeded supplies back to Earth.

Nevertheless, STS-114 also demonstrated that additional work needs to be done prior to the launch of the second Return to Flight test mission, STS-121. As of September 2005, the program had progressed through the normal post-flight disposition procedures for all STS-114 in-flight anomalies. In the case of the external tank foam loss events, NASA commissioned both program and independent teams to determine root causes and recommend mitigation activities. As of September 2005, these tasks were proceeding on a schedule that supported the May 2006 launch opportunity for STS-121.

Space Shuttle transition planning activities began soon after the announcement of the VSE. The subject of transition was a major focus of the Integrated Space Operations Summit in March 2005. The Summit provided a forum for individuals from government, industry, and academia to discuss mission execution and transition issues within the context of the Space Shuttle's 2010 retirement date.

As a result of recommendations made at the Summit, NASA established the position of the Space Shuttle transition manager. The transition manager gained responsibility for developing the Space Shuttle transition plan and reconciling Space Shuttle transition efforts with existing policies and practices in areas like dispositioning of Shuttle hardware and infrastructure, workforce transition, environmental remediation, and knowledge management.

Throughout 2005, the Space Shuttle program continued to benchmark previous program phase-outs for lessons learned in maintaining safety and mission assurance through the transition period. The program also convened several technical interchange meetings to prepare for an orderly Space Shuttle transition. The Associate Administrators for both Space Operations and Exploration Systems provide senior-level Agency leadership of the transition process through the Space Shuttle Transition Control Board. This group retained responsibility for overseeing the transition of Space Shuttle workforce, infrastructure, hardware, knowledge, and contracting mechanisms between the current Space Shuttle program and future exploration systems.

In FY 2005, overall ISS systems performance surpassed expectations. The highlight of the year was the first Space Shuttle visit to the ISS since 2003, bringing with it science payloads and hardware. By the end of FY 2005, the ISS vehicle was in its best operational condition since early 2003 and ready for assembly resumption.

The year began with a Station crew exchange. The Expedition 10 crew, U.S. Commander Leroy Chiao and Russian Flight Engineer Salizhan Sharipov, replaced Expedition 9 onboard the ISS on October 16, 2004. Chiao and Sharipov conducted two two-person extravehicular activities (EVA) safely and successfully without a crewmember inside the Station.

The Expedition 10 crew returned to Earth on April 24, 2005, replaced by Expedition 11. Russian Commander Sergei Krikalev and U.S. Flight Engineer John Phillips arrived at the ISS on April 17, 2005. Krikalev and Phillips performed one EVA. Phillips also participated in the first-ever Congressional hearing with

live testimony from orbit on June 14, 2005. Expedition 11 returned to Earth in October 2005.

Our Russian partners continued to support crew and cargo transportation to the ISS. In FY 2005, automated Russian Progress vehicles re-supplied the two-person crew four times, and Russian Soyuz vehicles transported two crews safely and reliably to and from the Station. This level of cooperation has enabled a continuous crew presence on the ISS. A highlight of Russia's re-supply was the delivery and successful activation of a new Elektron oxygen generation system.

The high point of the year came in August, when Space Shuttle Discovery visited the Station. The Shuttle transferred more than 15,000 pounds worth of supplies and hardware to the ISS, including food, water, nitrogen, lithium hydroxide canisters, and scientific equipment. In addition, the Shuttle returned more than 7,200 pounds worth of expended hardware and unneeded supplies from the ISS back to Earth.

Other highlights from Discovery's mission included the repair and/or replacement of two of the Station's four Control Moment Gyroscopes (which provide attitude control for ISS), thereby restoring the Station to its full capability. The Shuttle crew also installed the External Stowage Platform-2—an external platform for storing components and assisting astronauts in conducting EVAs from the ISS—replaced a Global Positioning System (GPS) antenna, reboosted the orbit of the ISS, and conducted a fly-around and complete photographic survey of the ISS prior to reentry.

Although the reduced crew size and transport capabilities of the Russian Progress and Soyuz spacecraft limited planned science activities on the Station, NASA maximized the research opportunities available through replanning and rescheduling science activities. Through the end of FY 2005, approximately 246 hours of combined crew time were dedicated to research.

The arrival of STS-114 enhanced the science capacity on board the Station by transferring the Human Research Facility-2 (HRF-2) to the U.S. Destiny module. This facility increased the on-orbit laboratory capabilities for human life science researchers to study and evaluate the physiological, behavioral, and chemical changes induced by space flight. Three new experiments also flew on STS-114; furthermore, the Discovery crew deployed another round of an on-going experiment called Materials on International Space Station Experiment (MISSE)

and returned two sets of materials that had been outside the ISS as part of this experiment. STS-114 Discovery also returned the first significant downmass of science data and samples since December 2002.

The International Partnership successfully met the challenge of continuing ISS operations while the Space Shuttle was grounded. The Partners met frequently at the technical and management levels to coordinate efforts to maintain our common goal of keeping the ISS crewed. The Partnership plans to resume assembly as soon as the Space Shuttle completes its second Return to Flight mission.

In May 2005, the Administrator directed the Shuttle/Station Configuration Options Team to evaluate options for completing ISS assembly within the parameters of the VSE. The planned launch manifest included the U.S. elements and accommodated almost all of the International Partner elements, with the exception of the Russian Science Power Module. The International Partners agreed to conduct a series of multilateral discussions to assess NASA's proposed plan in anticipation of ISS Multilateral Coordination Board and Heads of Agency meetings in early 2006.

Reliable communications connectivity for space flight programs via the Tracking and Data Relay Satellite System (TDRSS) remained the focus of Space Communications activities in FY 2005. TDRSS is a constellation of geosynchronous communications satellites and ground support facilities for use by the Space Shuttle, the ISS, the Hubble Space Telescope, and other low-Earth orbiting spacecraft. When first launched, the TDRS satellites were the largest and most sophisticated communications satellites ever built. In 2005, the TDRSS supported science and human space flight missions with a 99+% proficiency.

An Agencywide Space Communications Architecture Working Group (SCAWG) established a NASA space communications architecture to meet the needs of NASA's future exploration and science missions. The SCAWG put in place several preliminary architectures and continued to develop a communications technology roadmap as a basis for future investment in space communications technology initiatives.

Senior NASA Spectrum Management personnel remained actively involved in implementing the recommendations from the Task Force regarding the Presidential initiative to bring the United States Spectrum Management activities into the 21st Century. NASA submitted its portion of the National

Spectrum Long Range Forecast as required by these recommendations. NASA made a concerted effort to ensure efficient use of its spectrum requirements for all missions and programs, while also associating these uses with Capital Planning efforts to ascertain the cost of using spectrum. NASA continued to prepare for the next World Radiocommunications Conference 2007 by actively participating in all international activities and forums.

The Space Operations Mission Directorate Launch Services Program successfully managed the launches of five missions on expendable launch vehicles in FY 2005. The Swift spacecraft, Deep Impact spacecraft, and Mars Reconnaissance Orbiter spacecraft were launched from the Cape Canaveral Air Force Station, Florida, and the Demonstration of Autonomous Rendezvous Technology (DART) spacecraft and National Oceanic and Atmospheric Administration (NOAA-N) spacecraft were launched from Vandenberg Air Force Base, California. Swift began documenting gamma ray bursts as part of an effort to enable scientists to explain the origins and nature of these bursts. Deep Impact delivered a probe that slammed into the nucleus of comet Tempel 1, releasing an immense cloud of fine powdery material.

DART was to establish autonomous rendezvous capabilities for the U.S. space program, however, after a successful rendezvous, acquisition of the target spacecraft, and approach to within approximately 300 feet, DART placed itself in the retirement phase before completing all planned proximity operations, ending the mission prematurely. NOAA-N was another of the continuing series of polar orbiting weather satellites. For all of these missions, NASA competitively procured launch services from domestic commercial companies.

Science Mission Directorate

January 2005 started with the launch of Deep Impact, beginning its 268 million miles journey to the vicinity of comet Tempel 1. Composed of primitive debris from the solar system's distant and coldest regions that formed 4.5 billion years ago, comets hold clues about the formation and evolution of the solar system. Deep Impact, a NASA Discovery Mission, was the first space mission to probe beneath the surface of a comet and reveal the secrets of its interior. On July 3, 2005, the spacecraft deployed an impactor that was destroyed by the nucleus of comet Tempel the following day. This deep space July 4th fireworks display took

place at the velocity of about 23,000 miles per hour, and was witnessed by over 80 million Internet users. Before, during, and after the demise of this 820–pound impactor, a flyby spacecraft watched the approximately four-mile wide comet nucleus from nearby, collecting the most up-close personal data and images of a comet in the history of space exploration.

NASA airborne and orbiting science instruments yielded data that helped Federal authorities and the general public gain better insight into the devastating 2005 hurricane season. Observations of ocean surface winds made with the Agency's unique technologies, such as the SeaWinds instrument on ADEOS II and the Tropical Rainfall Monitoring Mission (TRMM) satellite, allowed scientists to see rainfall inside the storms and their eyewalls and to measure each storm's strength. Observations from a suite of satellites and aircraft, such as the LandSat satellite and the MODIS instrument on NASA's Terra satellite, were used to create before-and-after images of New Orleans's post-Hurricane Katrina flooding and provide post-storm views of damage from land-falling hurricanes.

NASA's new Hurricane Resource Web page brought NASA Earth Science to the general public this year and highlighted the huge array of the Agency's hurricane research. It became a resource for the global media on the latest NASA research, satellite imagery, hurricane updates, videos, and animations.

NASA and NOAA scientists at the Joint Center for Satellite Data Assimilation in Camp Springs, Maryland, came up with procedures to improve forecasting accuracy. Working with experimental data from the Atmospheric Infrared Sounder instrument on NASA's Aqua satellite, they found that incorporating the instrument's data into numerical weather prediction models improved the accuracy range of experimental six-day Northern Hemisphere weather forecasts by up to six hours.

Combining research efforts with National Snow and Ice Data Center in Colorado, NASA used satellite data from the Geoscience Laser Altimeter System (GLAS) instrument on ICESAT (Ice, Cloud, and Land Elevation Satellite) to confirm that the amount of sea ice floating in the Arctic is less than in previous years, a finding consistent with the Arctic's warmer temperature. Each September, the amount of sea ice floating in the Arctic Ocean is typically at its lowest amount for the entire year. Since 2002, the amount of sea ice has been 20 percent less than the average recorded amount between 1979 and 2000.

Despite near-record levels of chemical ozone destruction in the Arctic during the 2004–2005 winter, observations from NASA's Aura spacecraft allowed scientists to differentiate between chemical ozone destruction and the ozone level changes caused by air motions that vary dramatically from year to year. Analysis from Aura's Microwave Limb Sounder indicated Arctic chemical ozone destruction during the 2004–2005 winter peaked at near 50 percent in some regions of the stratosphere—a region of Earth's atmosphere that begins about 8 to 12 kilometers (5 to 7 miles) above Earth's poles. This was the second highest level ever recorded, behind the 60 percent level estimated for the 1999–2000 winter. Data from another instrument on Aura, the Ozone Monitoring Instrument, found that the total amount of ozone over the Arctic in March 2005 was similar to other years when much less chemical ozone destruction had occurred. NASA's Polar Aura Validation Experiment independently confirmed the data obtained by Aura. In January and February 2005, NASA's DC-8 flying laboratory flew underneath Aura as the spacecraft passed over the polar vortex. The experiment used ten instruments to measure temperatures, aerosols, ozone, nitric acid, and other gases.

Toni Scarmato, a high school teacher from Italy, discovered the Solar and Heliospheric Observatory (SOHO) spacecraft's 999th and 1,000th comet in August 2005 when two comets appeared in the same SOHO image. The SOHO spacecraft is a joint effort between NASA and the European Space Agency. In the history of astronomy, it has accounted for approximately one-half of all comet discoveries with computed orbits. SOHO successfully completed its primary mission in April 1998, but it continued to provide useful information through FY 2005.

NASA's Mars Exploration Rovers struggled with rocky slopes and loose sand this year, yet managed to reach new sites for reading the environmental history recorded in Martian rocks. In August 2005, Spirit arrived at the summit crest of a range of hills that had appeared on the distant horizon from the rover's original landing site. The composition and structure of rock outcrops on these hills told of explosive events—eruptions, impacts, or both—and alteration by water. Spirit then headed downhill to reach layered deposits to the south. Opportunity made southward progress all year toward a crater deeper than the ones where the rover had previously encountered evidence that water once soaked the ground and flowed across its surface. Opportunity's journey was punctuated by an examination of the spacecraft's own jettisoned heat shield and several weeks of digging itself out

of the sand. Late in 2005 and nearly twenty-three months into what had been planned as three-month missions, each rover had completed a full Martian year of exploring Mars.

In the ninth year of its extended mission around Mars, NASA's Mars Global Surveyor orbited over the Mars Exploration Rovers. It's observations included tracks made on the lunar surface by falling boulders in the last two years. In addition, the Surveyor's visualizations of new impact craters formed since the 1970s suggested changes need to be made to earlier age-estimating models. For three Mars summers in a row, deposits of frozen carbon dioxide near the planet's south pole have shrunk from the previous year, suggesting a climate change may be in progress. Mars years are nearly twice as long as Earth years. The orbiter's longevity has enabled monitoring of year-to-year patterns on Mars, such as seasonal dust storms and changes in the polar caps. Beyond its own investigations, the orbiter has provided support for other Mars missions, such as landing-site evaluations, atmospheric monitoring, communication relay, and imaging of hardware on the surface.

The Mars Reconnaissance Orbiter (MRO) took off from Cape Canaveral Air Force Station, Florida, on August 12, 2005, aboard the first Atlas V launch vehicle used for an interplanetary mission. The spacecraft was designed to scrutinize the physical features of Mars in unprecedented detail from the top of the atmosphere to underground layering. NASA expects the Orbiter to reveal the history and distribution of Martian water and to return more data than all previous missions combined. The MRO is expected to also support future Mars missions by characterizing possible landing sites and providing a high-data-rate communication relay.

The Cassini-Huygens mission began the year with the dramatic release and descent of the European Space Agency (ESA) Huygens probe through the murky atmosphere of Saturn's largest moon, Titan. Cassini and the probe discovered that the moon is remarkably Earth-like, complete with evidence of methane rain, erosion, stream-like drainage channels, dry lake beds, volcanism, and very few craters. After delivering the Huygens probe to Titan, Cassini began a whirlwind tour of Saturn's icy moons with over one dozen targeted flybys. The spacecraft returned breathtaking views of these icy worlds. In the midst of this multi-moon tour,

Cassini discovered that the moon Enceladus has an atmosphere, and that it appears to be contributing particles to Saturn's massive E-ring.

Astronomers partly funded by NASA discovered a planet-sized body larger than Pluto in the outlying regions of the solar system. Whether the new object, called 2003UB313, will be determined to be the tenth planet in our solar system is currently being decided by the International Astronomical Union. Using the Samuel Oschin Telescope at Palomar Observatory near San Diego, Mike Brown and his colleagues from the California Institute of Technology in Pasadena, California, discovered the putative planet.

Using NASA's Hubble Space Telescope to view Pluto, astronomers discovered that it may have three moons rather than only one. If confirmed, the discovery of the two additional moons could offer insights into the nature and evolution of the Pluto system, the Kuiper Belt Objects with satellite systems, and the early Kuiper Belt—a vast region of icy, rocky bodies beyond Neptune's orbit.

NASA also enlisted the Hubble Space Telescope's unique capabilities in support of future human exploration to the Moon. Hubble's resolution and sensitivity to ultraviolet light allowed it to begin searching for the presence of important minerals that may be critical for the establishment of a sustained human presence on the Moon. Preliminary assessment of the new class of science observations suggested new patterns in the prevalence of titanium and iron oxides, both of which are sources of oxygen—an essential ingredient for human exploration.

Pointing the versatile LEO space telescope to deep space, scientists using Hubble identified the source of a mysterious blue light surrounding a super-massive black hole in our neighboring Andromeda Galaxy (M31) —a strange light that had puzzled astronomers for more than a decade. Scientists concluded that the blue light is coming from a disk of hot, young stars whipping around the black hole in much the same way as planets in our solar system revolve around the Sun. These new observations by the Hubble's Imaging Spectrograph (STIS) revealed that the blue light consists of more than 400 stars that formed in a burst of activity about 200 million years ago. These stars are tightly packed in a disk only a light-year across and nested inside a ring of older, redder stars previously observed by the Hubble.

In late May, NASA announced that the Voyager 1 spacecraft, having traveled 8.7 billion miles from the Sun, had crossed outside the termination shock and

at last entered the heliosheath—the vast, turbulent expanse where the solar wind is much slower, thicker and hotter than the supersonic solar wind closer to the Sun.

Through the unprecedented coordination of observations from several ground-based telescopes and NASA's Swift and other satellites, scientists solved the 35-year-old mystery of the origin of powerful, split-second flashes of light known as short Gamma-Ray Bursts (GRBs)—the most powerful explosions the universe has seen since the Big Bang. These flashes occur approximately once per day and are brief, but intense, flashes of gamma radiation that last only a few milliseconds. Two recently detected bursts were featured in four papers in an October issue of *Nature* magazine. During Swift's two-year nominal mission, scientists anticipate retrieving data for approximately two hundred GRB's, yielding information about the GRB's origin while also providing insight into the activities of the early universe.

NASA's Spitzer Space Telescope captured for the first time the light from two known planets orbiting stars other than our Sun. Prior to this discovery, all observations of confirmed extrasolar planets were indirect. However, in this case, Spitzer picked up the heat radiation, or infrared glow, from Jupiter-sized planets. Spitzer's findings marked the beginning of a new age of planetary science in which scientists can measure and compare extrasolar planets directly.

Aeronautics Research Mission Directorate

It is possible to fly without motors, but not without knowledge and skill," said Wilbur Wright, American inventor and aviator, more than 100 years ago. In FY 2005, the aeronautics professionals at NASA continued to demonstrate their knowledge and skill by completing, or taking to the next level, a wide range of research efforts in aviation safety and security, aviation operations and systems, and revolutionary new vehicle capabilities. The year produced a long list of accomplishments in technology, especially those demonstrating NASA's ability to productively partner with industry, academia, and other government agencies.

The year took off at record-breaking speed in November 2004 with the third flight of the X-43A research vehicle. The flight was the last and fastest of three unpiloted tests in NASA's Hyper-X Program, whose purpose was to explore an alternative to rocket power for space access vehicles. The X-43A's air-breathing scramjet engine has no moving parts, instead compressing the air passing through

it to ignite the fuel. Reaching Mach 10—nearly 7,000 miles per hour—the November flight, which flew at 110,000 feet, broke an earlier record set during a March 2004 flight, and was later officially recognized by Guinness World Records as the newest world speed record by a jet-powered aircraft. Ultimately, the true prize to be gained is the new technology that will allow aircraft to reach supersonic speeds while retaining subsonic maneuverability.

In a related note, one month after that flight, NASA retired the B-52B "mother ship" launch aircraft that had carried the X-43A while mated to its Pegasus booster rocket for all its test flights. After nearly a half-century of carry-and-drop work assignments for numerous advanced flight research vehicles, the B-52B was retired during a ceremony at NASA Dryden Flight Research Center (DFRC).

FY 2005 also witnessed the last flights of NASA's Pathfinder-Plus, a solar-electric flying wing aircraft that was built in the 1990s to facilitate research of long-duration, high-altitude flight. The last short series of flights conducted in late summer provided improved capability to predict the performance of this class of flexible wing vehicles.

"It works! . . . we've proven the AAW concept," said Larry Myers, project manager for NASA's Active Aeroelastic Wing (AAW) project. In March 2005, second phase flight-testing of a modified F/A-18A fitted with flexible wings proved the concept that warping an aircraft's wing will improve its turning ability. The idea actually dates back to the Wright brothers, who used cables attached to the wingtips of their 1903 flyer to twist the wing and turn the airplane. More than 100 years later, NASA used software in the aircraft's flight control computer to react accurately to the flexible wings' movements during twisting maneuvers at various speeds and altitudes. NASA expects the results from these tests to be used to develop faster, more capable military aircraft, as well as high altitude, long-endurance, and uninhabited aerial vehicles, large transport aircraft, and high-speed, long-range aircraft.

After last fiscal year's agreement between NASA and the Federal Aviation Administration (FAA) to reach certain performance metrics related to operating uninhabited aerial vehicles (UAV) in the National airspace, NASA embarked on a series of UAV demonstration flights with Agency partners, including the FAA and the National Oceanic and Atmospheric Administration. Flights included the testing of UAVs' ability to react to obstacles (the "flocking"

effect); to capture Earth science data to fill in critical data gaps for weather, water, climate, and ecosystem monitoring; and to use thermal lifts to prolong flight and save fuel while making observations, such as forest fire monitoring, traffic control, and search and rescue.

In support of NASA's objective to increase capacity and mobility within the National airspace, the Aeronautics Research Mission Directorate (ARMD) conducted integrated flight experiments demonstrating the feasibility of the four Small Aircraft Transportation System (SATS) project operating capabilities: higher volume operations, en-route integration, lower landing minima, and single-pilot performance. SATS partners—the FAA, and the members of the National Consortium for Aviation Mobility—demonstrated those capabilities at a three-day public event in June 2005 at a regional airport in Virginia. The event, "SATS 2005: A Transformation of Air Travel," also represented the culmination of the five-year SATS project. Private-sector SATS partners sought certification on at least 22 products.

Flying an aircraft safely calls for an incredible degree of awareness of the environment in and around the aircraft, as well as in-flight and on the ground. The technology accomplishments in aviation safety and security at NASA revolve around improving that situational awareness in order to prevent accidents and to keep aircraft, crew, cargo, and passengers safe. In support of the ARMD objective to reduce the aviation fatal accident rate by 50 percent over the FY 1991-96 average, a number of these technologies reached a readiness level that allowed them to be tested during experimental flights and often through unique public/industry partnerships.

During FY 2005, NASA took a number of aviation safety technologies—many eagerly anticipated by commercial and general aviation industries, air transportation controllers and managers, and meteorologists—to their next level of development. These are as follows:

- NASA's Synthetic Vision Systems (SVS) project moved from small aircraft testing in FY 2004 to testing aboard a Boeing 757 in FY 2005. The SVS generates a computer-based, sensor-derived electronic picture that shows pilots what is outside the cockpit regardless of visibility limited by darkness or poor weather. Because of stellar testing results, SVS project partner Chelton Flight Systems developed the system for the commercial aviation

market. SVS now flies in hundreds of small planes across the United States and abroad, in addition to receiving numerous certifications in FY 2005 from small aircraft manufacturers for use in their aircraft. It was used aboard the Virgin Atlantic Global Flyer during its record-breaking non-stop flight around the world in late winter 2005.

- The Tropospheric Airborne Meteorological Data Report (TAMDAR) sensor measures a variety of weather factors and transmits them to a ground data center that processes the data for forecasters, pilots, and other aviation personnel. Operational testing of TAMDAR took place daily since January 2005 through the Great Lakes Fleet Experiment—a partnership between NASA and Mesaba Airlines of Minneapolis. Mesaba's 63 commuter aircraft generated over 25,000 TAMDAR observations daily.
- The Turbulence Auto-PIREP System (TAPS) was tested on more than 80 Delta Airlines passenger jets. TAPS takes over when pilots are too busy, automatically broadcasting turbulence encounter reports to other planes and monitors on the ground.

In support of a National airspace that can accommodate more aircraft, NASA, along with the FAA and industry partners, developed the Multi-Center Traffic Management Advisor (McTMA). The software is driven by a powerful trajectory synthesis engine that converts radar data, flight plans, and weather information into highly accurate forecasts of air traffic congestion. Tests at the Philadelphia International Airport in November 2004, and at a number of Air Route Traffic Control Centers, brought McTMA closer to full operation. An earlier version of this tool, Traffic Management Advisor, has been in use since 2002 at several major hubs. According to the FAA, TMA is estimated to have saved airspace users more than $180 million and reduced delays by more than 72,000 hours.

NASA also delivered the multi-volume results of a comprehensive data collection project supporting proposed operational changes in the Wake Vortex Avoidance guidelines. Wake turbulence is a major contributing factor to increased terminal delays and reduced terminal capacity. Defining a new acceptable level of wake vortex encounter would positively impact air transportation capacity. Results from the data collection efforts were vetted to the wake vortex community and then released to the public in June 2005.

NASA continued research on using modern communication network technologies to improve the National Airspace System's communications, navigation, and surveillance infrastructure. Draft roadmaps and benefits assessments will provide a blueprint for technological improvements to total system performance, as well as performance on the ground at airports and in the air over oceans.

In support of reducing aircraft emissions, NASA completed key studies on advanced fuel cell and hybrid systems that would support the use of solar-powered vehicles in science missions. In addition, a low-drag slotted wing concept at flight-design conditions was tested.

Testing of engine combustion technology that would reduce nitrous oxide emissions moved from last year's preliminary design stage to a series of full-annular rig tests of combustor configurations compatible with large commercial aircraft. NASA achieved a 67 percent reduction of emissions, just short of the target 70 percent reduction. Lowering aircraft emissions helps to reduce smog and to lower atmospheric ozone.

NASA's Quiet Aircraft Technology project installed more than 50 microphones and other sensor arrays aboard a Boeing 757 to isolate sources of noise that irritate crew and passengers as part of it's effort to reduce aviation noise 10 decibels by 2009. NASA also studied different propulsion technologies that would support development of a small, quiet supersonic vehicle that flies over land—a supersonic business jet. Along with the propulsion activities, NASA completed 10 test flights that produced 45 low sonic booms. The impact of sonic boom noise would need to be mitigated before aircraft could ever fly at supersonic speeds over land.

In support of efforts to improve the security of the National airspace, NASA implemented interactions and formal research agreements with the Transportation Security Administration, the Federal Air Marshall service, and the Department of Homeland Security Science and Technology Directorate. With those partners, NASA developed the Security Incidents Reporting System (SIRS), an anonymous incident reporting system that utilizes a limited immunity security structure. SIRS collects reports of real-world security incidents that personnel may never have reported through conventional channels. NASA also analyzed threat assessments and developed a concept for surveillance of protected areas.

FY 2005's string of productive partnerships continued as NASA, working with the Department of Defense and industry, completed studies of three different types of heavy-lift Vertical Take-Off and Landing rotorcraft configurations. The

studies are designed to provide strategic input to future decisions on commercial/military vehicles that operate independently of runways. NASA also conducted tests jointly with the Navy to determine whether planned upgrades to E-2C carrier-based aircraft would negatively impact gross weight and resulting performance.

FY 2005 saw the completion of two NASA research endeavors that have operated for nearly 10 years. The Advanced Air Transportation Technologies project—established in 1996 to develop technology that improved the capacity of transportation aircraft at and between major airports—ended in February 2005. Set up in 1997 to address the need for preventing actions that would cause damage, harm, or loss of life, the Aviation Safety & Security Program completed its work in November 2005.

Industry and educators often look to NASA for education materials on aviation safety, science, history, and careers. NASA released a free, online de-icing training course for pilots in FY 2005 as part of the Agency's goal to reduce the rate of aircraft accidents. Developed by an international team led by NASA researchers, the self-guided course provides pilots with general ground icing knowledge.

After several years of development, NASA premiered the online interactive education product, Fly By Math™, for students and teachers in grades 5–9 as part of NASA's Smart Skies™ program. Smart Skies teaches youth how aviation professionals manage and direct air traffic using distance, rate of speed, and time relationship calculations.

Of the 300 Small Business Innovation Research Phase I grants awarded by NASA in FY 2005, 43 of them were awarded by the Aeronautics Research Mission Directorate to businesses in 15 states. These businesses are expected to develop technologies in response to specific NASA mission-driven needs, including improved aviation safety, aircraft health management and analysis, breakthrough technologies for noise reduction, new propulsion technologies, and technologies to support next-generation air traffic management systems.

Finally, NASA continued its leadership role in the Joint Planning and Development Office (JPDO). The multi-agency JPDO vision and roadmap for the Next Generation Air Transportation System (NGATS) is expected to provide a foundation for our future Airspace research plans.

DEPARTMENT OF DEFENSE

DOD

During FY 2005, the Department of Defense (DOD) engaged in a wide variety of aerospace activities, from Science and Technology (S&T) efforts to full space system deployment and operations. The S&T efforts involved developing new technologies to enhance the warfighter's capabilities. The DOD conducted testing of these new technologies, often in coordination with NASA, to prove the concepts in a space environment and reduce the risks associated with incorporating them into full systems. The full system activities focused on continuing space-based missile warning systems, preparing for the next generation Global Positioning System constellation, developing new military communication systems, and partnering with NASA and the Department of Commerce (DOC) on the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The Air Force (USAF) continued its success with the Evolved Expendable Launch Vehicle (EELV) program while preparing to retire the Titan legacy launch vehicles.

In August 2005, the DOD Executive Agent for Space, Dr. Ronald Sega, and NASA Administrator Michael Griffin signed an agreement coordinating the space transportation strategy presented by NASA to support the Vision for Space Exploration. This agreement, in accord with National Security Policy Directive 40, outlines a strategy that separates human-rated space exploration systems from unmanned launch vehicles. Under the terms of the agreement, NASA will initiate development of a Crew Launch Vehicle and a super-heavy lift vehicle from shuttle-derived components. NASA has also agreed to use EELV to the maximum extent possible both for launches of robotic civil and science missions and for International Space Station cargo re-supply missions. The agreement, further-

more, commits the DOD and NASA to continued cooperation on the development of spaceflight technologies. This agreement serves the national interest by maintaining reliable and affordable access to space as well as both liquid and solid propulsion industrial bases.

DOD S&T programs touch on almost every facet of space technologies. For example, the USAF and NASA participated in a university nanosatellite program designed to improve performance and cost-effectiveness beyond that provided by current large satellite systems. The universities conducted creative, low-cost space experiments that explored the military and commercial usefulness of small satellites in areas such as formation flying, enhanced communications, miniaturized sensors, attitude control, and maneuvering. The USAF collaborated with various teams to develop a deployment structure, secure a launch, and provide advanced satellite hardware such as high-efficiency solar cells and micro-propulsion units. NASA Goddard demonstrated formation flying technologies and provided design and safety related guidance, as well as advanced crosslink communication, navigation hardware, and flight control algorithms.

The USAF continued to improve space sensor technologies, including the development of L-Band all-weather radar and hyperspectral and hypertemporal imaging. Space structures technologies were developed to support deployable large aperture arrays. Radiation hardening technologies were researched and tested, allowing for more robust components and further addressing critical electronic technology, commercial processor development, and manufacturing issues. Radiation Belt Remediation efforts focused on quickly cleaning up the effects of a high altitude nuclear detonation, which will preserve our space capabilities should we suffer, in Secretary Rumsfeld's words, "a space Pearl Harbor." The Air Force Research Laboratory (AFRL) built and operated the XSS-11 satellite, which is in the process of demonstrating an onboard autonomous rendezvous and circumnavigation capability specifically designed to identify U.S. Resident Space Objects. Under the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Program, the DOD and NASA continued the Integrated Powerhead Demonstration tests, developed smaller more efficient spacecraft propulsion systems, improved upper stage engine development tools, and developed new rocket fuels and components.

The DOD also pursued advanced technology development, testing some of these technologies through the MISSE.

The DOD Space Test Program (STP), Rocket Systems Launch Program (RSLP), and Research and Development Space and Missile Operations (RDSMO) assisted space lift missions by integrating payloads, supporting launches of both EELV and NASA Space Shuttles, and facilitating or directing operations to include efforts on the ISS. RDSMO provided launch and booster telemetry support and remote telemetry relay for the NASA Swift and Deep Impact programs, as well as the National Oceanic and Atmospheric Administration and the Geostationary Operational Environmental Satellite (GOES) programs. Space lift efforts included the rapid integration of NanoSat-2 and its subsequent launch on the EELV Heavy Lift Demonstration on 21 December 2004. The AFRL XSS-11 spacecraft was launched successfully on a Minotaur I Launch Vehicle in 11 April 2005, while a second Minotaur I launched STP-R1 in support of the Defense Advanced Research Projects Agency (DARPA). Additionally, RSLP completed the Preliminary Design Review of its Minotaur IV launch vehicle. RSLP continued efforts to provide access to lower cost, responsive small commercial space launch vehicles. For the Space Shuttle Return to Flight mission (July–August 2005), STP managed crew training, the on-orbit retrieval of MISSE 1 & 2, and the deployment of MISSE-5. At this time, RDSMO performed around-the-clock operations that allowed the USAF Satellite Control Network to conduct tracking and data acquisition.

In September 2005, the second advanced Space-Based Infrared System (SBIRS) payload, the Highly Elliptical Orbit-2 (HEO-2), was delivered for host-satellite integration.

The GPS Joint Program Office launched the thirteenth replacement GPS-II satellite (IIR-13) in November 2004 and the first modernized replacement GPS-II satellite (IIRM-1) in September 2005. Contract options with Boeing were exercised to procure GPS-II Follow-on (IIF) satellites 7–9 and long-lead parts for IIF satellites 10-12. The Modernized User Equipment (MUE) program continued with the concept phase and prepared to release a Request for Proposal for the development phase in early FY 2006. Following White House approval of the National Security Presidential Directive on Space-Based Position, Navigation,

and Timing (PNT) in December 2004, the DOD worked with other U.S. Government agencies to implement the National PNT Coordination Office, including providing USAF staff. Technical consultations with the European Commission continued to ensure that GPS and Galileo are compatible with each other within the radio-frequency spectrum. Consultations were also conducted with Japan and Russia to maximize cooperation and to increase support for GPS.

The operational DOD Military Satellite Communications (MILSATCOM) constellations—Defense Satellite Communications System, Global Broadcast Service, and Milstar—continued to support U.S. and allied operations throughout the world, and also assisted with relief effort operations in the aftermath of the December 2004 South Asia tsunami and Hurricane Katrina of August 2005. The DOD continued to develop of the Wideband Gapfiller Satellite system, the Advanced Extremely High Frequency satellites, the Mobile User Objective System, the Transformational Satellite Communications System constellation, and the programs forming the foundation of the Transformational Communications Architecture (TCA).

NPOESS is a tri-agency program of NASA, DOD, and DOC that converges the DOD and DOC/NOAA polar-orbiting weather satellite programs. NPOESS completed its System Preliminary Design Review in FY 2005. Additionally, the program's Svalbard ground station off the coast of Norway provided data recovery and routing services for NASA's Earth Observing System (EOS) missions and the U.S. Navy's Windsat/Coriolis mission.

The USAF achieved success with several legacy launch vehicle systems. Delta II successfully launched two GPS II satellites. Titan IVB (launch vehicle B30) launched the National Reconnaissance Office Launch (NROL)-16 satellite on April 29, 2005. Preparations for the final Titan IV launch on October 19, 2005, were conducted, followed by closeout activities that acknowledged the end to fifty years of launch operations. Atlas III AC-206 launched February 3, 2005, placing a NRO satellite in orbit. Closeout activities neared completion for the Atlas heritage launch vehicle program.

For the EELV program—the newest USAF launch vehicles—the major FY 2005 accomplishment was the launch of the Delta IV Heavy Lift Vehicle Demonstration. Three successful Atlas V launches also occurred in FY 2005—two

commercial payloads and the NASA Mars Reconnaissance Orbiter. Finally, the USAF revised the acquisition approach for EELV based on decreased commercial launch demand. This revised strategy, which assures access to space for our critical national security payloads, was developed to serve as the basis for subsequent launch service awards.

Federal Aviation Administration

FAA

To enhance and improve the safety of the national aerospace system, the FAA conducts and sponsors short-range research and development, as well as long-range planning for emerging technologies and changing circumstances.

FAA researchers and scientists had another successful year in FY 2005 developing and testing new products and procedures that will improve safety, efficiency, and environmental compatibility of aviation for years to come. The FAA's Office of Aviation Research and Development continued its successful partnership with government agencies, industry, and academic institutions.

Research in FY 2005 focused on assuring the continued safety of commercial aircraft. At the FAA Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) facility, specialists conducted strength tests of rivets in aircraft and analyzed data to predict and detect cracks in fuselage skins. FAA engineers experimented with new means to inspect aircraft properly and quickly without needing to disassemble them. Also, because manufacturers now construct aircraft with more composite materials than in the past, the FAA Airworthiness Assurance Center of Excellence worked with Iowa State University to develop a new nondestructive ultrasonic inspection technique. Having tested this technology successfully, the developers began licensing and transferring it to the commercial sector.

The FAA supported similar projects to improve helicopter technology. Researchers at the FAA Airworthiness Assurance Nondestructive Inspection Validation Center at Sandia National Laboratories collaborated with rotorcraft manufacturers to find innovative ways to discover small cracks hidden under fas-

teners. Researchers began their effort to transfer these inspection methods to industry for routine use in rotorcraft maintenance depots.

The FAA is committed to improving the quality and readability of aviation technical manuals. Along with aircraft manufacturers and specialists from the Wichita State University National Institute for Aviation Research, FAA researchers developed the online Evaluation Toolbox for Aviation Technical Writers. This toolbox contains concepts, evaluation methods, tools, templates, and references to educate and assist technical writers in developing easy to understand documents. The Agency also initiated a formal program to train technical writers.

The FAA continued to lead government-industry efforts to collect, analyze, and publish standardized information on aircraft and aerospace material and fastener properties. Under FAA auspices, the Battelle Memorial Institute issued the first commercial version of Metallic Materials and Elements for Aerospace Vehicle Structure, a text that has worldwide recognition for its contributions to the design and maintenance of aircraft, missiles, and space vehicles.

The increased use of composites in aircraft manufacturing has inspired FAA researchers to consider new fire resistance or flammability requirements for airplanes. Because polymer composite structures may be flammable, FAA scientists began searching for new environmentally-friendly strategies for reducing potential fire hazards. Working with NASA, FAA researchers synthesized and tested epoxy resins cured with agents containing phosphorus as a possible alternative to halogen flame retardants.

FAA engineers worked to increase the time available for passengers to escape from an airplane cabin in the unlikely event of a fire. They developed a flammability tester that needs only a tiny sample of a given substance to determine the contribution it would make to the growth rate of a fire. Last year, the FAA received a patent and licensed two companies to make and sell these microscale combustion calorimeters. In addition, FAA experts developed a new fire test method for thermal acoustic insulation and studied alternative ways to meet the mandate to replace flammable insulation blankets.

Research suggests that aircraft electrical wire that is bundled and then subjected to a severe ignition source may not meet flammability test requirements established in 1972. The FAA expanded its research to upgrade the fire test crite-

ria for electrical wiring and for materials used in hidden areas of an aircraft, such as the attic above the cabin ceiling, areas beneath the floor, and areas in or around the lavatories.

The FAA tested a new technology developed to reduce the risk of fuel tank explosions aboard aircraft. In this experimental fuel tank inerting system, nitrogen-enriched air is generated onboard to displace the air above the tank's level of jet fuel. In conjunction with NASA, FAA researchers tested this system on the Boeing 747 SCA that is used to transport the Space Shuttle Orbiter.

In 2005, researchers acquired a new vehicle to increase their ability to conduct more sophisticated Aircraft Rescue and Fire Fighting (ARFF) research. The new, larger ARFF research vehicle will help with extensive live fire testing needed to determine fire protection standards for new large aircraft, such as the Airbus A380. To enhance airport safety, FAA researchers also continued to evaluate the use of new technologies and existing products in new configurations. For example, they tested the experimental Tarsier Foreign Object Debris (FOD) Detection Radar under a wide range of weather conditions.

Lighting experts experimented with new uses for the arrays of red bulbs at taxiway entrances, known as runway status lights. These arrays have been used to warn pilots and vehicle operators that a runway is unsafe to enter. Evaluations at Dallas-Fort Worth International Airport indicated that it might be possible to create a standard procedure using runway status lights to alert pilots as to which aircraft have been granted clearance to depart. Researchers demonstrated a redesigned Runway Obstruction Warning System that monitors ground movements from the control tower through a network of sensors embedded in runways and taxiways. They also found that reversing the configuration for centerline lights of taxiway approaches to runway is a cost-effective way to inform pilots that they are moving from runways to taxiways.

FAA engineers at the FAA National Airport Pavement Test Facility evaluated the impact of the next generation of heavy aircraft on airport surfaces. They updated thickness design standards for concrete pavements and tested how different paving options might better reveal cracks and other wear. These experts also evaluated whether or not to allow thinner concrete overlay slabs to rehabilitate pavements at three general aviation airports.

The FAA made strides to increase airport capacity. At the Memphis International Airport, FAA researchers, collaborating with NASA colleagues, successfully demonstrated a tool to help controllers, traffic managers, and national airspace system users manage aircraft movements at busy airports. This surface traffic management system increases airport capacity, efficiency, and flexibility. It shows a real-time computer map of the airport layout, aircraft, taxiways, runways, and gates. A mouse click can target individual aircraft and display pertinent information regarding its scheduled flight. The technology predicts arrival time, touchdown, and taxi time to the gate. The FAA installed a system for use by United Parcel Service controllers monitoring the unloading, loading, and refueling of cargo jets.

The Traffic Management Advisory-Multi-Center (TMA-MC) system, created to reduce widespread flight delays, grew out of the Single-Center TMA Decision Support Tool used currently at more than half of the FAA Air Route Traffic Control Centers. Researchers used statistics from Philadelphia International Airport to prove that controllers assisted by TMA-MC could cut delays in comparison with other unassisted professionals operating under similar weather and demand conditions.

Automatic Dependent Surveillance-Broadcast (ADS-B)—the FAA's leading technology opportunity—is a two-way data link system that provides an aircraft's identification, position, velocity, and other information via radio messages issued at one-second intervals. Work continued on development of the ground infrastructure needed to integrate ADS-B. ADS-B is in use at the lower two-thirds of the East Coast and parts of Ohio, North Dakota, and Arizona.

Capstone, a similar program in Alaska, works at lower altitudes and has resulted in safer skies. The accident rate for Capstone-equipped aircraft was nearly 50 percent lower than for non-equipped aircraft over the past three years. Combining Global Positioning System technology with Wide Area Augmentation System technology, Capstone helps pilots in areas that lack radar coverage. Given its ability to improve safety while reducing operational costs, Capstone holds the potential to replace existing navigational aids.

Human factors researchers developed a Web-based tool to assist planners and construction engineers in making informed decisions on the construction of

airport traffic control towers. Until recently, the FAA based its height and location determinations for the siting of towers on criteria issued in 1972. To create a more efficient tower cab design, human factors researchers studied controller work patterns and tower cab layouts, resulting in the development of an innovative modular design criteria. A new, draft siting policy mandates use of revised visibility performance measures. The new criteria promises to resolve potential costly problems before the start of tower construction.

Human factors experts contributed to the design of the future en route workstation to increase productivity of air traffic controllers. One of their most complex person-in-the-loop simulation studies exposed controllers to various workstation concepts operating with increasing levels of aircraft traffic. The FAA also assessed prototype en route information display systems at the Boston, Jacksonville, and Salt Lake City Air Route Traffic Control Centers.

The FAA made improvements over the past year to the Human Factors Analysis and Classification System. This tool is now integrated with other traditional situational and demographic variables listed by the National Transportation Safety Board into a single Web-based database to examine possible human error in accidents. In 2005, FAA-funded researchers at the American Institutes for Research helped develop, test, and validate the method that details seven high-level contributors to human error in aviation. Another study investigated factors underlying a pilot's ability to recognize and react to various flight abnormalities, including upset recovery.

The FAA collaborated with NASA, Boeing, FedEx, passenger carriers, airline labor unions, and St. Louis University to develop the Operator's Manual for Human Factors in Aviation Maintenance. This publication provides concise listings of six key elements that help ensure appropriate human factors input into any aviation maintenance and repair organization. FAA-funded researchers at Clemson University developed a prototype computer-based training tool, the General Aviation Inspection Training System, which improves the ability of inspectors to detect defects.

Forensic toxicologists in the Aerospace Medical Research Division of the FAA Civil Aerospace Medical Institute made significant advances in analyzing fluids and tissues following fatal aircraft accidents. For example, they are now easily and quickly able to detect the difference between individuals who used

codeine and those who had merely eaten food with poppy seeds. Researchers also worked to identify human genes associated with alcohol impairment and evaluated heart conditions to validate current health certification procedures for pilots.

The FAA Aviation Weather Research Program continued to fund scientists, meteorologists, and engineers from the National Center for Atmospheric Research, Massachusetts Institute of Technology Lincoln Laboratory, the National Oceanic and Atmospheric Administration's Global Systems Division, National Severe Storms Laboratory, and Aviation Weather Center to develop more accurate and timely forecasts of meteorological conditions. FY 2005 saw an upgrade to the Weather Support to Decision Making System in use at Denver International Airport. Researchers completed development of a product that detects freezing drizzle. FAA-funded researchers worked toward finding solutions to poor visibility conditions and low cloud ceilings. They began receiving feedback on National Ceiling and Visibility Analysis Tools used in the continental United States and Alaska. FAA research into convective weather included a demonstration near Chicago that led to new methods of detecting surface effects and predicting thunderstorms sooner.

Researchers continued to develop a Real-Time Verification System to verify and assess the quality of weather forecasts. The National Weather Service installed the system last summer as a prototype. Users of the Web-based interface include aviation researchers, the National Weather Service's Aviation Weather Center, the FAA Air Traffic Control System Command Center, the FAA/National Weather Service Aviation Weather Technology Transfer Board, and several airline dispatch centers. Researchers updated the Rapid Update Cycle model to increase forecast accuracy with higher resolution graphics and additional weather information.

FAA and NASA researchers joined together to educate the public about the effects of aviation noise and emissions. They worked toward creating an integrated suite of analytical tools, the Environmental Design Space (EDS), Aviation Environmental Design Tool (AEDT), and the Aviation environmental Portfolio Management Tool (APMT). Universities in the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) began developing the EDS and APMT modules. In addition, Volpe National Transportation

Systems Center led a team of industry partners that completed a prototype of the AEDT module's components.

In FY 2005, two new universities joined the PARTNER Center of Excellence, a highly regarded research facility sponsored by the FAA, NASA, and Transport Canada and administered by the Massachusetts Institute of Technology. The additional participants are York University of Toronto and the Georgia Institute of Technology. One PARTNER team, led by Purdue University and Florida International University, began researching issues of airport encroachment and land use. Another team studied the sources and impact of low frequency noise. This work may have implications for airport operations and future aircraft design and regulations.

The FAA continued to support research to mitigate the environmental impact of aviation technologies. To reduce aircraft noise, FAA, NASA, and aerospace industry partners flight-tested new noise reduction technologies. These included two improved chevron designs on the engine housing and a cover that fits on the landing gear. In 2005, the FAA, NASA, and private businesses developed accurate profiles to focus on the particulate matter emitted by aircraft engines. The FAA also cooperated with Federal agencies, engine and aircraft manufacturers, airports and airlines, and other stakeholders to collect data for a "Particulate Roadmap." This research is intended to improve understanding of the effects of particulates on air quality and the earth's climate to guide future aviation technology development.

During FY 2005, the FAA monitored the Ansari X Prize-winning flight of SpaceShipOne, which received a FAA launch license in FY 2004. The suborbital flight on October 4, 2005, set the stage for future commercial suborbital development and private passenger launches. With the $10 million prize, the total value of FY 2005 FAA-licensed launches was about $395 million.

Five FAA-licensed orbital space launches occurred in FY 2005, including two Atlas 5 vehicles from Cape Canaveral Air Force Station, and three Zenit 3SL launches conducted by the multinational Sea Launch service provider. The orbital launch count is lower than for the previous fiscal year, in which there were nine, but matches the number of launches licensed in FY 2001 and FY 2002. Up to 10 FAA-licensed launches are expected in FY 2006.

The Office of Commercial Space Transportation released a number of important regulatory documents during FY 2005, including: Guidelines for Experimental Permits for Reusable Suborbital Rockets; Draft Guidelines for Commercial Suborbital Reusable Launch Vehicle (RLV) Operations with Flight Crew; Draft Guidelines for Commercial Suborbital RLV Operations with Space Flight Participants; the Guide to Commercial Reusable Launch Vehicle Operations and Maintenance; and the Guide to Reusable Launch and Reentry Vehicle Reliability Analysis.

In support of the NASA Shuttle Return to Flight operations, the FAA established a plan to mitigate the risks to the uninvolved public in the event of an accident. This plan included defining requirements for airspace restrictions and the establishment of real-time communication links between NASA and FAA facilities.

Three new research initiatives commenced in FY 2005 and work continued on two other projects, one initiated in FY 2003 and the other in FY 2004. These projects were: validation of computer models used for debris risk analysis; reconfigurable control allocations for next generation reusable launch vehicles; identification of communications frequencies that are less susceptible to radio frequency blackout during reusable launch vehicle reentry; evaluation of an autonomous launch vehicle flight safety system; and evaluation of expendable launch vehicle weather delays.

The FAA released several informative research reports of interest to the space industry, the U.S. Government, and the public. These include: Suborbital Reusable Launch Vehicles and Emerging Markets; the 2005 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports report; a summary of Office of the Associate Administrator for Commercial Space Transportation (AST) Research and Development accomplishments; and the 2005 Commercial Space Transportation Forecasts. The forecasts, prepared by the FAA and its Commercial Space Transportation Advisory Committee, projected an average worldwide demand of 16.4 launches per year to geosynchronous orbit and 6.4 launches per year to non-geosynchronous orbits between 2005 and 2014.

DEPARTMENT OF COMMERCE

DOC

In FY 2005, the Department of Commerce (DOC) engaged in a wide variety of activities that furthered U.S. interests in aeronautics and space, including national policy development, satellite operations, technology development, measurement and calibration, international cooperation, trade promotion, and spectrum management.

At the departmental level, DOC continued its active role on the National Security Council's Space Policy Coordinating Committee (Space PCC) through the direct participation of the Deputy Secretary of Commerce and staff from the National Oceanic and Atmospheric Administration (NOAA), the International Trade Administration (ITA), the Office of Space Commercialization (OSC), and the National Telecommunications and Information Administration (NTIA). Among the Space PCC's accomplishments was the release of new U.S. policies on space-based PNT in December 2004 and on space transportation in January 2005. In order to ensure that commercial interests were adequately addressed, ITA kept U.S. industry briefed while these policies were developed.

In February 2005, Secretary of Commerce Carlos Gutierrez led the U.S. delegation at the Third Earth Observation Summit in Belgium during which ministers from 58 countries and the European Commission established the intergovernmental Group on Earth Observations (GEO) as a body to implement a Global Earth Observation System of Systems (GEOSS). Ministers also endorsed and stated their intent to execute the 10-Year Implementation Plan, which outlines collective targeted actions for establishing a GEOSS. At the first meeting of the GEO in May 2005, the United States, European Commission, China, and South Africa were selected as GEO co-chairs, and an Executive Committee was

created to facilitate and implement decisions of the GEO Plenary. The GEO also addressed mechanisms for obtaining scientific and technical advice, interfacing with the user community, and taking action to support tsunami warning, response, and recovery.

Also at the departmental level, DOC continued to play a key role on the Interagency GPS Executive Board (IGEB) and its successor organization, the National Space-Based Positioning, Navigation, and Timing Executive Committee. DOC continued to host the offices and meetings of the IGEB, providing both personnel and resources, and worked towards the establishment of the National Space-Based PNT Coordination Office inside the DOC building. DOC participated in the completion of the Charters for the Executive Committee, Coordination Office, and National Space-Based PNT Advisory Board. OSC staff participated in bilateral consultations with South Korea, India, Japan, and Russia to promote global interoperability between GPS and other satellite navigation systems. OSC also organized meetings with U.S. industry to discuss trade concerns under the auspices of the U.S.-European agreement on cooperation in satellite navigation.

DOC participated in an interagency initiative to develop an Integrated Plan for the Next Generation Air Transportation System issued on December 12, 2004. ITA contributed to the formation of the interagency Joint Planning and Development Office and to related technical working groups. NOAA led the interagency integrated product team (IPT) in developing a national aviation weather strategy, in addition to participating on the Global Harmonization IPT. ITA participated in a joint government-industry initiative designed to identify aerospace workforce and education concerns in order to create a coordinated industry-government workforce action plan. ITA also contributed to the Administration's review of the U.S. export control regime.

DOC continued to represent commercial remote sensing interests within the Remote Sensing Interagency Working Group (RSIWG). RSIWG coordinates policy for the export of remote sensing satellite systems and negotiates government-to-government agreements that cover the safeguarding of those systems' technology. The group held consultations with several countries on remote-sensing satellite cooperation.

Within NOAA, space-related activities occurred across the entire organization. During the record-breaking 2005 Atlantic hurricane season, NOAA's Geostationary Operational Environmental Satellite system provided a continuous flow of imagery that contributed significantly to the development of storm forecasts. These forecasts helped minimize loss of life in the United States from three tropical storms and five hurricanes, four of which—Dennis, Katrina, Rita, and Wilma—were considered major hurricanes. GOES satellites also continued to provide space weather monitoring that protected spacecraft and power grids.

NOAA's Polar-orbiting Operational Environmental Satellite (POES) system provided an uninterrupted flow of global environmental information to support weather, oceanic, and space environmental modeling, as well as tropical storm analysis and forecasting, local weather forecasting, and ecosystem and climate monitoring. The global data from these satellites were used extensively in NOAA's weather and climate prediction numerical models. The NOAA-N spacecraft was launched in May 2005 and began operations in August 2005. Renamed NOAA-18, it replaced NOAA-16 and continued the series of POES spacecraft with improved imaging and sounding capabilities. NOAA-18 started a new era of cooperation between NOAA and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). NOAA-18 and its follow-on, NOAA-N Prime, will carry a EUMETSAT instrument on an afternoon orbit, while three European Metop satellites will be launched into morning orbits carrying key NOAA instruments.

NOAA solidified its presence on the Internet in 2005 when a record number of users visited its Web sites to find information ranging from the status of current satellites to real time imagery from those satellites. The highlight of the year was the record number of hits on NOAA's Web sites due to Hurricane Katrina. Users from around the world logged on to view updates on the storm position, satellite imagery, and rainfall potential gleaned from sensors on board NOAA's Polar Operational Environmental Satellites. The week prior to Katrina's landfall, NOAA's Office of Satellite Data Processing and Distribution received a total of 206,814,261 Web site hits and pushed out 6.03 Terabytes of data.

NOAA provided backup satellite data to the U.S. Navy after Hurricane Katrina's eye moved across Stennis Space Center (SSC), home to the Navy

Oceanographic Center. Through the efforts of a joint NOAA/DOD team, the Committee for Operational Processing Centers & the Working Group for Cooperative Support and Back-up, NOAA provided routine environmental sea surface temperature and some telemetry data to the Navy's Fleet Numerical Oceanographic Center for a two-week period following Katrina.

NOAA leveraged its nighttime lights program to provide national hurricane damage assessments and support tsunami relief efforts. The nighttime lights program uses space-based Earth imagery from the Defense Meteorological Satellite Program to create global and regional assessments following natural catastrophic events. For example, detailed images following Hurricanes Katrina and Wilma indicated the extent of and recovery from widespread power outages along the Louisiana coast and in Florida. In addition, the international community used nighttime imagery to determine the extent of damage following the December 2004 tsunami. These efforts dovetailed well with NOAA's responsibility for recording the societal impacts of natural hazards, which remains an important element in the planning of hazard response and mitigation.

The NOAA/DOD/NASA Integrated Program Office (IPO) continued development of NPOESS. Significant accomplishments included integration of the engineering model of the Cross Track Infrared Sounder onto the NPOESS Preparatory Project (NPP) spacecraft and installation of the NPP/NPOESS Command, Control, and Communication Equipment at facilities in Maryland, New Mexico, and Norway. The NPOESS Airborne Sounder Testbed was deployed in campaigns designed to better understand and measure atmospheric conditions. This information can be used to create weather forecast models and to provide risk reduction for temperature and humidity measuring sensors. Windsat/Coriolis, a joint satellite mission among the IPO, U.S. Navy, and DOD Space Test Program to test new methods for characterizing winds over the ocean surface, continued to supply valuable data that measured, among other things, wind fields around hurricanes. The IPO continued its outreach efforts to the science, operational, defense, and climate communities through special sessions at meetings of the American Meteorological Society, International Geosciences and Remote Sensing Symposium, American Institute of Astronautics and Aeronautics, Society of Photo-optical Instrument Engineers, American Geophysical Union, and National Space Symposium.

In FY 2005, NOAA's National Ice Center (NIC) responded to high resolution imagery requests in support of Hurricanes Katrina and Rita and other national activities. Using RADARSAT data, during Hurricane Rita the NIC provided emergency support to NOAA, the Office of Hazardous Materials Safety (HAZMAT), NOAA Fisheries, Federal Emergency Management Agency (FEMA), and U.S. Geological Survey Earth Resources Observation Systems Data Center. The NIC also provided the Niagara River Control Group with tailored, annotated imagery in support of the Ice Boom Project. The NIC provided RADARSAT data to the National Science Foundation's River Influences on Shelf Ecosystems Research Project, which studies fronts and regions where river water and ocean water mix.

In February 2005, NOAA signed an agreement with the Japan Meteorological Agency (JMA) to provide long-term, mutual geostationary satellite backup. This will help NOAA and JMA mitigate the costs and risks associated with operating satellites while ensuring that the continental United States has continuous access to geostationary satellites critical to monitoring weather monitoring.

In June 2005, NOAA participated in the U.S.-India Joint Working Group on Civil Space Cooperation. The two countries established the working group in March 2005 to expand their cooperation in civilian space programs and to build on the pioneering work of the 2004 India-U.S. Conference on Space Science, Applications and Commerce. Accomplishments included an agreement in principle to establish an NPOESS Earth reception station in India, commitment by the Indian Space Research Organization to work with the Indian Meteorological Department to ensure that INSAT (Indian National Satellite) and Kalpana data transmitted to the United States is geo-located, and agreement to collaborate on several Earth observation projects while establishing a process for reviewing new proposals. The group also encouraged active participation in the GEO, discussed the critical nature of timely data access, and acknowledged that the development of a multiple hazards early warning and response system would serve the national objectives of both countries.

NOAA participated in the 20th anniversary commemoration and 18th Plenary of the international Committee on Earth Observation Satellites (CEOS) in Beijing, China. The 18th Plenary established a high-level CEOS Task Force

that worked throughout FY 2005 to focus on CEOS's future role and contributions to the GEOSS Implementation Plan. NOAA also participated in similar discussions related to the future inputs that the Integrated Global Observing Strategy will make to GEOSS implementation.

In FY 2005, NOAA used products from NASA's Aqua and Terra satellites in conjunction with GOES products to improve analysis and forecasting of heavy precipitation events. High spatial resolution products derived from instruments on those satellites were used to provide measurements of the amount of precipitable water in the atmosphere, produce rain rate estimates, and determine whether the atmosphere is conducive to thunderstorm or convective activity.

In FY 2005, NOAA's Search and Rescue Satellite Aided Tracking (SARSAT) program contributed to the rescue of 244 people. The user base for the new, digital 406 MHz emergency beacons increased 16 percent to 139,347. The SARSAT program helped facilitate the relocation from London to Montreal of the Secretariat for the International Cospas-Sarsat Program, a cooperative search-and-rescue effort established in 1988 among the United States, Canada, France, and the former Soviet Union. The move ensured that the organization is afforded the same privileges and immunities as other international organizations while reducing operating costs approximately 15 percent and improving operating reserves. The SARSAT program implemented several new communication paths to reduce the cost of domestic and international communications while retaining security and reliability.

The Argos Data Collection and Location System grew to meet the needs of the climate observation community. Administered under a joint agreement between NOAA and the French space agency CNES, Argos supports NOAA's goals to understand climate variability and change and serve society's needs for weather and water information. The system provides a means to collect environmental data from remote locations such as the polar ice caps, African savannah, and the South Pacific Ocean. From April 2004 to April 2005, the number of Argos data collection platforms increased 23 percent to a total of 14,320. Applications of the data include weather forecasting, weather modeling, climate prediction, pollution monitoring, polar research, and ocean circulation research.

In 2005, NOAA's Coral Reef Watch Program launched a Satellite Bleaching Alert system that provides coral reef managers and researchers with

automated alerts of potential coral bleaching outbreaks at 24 reefs around the world, up to three weeks before they occur. The system utilizes global satellite data to track sustained high water temperatures, which can cause bleaching to occur. The alerts proved invaluable in late 2005 when a long-lasting warm anomaly across the tropical Atlantic led to the greatest thermal stress and coral bleaching event ever observed in the Caribbean.

NOAA developed the 2005-2010 World Magnetic Model, released in collaboration with the National Geospatial-Intelligence Agency and the British Geological Survey. The World Magnetic Model became the standard navigation magnetic field reference for NOAA, DOD, the U.K. Ministry of Defense, North Atlantic Treaty Organization (NATO), and the World Meteorological Organization. Ground-based observations from over 200 stations in more than 80 countries, augmented by global magnetic field measurements obtained from two satellites, created the most accurate model available of the terrestrial magnetic field. Also modeled were changes in the global magnetic field topology, including the drifting of the north and south magnetic poles in relation to epochal changes (reversals) in the field orientation.

The global archives within NOAA's Space Physics Interactive Data Resource (SPIDR) system were updated in China, Australia, and South Africa to improve Web access to international space environmental data sets. Originally developed within NOAA, SPIDR is now hosted at eight locations worldwide. FY 2005 saw the completion of efforts to standardize formats for archived geomagnetic and ionospheric data. Improved search engines for historical data sets were also developed and incorporated throughout the global network, substantially enhancing the ability of researchers to access and manage historical space physics data for integration with environment models and space weather forecasts.

NOAA licensed the operation of U.S. commercial remote sensing satellites, bringing the total number of licensees to over 30, along with over 40 license amendments, and more than 30 foreign agreements. NOAA continued to oversee technical Analysis and support efforts to better characterize the remote sensing market and foreign commercial availability of these sensitive technologies. In addition, the Federal Advisory Committee on Commercial Remote Sensing remained under NOAA's management.

During FY 2005, DOC transferred the Office of Space Commercialization to NOAA from the Technology Administration. While retaining its basic mission to represent commercial space interests within the government, the office was reorganized and moved to NOAA's Satellite and Information Service.

Outside of NOAA, the National Institute of Standards and Technology (NIST) performed a broad range of aeronautics and space-related measurements, technology development, and industry support activities in FY 2005. In support of NASA's human space flight program, NIST evaluated the electromagnetic shielding properties of the Space Shuttle Endeavour. The radar power levels required for detecting foam debris held the potential to interfere with critical Shuttle electronic systems, such as engine and flight controllers. With NIST data, NASA gained the ability to assess the risk associated with the use of high-power radar for imaging an orbiter during launch, particularly during critical night launches. The NIST Space Shuttle measurements were part of a broader effort to support the aerospace industry through the development of efficient techniques to measure the shielding of aircraft to electromagnetic radiation.

NIST continued to collaborate with NASA to develop cryogenic transition-edge-sensor microcalorimeter x-ray detectors for future Constellation-X and other x-ray satellite missions. New results on NIST detector arrays demonstrated greatly improved energy-resolving power (the key performance characteristic), and NIST achieved a record-breaking result of 2.4 electron volts energy resolution at an x-ray energy of 5.9 kilo-electron volts. NIST expects to further improve sensor performance to reach the 2 electron volt resolution goal set by NASA, which will enable future x-ray satellite missions to better determine the temperature and motion of matter in space.

NIST developed new Micro-Electro-Mechanical Systems (MEMS) apertures for NASA's Terrestrial Planet Finder mission, a program that requires the development of novel optical systems for the detection of planets around other stars. Working with researchers at Princeton, NIST fabricated complex silicon structures using deep reactive ion etching and incorporated them in a shaped pupil coronagraph to produce the highest contrast results ever achieved in a laboratory setting. NIST also characterized the magnetic behavior of magnetic micro-shutters for space-based telescope arrays.

NIST studied problems of calibration and validation of microwave radiometers used to remotely sense the Earth's surface and atmosphere. Work in FY 2005 focused on developing methods to measure the characteristics of blackbody calibration targets used in microwave remote sensing.

In support of NASA's Next Generation Launch Technology Program, NIST provided improved thermodynamic data for a kerosene-based fuel, RP-1, that will be combusted in advanced rocket engines. NIST researchers conducted measurements of chemical composition, boiling temperature, density, heat capacity, viscosity, and thermal conductivity in a range of temperatures up to 700 K and pressures to 60 MPa. The NIST data removed a key source of uncertainty in RP-1 propulsion system design.

NIST, NASA, and Rowan University began a collaborative effort to explore the use of smart sensor technology and sensors for diagnosing spacecraft health. Smart sensors may play a key role in Integrated Health Monitoring Systems that monitor and predict spacecraft performance. NASA plans to include smart sensors in the design of the next generation of space exploration vehicles.

NIST continued efforts to improve acoustic emission techniques for the nondestructive evaluation (NDE) and inspection of aircraft and spacecraft structures. Researchers achieved increases in sensitivity and bandwidth. This effort supports NASA's general NDE program, which has among its overall goals improving sensitivity, reducing uncertainty, and ensure reliable use of NDE in the field.

NIST participated in the internally-funded NASA Peer-to-Peer project for Assembly in Space in FY 2005. The goal of the project is to develop a Human-Robot Interaction operating system that facilitates cooperation between astronauts and robots in assembling structures in space. NIST developed human-robot interaction metrics for assessing this work. In November 2005, researchers conducted an experiment in the Moonscape at NASA Ames that involved using two robots to place, weld, and inspect panels in a structure.

The NIST Center for Neutron Research (NCNR) continued to support NASA on the Neutron/Gamma-ray Geologic Tomography (NUGGET) project. The NUGGET team intends to use neutrons from a space-rated nuclear reactor to perform precise chemical Analysis of asteroids, Kuiper Belt objects, and small

moons like Phobos and Demos of Mars using Prompt Gamma-ray Activation Analysis. NUGGET could also provide a powerful tool for use on a Mars rover astrobiology mission, allowing scientists to image fossils embedded in rock or beneath soil.

NIST's Manufacturing Extension Partnership (MEP) supported the aerospace industry by increasing understanding of the future needs of original equipment manufacturers and by conveying these market needs to suppliers. For example, MEP expanded its partnership with the Boeing Company by increasing the number of states involved in the Boeing/MEP State Supplier Training Program to eight by the end of 2005. Since the program's inception in 2002, over 250 Boeing suppliers, primarily small manufacturers, have received support on integration of Lean Manufacturing techniques, Quality Systems, and Strategic Management to improve business operations.

NIST's Synchrotron Ultraviolet Radiation Facility (SURF III) served as a source of soft x-rays and vacuum ultraviolet light. As such, SURF III technology calibrated the mirrors, detectors, and spectrometers used aboard NASA spacecraft to study solar flares and astronomical bodies. The Extreme-ultraviolet Variability Experiment, which is part of NASA's Solar Dynamics Observatory mission, is representative of these studies. The facility also calibrated the NOAA-supported Avalanche-photodiode X-ray Spectrometer. SURF III continued to provide the calibration standard for experimental determination of atomic radiation intensities required for interpretation of Hubble Space Telescope data.

In addition to the calibration work cited above, NIST worked with other agencies on a variety of calibration methods and standards for satellite and spacecraft sensors. With funding from the European Space Agency, a NASA partner, NIST developed better calibration standards for the Space Telescope Imaging Spectrograph on the Hubble Space Telescope. NIST partnered with the Air Force Research Laboratory to improve the accuracy of infrared signature measurements on aerospace vehicles. NIST collaborated with NOAA and NASA on the GOES-R satellite program to aid the future calibration and validation of the satellite optical sensors, participated in the review of calibration-validation plans, and developed technology to ensure that GOES-R measurements comply with international standards. In partnership with the U.S. Geological Survey (USGS) and NASA, NIST improved the optical characterization and calibration of the

Robotic Lunar Observatory, which is used to investigate the spectral reflectance of the lunar surface for the calibration of satellite sensors important in climate research. Finally, NIST sponsored a workshop with NASA's Earth Observing System to address discrepancies in satellite measurements of the top-of-the-atmosphere solar irradiance. In collaboration with workshop participants, NIST developed a plan to test various aspects of the calibration of these satellite sensors.

Vital to NASA's goal of space-based precision interferometry for gravity-wave detection and enhanced extragalactic imaging, NIST continued to provide state-of-the-art laser stabilization technologies to NASA in order to precisely determine the orbital position of spacecraft and the distances between them. NIST performed pre-flight, ground-based research to explore emerging new techniques in optical frequency measurement, stabilization, and transfer; precise and highly sensitive atomic and molecular spectroscopy; solid-state laser development; and time keeping and distance ranging. NIST's development of compact ultra-fast lasers with robust phase stabilization is expected to have a strong impact on the on-board time keeping, distance ranging, and other LIght Detection and Ranging (LIDAR) applications in space.

DOC's International Trade Administration 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 and remote sensing satellites, commercial space projects, and air traffic management projects.

ITA was involved in preparations for the Organization for Economic Cooperation and Development's (OECD) February 2005 formal opening of negotiations aimed at revising the Aircraft Sector Understanding. The governments of almost all countries with major aircraft manufacturers are signatories to the OECD Arrangement of Officially Supported Export Credits, which establishes rules for export credit agencies and the way they finance civil aircraft sales. The Arrangement, along with an annexed Aircraft Sector Understanding, is aimed at ensuring that government-provided export financing is not a competitive factor in civil aircraft sales competitions. ITA supported the U.S. delegation's successful efforts to engage Brazil as a full negotiating partner in these talks given the emer-

gence of Brazilian-based Embraer as a leading exporter of aircraft that will soon compete directly with U.S. firms. Leading up to the negotiations, DOC hosted six meetings to consult with industry in this area.

In March 2005, ITA delivered to Congress the report "The U.S. Jet Transport Industry: Competition, Regulation, and Global Market Factors Affecting U.S. Producers." This report to Congress, mandated under section 819 of the "Vision 100-Century of Aviation Reauthorization Act" (P.L. 108-176), presents a study of the airline and jet transport aircraft manufacturing industries over the last 25 years and the impact of U.S. and European government policies and regulations on the global competitive position of U.S. aerospace manufacturers. The report offers several conclusions as to which policies are likely to have the most significant future impact on open and fair trade in the civil aircraft manufacturing sector. ITA developed the study in consultation with the Department of Transportation (DOT) and other federal agencies.

In May 2005, ITA co-sponsored the "Space at the Crossroads" conference along with several industry associations, including the Space Foundation and the Satellite Industry Association, to address the balance between commercial and military space. The event drew an international audience of over 200 participants and included speakers from the Departments of Defense, Commerce, and Homeland Security, NASA, industry, and foreign governments.

In June 2005, ITA organized and supported the Commerce Department's participation in the Paris Air Show and arranged senior-level meetings for DOC leadership with foreign government and industry officials as well as U.S. industry executives. ITA also sponsored Aerospace Products Literature Centers at the Paris Air Show and the Australian Air Show in March, offering low-cost, efficient venues for U.S. small-to-medium-sized aerospace companies to explore international and niche aerospace markets. These events provided hundreds of trade leads for participating companies, allowing them to enter or expand their exports to international markets.

In August 2005, Deputy Assistant Secretary for Manufacturing Joseph Bogosian co-chaired the 2005 meeting of the Russian-American Commercial Aerospace Working Group as part of Secretary Gutierrez's initiative for increased cooperation with Russia in trade and investment. The 2005 meeting was the most substantive in the four-year history of the Working Group. Issues addressed by the

United States included improving cooperation between nations, the ratification by Russia of the Cape Town Convention in partnership with the Aviation Working group, and removing aerospace trade barriers. In addition, the U.S. advocated for the Draft Law on Investment in Strategic Enterprises.

In October 2005, ITA and the American Association of Airport Executives co-sponsored an International Airport and Infrastructure Conference and Trade Show in Miami, Florida, which focused on Latin America, Caribbean, and the United States. Spurred on by the signing of the Central American Free Trade Agreement (CAFTA), this event attracted more than 65 U.S. airport businessmen and 10 foreign delegations. Tim Thompson, Executive Director of the U.S. & Foreign Commercial Service's Global Trade Programs, delivered a keynote address highlighting the benefits CAFTA is expected to bring to the aviation communities in Central America. The event demonstrated a variety of U.S. airport products and services to the emerging markets in Latin American and Central and Eastern Europe.

ITA played an instrumental role in the U.S. signature and ratification process for the Cape Town Convention, an international treaty designed to facilitate asset-based financing and leasing by reducing risks to the seller, lender, and/or leaser. Having signed the treaty in May 2003, the United States ratified it on October 28, 2004.

ITA participated in the review of Administration policies on aeronautical research and development through the National Science and Technology Council's Aeronautics Science and Technology Subcommittee. ITA participated in subcommittee assessments of federal science and technology priorities, infrastructure, policies, and related activities across relevant federal agencies.

As the lead advisory agency for Federal government telecommunications issues, DOC's National Telecommunications and Information Administration undertook a number of policy initiatives regarding satellites and other space-based communications systems. NTIA provided policy guidance on issues concerning the International Telecommunications Satellite Organization and the International Mobile Satellite Organization. NTIA also continued to manage the Federal government's assignments, nationally and internationally, for use of the radio spectrum for NOAA, NASA, DOD, and other government agencies with satellite programs.

NTIA worked closely with Federal agencies, the Federal Communications Commission, and non-federal entities to implement the decisions reached at the International Telecommunication Union World Radiocommunication Conference in 2003. The results included updating satellite regulations and protecting existing and new spectrum allocations for GPS.

Department of the Interior

DOI

In the aftermath of the South Asia tsunami that resulted from the December 2004 earthquake in the eastern Indian Ocean, the U.S. Office of Foreign Disaster Assistance (OFDA) immediately needed to identify areas damaged by the event. Within hours of the disaster, staff of the USGS began providing pre- and post-tsunami satellite images to relief organizations worldwide. USGS scientists used these images to delineate damage zones in Indian Ocean coastal areas based on manual interpretation of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) scenes. Scientists compared more than 50 pre- and post-tsunami Landsat scenes to assess areas impacted by the natural disaster.

Famine Early Warning System Network (FEWS NET) scientists at the USGS have been assessing crop-growing conditions, climate, and water supplies in Afghanistan since early 2002. Irrigated agriculture is crucial to food security throughout the region, and the ability to irrigate crops can be directly related to the availability of water from snowmelt. USGS scientists used data from the Moderate Resolution Imaging Spectroradiometer (MODIS) to monitor the extent of snow cover as well as the timing of snow accumulation and depletion for the 2004-05 snow season. By monitoring of snow conditions, FEWS NET scientists provided critical information to decision makers on both the positive and negative impacts of a good snow season.

USGS scientists used satellite images acquired before and after Hurricane Katrina to measure the extent of flooding and to estimate the volume of water for defined areas of New Orleans. Results from the data analysis showed that the maximum volume of water inundating the city on September 2, 2005, was nearly a half billion cubic meters, but that by September 15, 2005, more than half of the water

had been drained, or pumped, from New Orleans. The RADARSAT analysis identified several possible oil slicks in both the September 2 and September 5 images. Furthermore, the September 5 image also showed a large plume in Lake Pontchartrain and a spectral signal indicative of a debris flow.

The Commercial Remote Sensing Space Policy implementation activity leverages many of the USGS core competencies in ways specific to commercial high-resolution data. In FY 2005, the USGS focused on the design, development, and implementation of an infrastructure capable of managing the ingest, storage, and distribution of commercial data. This work involved heavy re-use of USGS system and software assets for storage, discovery, and delivery of data. Commercial assets from vendors such as Space Imaging, DigitalGlobe, and ORBIMAGE may now be collected, stored, and redistributed to any Federal user.

In support of the Administration's 2003 Commercial Remote Sensing Space Policy, the USGS led an interagency study, involving over 20 Federal agencies, of commercial land remote sensing data requirements. The USGS developed a Web-based tool to aid in gathering and synthesizing these requirements in order to identify data purchase partnerships and to provide market information to industry. The USGS modified its data management infrastructure to allow customers to search and order commercial satellite imagery from USGS archive holdings.

The USGS and NASA successfully extended Earth Observing-1 (EO-1) satellite operations through FY 2005, allowing the collection, archiving, and distribution of multispectral and hyperspectral data to continue. A broad range of Federal and public scientists, researchers, and land managers use EO-1 data products. Launched by NASA in November 2000 as a one-year technology demonstration mission to capture some 2,000 images, the NASA/USGS extended mission has resulted in the acquisition of 45,000 EO-1 scenes, which are housed in the USGS-managed National satellite data archive.

Since its launch from California's Vandenberg Air Force Base on March 1, 1984, Landsat 5 has been in operation seven times longer than its original three-year design life. Now in year 21, the satellite has orbited the earth over 112,420 times and traveled over three times the distance from Earth to the Sun.

On June 21, 2005, Landsat 5 captured a scene of the Sheenjek River fire near Fort Yukon, Alaska. An agreement between the USGS, NOAA's National Environmental Science, Data, and Information System (NESDIS) Fairbanks

Command and Data Acquisition Station (FCDAS), and the University of Alaska, Geographic Information Network of Alaska (GINA) made collection of this satellite image possible. Data were received by FCDAS—located at Gilmore Creek just outside Fairbanks—and transmitted by GINA via high-speed network to USGS Earth Resources Observation Systems (EROS) for processing. In less than 24 hours, the Sheenjek River fire scene was captured, processed, and provided to wildfire managers in the Alaska Fire Service.

Landsat 7 turned off one of its three gyroscopes on May 5, 2004, due to anomalous indications of the gyroscopes behavior. Two gyroscopes must remain operational at any time to maintain attitude control. A study team from USGS, NASA, Honeywell, Hammers, and Lockheed Martin was assembled to provide options that allow for the longest possible mission-life, thereby reducing the risk of potential data gaps, in order to mitigate the risks associated with future gyroscope failures. No indications of any problems with Landsat 7's remaining gyroscopes were evident; therefore, the team deemed that the risk of an additional gyroscope failure is low.

As a precaution, the team investigated a solution to use other sensors to provide attitude rate information to the flight control system. These alternate sensors provide the same information as a gyro but use different principles, creating a 'virtual gyro' or V-gyro. The Landsat team tested the V-Gyro in the performance of orbit maneuvers and the safe hold mode, and then as Landsat 7's contingency gyroscope.

Landsat is the backbone of the global moderate resolution remote sensing community. The continuity of its data delivery allows scientists and policymakers to understand land cover and land use changes on global, regional, and continental scales. In anticipation of a possible Landsat data gap, the Federal agencies responsible for Landsat program management—NASA and DOI's USGS—convened a Landsat Data Gap Study Team (LDGST). The LDGST recognized that, while no current or near-future satellite system could fully replace the Landsat satellites, archiving data from comparable systems into the National Satellite Land Remote Sensing Data Archive (NSLRSDA) could reduce the impact of a Landsat data gap.

The USGS developed a new Landsat 7 scan line corrector (SLC-off) gap-filled product to interpolate missing data resulting from the SLC anomaly. Part of

the sensor package on Landsat 7, the scan line corrector compensates for the forward motion of the satellite during data collection periods. The failure of the SLC led to gaps in the lines of data collected. Engineers developed systems to extract the best imagery from the partially degraded imagery. This product uses a multi-scale segment model based on historical landscape structure to guide the interpolation of spectral data across the gaps in the SLC-off imagery. Feedback on the product ensured that the highest quality product was developed for Landsat customers.

Under an agreement with NASA and the National Geospatial-Intelligence Agency (NGA), the USGS distributes elevation data from the Shuttle Radar Topography Mission (SRTM). In October 2004, USGS achieved the capability to digitize aerial film archives, creating browse and medium resolution images files through high performance digital cameras.

The Landsat archive maintained at the USGS previously contained over 60,000 High Density Tapes (HDTs), more than 21,000 Wide-band Video Tapes (WBVTs), and over 16,000 9-track tapes. During FY 2005, the Landsat Program continued converting these aging tapes to new media. This conversion enhances accessibility and assures that the valuable archive of Landsat data remains available for scientists. When finished, the Landsat 1-5 archive is expected to contain approximately 2500 digital tapes in a near-line automated retrieval tape silo.

Scientists from the USGS, the National Drought Mitigation Center, and the High Plains Regional Climate Center completed their fourth year of analysis of drought in the northern Great Plains States. The project team produced models capturing drought patterns over the landscape at a relatively high spatial resolution by using data mining techniques to combine large volumes of remotely sensed information with climate data and other environmental data, such as soils and land cover types.

Satellite interferometric synthetic aperture radar (InSAR) images of historically-active Aniakchak Volcano, Alaska, revealed that its 10 km wide caldera subsided about 13 mm/yr since 1992.

U.S. Fish and Wildlife Service (FWS) scientists use GPS technology and remotely sensed data in several ways to support their mission activities. Some of these are ongoing actions, while others are new applications of the technology. The FWS has been using GPS and remote sensing data for many years to conduct a trend analysis that monitors changes to vegetation and habitat in order to create

new maps of their locations. These changes may be a result of management actions or unplanned events, such as fires and hurricanes. In some cases, the data are used to monitor invasive species as well. Recent applications include:

- In coordination with the Gulf of Maine Rivers Ecoteam, FWS staff in the Gulf of Maine Program identified, mapped, and ranked important fish and wildlife habitat for priority species throughout the Gulf of Maine watershed. The team used Landsat 7 and National Wetlands Inventory data as a basis for the habitat mapping.
- Biologists and GIS support personnel from the South Florida Ecological Services Field Office in Vero Beach, Florida, with assistance from state and county agencies, developed a detailed vegetation map of the Biscayne Bay Coastal Wetlands Project area using 2004 high-resolution natural color aerial photographs.
- Personnel at Big Stone National Wildlife Refuge (NWR) in Minnesota used GPS units to acquire location data for habitat transects that were used to develop the vegetation monitoring program.
- Both GPS technology and satellite data were used to protect the newly rediscovered Ivory-Billed Woodpecker. Satellite imagery identified areas in the southeastern U.S. that have large blocks of bottomland hardwood forest that may harbor remnant populations of Ivory-Billed Woodpeckers. In addition, the FWS Migratory Bird Program continues to use GPS technology and Geographic Information Systems (GIS) data to conduct waterfowl surveys, particularly in the roadless areas of northern Canada.

FWS biologists acquired the collection of QuickBird satellite imagery of Round Island, Alaska, to evaluate the suitability of commercial satellite imagery to monitor Pacific walrus haulouts.

The Bureau of Reclamation (BOR) mapped topography and bathymetry of portions of the Naches and Yakima Rivers in Washington using both water-penetrating LIDAR and digital multispectral imagery. This information is intended to complement water storage and irrigation demand data, allowing BOR dam operators to develop water release scenarios that minimize conflicts between competing interests.

The BOR continued to use Landsat Thematic Mapper (TM) imagery, Indian Remote Sensing satellite imagery, USGS Digital Orthophoto Quadrangles

(DOQs), and Farm Service Agency National Agricultural Imagery Program (FSA NAIP) imagery to map agricultural crops in the Colorado River basin, as well as in the Southeastern and Central Valley regions of California.

BOR scientists used Landsat TM imagery to map areas where land cover changed in California's Central Valley. BOR personnel used this information during negotiations with irrigation districts and FWS.

A study that evaluated the utility of Landsat 5 TM and Landsat 7 ETM+, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Hyperion, Advanced Land Imager (ALI), IKONOS, and DigitalGlobe satellite data—in conjunction with high-resolution DOQs for discriminating and mapping percent imperviousness at the sub-pixel level—was completed for several environs: Tampa Bay, Florida; Las Vegas, Nevada; Seattle, Washington; and Minneapolis, Minnesota. These urban areas present unique challenges for identifying impervious land cover because they are experiencing significant growth and development.

The USGS is integrating information about animal behavior and physiology with information on landscape characteristics and landscape change. These interdisciplinary efforts originated with support from the USGS Amphibian Research and Monitoring Initiative (ARMI). In FY 2005, activities included broad assessments of the effects of landscape change on amphibians at local and global scales, and fine-scale modeling in which field- and laboratory-based measurements of amphibian biophysical responses to environmental conditions were mapped back to the landscape in order to determine landscape suitability for individual species

The Bureau of Land Management (BLM) has used an array of remote sensing technologies to inventory, monitor, and address concerns about resource conditions, as well as energy and mineral resource extraction on public lands. During FY 2005, GPS and GIS supplemented data from multispectral and aerial cameras to support management activities associated with minerals, fire, oil and gas, cadastral, wildlife habitat, forestry, wilderness, land exchanges, recreation, rangeland and hazardous materials. These projects provided appropriate information for the Federal and state agencies to make the best possible decisions on management of natural resources in the area. In January 2005, the USGS hosted a two-day DOI Land Cover Summit with the goal of promoting the integration of land cover mapping and monitoring activities across the Department. Land cover mapping, characterization, monitoring and forecasting are critical elements of

many environmental monitoring programs in Federal, state, and local governments, as well as industry, academia, and other non governmental sectors. Land cover data provide a direct, objective indication of land use effects on natural resources, ecosystem conditions, environmental and human health, and water quality and quantity.

The National Land Cover Database 2001 (NLCD 2001) is a project sponsored by a consortium of federal agencies to map the land cover of the United States Partners in the Multi Resolution Land Characteristics (MRLC) Consortium—USGS, the EPA, NASA, U.S. Forest Service (USFS), NOAA, BLM, NPS, U.S. FWS, Office of Surface Mining (OSM)—provide funding and personnel to map the land cover at a spatial resolution of 30 meters, using 2001-era Landsat satellite imagery and supporting data. Federal agencies use the database to examine and evaluate land cover, calculate canopy density, and analyze impervious surface over a series of test sites.

The Land Cover Trends study uses Landsat imagery to study the rates, causes, and consequences of land cover changes over the past 30 years. In 2005, the U.S. Geological Survey completed the assessment of land use and land cover change for 10 U.S. ecoregions and initiated analysis on six new ecoregions. Progress on the national assessment begun in 2002 now stands at 31 out of 84 ecoregions completed (i.e. 37% of the conterminous U.S. done). The results portray a quilt of variability across the country with significant differences in the rates of change among ecoregions.

The USGS completed an analysis of statewide status and trends of Alaska's land cover in 2005. This study found that anthropogenic changes to the Alaskan landscape are concentrated in the south central portion of the state with land development limited to specific localities, such as areas surrounding population centers, mining sites, and oil production facilities.

Forecasting land cover changes throughout the U.S. is an essential element of the USGS science strategy for geographic research. It is also a critical element of land use planning, watershed management, and environmental restoration activities. State and Federal natural resource agencies and land conservation organizations relied on a variety of approaches to forecast future land cover changes at regional scales.

Monitoring fire danger, and thus the potential for wildfire, is a national effort of Federal, state, and local fire managers. At the National level, daily satellite observations are compiled to monitor vegetation conditions. These satellite observations allow direct analysis of vegetation conditions and changes, both temporally and spatially. The USGS's focus on landscape monitoring and fire science has fostered an interagency approach that integrates remote sensing-based monitoring of the vegetation condition with weather information and other model results to predict fire danger conditions.

In FY 2005, scientists from the USGS, working with an interagency team of researchers, refined the 16-year time series of satellite observations using advanced processing techniques to improve the sensitivity of vegetation condition information to changes affecting fire potential.

The Minerals Management Service (MMS) continued to support research by University of Colorado scientists on applications of satellite altimetry, aimed at improving estimates of sea surface height and ocean currents, particularly for the large Loop Current eddies in the Gulf of Mexico. Accurate measurement of ocean currents is important for monitoring offshore oil and gas operations and estimating oil-spill trajectories.

USGS scientists evaluated land cover classifications derived from fused airborne, high resolution Inter-Ferometric Synthetic Aperture Radar (IFSAR) with Landsat ETM+ data and IFSAR derived digital elevation models and DOQs. The objective was to evaluate the IFSAR/Landsat fusion and DOQ products for generating land cover maps using digital image processing techniques.

Land cover information is one of the highest priority information layers requested by land management agencies, but no consistent medium-scale land cover information exists for Alaska. National Land Cover Dataset (NLCD) 2001, established through the Multi-Resolution Land Cover (MRLC) consortium, is a national effort to provide such data.

USGS and the BLM have used Landsat 7 and RADARSAT imagery to map the rapid wastage of the Bering Glacier in Alaska. The Bering Glacier thinned and retreated from its advanced position that developed due to a major glacial surge in 1993-95. The satellite observations have been combined with ground-based data to determine a suite of glacier parameters including the surface flow velocities and calv-

ing rates of the glacier, as well as the expansion of Vitus Lake. This large ice marginal lake is rapidly expanding as the glacier retreats and if current climate and glacier wastage conditions continue, the lake will expand to the north by up to 35 km in the next few decades. The possible result of Vitus Lake's expansion would be a dramatic shift from a glacial ecosystem to a lacustrine ecosystem. BLM began using this information to formulate a new land use plan for the Bering Glacier region.

USGS scientists used National Systems data to monitor glaciers in Washington, Montana, and Alaska. The small mid-latitude mountain glaciers of Washington and Montana are ideal subjects for monitoring because they are remote, have an appropriate spatial scale, and require infrequent but repetitive observations. The observations obtained from monitoring these glaciers over the past several years served as a baseline archive for assessing recent glacier fluctuations.

USGS scientists collaborated with scientists at the University of Washington, Seattle, on a NASA-funded project to improve the long-term predictive capabilities of hydrologic models. The project combined a hydrologic model, a snow pack model, and a recently developed electromagnetic scattering model—the Quasi-Crystalline Approximation/Dense Media Radiative Transfer model—to extract snow pack information from the passive microwave observations made by the Advanced Microwave Scanning Radiometer – EOS (AMSR-E). The combination of the snow pack model and the scattering model data, driven by atmospheric conditions, provided the snow depth, density, grain size, and wetness that are key parameters for the hydrologic model. These scientists developed data assimilation techniques to use past observations and long-term predictions of future conditions to yield more accurate long-term runoff forecasts.

The USGS remained involved in the ongoing operations phase (2004 to present) of the Mars Exploration Rover (MER) mission. Spirit and Opportunity rovers landed on Mars in January 2004 and continued to make important discoveries that advance Mars science, especially regarding the search for water on Mars. USGS scientists also served as team members in the ongoing NASA Cassini-Huygens Mission to Saturn and its moon, Titan.

The USGS supported the testing and calibration of the High Resolution Imaging Science Experiment (HiRISE) camera launched toward Mars aboard the 2005 Mars Reconnaissance Orbiter. This camera was designed to provide the high

resolution images of Mars from orbit (~30 cm/pixel) for analysis of sites of past fluvial and lacustrine activity, polar regions, and major channels and impact craters on Mars.

Since 1975, the USGS has chaired the Civil Applications Committee (CAC). This committee was chartered under the signatures of the National Security Advisor to the President, the Director of Central Intelligence, and the Director of the Office of Management and Budget, in order to facilitate the use of National Systems data for applications central to civil agency missions. Examples of these applications include mapping, charting, and geodesy; environmental monitoring, studies, and Analysis; resource management; homeland security; natural hazards; and emergency response applications.

The CAC participated on a regular basis in 2005 with the National Security Space Office (NSSO) to represent civil requirements related to future space remote sensing architectures, the Department of Homeland Security to explore how civil agencies will use National Systems data in support of homeland security activities, and the United States Northern Command (USNORTHCOM) Interagency Directorate to explore how the civil community can facilitate USNORTHCOM access to and application of domestic imagery and geospatial data for homeland defense activities. The Committee also worked with the National Air and Space Intelligence Center (NASIC) to identify key issues involved in adapting advanced data exploitation tools to civil agency missions, such as the early identification of emergency service needs and the management of emergency response.

FEDERAL COMMUNICATIONS COMMISSION

FCC

The Federal Communications Commission formulates rules to facilitate the provision of commercial satellite services in the United States. It also issues licenses for the launch and operation of all nongovernmental U.S. satellites. Internationally, the FCC coordinates satellite radio-frequency usage with other countries. The FCC's accomplishments for FY 2005 related primarily to commercial communications and Earth observation satellites.

The FCC completed several major rule-making proceedings in FY 2005. These proceedings focused on revising the FCC's rules to provide for technological developments related to the Earth stations that comprise the ground-based components of satellite communications networks. In one proceeding, the FCC adopted rules for the operation of Earth stations on vessels (ESVs). ESVs operate on ships by using special mounting hardware that keeps the antenna stably pointed toward a geostationary satellite. ESV technology allows operation of mobile Earth stations in certain frequency bands previously restricted to fixed Earth stations. The FCC initiated a proceeding to adopt rules for a similar service used in aircraft. The FCC also streamlined and updated its Earth station licensing rules to address newer technologies, particularly those used for provision of newer types of broadband services, such as internet access.

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

- January 10, 2005: Mobile Satellite Venture Subsidiary LLC to launch and operate a satellite at the longitude 63.5° west orbit location.

- January 26, 2005: XM Radio Inc. to launch and operate two replacement satellites, one at the longitude 85° west orbit location, one at the longitude 115° west orbit location.
- May 23, 2005: Mobile Satellite Venture Subsidiary LLC to launch and operate a satellite at the longitude 101° west orbit location.
- June 23, 2005: Lockheed Martin Corporation to launch and operate a radionavigation service payload, to be carried on PanAmSat Corporation's Galaxy 15 satellite, at the longitude 133° west orbit location.
- June 28, 2005: SES Americom, Inc., to modify the operations of the Satcom SN-4 satellite, at the longitude 172°east orbit location, to reorient the satellite's coverage area so as to provide improved coverage for service to transoceanic aircraft flights.
- July 18, 2005: Skybridge LLC to launch and operate a constellation of eighty low-Earth orbit satellites (Skybridge LLC subsequently surrendered that authorization on the due date of the performance bond required by the terms of the license).
- September 8, 2005: Lockheed Martin Corporation to launch and operate, at the longitude 107.3° west orbit location, a radionavigation service payload to be carried on Telesat Canada's Anik-F1R satellite, a satellite licensed by Canada.
- September 30, 2005: DigitalGlobe, Inc., to launch and operate three imaging satellites in low-Earth orbit.

The FCC granted a number of Special Temporary Authorizations (STAs) for satellite networks. Many involved routine testing or redeployment of satellites within a multiple-satellite system. Several actions, however, warrant particular mention.

- June 30, 2005: Intelsat North America, LLC was granted authority to move the Intelsat 602 satellite from the longitude 50.5° east orbit location to the longitude 150.5° east orbit location, pursuant to an agreement between Intelsat and the Indonesian satellite operator Indosat.
- June 30, 2005: Echostar Satellite LLC was granted authority to move the Echostar 5 satellite from the longitude 119° west orbit location to the longitude 129° west orbit location. At the new location, the satellite would operate pursuant to a Canadian authorization. The FCC also authorized

reception of signals from Echostar 5 in the United States in order to provide increased capacity for delivery of signals to U.S. consumers.

- July 6, 2005: Echostar Satellite LLC was granted authority to locate the Echostar 4 satellite at the longitude 77° west orbit location and to operate under a U.S. authorization at that location. Echostar made this request pursuant to an agreement with Mexican satellite operator Quetzsat.

In the aftermath of Hurricanes Katrina, Rita, and Wilma, the FCC granted a number of STAs for the deployment of Earth stations in the affected regions, particularly where additional capacity or special regulatory measures were required. The STAs granted facilitated deployment of networks for data transmissions, internet access, and information sharing for use by a wide range of entities, including emergency response providers.

The FCC added two non-U.S.-licensed space stations to the Commission's permitted space station list in order to allow these space stations to provide domestic and international satellite service to U.S. Earth stations that have routine technical parameters. Specifically, on July 21, 2005, the FCC added the Canadian Anik F1R satellite and the Brazilian Star One C2 satellite to its permitted list for C- and Ku-band frequencies.

The FCC also authorized a number of non-U.S.-licensed space stations to provide service in the United States on a non-routine basis as listed below.

- May 23, 2005: authority granted for an Earth station to communicate with the AMOS 2B spacecraft in certain Ku-band frequencies.
- June 21, 2005: authority granted for an Earth station to communicate with the JCSAT-1B satellite. On July 6, 2005, the FCC granted authority for several Earth stations to access India's Resourcesat-1 earth exploration satellite.
- August 16, 2005: authority granted for Earth stations to communicate with the Hispasat C1 in certain Ku-band frequencies.
- August 23, 2005: authority granted for an Earth station to communicate with the Amazonas 1 spacecraft in certain Ku-band frequencies.

The FCC also was active in international satellite coordination. In the first quarter of FY 2005, the FCC reached a total of two Administration-to-

Administration Coordination Agreements for U.S. networks with Brazil and the Netherlands. In the second quarter of FY 2005, the FCC reached a total of four Administration-to-Administration Coordination Agreements for U.S. networks with Canada and Mexico. In the third quarter of FY 2005, the FCC reached a total of 50 Administration-to-Administration Coordination Agreements for U.S. networks with Canada and Brazil. In the fourth quarter of FY 2005, the FCC reached a total of 195 Administration-to-Administration Coordination Agreements for U.S. networks with Brazil, Canada, Japan, and Russia.

DEPARTMENT OF AGRICULTURE

USDA

The U.S. Department of Agriculture (USDA) continued to use remote sensing data and related technologies to support research, program, and operational activities. The wide aerial coverage and geographic detail of satellite images and aerial photography benefited USDA by providing a comprehensive view of the landscape not attainable through ground-based observations or sensors. USDA agencies that used such data and technologies include the Agricultural Research Service (ARS), Animal and Plant Health Inspection Service (APHIS), Cooperative State Research, Education, and Extension Service (CSREES), Economic Research Service (ERS), Farm Service Agency (FSA), Foreign Agricultural Service (FAS), the USFS, National Agricultural Statistics Service (NASS), Natural Resources Conservation Service (NRCS), and Risk Management Agency (RMA). Significantly, although each USDA agency had different missions and responsibilities, several of these agencies shared data and technologies to ensure the most efficient and cost-effective use of departmental resources.

ARS continued to investigate and develop ground-based, airborne, and satellite-based remote sensing technologies for agricultural and natural resources applications. These technologies facilitated the measurement and mapping of a variety of agricultural, biological, and environmental properties, such as soil moisture, crop stress, invasive species, carbon sequestration, and range forage quality. The research ranged from basic remote sensing science with an emphasis on understanding linkages between remotely sensed observations and characteristics of plants and soils, to developing algorithms and decision support systems. Decision

support system activities targeted agricultural producers and land managers needing information for day-to-day decisions, and strategic decision-makers requiring accurate and timely information for policy decisions. Example technologies include the use of airborne hyperspectral imagery, microwave and radar systems, unmanned aerial vehicles, in-field "on-the-go" sensors mounted on farm machinery, and high spatial resolution imagery from spacecraft systems such as Ikonos, Landsat, and Earth Observer-1. Use of GPS figured prominently during the research for all applications. ARS operated two sunphotometers as part of the world-wide Aerosol Robotic Network. Collaborating U.S. investigators for ARS remote sensing activities included representatives from industry, academia, state and local governments, other USDA agencies, and other Federal agencies including NASA, EPA, USGS, and NOAA. ARS conducted remote sensing research as part of the interagency Climate Change Science Program (CCSP), and participated in the U.S. Group on Earth Observations (USGEO). ARS also conducted numerous colleague-to-colleague international scientific collaborations.

The APHIS Plant, Protection, and Quarantine (PPQ) division used remote sensing analysis to study landscape features in support of their emergency, regulatory, and phytosanitary programs. The APHIS PPQ Center for Plant Health Science and Technology (CPHST) sought to expand the understanding and application of remotely sensed data within the plant health and protection field. For example, CPHST applied remote sensing techniques to the survey and detection of the emerald ash borer (EAB) beetle. The project used remotely sensed hyperspectral imagery to discriminate ash trees from other deciduous trees, as well as to identify ash trees under varying degrees of stress as a result of EAB infestation. In a separate project, CPHST evaluated the effectiveness of using airborne collected hyperspectral imagery to map the distribution of saltcedar, an invasive plant species. Results from this phytosanitary program helped measure the performance of a biocontrol effort. Finally, CPHST evaluated pattern recognition software to perform automated feature extraction from three band aerial photographs. Specifically, this task extracted various landscape features to support invasive weed distribution analysis.

CSREES, the extramural research arm of USDA, provided financial assistance in the form of grants for high priority agricultural research and education. Numerous research projects conducted under CSREES grants utilized NASA data

products to solve complex environmentally-related problems in topics such as water quality, atmospheric science, soil science, and land-use change. For example, CSREES supported research that used Landsat imagery to assess the change in the quantity and quality of east Texas forests and their associated ecosystems over time. A separate CSREES supported project in Colorado used Landsat data to develop accurate inventory and assessment methods to evaluate current and future emissions of greenhouse gases. CSREES also supported a Rutgers study that used aerosol optical thickness in association with a NASA climate network at the Goddard Institute for Space Studies to calculate downwelling radiation as part of efforts to predict the impact of climate change on surface radiation. CSREES-supported scientists in Utah developed a unique multi-spectral carbon sequestration index that can separate soil organic carbon from surface moisture effects via remotely sensed platforms. CSREES also funded long-term studies in Mississippi, Kentucky, Alabama, and Wisconsin that utilized remote sensing and geospatial technologies to develop precision management techniques for various agricultural production strategies and to evaluate land use practices. CSREES and the Science Mission Directorate of NASA jointly funded several geospatial extension programs at land-grant, sea-grant, and space-grant institutions. These geospatial outreach programs trained local and regional technologists to better utilize NASA data products and geospatial technologies.

ERS used extensively derived remote sensing products such as the National Land Cover and the Global Land Cover datasets for agency economic Analysis. These derived products helped ERS to quantify domestic and international agricultural efficiency and environmental responses to changes in agricultural markets and policies. ERS also collected and tabulated information on the usage of remote sensing and GPS technologies by farmers through the ERS farm and field-level survey program. While the adoption of these technologies was in its infancy, there was an expectation that usage would increase partly due to the increased reliance on geographic information systems GIS by many domestic program agencies, such as NRCS and FSA, which have direct contact with farmers. In addition, many Land-Grant Universities and government agencies conducted research on the use of remote sensing, GPS, and other precision farming technologies to enhance economic opportunities and reduce the environmental risks associated with agricultural production.

FSA administers a variety of farm programs that ensure a strong and viable agriculture sector in the United States. These programs help America's farmers, ranchers, and other agricultural producers cope with weather, volatile markets, and natural disasters; conserve land and water resources; receive farm credit; and provide humanitarian aid to hungry people in the United States and abroad. Because nearly all programs are related to individual farms and tracts of land, FSA uses digital imagery, boundary data, soil survey, and other data sets to manage farm programs and respond to natural disasters. Some examples of FSA remote sensing activities include farm and field boundary maintenance, crop compliance and monitoring, production reporting, facility identification, and land management.

In 2005, FSA made significant progress in remote sensing. The Common Land Unit, a nationally-consistent geospatial dataset that represents farm and field boundaries and includes over 30 million polygons, was completed. The National Agriculture Imagery Program (NAIP) finished its third year of large scale operation, collecting over 10.5 terabytes of one and two meter resolution imagery in 34 states for program compliance and base layer imagery replacement purposes. In partnership with other Federal, state, and local agencies, NAIP acquired imagery for nine of the 34 states. During the hurricane season, NAIP delivered over 6 terabytes of NAIP imagery to Federal, state, and local agencies to support disaster recovery efforts. FSA actively supported remote sensing activities through involvement in Federal remote sensing and geodata coordination committees. The agency devoted time and resources in support of initiatives such as Geospatial One Stop, Federal Geographic Data Committee, the National Digital Orthophotography Program, the USDA Remote Sensing Coordination Committee.

In addition to serving as the USDA Imagery Archive, the FAS Production Estimates and Crop Assessment Division (PECAD) is the focal point within FAS and USDA for assessing the global agricultural production outlook and conditions that affect world food security. The FAS satellite remote sensing program remained a critical element in USDA's analysis of global agricultural production and crop conditions by providing timely, accurate, and unbiased estimates of global area, yield, and production. Satellite derived early warning of unusual crop conditions and production enabled more rapid and precise determinations of global supply conditions. FAS exploited

many global imagery datasets, including global Advanced Very High Resolution Radiometer (AVHRR) Global Area Coverage data from NOAA. FAS also used 10-day global composites from the spot vegetation sensor. FAS had standing orders for Landsat 5 and 7 imagery. All operational imagery had delivery requirements within five days of acquisition. In addition, FAS and NASA cooperated on several projects designed to exploit space technologies, including MODIS Rapid Response and global reservoir monitoring. This partnership for Global Agriculture Monitoring expanded to include multiple universities, commercial companies, and international organizations.

As part of the MODIS Active Fire Mapping Program, FS continued to process data from the MODIS sensor on board NASA's Terra and Aqua satellites. FS used these data to produce daily active wildland fire mapping products for the continental United States, Alaska, and Canada. The program utilized real time MODIS imagery and derived fire detection data for the western United States. The receiving station located at the agency's Remote Sensing Applications Center (RSAC) in Salt Lake City, UT, collected these data. The program also utilized additional real time MODIS fire detection data for Alaska, western Canada, and the eastern United States. The agency posted these products on the Internet (http://activefiremaps.fs.fed.us). Nearly one million users accessed the MODIS Active Fire Mapping Web site during 2005. In addition, MODIS fire mapping products provided the interagency fire community with a synoptic view of the wildland fire situation, aiding in the strategic allocation of fire-fighting resources and assets throughout the country. A collaborative effort with NASA Goddard Space Flight Center (GSFC) and the University of Maryland, this service has been provided on a daily basis since July 4, 2001. Several major media entities used the maps and fire detection data, including the Washington Post, New York Times, the Cable News Network, the Associated Press, and the Los Angeles Times. The Forest Service also continued to work with both NASA Ames Research Center and NASA GSFC on a number of fire-related technologies. ARC work included advanced sensor design and image processing from airborne platforms, as well as UAV development and mission profiling for tactical wildland fire mapping. NASA GSFC completed development and construction of an air-to-ground communications system that will enable rapid transmission of Forest Service airborne thermal

image products to incident command personnel. Utilized extensively during the 2005 fire season, this system provided the incident commands current fire imagery in minutes rather than hours. The Forest Service also conducted a UAV demonstration in July 2005 of UAV capabilities to support wildfire mapping, management, and suppression activities.

The mission of NASS is to provide timely, accurate, and useful statistics in the service of U.S. agriculture interests. These statistics cover virtually every facet of U.S. agriculture, from production and supply of food and fiber to prices paid and received by farmers and ranchers. Every five years NASS conducts the Census of Agriculture, which provides a comprehensive statistical summary of aspects of U.S. agriculture. Remote sensing data and techniques are valuable tools used to improve the accuracy of some NASS statistics. During FY2005, NASS used remote sensing data to construct and sample area frames for statistical surveys, estimate crop area, and create crop-specific land-cover data layers for GIS. For example, NASS used Landsat imagery, digital orthophoto quadrangles, and other remotely sensed inputs for all 48 continental states and Puerto Rico to select the yearly area-based samples. In addition, NASS constructed new area-based sampling frames in three states and portions of four additional states. The remote-sensing acreage estimation project analyzed Landsat data from the 2004 crop season and collected data for the 2005 crop season in 9 Midwestern and Mississippi Delta States to produce crop acreage estimates for major crops at state and county levels, and a crop-specific categorization in the form of a digital mosaic of thematic mapper scenes distributed to users on a CD-ROM. In addition, NASS conducted pioneering research on the use of Advanced Wide Field Sensor (AWiFS) imagery to ensure the continued use of mid-resolution imagery for the production of crop-specific land cover data layers.

NASS also forged new remote sensing partnerships while maintaining existing partnerships. These partnerships included: 1) existing and new agreements with state organizations and universities to decentralize Landsat processing and analysis; 2) existing and new agreements with state organizations and universities to produce additional or enhanced crop-specific categorizations on a one-time basis such as the 2002 crop year for a 10-state mid-Atlantic region; 3) a continuing agreement with the Florida Department

of Citrus to develop a GIS of citrus groves in Florida; and 4) a continuing partnership with the ARS to use MODIS sensor data as an input for setting small-area yield estimates in Illinois and Iowa.

NRCS is the primary Federal agency working with private landowners to protect and conserve the Nation's natural resources. For over 50 years, NRCS has used remote sensing products to carry out conservation programs. Aerial and satellite imagery processed in the form of digital orthoimagery was the primary remote sensing product that NRCS used to inventory, monitor, manage, and assess our natural resources in GIS nationwide. By partnering with FSA and other Federal and state agencies, NRCS acquired statewide one-meter or better resolution orthoimagery for 10 states and parts of Alaska and Hawaii. NRCS made available all of the orthoimagery it purchased to internal users and the general public via the USDA Geospatial Data Gateway website. NRCS contracted for high-resolution aerial photography (4" ground resolving distance) over 70,000 confidential statistical sites to collect natural resource data for the annual National Resources Inventory (NRI) program. The use of remote sensing techniques has replaced expensive onsite visits to collect the same data. NRCS acquired high resolution satellite imagery for conducting the NRI in Alaska and Hawaii. NRCS continued to acquire Landsat scenes from FAS for statewide natural resource analysis and change detection. NRCS acquired, enhanced, and delivered one-foot resolution digital imagery to NRCS offices to support recovery efforts in areas affected by Hurricanes Katrina and Rita. The NRCS used the imagery to assess streams and drains clogged with debris and contract for debris removal. NRCS began to purchase licensed IFSAR digital elevation data at five meter posting to evaluate its use in automating soil survey mapping in 3-dimensional form and improving the overall accuracy of digital orthoimagery.

RMA is the primary source of risk protection for our Nation's farmers. In FY2005, the Agency used high tech tools, such as satellite imagery, to support farmers' claims and to help monitor the over $44 billion of insurance provided to farmers and ranchers. For example, RMA used Landsat data for its crop insurance compliance program. In 2005, Landsat data played a critical role in the conviction and sentencing of 12 individuals, which included insurance agents, adjusters, and producers, resulting in a total of $34,442,611 in restitution, a

total of 413 months of prison, 29 years of supervised release, and six months of home detention. RMA acquired these Landsat data from the FAS PECAD-operated USDA Imagery Archive. During the past three years, RMA has used an average of 600 Landsat scenes per year.

National Science Foundation

NSF

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

The NSF supported the development of advanced technologies and instrumentation for astronomical sciences, in addition to providing core support for optical and radio observatories with state-of-the-art instrumentation and observing capabilities. The NSF's national astronomical facilities included the National Radio Astronomy Observatory (NRAO), the National Astronomy and Ionosphere Center (NAIC), the National Optical Astronomy Observatory (NOAO), and the National Solar Observatory (NSO). The NSF also served as the executive agency for the Gemini Observatory—an international partnership operating optical/infrared telescopes in both the Northern and Southern Hemispheres—providing the U.S.'s share of support for the program. In partnership with Europe, Canada, and Japan, construction continued on the Atacama Large Millimeter Array, an interferometer located near San Pedro de Atacama, Chile. Initial groundbreaking in Chile occurred on November 6, 2003. NRAO also initiated a contract with Vertex Communications, Inc., for the construction of twenty-five

antennas. The European Southern Observatory (ESO) contracted with Alcatel for an additional twenty-five antennas.

The NSF continued a joint activity with the U.S. Air Force Office of Scientific Research (AFOSR) to provide the U.S. astronomical community with access to state-of-the-art facilities at the Advanced Electro-Optical System telescope on Maui, Hawaii.

In FY 2005, the NSF's Division of Astronomical Sciences and Office of Multidisciplinary Activities began funding a four-year technology development and design effort for the Large Synoptic Survey Telescope (LSST). The LSST will be a 6.5 meter effective aperture telescope with a field of view exceeding three degrees. In addition, the LSST will use a three gigapixel camera to repeatedly image the entire accessible sky, producing approximately twenty terabytes of data nightly. The science goals of the LSST project are extremely broad, spanning the fields of cosmology, galactic structure, and solar system astronomy. The LSST will undertake both a census of distant (trans-Neptunian) solar system objects as well as surveys of near-Earth and potentially hazardous asteroids. Over a ten-year lifetime, the LSST is expected to provide a 90 percent complete sample of potentially hazardous objects with diameters greater than 250 meters and 80 percent down to 140 meters.

The NSF's Division of Astronomical Sciences, in collaboration with the Division of Atmospheric Sciences, supported the development of the Advanced Technology Solar Telescope (ATST), the next-generation U.S. ground-based solar telescope. The ATST, a collaboration of twenty-two institutions representing a broad segment of the U.S. solar physics community, had previously earned the strong recommendation of the National Research Council of the National Academy of Sciences. In FY 2005, the ATST advanced to the Readiness Stage in NSF's Major Research Equipment Facilities Construction queue. The ATST Site Selection and Science Working Groups selected the Haleakala Observatories on the Island of Maui as the preferred site for the telescope. Selection criteria included atmospheric turbulence, fraction of clear skies, and sky brightness. Project leaders also began preparing an environmental impact statement and application for a land use permit.

The Upper Atmospheric Research Section (UARS) in NSF's Division of Atmospheric Sciences supported a wide variety of research programs in space sci-

ence. These included the funding of advanced radar systems to study the ionosphere and magnetosphere, ground-based optical equipment to study the aurora and airglow, partial support to ground-based solar telescopes and instruments, and a wide-ranging portfolio of basic research in space physics. Major UARS-funded activities included the Upper Atmospheric Facilities (UAF), the National Space Weather Program (NSWP), the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program, the Geospace Environment Modeling (GEM) program, and the Solar, Heliosphere, and INterplanetary Environment (SHINE) program. In addition, a formal NSF Science and Technology Center called the Center for Integrated Space Weather Modeling (CISM) continued to develop and test an end-to-end computer simulation for space physics research and applications. CISM's coupled models simulated the processes by which energy from the Sun and solar wind propagates to Earth, as well as the resulting effects on Earth's magnetosphere, ionosphere, and thermosphere. CISM researchers integrated these results with education and outreach activities. An effective knowledge transfer program also ensured that CISM models were transferred for use in operational space weather forecasting centers.

Research facilities have long been a key component of UARS's efforts. The major goal of the UAF program in FY 2005 remained the promotion of basic research on the structure and dynamics of Earth's upper atmosphere. Research efforts utilizing these facilities were linked strongly to the CEDAR and GEM programs. The recent addition of the Advanced Modular Incoherent-Scatter Radar (AMISR) as a UAF asset, which was under construction in 2004 and saw first light in 2005, has been a true success story. AMISR is deployable to any geographic location on the globe for ionospheric research. In 2005, small prototype AMISR systems were successfully deployed for testing at Jicamarca, Peru, and at Gakona, Alaska.

In response to several recent community surveys of the health and vitality of solar and space sciences within university teaching faculties, UARS made awards to create new tenure-track faculty positions under the Faculty Development in the Space Sciences (FDSS) program. FDSS awards were targeted to facilitate the integration of solar and space physics research into university programs in basic physics, astronomy, electrical engineering, geoscience, meteorology, computer science, and applied mathematics. In so doing, space physics graduate programs would be devel-

oped that are capable of training the next generation of scientific leadership. Eight FDSS awardee institutions began their faculty selection process in 2005, and four employment offers have been tendered to date.

The NSWP is a multi-agency Federal program whose goal is to mitigate the adverse effects of space weather on the Nation's technological infrastructure by providing timely, accurate, and reliable space environment observations, specifications, and forecasts. Information about the NSWP can be obtained from the NSWP Strategic Plan and Implementation Plan, available online through the Office of the Federal Coordinator for Meteorology (OFCM). In 2005, OFCM, under its broad mandate to coordinate U.S, environmental research, initiated a formal yearlong assessment of the accomplishments and progress of the NSWP over the last decade. OFCM commissioned a panel of eight scientists, including Dr. Louis Lanzerotti, a member of the National Science Board, to perform this function and to solicit input from the space weather community. In order to accomplish NSWP objectives, in FY 2005, space physicists implemented and validated eight new space physics computer models at the multi-agency Community Coordinated Modeling Center (CCMC) located at NASA's Goddard Space Flight Center.

The Division of Atmospheric Science's high-altitude aircraft project HIAPER (High-performance Instrumented Airborne Platform for Environmental Research) centers on a highly modified Gulfstream V mid-size jet aircraft certified to operate at 51,000 feet. The jet is certified to fly at the highest altitude of any civilian aircraft, and its long duration (over 12 hours), range (over 6,000 nm), and scientific payload (6,000 pounds) is expected to enable scientific research heretofore not possible. The aircraft represents the most advanced airborne research platform in the U.S. civilian fleet, if not the world. In FY05, the construction project proceeded on schedule and under budget ($81.5 million). The aircraft's expected lifetime is 10–25 years, during which time new instrumentation innovations will be integrated onto the airframe as appropriate. The National Center for Atmospheric Research (NCAR), a NSF Federally funded research and development center, manages the HIAPER project.

In the first quarter of FY 2005, Lockheed Martin completed the aircraft's structural modifications, and the aircraft was ferried to Gulfstream Aerospace in Savannah, Georgia. Gulfstream completed the interior outfitting and research

power wiring during the second quarter of FY05. The aircraft was delivered to NCAR, Boulder, Colorado, after a ferry flight in March. During the third and fourth quarters of FY 2005, NCAR completed the outfitting of the science stations, installation of SATCOM, and the data display system.

In FY 2005, NSF continued its participation in the Constellation Observing System for Meteorology, Ionosphere and Climate and Taiwan's Formosa Satellite Mission #3 (COSMIC/FORMOSAT-3), a joint Taiwan-U.S. project. The scientific foundation for COSMIC/FORMOSAT-3 is the radio occultation (limb sounding) technique, which the Jet Propulsion Laboratory (JPL) and Stanford University developed in the late 1960s to study planetary atmospheres. COSMIC/FORMOSAT-3 is a follow on project designed to use GPS beacons for Earth weather and space weather prediction, climate change detection, and general atmospheric research.

The COSMIC/FORMOSAT-3 satellite constellation was in its final stages of testing and launch preparation during FY 2005. The COSMIC/FORMOSAT-3 consists of: 1) six low-Earth orbit spacecraft, each with three instruments that include GPS radio occultation receivers, tiny ionospheric photometers, and tri-band beacons; 2) a satellite operations control center at the National Space Organization (NSPO) in Hsin-Chu, Taiwan; 3) a COSMIC Data Analysis and Archive Center in Boulder, Colorado; and 4) a global ground fiducial network. The total mission cost for COSMIC/FORMOSAT-3 is approximately $100 million, with approximately 80 percent contributed by NSPO in Taiwan. U.S. agencies, including NSF, NASA, NOAA, US Air Force, US Navy, and STP, provided the remaining 20 percent.

COSMIC/FORMOSAT-3 not only has great value for weather, climate, and space weather research and forecasting, but also for geodesy and gravity research and other applications. Development of data assimilation schemes was begun to integrate the COSMIC data into existing weather forecasting models. COSMIC/FORMOSAT-3 will also complement a variety of related GPS missions, including the Challenging Minisatellite Payload (CHAMP), Satelite de Aplicaciones Cientificas-C (SAC-C), and Gravity Recovery and Climate Experiment (GRACE). During FY 2005, the CHAMP, SAC-C, and the Global Positioning System/Meteorology (GPS/MET) missions were completely reprocessed with new software. Also completed were improvements to low-Earth

orbit computation, enhancements so that post-processing can be spread to all nodes of a cluster, improved statistical optimization and error characterization in atmospheric inversions, automatic Ionosonde comparisons, and a new 1D variational assimilation for moisture computation. In the early summer of 2005, the ROCSAT-3 (now FORMOSAT-3)/COSMIC Science Summer Camp took place in Taipei, Taiwan.

DEPARTMENT OF STATE

DOS

The Department of State (DOS) supports U.S. space activities through the negotiation of bilateral and multilateral agreements of scientific and technical cooperation with partner countries. DOS also maintains outreach programs to advance U.S. foreign and space policy objectives.

FY 2005 saw extensive integration of space issues into Presidential diplomacy. As part of the Presidential initiative to transform the U.S. relationship with India into a "strategic partnership," DOS developed and began implementation of an ambitious plan to foster space cooperation between the two countries. One example of this extensive effort was the Joint Statement of President Bush and India's Prime Minister Singh during the latter's state visit to the U.S. in July. As a result, DOS negotiated with India various space cooperation agreements and cooperative projects, including a Technology Security Agreement and a Commercial Space Launch Agreement. DOS also provided support to the President during the Bratislava Summit in February on space initiatives, especially in regard to the sensitive and intricate issues concerning the International Space Station partnership with Russia, the E.U., Japan, and Canada.

DOS began working extensively with foreign governments to coordinate the use of the communications spectrum in support of various Presidential Initiatives. As part of the Vision for Space Exploration, DOS established the Lunar and Planetary Spectrum Initiative to ensure international cooperation on communications bandwidth. DOS also embarked on an initiative to integrate foreign communication management efforts with the Global Positioning System—a major commercial and security asset of the United States.

DOS led consultations with Japan in November 2004 to review and discuss ongoing cooperation on the civilian use of GPS. Among the topics discussed were Japan's plans to construct a regional satellite positioning system, known as the Quasi-Zenith Satellite System (QZSS), that would be supplementary and interoperable with GPS. QZSS is also expected to strengthen cooperative relations between the United States and Japan, provide new economic and public transportation safety benefits to Japan and its neighbors, and contribute to the peaceful development of the Asia-Pacific region.

DOS set up working group meetings under the 2004 U.S.-European Union Agreement on cooperation between the U.S. Global Positioning System and Europe's planned Galileo satellite navigation system to ensure the radio frequency compatibility and interoperability of these systems. In addition, DOS launched negotiations with Russia on cooperation between GPS and its Russian counterpart, Global Navigation Satellite System (GLONASS).

In cooperation with the Government of Colombia and the United Nations Office of Outer Space Affairs, DOS co-sponsored a South American regional workshop to promote the use of GPS and its applications. DOS provided financial support and the keynote speaker for the workshop.

Exploiting similar U.S. advantages in another area, DOS worked extensively with foreign governments and private industry to promote U.S. satellite imagery exports. For example, DOS negotiated within the Administration and then with Latin American countries to redeploy a GOES meteorological satellite to cover the Caribbean. DOS joined the Geographic Information for Sustainable Development (GISD) program—an international effort to meld maps, remote sensing data from satellites, and cutting edge software. The space imagery export efforts made by DOS were not only of commercial advantage to the U.S., they also enhanced foreign capabilities to pursue other U.S. interests in natural resources management, disaster mitigation, and economic development. DOS sponsored or co-sponsored workshops in Africa on the distribution and use of Landsat data. Another effort supported by DOS produced a cooperative telemedicine project that involved the use of space and communications technologies with the Indian Space Research Organization (ISRO) at the Indira Gandhi Hospital in Kabul, Afghanistan.

DOS continued to represent the U.S. on the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), and worked with the UN

International Committee on GNSS (the Global Navigation Satellite System) to develop and exploit GNSS applications. DOS provided funding for regional GNSS workshops and experts meetings held under the auspices of the U.N. and the United States, bringing together regional experts and decision makers in order to advance awareness and support for the use of GNSS applications for sustained growth, transportation safety, and environmental management.

With so many countries now engaged in space activities, promoting the safe use of space has become an important DOS goal. In FY 2005, DOS promoted an international strategy for mitigating orbital debris, modernized the U.S. Registry of Objects Launched into Outer Space, and placed this registry online. In September 2005, the USG offered to provide China with advance warning if its Shenzhen VI manned spacecraft was in danger of colliding with space objects. China agreed, although ultimately Shenzhen VI returned safely to Earth without having triggered such a warning. At UNCOPUOS, DOS led U.S. efforts on the problem of orbital space debris, meteorology, astronomy and astrophysics, space transportation, nuclear power sources in space, and legal issues related to international liability and responsibility of launching nations.

DEPARTMENT OF ENERGY

DOE

In FY 2005, the Department of Energy's (DOE) Office of Science (SC) cooperated with NASA in a wide variety of activities, such as developing experimental techniques of fundamental physics for use in outer space, using plasma science to devise new propulsion systems, engaging in joint efforts to understand atmospheric and environmental phenomena, and entering into a working partnership in advanced computing research. These activities were carried out under a memorandum of understanding between NASA and DOE signed by NASA Administrator Daniel Goldin and DOE Secretary James Watkins in 1992. NASA and DOE revitalized their joint space nuclear efforts in FY 2004, including new work in the space nuclear technology area and commencement of a civilian space nuclear reactor engineering design and development effort for Prometheus-1, the Jupiter Icy Moons Orbiter mission. In September 2005, NASA and DOE (Naval Reactors) mutually agreed to bring to orderly closure all activities associated with this space reactor engineering development work. This decision was made in view of NASA's need to properly support near-term space exploration goals, such as developing and launching the Crew Exploration Vehicle.

Through an Implementing Arrangement with NASA signed in 1995, the SC continued to work on the Alpha Magnetic Spectrometer (AMS) for use on the International Space Station. In FY 2005, this work focused on the integration of the instrument at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland. The AMS is an international experiment designed to use the unique environment of space to search for and measure, with a much greater sensitivity than heretofore possible, various unusual types of matter. The AMS will

study the properties and origin of cosmic particles and nuclei, including antimatter and dark matter. Discovering the presence of either material will increase scientists' understanding of the early universe and could lead to a clearer understanding of the actual origin of the universe. DOE provided funding in FY 2005 to support the research group at MIT that is leading the AMS program.

The SC and NASA's Science Mission Directorate have collaborated since FY 2000 on the Large Area Telescope (LAT), the primary instrument for NASA's Gamma-ray Large Area Space Telescope mission scheduled for launch in September 2007. This device, using the techniques of experimental particle-physics research, is designed to detect gamma rays emitted by the most energetic objects and phenomena in the universe. The Stanford Linear Accelerator Center, a DOE facility at Stanford University, is responsible for the overall management of the LAT project. Fabrication of the LAT was completed in FY 2005. DOE provided funding in FY 2005 in conjunction with NASA and international partners.

A high priority science objective for both DOE and NASA is to determine the nature of dark energy, which is causing the acceleration of the expansion of the universe. The Joint Dark Energy Mission (JDEM) is a plan for a space-based mission endorsed by both DOE and NASA for the study of dark energy. In FY 2005, DOE supported R&D activities for the Supernova Acceleration Probe (SNAP) collaboration, led by LBNL. The SNAP concept is expected to be part of the JDEM mission.

The Office of Nuclear Physics, within SC, continued to make available the Alternating Gradient Synchrotron (AGS), an essential component of the Relativistic Heavy Ion Collider (RHIC) complex at Brookhaven National Laboratory (BNL). The AGS is the only accelerator in the United States capable of providing heavy ion beams at energies (up to 1 GeV/nucleon) of interest to the space radiobiology community. This capability has been in place since 1995 with radiobiology experiments, funded by NASA, performed with silicon, iron, and even gold beams. In FY 2003, a NASA-funded facility, named the NASA Space Radiation Laboratory or NSRL, was commissioned at BNL. This facility continued to operate as an efficient and effective radiation simulation facility for human space exploration. The SC and NASA continued to work on a range of technical resources that can be mutually beneficial for experimentation and data analysis at BNL. For example, DOE and NASA initiated support for the construction of the Electron Beam Ion Source (EBIS) at BNL in FY

2005. This joint DOE/NASA project will enhance the range and intensities of heavy ion beams available to the RHIC complex, including the NSRL.

In FY 2005, the DOE Nuclear Physics Program continued to support astrophysicists who used greater than a million processor hours at the National Energy Research Scientific-computing Center (NERSC), funded by DOE's Office of Advanced Scientific Computing Research, for simulations of supernovae explosions, such as those observed by the Hubble Space Telescope. The total computational hours to support astrophysics for the Offices of High Energy Physics and Nuclear Physics is close to 12.5 million processor hours.

Other space-related aspects of the Nuclear Physics Program have relevance to NASA, other Federal agencies (e.g., National Reconnaissance Office and the U.S. Air Force), and the private sector. In the area of radiation effects, the Nuclear Physics Program regularly provided beams from accelerator facilities (BNL Tandem, Lawrence Berkeley National Laboratory's 88-Inch Cyclotron, Texas A&M Superconducting Cyclotron) to NASA, DOE applied laboratories, European and Japanese space agencies, and private companies for testing of electronic components used in high-radiation space environments and investigation of radiation effects on biological systems.

Through the use of plasma and fusion propulsion, NASA-funded research activities have the potential of revolutionizing interplanetary space travel. Transfer of knowledge to NASA and the Agency's use of research capabilities developed in the SC's fusion energy program continued in FY 2005.

NASA studied fusion propulsion concepts for advanced interplanetary missions based upon the spherical torus and plasma-jet-driven magneto-inertial fusion. The DOE's Office of Science investigated the physics of the spherical torus in its National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL) as part of its fusion energy program. The DOE's SC investigated plasma-jet-driven magneto-inertial fusion for magnetic fusion energy applications at General Atomics, Lawrence Livermore National Laboratory, and the University of Wisconsin at Madison. Using a computer code developed in the inertial fusion energy program of the SC, researchers at the University of Wisconsin completed a preliminary computational study for Marshall SFC on the feasibility of plasma-jet-driven magneto-inertial fusion for space propulsion. The two fusion rocket concepts based upon the spherical torus and the magneto-inertial

fusion approach have the potential of reducing traveling times to the planets by more than a factor of 10.

PPPL researchers also worked on a high-power Hall thruster, a form of electric thruster. The high-power Hall thruster has the potential to achieve performance levels required to send advanced NASA science missions to the outer planets.

DOE's Oak Ridge National Laboratory (ORNL), PPPL, the Institute of Fusion Studies at the University of Texas in Austin, and NASA Johnson Space Center continued to collaborate on the development of an advanced plasma rocket technology called the Variable Specific Impulse Magneto-plasma Rocket that has the potential of cutting in half the time required to reach Mars. A key to the technology is the capability to vary the plasma exhaust to maintain optimal propulsive efficiency.

PPPL worked on several other, basic plasma science projects that complement and enhance the science activities at NASA. These projects focused on magnetic reconnection and other work on ionosphere and space-related plasma physics topics. They are partially funded under the DOE/NSF Plasma Science Partnership. The Magnetic Reconnection Experiment investigates the coupling between microscale reconnection layers and global forcing and plasma topology evolution.

The SC and NASA worked together to calculate the daily primary productivity of terrestrial ecosystems at diverse sites in Northern and Central States. Research initiated in FY 2002 continued in FY 2005 with the SC's AmeriFlux program. The program provided real-time meteorological, solar radiation, and CO2 flux data that was combined with NASA/MODIS data to calculate annual net and gross primary productivity. Researchers involved in this joint work continued to investigate continental-scale seasonal and geographic patterns of carbon-cycle processes related to the North American carbon program. The AmeriFlux program produced unique ground-based measurements of net ecosystem production and atmospheric CO2 concentration from some 30 locations across the United States. These results provided baseline data for calibrating planned carbon and CO2 observations from the NASA 2008 Orbiting Carbon Observatory (OCO) satellite platform.

SC's Atmospheric Radiation Measurement (ARM) contributed ground validation support for NASA's Atmospheric Infrared Sounder (AIRS) instrument.

The AIRS is a high spectral resolution infrared sounder on the EOS Aqua platform. Additional measurements were conducted to coincide with overpasses of the Aqua satellite carrying the AIRS sensor at the Tropical Western Pacific (TWP) and North Slope of Alaska sites. The ARM data are used to improve the water vapor and temperature profiles retrieved from the AIRS sensor. Water vapor and temperature data are important for the development and validation of climate models. In 2005, NASA deployed a solar-viewing Bruker 125 HR Fourier transform spectrometer (FTS) at the TWP facility to validate space-based column CO2 retrievals. The installation and validation of the FTS are planned to coincide with both aircraft and satellite overflights in 2006. Long term operations would extend through the end of the OCO mission (December 2009).

The first of a series of proposed workshops jointly sponsored by NASA, NOAA, and DOE was held during 2004 on the use of UAVs for making critical measurements needed for climate change research. These workshops continued in FY 2005 and brought together distinguished scientists from the agencies, universities, and private industry. The focus of the workshops was to identify the key scientific questions that could be addressed using the unique capabilities of UAVs and to identify aircraft or instrument technology gaps that would require future investment in the development of UAV capabilities and their applications in research on climate change and other environmental systems. One goal of the proposed collaboration is to define how to efficiently use the resources of the three agencies to extend climate-relevant measurements using UAVs over regions of Earth that are currently undersampled.

The SC, NSF, and NASA continued a three-way collaboration on the development and implementation of climate models. All three agencies supported a variety of collaborative activities associated with the Community Climate System Model. SC's Scientific Discovery through Advanced Scientific Computing project continued to develop and increase the level of sophistication in complex climate models. NASA, DOE, NOAA, and NSF participated in the interagency Climate Model Evaluation Project to support the evaluation of U.S. coupled-climate model simulations. The aim of this effort is to increase community-wide diagnostic research on the quality of model simulations to improve evaluations of model predictions and quantification of uncertainty in projections of future climate.

DOE and NASA principal investigators coordinated an effort that uses computing resources at the National Leadership Computing Facility (NLCF) at ORNL to incorporate biogeochemistry in coupled-climate models. A carbon data assimilation activity was initiated to couple the Global Earth Observation System of Systems to various ocean models as well as an ecosystem model in development at NASA. With the launch of the OCO, the carbon data assimilation activity will utilize the data towards improved characterization of carbon sources and sinks.

The SC's Low Dose Radiation Research Program continued to interact with the Space Radiation Health Program in NASA's Office of Biological and Physical Research. The focus of research supported by the DOE Low Dose Radiation Research Program is on doses of radiation that are at or below current workplace exposure limits. The primary area of emphasis of the NASA Space Radiation Health Program is to understand the biological effects of space radiation that account for radiation risks. In FY 2001, NASA and DOE developed a Memorandum of Agreement (MOA) to better coordinate their common interests. This close collaboration between NASA and DOE was intended to enhance progress in understanding and predicting the effects and health risks resulting from low-dose radiation. DOE and NASA also issued joint Requests for Applications in FY 2002, 2003, and 2004 for research that addressed both DOE and NASA needs to understand the human health effects and risks of exposures to low doses of radiation. Ten jointly funded projects were in existence in FY 2005, and these include two new NSCOR (NASA Specialized Center of Research) projects.

DOE's Energy Sciences Network (ESnet) and NASA's Research and Education Network (NREN) continued their close working relationship. For a number of years, ESnet has used its contracts to procure the long-haul telecommunications circuits and some of the associated equipment that NREN uses to build its network. One of ESnet's major peering points (where it connects to other networks) is located at NASA ARC.

NASA and DOE also collaborated on the deployment and testing of advanced networking technologies, such as high-speed transport protocols, high-speed data transfer services, and end-to-end network monitoring toolkits developed by SC researchers at Los Alamos and Argonne National Laboratories, and the Stanford Linear Accelerator Center.

DOE's Office of Nuclear Energy, Science, and Technology continued to support NASA's space exploration program by pursuing development of specific technologies for future space missions and by maintaining the necessary program and nuclear facilities infrastructure to provide radioisotope power systems and heater units. In FY 2005, DOE continued to develop two new radioisotope power systems for future use in multiple mission environments, including planetary surfaces and deep space.

These two systems, a Multi-Mission Radioisotope Thermoelectric Generator and a Stirling Radioisotope Generator, will each provide greater than 100 Watts-electric for over 10 years. DOE also supported fabrication of the Radioisotope Thermoelectric Generator for the New Horizons mission to Pluto, launched in January 2006. As part of maintaining the required infrastructure, DOE initiated operation of the Space and Security Power Systems Facility at its Idaho National Laboratory site. This facility serves as the fueling and test facility for multiple types of radioisotope power systems and is expected to support a variety of future missions. This facility was used in FY 2005 to fuel and test the generator for the New Horizons mission. In FY 2005, DOE's Office of Nuclear Energy, Science, and Technology focused its long-term space reactor science and technology development on surface fission power concept studies and support for NASA's strategic road mapping and planning efforts.

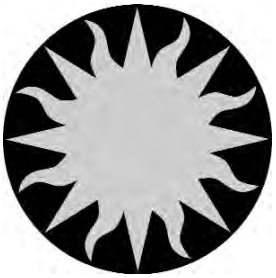
Many of the NASA-funded activities listed above enter the DOE system through the Work for Others program. This program allows non-DOE sponsors access to SC laboratories' unique and specialized facilities and expertise. Other scientific and technological efforts NASA supported through this program include research in the space radiation environment and its implications for human presence in space, aerogel-based materials, combustion under microgravity conditions, the biological impact of solar and galactic cosmic radiation exposure on astronaut health, and the genetic and epigenetic effects produced by high-energy heavy ions.

SMITHSONIAN INSTITUTION

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

This year, SAO and the University of Arizona appointed a new director of the Multiple Mirror Telescope (MMT) Observatory, a joint facility south of Tucson, Arizona. Dr. Faith Vilas took up her new responsibilities at the Observatory at the end of the year. FY 2005 also saw the achievement of an important milestone with the casting of the first mirror for the Giant Magellan Telescope. This telescope, whose completion is anticipated in about a decade, will unite seven large mirrors into one powerful telescope—the first in a new generation of ground-based observatories.

FY 2005 marked the second year of operations for NASA's Spitzer Space Telescope, whose Infrared Array Camera (IRAC) was developed at SAO. Spitzer studies the Universe at infrared wavelengths of light, enabling it to spot distant, highly redshifted galaxies and peer into nearby dust-obscured regions. This year, Spitzer achieved an important astronomical milestone by becoming the first telescope to directly detect light from a planet orbiting a distant star. Using Spitzer, researchers now can directly measure and compare planetary characteristics such as color, reflectivity, and temperature. Spitzer also spotted dusty disks around a number of young, low-mass objects known as brown dwarfs, including one brown dwarf that is only 15 times the



mass of Jupiter. Such disks eventually may form miniature solar systems. Furthermore, in the distant universe, Spitzer observed a collection of galaxies more than 10 billion light-years from Earth, revealing a surprising diversity of properties and showing that the early universe was wildly complex, not the simple universe that theories had once postulated. The Jet Propulsion Laboratory operates NASA's Spitzer Space Telescope

In FY 2005, SAO astronomers teamed with amateur observers using backyard telescopes to discover a new planet circling a distant star. Indeed, the first Earth-sized planet may be found by a similar collaboration. Researchers also predicted that asteroid-sized objects from another star might have been captured by our Sun billions of years ago, offering the possibility of finding extrasolar planets at the outskirts of our solar system. SAO scientists examined our own solar system by awakening a hibernating spacecraft in order to watch NASA's Deep Impact probe plunge into a passing comet and blast off surface material. Their research showed that the comet emitted little extra water vapor, indicating that theories about cometary surfaces may have to be revised.

SAO scientists using the Ultraviolet Coronagraph Spectrometer (UVCS) on the Solar and Heliospheric Observatory spacecraft have made new discoveries about the explosive ejections of matter and magnetic fields from the Sun. Such eruptions, called flare/coronal mass ejection (CME) events, are believed to be the source regions of high-energy particles—a known radiation hazard to astronauts and their equipment. Detailed descriptions of the source regions by a UVCS-like instrument combined with theoretical studies could ultimately lead to the capability of predicting such hazardous events. In one such study, UVCS scientists investigated how rising magnetic fields in the Sun's corona become unstable in the process of creating a flare/CME event. They found that the critical height for this instability is much lower than was previously believed. In another study, UVCS observations were used to measure the rate at which opposite polarities of the magnetic field behind a CME meet and annihilate, resulting in the release of enormous quantities of energy. This reconnection rate is a key parameter for specifying the energy release and the strength of the electric field that may accelerate many of the energetic particle hazards. SAO scientists also studied the production of energetic particles by CME-associated shock waves. Most energetic particle hazards are believed to be produced by these shocks. Initial results from a promising new UVCS diagnostic technique provided the first measurements of suprathermal pro-

tons in the solar corona prior to the CME arrival—a condition that is believed to be required for shock acceleration of the particle hazards.

In FY 2005, SAO's operation of NASA's Chandra X-ray Observatory continued to produce impressive science results. The discoveries made spanned distances ranging from Jupiter and Saturn to the far reaches of the universe, where evidence for a cosmic web of hot gas was found.

In addition, a team of astronomers discovered evidence that a rapidly growing, supermassive black hole at the center of a distant galaxy had generated one of the most powerful eruptions in the universe. Other findings from this past year include new insight into how supermassive black holes limit their own growth, the detection of a swarm of stellar black holes near the center of the Milky Way, and further support for the existence of mid-sized black holes.

Chandra also advanced the understanding of many other important astronomical phenomena in FY 2005. For example, studies of Sun-like stars may solve a mystery of how much neon exists in our own Sun. Another study of young stars suggested that X-ray superflares could have aided the formation of the solar system. Chandra's images of supernova remnants—the debris of exploded stars—provided vital information to scientists in their quest to better understand how stars end their lives.

FY 2005 marked the second year of operation of SAO's Submillimeter Array (SMA). The SMA consists of eight movable antennas that together combine to make uniquely detailed images in the submillimeter part of the spectrum, through atmospheric "windows" that open up on the high, dry summit of Mauna Kea, Hawaii. The SMA currently is the forefront telescope for high-resolution studies of cold material in the universe, which is unseen or unknown to radio, optical, and X-ray telescopes. This cold gas and dust has a rich chemistry and provides the raw material to form stars and planetary systems. SAO scientists submitted more than 150 SMA observing proposals this year as either lead authors or co-authors.

SAO scientists used the SMA to investigate many topics in astrophysics. Highlights included the observation that many young stars in the Orion Nebula stellar nursery are surrounded by enough orbiting material to form new solar systems like our own, despite the presence of harsh winds and radiation in the nebula environment. The SMA also observed complex organic molecules on solar system scales around newly formed stars for the first time. This observation increased our understanding of

how organic material is modified and incorporated into protostellar disks, as well as how it may survive through planet formation and beyond. By focusing the SMA on a faint object within a dust cloud, scientists found that the object hidden within had a weak outflow as predicted by star formation theories, and discerned it to be a baby star only 10,000 to 100,000 years old and with only twenty-five times the mass of Jupiter. The SMA also made the first direct temperature measurements of Pluto and its moon, Charon, which showed clearly that Pluto is the colder object due to the presence of nitrogen ices on its surface. In another study, the SMA looked far back in time by observing galaxies at the most distant reaches of the universe, including one forming stars at a fantastic rate that had been nearly invisible to the Hubble Space Telescope. Such galaxies are the likely progenitors of the largest galaxies we see today.

During FY 2005, the Cosmic Questions traveling museum exhibition developed by SAO's Science Education Department (SED) staff spent time in the Flandrau Science Center in Tucson, Arizona, and the Museum of the Rockies in Bozeman, Montana. Cosmic Questions is a 5,000 square-foot exhibition for science centers and museums, which invites audiences to examine fundamental questions and recent discoveries about the origin, evolution, and structure of the universe. Over 100,000 visitors explored the exhibition this year, and over one million visitors have seen the exhibition to date.

A team of SAO scientists and educators, through the NASA-funded Universe Education Forum, collaborated to develop a DVD-based teaching and learning tool for Earth science, physical science, physics, and chemistry teachers of grades 8-12. The DVD contains resources for teaching about the structure and evolution of the universe (SEU), including the evidence and explanations for the Big Bang and for the expansion of the universe.

The SEU Forum supports a network of online robotic telescopes called MicroObservatory that allows students and teachers in middle and high schools nationwide to investigate the night sky from the convenience of their classrooms. Users control the telescopes by means of an intuitive Web interface. MicroObservatory telescopes are also accessible to museum visitors through the Cosmic Questions exhibition. In FY 2005, SED expanded its audience to after-school programs that target teens from urban districts with large populations of underserved youth. In 2005, the MicroObservatory telescopes delivered over 30,000 images to classroom users, 20,000

images to museum visitors, and over 3,000 images to participants from community after-school organizations.

Inside Einstein's Universe (IEU) is an education outreach program for museums, planetariums, and other venues across the country. Associated with the World Year of Physics, IEU is a celebration of the Einstein Centennial and the astronomical implications of his 1905 "miracle year." Over 100 participating organizations received educational and content support surrounding the topics of cosmology, black holes, general astronomy, and space science explorations.

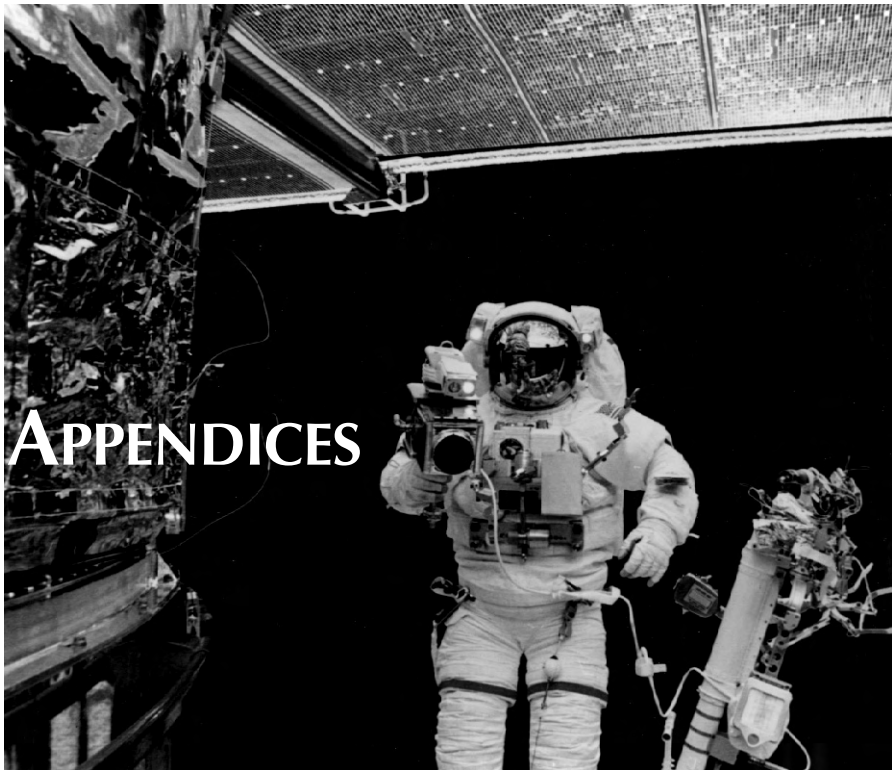
This year, SAO maintained its productive collaboration with the Boston Museum of Science by cosponsoring a series of Lowell Lectures on astronomy. In honor of the World Year of Physics, these lectures focused on the interdependence of physics and astronomy, and how the basic laws of nature can teach us why stars shine, how planets form, and where we fit into the vastness of the universe. SAO also continued to offer its popular Observatory Night lectures and telescope observing to the public on a monthly basis, as well as its Kids' Night programs for younger audiences and Sci-fi Movie Nights that explored the theme, "Everything I learned about science, I learned at the movies." Observatory Night programs in particular were frequently so well attended that lectures were standing-room-only.

In FY 2005, the National Air and Space Museum (NASM) made a spectacular addition to its companion facility, the Steven F. Udvar-Hazy Center, with the opening of the James S. McDonnell Space Hangar. The space hangar is home to 141 large space artifacts, including its centerpiece, the Space Shuttle Enterprise, and scores of missiles, satellites, and space telescopes.

Staff members in NASM's Center for Earth & Planetary Studies (CEPS) continued to participate on the science teams of several spacecraft missions in FY 2005. Dr. John Grant served as a Participating Scientist for the Mars Exploration Rover mission that is currently operating on Mars. As a Chair of the MER Science Operations Working Group, Dr. Grant directed the science team to consensus on targets and operations for the rovers. He conducted real-time mission planning from a control station installed on site at the Center for Planetary and Earth Studies (CEPS). CEPS staff also served on the science teams for the Messenger mission to Mercury, the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) radar instrument on Mars Express, and both the HiRISE and Shallow Subsurface Radar (SHARAD) instruments on the Mars Reconnaissance Orbiter launched this year.

CEPS continued its active research program in planetary and terrestrial geology and geophysics using remote-sensing data from Earth-orbiting satellites, as well as both piloted and unpiloted space missions. The scope of research activities included work on Mercury, Venus, Earth, Moon, and Mars, resulting in 15 peer-reviewed publications. Research topics included MER results, Martian aeolian processes, properties of lunar regolith, paleolakes on Earth and Mars, ground-penetrating radar at Martian analog sites in the Arctic and Argentina, Martian valley networks, and Mercury structural geology. In addition, the Smithsonian developed, in cooperation with colleagues at Cornell University, the capability to produce Earth-based radar images of the Moon at 20-meter resolution, often exceeding the resolution of available space-based optical photographs. This work has implications for future exploration of the lunar poles.

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



APPENDICES

U.S. Government Spacecraft Record

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

Calendar Year	Earth Orbit[a] Success	Earth Orbit[a] Failure	Earth Escape[a] Success	Earth Escape[a] 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, g]	0	2	0
2004	8 [c]	0	1	0
2005 *(through September 30, 2005)*	8	0	2	0
TOTAL	1,568	153	102	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 the five orbital debris radar calibration spheres that were launched from STS-63 as one set of spacecraft.
e. This includes the SSTI Lewis spacecraft that began spinning out of control shortly after it achieved Earth orbit.
f. Counts OCS, OPAL, FALCONSAT, and ASUSAT microsatellites as one set, and the Picosats 4–8 as another set.
g. This includes American spacecraft not launched in the U.S.

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
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	14	18			2	4			2	1	
(through September 30, 2005)											
TOTAL	1,316	2,744	10	8	62	87	1	1	159	18	4

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.

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 2004–September 30, 2005

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Nov. 6, 2004 Navastar 56 2004-045A Delta 2	GPS/Navigational satellite	20412 km 19,810 km 715.1 min 54.8°	Also known as USA 180 and GPS 2R-13
Nov. 20, 2004 Swift 2004-047A Delta 2	Scientific satellite	604 km 585 km 96.6 min 20.6°	NASA gamma-ray burst detector
Dec. 17, 2004 AMC 16 2004-048A Atlas 5	Communications satellite	Geosynchronous	
Dec. 21, 2004 Demosat 2004-050A Delta 4 (heavy)	Dummy satellite	36,420 km 19,041 km 1,045 min 13.5°	Mockup carrying two smaller university-made satellites
Jan. 12, 2005 Deep Impact 2005-001A Delta 2	Cometary probe		
Feb. 3, 2005 USA 181 2005-004A Atlas 3B/Centaur B	Military reconnaissance satellite		NRO satellite
Mar. 1, 2005 XM Radio 3 2005-008A Zenit-3SL	Communications satellite	Geosynchronous	
Mar. 11, 2005 Inmarsat 4 F-1 2005-009A Atlas 4 (431)	Communications satellite	Geosynchronous	
Apr. 11, 2005 XSS-11 2005-011A Minotaur (OS)	Military satellite	875 km 839 km 102.1 min 98.8°	
Apr. 15, 2005 DART 2005-014A Pegasus XL/HAPS	Technology test satellite	747 km 395 km 96.1 min 96.6°	

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 2004–September 30, 2005

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Apr. 26, 2005 Spaceway 1 2005-015A Zenit-3SL	Communications satellite	Geosynchronous	DirecTV satellite
Apr. 30, 2005 USA 182 2005-016A Titan 4B	Military reconnaisance satellite	Geosynchronous	National Reconnaisance Office
May 20, 2005 NOAA 18 2005-018A Delta 2	Weather satellite	866 km 847 km 102 min 98.74°	
June 23, 2005 Intelsat Americas 8 2005-002A Zenit-3SL	Communications satellite	Geosynchronous	Also known as IA 8
July 26, 2005 STS-114/Discovery 2005-026A Space Shuttle	ISS docking	287 km 273 km 90.12 min 51.65°	
Aug. 12, 2005 Mars Reconnaisance 2005-025A Atlas 5 (401)	Interplanetary probe		
Sept. 23, 2005 STP-R1 2005-037A OSC Minotaur	Technology test satellite	321 km 296 km 90.69 min 96.3°	Also known as USA 185
Sept. 26, 2005 Navstar 57 2005-038A Delta 2	GPS/Navigation satellite	20,328 km 266 km 357 min 39.62°	Also known as USA 183 and GPS 2R-M1

* U.N. Committee on Space Research

Human Space Flights

October 1, 2004–September 30, 2005

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TMA 5 (Expedition 10)	Oct. 13, 2004	Leroy Chiao Salizhan Sharipov Yuri Shargin	12:15:39	The crew continued construction of the station and conducted scientific experiments.
Soyuz TMA 6 (Expedition 10)	Apr. 15, 2005	Sergei Krikalev John Phillips Roberto Vittori	11:00:23	Carried crew to ISS. During the mission, Krikalev broke the record for total time in space.
Space Shuttle Discovery	July 26, 2005	Eileen M. Collins James M. Kelly Charles Camarda Wendy Lawrence Soichi Noguchi Stephen Robinson Andrew Thomas	13:21:33	First Space Shuttle flight since the destruction of Columbia during re-entry of STS-107 in February 2003. Resupplied ISS and evaluated new safety evaluation techniques.

APPENDIX D-1A

Space Activities of the U.S. Government

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of real-year dollars)

FY	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	331	261	490	34	34						785
1960	524	462	561	43	43						1,066
1961	964	926	814	68	68						1,808
1962	1,825	1,797	1,298	199	148	51					3,294
1963	3,673	3,626	1,550	257	214	43					5,433
1964	5,100	5,016	1,599	213	210	3					6,828
1965	5,250	5,138	1,574	241	229	12					6,953
1966	5,175	5,065	1,689	214	187	27					6,968
1967	4,966	4,830	1,664	213	184	29					6,707
1968	4,587	4,430	1,922	174	145	28	0.2	1			6,526
1969	3,991	3,822	2,013	170	118	20	0.2	1	31		6,005
1970	3,746	3,547	1,678	141	103	8	1	1	28		5,366
1971	3,311	3,101	1,512	162	95	27	2	1	37		4,775
1972	3,307	3,071	1,407	133	55	31	6	2	39		4,611
1973	3,406	3,093	1,623	147	54	40	10	2	41		4,863
1974	3,037	2,759	1,766	158	42	60	9	3	44		4,683
1975	3,229	2,915	1,892	158	30	64	8	2	54		4,965
1976	3,550	3,225	1,983	168	23	72	10	4	59		5,376
TQ*	932	849	460	43	5	22	3	1	12		1,352
1977	3,818	3,440	2,412	194	22	91	10	6	65		6,046
1978	4,060	3,623	2,738	226	34	103	10	8	71		6,587
1979	4,596	4,030	3,036	248	59	98	10	8	73		7,314
1980	5,240	4,680	3,848	231	40	93	12	14	72		8,759
1981	5,518	4,992	4,828	234	41	87	12	16	78		10,054
1982	6,044	5,528	6,679	313	61	145	12	15	80		12,520
1983	6,875	6,328	9,019	327	39	178	5	20	85		15,674
1984	7,458	6,858	10,195	395	34	236	3	19	103		17,448
1985	7,573	6,925	12,768	584	34	423	2	15	110		20,277
1986	7,807	7,165	14,126	477	35	309	2	23	108		21,768
1987	10,923	9,809	16,287	466	48	278	8	19	112	1	26,562
1988	9,062	8,322	17,679	741	241	352	14	18	115	1	26,742
1989	10,969	10,097	17,906	560	97	301	17	21	121	3	28,563
1990	12,324	11,460	15,616	506	79	243	31	25	124	4	27,582
1991	14,016	13,046	14,181	772	251	251	29	26	211	4	27,999
1992	14,317	13,199	15,023	798	223	327	34	29	181	4	29,020
1993	14,310	13,064	14,106	731	165	324	33	25	180	4	27,901
1994	14,570	13,022	13,166	632	74	312	31	31	179	5	26,820
1995	13,854	12,543	10,644	759	60	352	31	32	278	6	23,946
1996	13,884	12,569	11,514	828	46	472	36	37	231	6	24,911
1997	13,709	12,457	11,727	789	35	448	42	39	219	6	24,973
1998	13,648	12,321	12,359	839	103	435	43	39	213	6	25,519
1999	13,653	12,459	13,203	982	105	575	59	37	200	6	26,644
2000	13,601	12,521	12,941	1,056	164	575	60	44	207	6	26,518
2001	14,230	13,304	14,326	1,062	145	577	60	36	232	12	28,692
2002	14,868	13,871	15,740	1,196	169	644	74	31	266	12	30,807
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	15,244	19,842	1,549	229	807	70	71	360	12	36,635

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

b. DOE has recalculated its space expenditures since 1998.

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

SOURCE: Office of Management and Budget

* Transition Quarter

APPENDIX D-1B

Space Activities of the U.S. Government

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of equivalent FY 2005 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	5.3319	1,765	1,392	2,613	181	181						4,186
1960	5.2496	2,751	2,425	2,945	226	226						5,596
1961	5.1871	5,000	4,803	4,222	353	353						9,378
1962	5.1141	9,333	9,190	6,638	1,018	757	261					16,846
1963	5.0571	18,575	18,337	7,839	1,300	1,082	217					27,475
1964	4.9945	25,472	25,052	7,986	1,064	1,049	15					34,102
1965	4.9357	25,912	25,359	7,769	1,189	1,130	59					34,318
1966	4.8521	25,110	24,576	8,195	1,038	907	131					33,810
1967	4.7505	23,591	22,945	7,905	1,012	874	138					31,862
1968	4.6020	21,110	20,387	8,845	802	667	129	0.9	5			30,034
1969	4.4443	17,737	16,986	8,946	757	524	89	0.9	4	139		26,690
1970	4.2501	15,921	15,075	7,132	599	438	34	4	4	119		22,806
1971	4.0300	13,343	12,497	6,093	653	383	109	8	4	149		19,243
1972	3.8383	12,693	11,787	5,400	512	211	119	23	8	151		17,700
1973	3.6652	12,484	11,336	5,949	540	198	147	37	7	152		17,825
1974	3.5105	10,661	9,685	6,199	555	147	211	32	11	155		16,440
1975	3.2741	10,572	9,544	6,195	517	98	210	26	7	176		16,255
1976	2.9657	10,528	9,564	5,881	499	68	214	30	12	176		15,944
TQ*	2.7661	2,578	2,348	1,272	119	14	61	8	3	33		3,740
1977	2.6810	10,236	9,223	6,467	519	59	244	27	16	173		16,208
1978	2.5734	10,448	9,323	7,046	582	87	265	26	21	183		16,951
1979	2.4110	11,081	9,716	7,320	598	142	236	24	19	176		17,634
1980	2.2313	11,692	10,442	8,586	516	89	208	27	31	161		19,544
1981	2.0514	11,320	10,241	9,904	481	84	178	25	33	161		20,625
1982	1.8684	11,293	10,329	12,479	584	114	271	22	28	149		23,392
1983	1.7488	12,023	11,066	15,772	572	68	311	9	35	149		27,410
1984	1.6748	12,491	11,486	17,075	661	57	395	5	32	172		29,222
1985	1.6152	12,232	11,185	20,623	943	55	683	3	24	177		32,751
1986	1.5644	12,213	11,209	22,099	746	55	483	3	36	169		34,054
1987	1.5288	16,700	14,996	24,900	712	73	425	12	29	171	2	40,609
1988	1.4899	13,502	12,399	26,341	1,104	359	524	21	27	171	1	39,844
1989	1.4445	15,845	14,585	25,865	809	140	435	25	30	175	4	41,259
1990	1.3905	17,136	15,935	21,714	703	110	338	43	35	172	6	38,352
1991	1.3407	18,791	17,490	19,012	1,035	337	337	39	35	283	5	37,538
1992	1.2922	18,500	17,055	19,412	1,031	288	423	44	37	233	5	37,498
1993	1.2605	18,037	16,467	17,780	921	208	408	42	32	227	5	35,168
1994	1.2325	17,958	16,050	16,227	779	91	385	38	38	221	6	33,057
1995	1.2066	16,716	15,134	12,843	915	72	425	37	39	335	7	28,892
1996	1.1817	16,407	14,853	13,606	978	54	558	43	44	273	7	29,437
1997	1.1594	15,895	14,443	13,597	915	41	519	49	45	254	7	28,955
1998	1.1396	15,553	14,040	14,084	957	117	496	49	44	243	7	29,081
1999	1.1259	15,372	14,027	14,865	1,106	118	647	66	42	225	7	29,998
2000	1.1113	15,115	13,915	14,381	1,173	182	639	67	49	230	7	29,469
2001	1.0893	15,501	14,492	15,605	1,157	158	629	65	39	253	13	31,254
2002	1.0624	15,822	14,761	16,750	1,273	180	685	79	33	283	13	32,784
2003	1.0442	16,043	14,995	20,245	1,363	199	678	77	44	352	13	36,602
2004	1.0240	15,748	14,665	19,573	1,499	214	763	73	62	375	12	35,738
2005	1.0000	16,198	15,244	19,842	1,549	229	807	70	71	360	12	36,635

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

b. DOE has recalculated its space expenditures since 1998.

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

SOURCE: Office of Management and Budget

* Transition Quarter

APPENDIX D-2

Federal Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority				Budget Outlays	
	2004 actual	2005 actual	2006 est.	2007 est.	2004 actual	2005 actual
NASA[1]	14,322	15,244	15,739	16,071	14,270	14,747
Defense	19,115	19,842	21,256	22,855	17,776	17,858
Energy	209	229	240	230	202	223
Commerce	745	807	860	965	670	727
Interior[2]	71	70	82	86	72	70
Agriculture[2, 3]	61	71	80	84	56	67
Transportation	12	12	12	12	12	12
NSF	366	360	362	375	313	329

1. 2006 Budget Authority from initial NASA Operating Plan, February 6, 2007.
2. Includes aerial remote sensing activity.
3. In 2004, the Department of Agriculture began to report the National Agriculture Imagery Program within its totals.

APPENDIX D-3

Federal Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority				Budget Outlays	
	2004 actual	2005 actual	2006 est.	2007 est.	2004 actual	2005 actual
NASA[1 2]	1,057	954	884	723	919	866
Defense	10,301	9,327	9,671	9,279	9,687	9,586
Transportation	2,981	2,638	2,636	2,617	2,873	2,643

1. Total does not include the Inspector General budget.

2. 2006 Budget Authority from initial NASA Operating Plan, February 6, 2007.

ACRONYMS

A

AAW	Active Aeroelastic Wing
ADS-B	Automatic Dependent Surveillance-Broadcast
AEDT	aviation environmental design tool
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AGS	Alternating Gradient Synchrotron
AIRS	Atmospheric Infrared Sounder
ALI	Advanced Land Imager
AMISR	Advanced Modular Incoherent-Scatter Radar
AMS	Alpha Magnetic Spectrometer
AMSR-E	Advanced Microwave Scanning Radiometer - EOS
APFO	Aerial Photography Field Office
APHIS	Animal and Plant Health Inspection Service
APMT	Aviation environmental Portfolio Management Tool
ARC	Ames Research Center
ARFF	Aircraft Rescue and Fire Fighting
ARM	Atmospheric Radiation Measurement
ARMD	Aeronautics Research Mission Directorate
ARMI	Amphibian Research and Monitoring Initiative
ARS	Agricultural Research Service
AST	FAA Office of the Associate Administrator for Commercial Space Transportation
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATST	Advanced Technology Solar Telescope
AVHRR	Advanced Very High Resolution Radiometer
AWiFS	Advanced Wide Field Sensor

B

BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory
BOR	Bureau of Reclamation

C

CAFTA	Central American Free Trade Agreement
CAIB	Columbia Accident Investigation Board
CCMC	Community Coordinated Modeling Center
CCSP	Climate Change Science Program
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEOS	Committee on Earth Observation Satellites
CEPS	Center for Earth & Planetary Studies
CEV	Crew Exploration Vehicle
CISM	Center for Integrated Space Weather Modeling
CHAMP	Challenging Minisatellite Payload

CLV	Crew Launch Vehicle
CME	coronal mass ejection
COSMIC/FORMOSAT-3	Constellation Observing System for Meteorology, Ionosphere and Climate and Taiwan's Formosa Satellite Mission #3
CPHST	APHIS PPQ Center for Plant Health Science and Technology
CSREES	Cooperative State Research, Education, and Extension Service

D

DARPA	Defense Advanced Research Projects Agency
DART	Demonstration of Autonomous Rendezvous Technology
DFRC	Dryden Flight Research Center
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOQs	digital orthophoto quadrangles
DOS	Department of State
DOT	Department of Transportation

E

EAB	emerald ash borer beetle
EBIS	Electronic Beam Ion Source
EDS	Environmental Design Space
EELV	Evolved Expendable Launch Vehicle
EO-1	Earth Observing-1
EOS	Earth Observing System
EPA	Environmental Protection Agency
EROS	Earth Resources Observation Systems
ERS	Economic Research Service
ESA	European Space Agency
ESAS	Exploration Systems Architecture Study
ESMD	Exploration Systems Mission Directorate
ESnet	Energy Sciences Network
ESP	European Southern Observatory
ETM+	Enhanced Thematic Mapper Plus
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites

F

FAA	Federal Aviation Administration
FAS	Foreign Agricultural Service
FASTER	Full-Scale Aircraft Structural Test Evaluation and Research
FCC	Federal Communications Commission
FCDAS	Fairbanks Command and Data Acquisition Station
FCF	Federal Combustion Facility

FDSS	**Faculty Development in the Space Sciences**
FEMA	**Federal Emergency Management Agency**
FEWS NET	**Famine Early Warning System Network**
FOD	**Foreign Object Debris**
FSA	**Farm Service Agency**
FSANAIP	**Farm Service Agency National Agricultural Imagery Program**
FTS	**Fourier transform spectrometer**
FWS	**U.S. Fish and Wildlife Service**
FY	**fiscal year**

G

GEM	**Geospace Environment Modeling**
GEO	**Group on Earth Observations**
GEOSS	**Global Earth Observation System of Systems**
GINA	**Geographic Information Network of Alaska**
GIS	**geographic information systems**
GISD	**Global Information for Sustainable Development**
GLAS	**Geoscience Laser Altimeter System**
GLONASS	**Global Navigation Satellite System**
GNSS	**Global Navigation Satellite System**
GOES	**Geostationary Operational Environmental Satellites**
GPS	**Global Positioning System**
GPS/MET	**Global Positioning System/Meteorology**
GRACE	**Gravity Recovery and Climate Experiment**
GRC	**Glenn Research Center**
GRB	**Gamma-Ray Burst**
GSFC	**Goddard Space Flight Center**

H

HAZMAT	**Office of Hazardous Materials Safety**
HDTs	**High Density Tapes**
HEO-2	**Highly Elliptical Orbit-2**
HIAPER	**High performance Instrumented Airborne Platform for Environmental Research**
HiRISE	**High-Resolution Imaging Science Experiment**
HHLV	**Heavy Lift Launch Vehicle**
HQ	**Headquarters**
HRF-2	**Human Research Facility-2**

I

ICESAT	**Ice, Cloud, and Land Elevation Satellite**
IEU	**Inside Einstein's Universe**
IFSAR	**Interferometric Synthetic Aperture Radar**
IGEB	**Interagency GPS Executive Board**
IHPRPT	**Integrated High Payoff Rocket Propulsion Technology**
InSAR	**interferometric synthetic aperture radar**

INSAT	**Indian National Satellite**
IPO	**Integrated Program Office**
IPT	**integrated product team**
IRAC	**Infrared Array Camera**
ISRO	**Indian Space Research Organization**
ISS	**International Space Station**
ITA	**International Trade Administration**

J

JDEM	**Joint Dark Energy Mission**
JIMO	**Jupiter Icy Moon Orbiter**
JMA	**Japan Meteorological Agency**
JPDO	**Joint Planning and Development Office**
JPL	**Jet Propulsion Laboratory**
JSC	**Johnson Space Center**

K

KSC	**Kennedy Space Center**

L

LaRC	**Langley Research Center**
LAT	**Large Area Telescope**
LDGST	**Landsat Data Gap Study Team**
LEO	**low-Earth orbit**
LIDAR	**Light Detection and Ranging**
LSST	**Large Synoptic Survey Telescope**

M

McTMA	**Multi-Center Traffic Management Advisor**
MEMS	**Micro-Electro-Mechanical Systems**
MEP	**Manufacturing Extension Program**
MER	**Mars Exploration Rover**
MILSATCOM	**Military Satellite Communications System**
MISSE	**Materials on International Space Station Experiment**
MMS	**Minerals Management Service**
MMT	**Multiple Mirror Telescope**
MOA	**Memorandum of Agreement**
MODIS	**Moderate Resolution Imaging Spectroradiometer**
MRO	**Mars Reconnaissance Orbiter**
MRLC	**Multi-Resolution Land Cover**
MSFC	**Marshall Spaceflight Center**

N

NAIC	**National Astronomy and Ionosphere Center**
NAIP	**National Agriculture Imagery Program**
NASM	**National Air and Space Museum**
NASS	**National Agricultural Statistics Service**

NATO	**North Atlantic Treaty Organization**
NCAR	**National Center for Atmospheric Research**
NCNR	**NIST Center for Neutron Research**
NDE	**nondestructive evaluation**
NERSC	**National Energy Research Scientific-computing Center**
NESDIS	**National Environmental Science, Data, and Information System**
NGA	**National Geospatial-Intelligence Agency**
NIC	**National Ice Center**
NIST	**National Institute of Standards and Technology**
NLCD	**National Land Cover Dataset**
NLCF	**National Leadership Computing Facility**
NMD	**National Missile Defense**
NOAA	**National Oceanic and Atmospheric Administration**
NOAO	**National Optical Astronomy Observatory**
NPOESS	**National Polar-orbiting Operational Environmental Satellite System**
NPP	**NPOESS Preparatory Project**
NRAO	**National Radio Astronomy Observatory**
NRCS	**Natural Resources Conservation Service**
NREN	**NASA's Research and Education Network**
NRI	**National Resources Inventory**
NROL	**National Reconnaissance Office Launch**
NSF	**National Science Foundation**
NSLRSDA	**National Satellite Land Remote Sensing Data Archive**
NSO	**National Solar Observatory**
NSPO	**National Space Organization**
NSTX	**National Spherical Torus Experiment**
NSWP	**National Space Weather Program**
NTIA	**National Telecommunications and Information Administration**
NUGGET	**Neutron-Gamma-ray Geologic Tomography**
NWR	**National Wildlife Refuge**

O

OCO	**Orbiting Carbon Observatory**
OECD	**Organization for Economic Cooperation and Development**
OFCM	**Office of the Federal Coordinator for Meteorology**
OFDA	**U.S. Office of Foreign Disaster Assistance**
ORNL	**Oak Ridge National Laboratory**
OSC	**Office of Space Commercialization**
OSM	**Office of Surface Mining**

P

PARTNER	**Partnership for Air Transportation Noise and Emissions Reduction**
PECAD	**Production Estimates and Crop Assessment Division**
POES	**Polar-orbiting Operational Environmental Satellites**
PNST	**Prometheus Nuclear Systems and Technology**

PNT	Position, Navigation, and Timing
PPPL	Princeton Plasma Physics Laboratory
PPQ	APHIS Plant, Protection and Quarantine

Q

QZSS	Quasi-Zenith Satellite System

R

RDSMD	Research and Development Space and Missile Operations
RHIC	Relativistic Heavy Ion Collider
RLEP	Robotic Lunar Exploration Program
RLV	reusable launch vehicle
RMA	Risk Management Agency
RPIF	Regional Planetary Imagery Facility
RSAC	Remote Sensing Applications Center
RSIWG	Remote Sensing Interagency Working Group
RSLP	Rocket Systems Launch Program

S

S&T	Science and Technology
SAC-C	Satelite de Aplicaciones Cientificas-C
SAO	Smithsonian Astrophysical Observatory
SARSAT	Search and Rescue Satellite-Aided Tracking
SATS	Small Aircraft Transportation System
SBIRS	Space-Based Infrared System
SC	DOE's Office of Science
SCAWG	Space Communication Architecture Working Group
SDSU	South Dakota State University
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SED	Science Education Department
SE&I	Systems Engineering and Integration
SHARAD	Shallow Subsurface Radar
SHINE	Solar, Heliosphere, and INterplanetary Environment
SIRS	Security Incidents Reporting System
SLC	Scan Line Corrector
SMA	Submillimeter Array; safety and mission assurance
SMD	Science Mission Directorate
SNAP	Supernova Acceleration Probe
SOHO	Solar and Heliospheric Observatory
SOMD	Space Operations Mission Directorate
Space PCC	Space Policy Coordinating Committee
SRR	Systems Requirement Review
SRTM	Shuttle Radar Topography Mission
SSC	Stennis Space Center
STA	Special Temporary Authorization
STIS	Space Telescope Imaging Spectrograph

STP	**Space Test Program**
SURF	**Synchrotron Ultraviolet Radiation Facility**
SVS	**Synthetic Vision Systems**

T

TAMDAR	**Tropospheric Airborne Meteorological Data Report**
TAPS	**Turbulence Auto-PIREP System**
TCA	**Transformational Communications Architecture**
TDRSS	**Tracking and Data Relay Satellite System**
TM	**Thematic Mapper**
TMA	**Traffic Management Advisory**
TMA-MC	**Traffic Management Advisory-Multi-Center**
TRMM	**Tropical Rainfall Monitoring Mission**
TWP	**Tropical Western Pacific**

U

UAF	**Upper Atmospheric Facilities**
UARS	**Upper Atmospheric Research Section**
UAV	**Uninhabited Aerial Vehicle**
U.N.	**United Nations**
UNCOPUOS	**United Nations Committee on the Peaceful Uses of Outer Space**
U.S.	**United States**
USAF	**U.S. Air Force**
USAID	**U.S. Agency for International Development**
USDA	**U.S. Department of Agriculture**
USFS	**U.S. Forest Service**
USFWS	**U.S. Fish and Wildlife Service**
USGEO	**U.S. Group on Earth Observations**
USGS	**U.S. Geological Survey**
USNORTHCOM	**United States Northern Command**
UVCS	**UltraViolet Coronagraph Spectrometer**

V

VSE	**Vision for Space Exploration**

W

WBVTs	**Wide-band Video Tapes**

NP-2007-03-465-HQ