NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WEATHER PROGRAMS

The National Aeronautics and Space Administration (NASA) Headquarters Weather Support Office has continued to improve NASA's weather support capabilities for both manned and unmanned space launch vehicles. It is expected that these improvements will strengthen and enhance the information provided to the ground-based decision makers and astronaut observers to insure that NASA achieves the best operational posture for Space Shuttle launches and landings. The goal of the operations program is to provide the specialized meteorological data needed by operational forecasters at the Kennedy Space Center (KSC) and Johnson Space Center (JSC). NASA also maintains a sophisticated fleet of eighteen Earth-monitoring satellites, measuring a vast number of Earth properties. The focus of Earth Science Research is to integrate satellite observations, numerical model and theoretical studies of various Earth system attributes. These attributes include ocean currents, temperature and biological activity; atmospheric ozone and aerosols; tropical rainfall, lightning; atmospheric temperature and humidity structure; Antarctic and Arctic sea ice; volcanic emissions and gravitational anomalies in the Earth's crust. NASA also performs aviation research to improve safety, develop weather information technologies, and increase aviation system capacity. Advanced operations technologies can increase the number of operations per runway in all weather conditions. The research applies to both commercial and general aviation.

OPERATIONS

BACKGROUND

The goal of the National Aeronautics and Space Administration (NASA) weather operations program is to provide specialized meteorological data and techniques needed by Air Force forecasters at Cape Canaveral Air Force Station (CCAFS), adjacent to Kennedy Space Center (KSC); by the NWS' Spaceflight Meteorology Group (SMG) at Johnson Space Center (JSC); and by MSFC Natural Environments Branch to support NASA's Space Shuttle and Expendable Launch Vehicle (ELV) programs. The greatest challenge is to accurately measure and forecast the mesoscale weather events that strongly impact ground processing, launch, and landing operations. To successfully support the diverse, unique and complex requirements of the many customers' 24/7 operations, in the mesoscale driven lightning capital of America, requires:

1. A sophisticated weather infrastructure which includes systems normally found only in research field programs rather than operations;

2. A dedicated capability to transition research and technology to support new or poorly satisfied operational requirements;

3. Rigorous training to ensure the weather infrastructure, diverse customer requirements, and dynamic, mesoscale weather are thoroughly understood; and

4. At least 2-3 years on-site experience to adequately master the infrastructure, the weather, and the requirements to provide timely, tailored, accurate support to NASA's many weather sensitive daily operations.

The KSC Weather Office is also responsible for ensuring the weather support for NASA missions aboard Expendable Launch Vehicles meets requirements. Thus, if NASA launches a payload on an ELV from Vandenberg AFB (VAFB) (Western Range) or from the Kodiak, AK Launch Complex (KLC), or from Wallops Flight Facility, the Weather Office coordinates with the local weather support agency, such as 30th Weather Squadron at VAFB, to ensure the unit understands NASA's requirements and has the infrastructure and skilled forecasters to satisfy them. For instance, KLC had neither, thus the KSC Weather Office determined the requirements and coordinated the procurement, installation and testing of needed sensors; and identified a skilled 45WS Launch Weather Officer to provide on scene support during ground processing and launch operations.

The most vexing, unsolved atmos-

pheric problem for space launches and landings is *triggered* lightning. Today's spacecraft, payloads, and flight termination systems are insufficiently protected from the damaging impacts of direct or nearby lightning strikes. Unfortunately when the spacecraft penetrates even a weak electric field it can trigger lightning strikes which would not have otherwise occurred, especially during launch while trailing a long ionized plume. Also unfortunately, we've been unable to identify a method to directly and cost effectively measure the electric field aloft with sufficient spatial and temporal resolution. Thus to assess the threat of triggered lightning we must infer whether the electric field aloft is sufficient to trigger a strike based on a very complex and restrictive set of meteorological conditions such as cloud thicknesses and temperature levels, radar reflectivity, surface based field mills, etc. Weather is responsible for 50 percent of all launch scrubs from the Eastern Range and KSC, and triggered lightning constraints are the leading weather impact by far.

Triggered lightning is a threat no matter where vehicles are launched, even at locations with little or no natural lightning such as Vandenberg AFB, CA and Kodiak, AK - all that's needed is a weak electric field aloft. Thus research into triggered lightning and the impact of launch vehicles on weak electric fields significantly benefits the entire Space Program

APPLIED METEOROLOGY UNIT

The focal point for satisfying the launch support requirements is the Applied Meteorology Unit (AMU). The AMU, co-located with the Air Force's Range Weather Operations at CCAFS, develops, evaluates and, if warranted, transitions new meteorological technology into operations. For instance, the AMU strives to develop techniques and systems to help predict and avoid the impacts of Central Florida's frequent thunderstorms which endanger the ground processing, launch, and landing operations of the American Space Program - Space Shuttle, DOD, and commercial. The AMU has focused special attention on evaluating and transitioning mesoscale numerical models, and developing forecast techniques applicable to Central Florida. The AMU functions under a joint NASA, Air Force, and National Weather Service (NWS) Memorandum of Understanding.

KSC RESEARCH AREAS

LIGHTNING RESEARCH

Lightning Launch Commit Criteria (LLCC) [Airborne Field Mill (ABFM)] Program

The Weather Office continued to direct the analysis of data gathering from KSC's major field research program called the Lightning Launch Commit Criteria (LLCC) program. The LLCC program used an aircraft equipped with field mills and cloud physics sensors, in combination with several ground based radars and other sensors, to collect the data necessary to relax the lightning launch constraints while making them even safer. LLCC was cooperatively funded by the Shuttle program, NASA ELVs and the USAF. The team included more than 50 personnel from eleven organizations including other Governmental agencies, NASA Centers, universities and their contractors.

Based on analyses of the extensive data base of in-situ and radar measurements, the team developed revised LLCC for both Attached Anvils and Detached Anvils. These revised LLCC use a new radar quantity, the Volume Averaged Height Integrated Radar Reflectivity (VAHIRR). VAHIRR is not available as a standard product on either the WSR-88D used at the Eastern and Western Range or the Eastern Range WRS-74C weather radar. Software to generate the VAHIRR product for WSR-88D installations is being developed by the AMU. Meanwhile, a conservative work-around using conventional cross-section and maximum reflectivity products was developed by KSC and implemented by the 45th Weather Squadron at the Eastern Range. The team has begun additional analyses to determine if additional improvements to the LLCC can be derived from the ABFM data set. The two primary targets are application of the VAHIRR quantity to the Debris Cloud Rules, and reduction of the "stand-off distances" in the anvil and debris cloud rules. The stand-off distance is the distance by which a launch vehicle must avoid flying near to a subject cloud.

Improve Lightning Launch Criteria and Lightning Forecasts

Improved natural lightning Launch Commit Criteria evaluations and natural lightning warnings and strike point assessments needed to be studied. The following tasks were undertaken.

1. Initiated and managed Grant to U. of Arizona to:

a. Develop improved field mill algorithm for locating lightning discharge centers outside field mill network;

b. Install field mill on Western Range (WR) to study triggered lightning threat and validity of lightning LCC on WR;

c. Provide data analysis to Airborne Field Mill program; and

d. Chair Lightning Advisory Panel.

2. Sound Lightning Location (SOLLO) system: Over a period of several years, initiated and funded Task Orders to KSC Engineering Contractor to develop accurate lightning detection/location system using time delay of arrival from thunderstorm sound waves (SOLLO). Also issued new Task Orders to:

a. Revise/simplify installation

design to deploy SOLLO operationally--less expensive design enabled sufficient funds to begin development testing.

b. Add following to SOLLO: lightning amperage, 10-90 percent rise time, mean duration and number of strokes, and wave shape with 100-nanosecond resolution (Complete); and

c. Ruggedize system components to ensure SOLLO is more operationally robust in outdoor environment.

Data was gathered by U of AZ and analyzed on threat of triggered lightning at Eastern Range and other launch sites where NASA launches unmanned launch vehicles. Data is being incorporated into improved, safer ground operations procedures, lightning launch commit criteria, and landing weather rules. In addition, SOLLO will improve lightning location accuracy from 400 meters to 5 meters and thus eliminate much of the risk caused by guessing lightning occurrence/location from cameras. KSC/Advanced Technology unit is currently testing SOLLO to resolve echo problems when SOLLO is too close to facilities. Further, KSC Engineering Contractor added current characteristics (amperage, rise time, polarity, etc.) to SOLLO -- greatly increased its value by allowing much more precise risk estimates of possible damage to electronic components on orbiter, ground support equipment, and payloads. Hardening SOLLO enables more reliable outdoors operations.

Lightning Cessation Forecasts

Many operational support requirements were not receiving full benefit from technology advances. We worked with Chief 45th Weather Squadron Staff Meteorologist to solicit and exploit untapped potential of numerous graduate students with requirements to research and publish solutions to problems in the atmospheric sciences. Provided students list of topics with important operational value to NASA space flight; data from our extensive weather infrastructure; and mentoring. Larger projects were divided into smaller sequential pieces to fit students' fiscal and time budgets. Following is a list of examples of high quality research projects currently underway or just completed:

1. Florida State University and Univ of Oklahoma: Tools consisting of statistical relationships between lightning cessation and radar and lightning data to predict which lightning strike was the final one and thus reduce the unnecessary downtime caused by excessively long lightning warnings

2. Plymouth State Univ.: Development of forecast tool to improve prediction of convective wind gusts.

3. Penn State Univ.: Detailed lightning climatology that fed into larger AMU task supporting 45WS, SMG, MSFC and NWS/MLB forecast and design support requirements.

4. AF Institute of Technology: Analysis of accuracy and value of new Hurricane Center product to provide objective probabilities of wind speed as function of wind speed, location, and time.

WINDS

915 MHz Wind Profilers

The KSC Weather Office provided additional data and analyses on boundary layer winds measured with the Eastern Range network of five 915 MHz wind profilers requested by the Shuttle Program. These data and analyses assisted the Natural Environments Group at Marshall Spaceflight Center to respond to the Shuttle Program request for a detailed analysis of proposed Shuttle launch constraints on boundary layer wind changes. In response to an inquiry concerning the extent to which the five profilers in the Eastern Range network may be redundant, a correlation and coherence analysis was undertaken. The results show that the data are independent for atmospheric phenomena with time scales less than one to two hours.

Continuous Balloon-Sonde Measurements

Using NASA Innovative Partnership Program (IPP) funding, KSC and Ensco, Inc. began a one year project in late FY06 to develop a long-duration constant density altitude autonomous balloon sonde to measure temperature, relative humidity and winds. The project, called GEMSTONE (GEMS Sonde Test Operations in the Natural Environment), is based on previous ENSCO work on GEMS (Global Environmental MEMS Sensors) miniaturized sensing technology. The sondes will be solar powered and transmit their data to the ground by satellite link. They are expected to have a residence time in the atmosphere of up to two weeks. The GEMSTONE project is complete. Several atmospheric test flights were made that validated the concepts and demonstrated the prototype hardware and software. Additional development will be necessary to improve the reliability of power, GPS tracking and data communications before the system is suitable for operational support.

INFRASTRUCTURE FOR OPERATIONS

In addition to Supporting Research, the KSC Weather Office continues to work with the Eastern Range (ER) to improve the KSC and ER weather infrastructures and improve operational processes and facilities.

50 MHZ DOPPLER RADAR WIND PROFILER (DRWP)

The upgrades the AF installed on the DRWP in FY04 and FY05 have been thoroughly tested and the end to end accuracy of the system verified as meeting or exceeding the accuracy of

the pre-modification system. Overall system accuracy, about 1 m/s RMS with zero bias, is comparable with high-resolution wind-finding balloons such as Jimspheres or AMPS HR balloons. The vertical resolution of the DRWP was not affected by the modification. It is Nyquist limited at 300m compared with AMPS HR vertical resolution of about 100m. Despite the excellent performance of the modified instrument, the Eastern Range withdrew from its agreement to accept the DRWP into the ER inventory because of maintenance and documentation concerns. KSC will continue to operate, maintain, and sustain the DRWP through the life of the Shuttle Program (~2010). The 45th Weather Squadron has submitted a requirements statement for the acquisition of a COTS 50 MHz DRWP to replace the KSC instrument before it becomes unmaintainable and/or Shuttle operations and maintenance funding ceases.

LIGHTNING DETECTION AND RANGING (LDAR) SYSTEM

LDAR provides real-time 4D lighting data. Since LDAR was originally developed as a research system by KSC in the late 80s, its components are increasingly subject to obsolescence, thus costs and the risk of system failure are increasing. KSC worked with the Eastern Range and SLRS-C to help the Range acquire and install a COTS replacement for LDAR. The new system, LDAR-II by Vaisala, was installed in FY06. Testing and certification is expected to be completed in FY07. At that time KSC will decommission LDAR and the Range will own, operate and maintain, and sustain the LDAR II system (called the 4-D Lightning Surveillance System).

AIRCRAFT TRIGGERED LIGHTNING

Major airlines are concerned about their aircraft lightning strikes. Their data indicated maximum strike rate was in April, not during summer. A clarification of this fact was required. We provided airlines information on triggered lightning, its causes, NASA/AF lightning launch commit criteria, and why the strikes were more prevalent in Spring and not in Summer. (Aircraft more likely to fly in seemingly innocuous layered clouds between 0 degrees C and -20 degrees C during Spring.). We have responded to several lists of questions from Airline as they considered the information and studied changes to their procedures.

LAUNCH COMPLEX ELECTROMAGNETIC PULSE (EMP) DETECTION SENSORS

The Shuttle Lightning Hazard Analyses concluded existing on-pad electromagnetic pulse (EMP) detection sensors were inadequate. An alternate, faster, method to determine if retest of GSE, launch vehicle, or payloads is required was needed. We initiated and led project to provide lightning strike data (time, location, current strength, and polarity) from weather infrastructure lightning detection systems via e-mail to pre-designated individuals every hour lightning strikes were within a specified distance from a specific location. Currently working to integrate National Lightning Detection Network (NLDN) data into database to supplement Cloud-Ground Lightning Surveillance System (CGLSS) data. The task involved resolution of licensing, data format, security, and communication issues. The project is 90 percent complete within just 2 months and formal testing is underway. Will provide 24/7 hourly lightning strike information to key Shuttle engineers and managers. This work will likely be expanded to Atlas, Delta, and other EMP sensitive customers once fully operational for Shuttle.

WEATHER WARNING DISSEMINATION SYSTEM

Weather Warning and Advisory dissemination system primarily relied on antiquated public address system which most people either didn't hear the warnings or misunderstood them or couldn't remember all the specifications-start/stop time, location, hazard, etc. We sought and gained funding to take advantage of new technology to greatly reduce the communication shortfall. Identified competent software engineers and managers to design solutions; and helped coordinate project thru the complex Eastern Range, KSC, contractors, and off-site customer's bureaucracies to overcome communications, security fiefdoms and other hurdles. When fielded, the system will disseminate warnings over TV as scrolling information at bottom of screen; as icons on PCs alerting personnel of warnings; on pagers/cell phones/PDAs, etc. The last of the system bugs now being corrected, and IT security issue with off-base contractor being resolved, before final testing and implementation.

ENGINEERING STUDIES

Return to Flight and the Constellation project (CxP) established under the President's Space Exploration Vision generated dozens of engineering studies involving operational anomalies; proposed operations concept and sub-system changes; and design issues. CxP included the new Crew Launch Vehicle (Aries I); Crew Exploration Vehicle (Orion); and Heavy Lift Vehicle (Aries V). Each study required KSC Weather Office to provide and apply environmental data. Before we supplied any weather or climatological data to a project manager, we asked numerous questions about the project's goal and the proposed application of requested data. The purpose of this interaction was to ensure atmospheric and space weather impacts were properly identified and understood; to provide correct environmental data; and ensure the data was properly used. We worked with 45th

Weather Sq, AF Combat Climatology Center, MSFC, or just internally, to provide analyses, evaluations, data and products assessing risks to Constellation designs and concepts of operations options due to lightning, wind, temperature, moisture, pressure, etc and their various combinations.

SUPPORTING RESEARCH

The Earth is a complex, dynamic system not yet fully understood. The Earth system, like the human body, is comprised of diverse components that interact in complex ways. We need to understand the Earth's atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere as a single connected system.

From space the Earth can be viewed as a planet, with evident interconnectedness of the oceans, atmosphere, continents, ice sheets, and life itself. Global-scale changes are observed and tracked, and regional changes can be studied in their global context. The role that human civilization increasingly plays as a force of change can be observed. NASA studies this dynamic planet to trace effect to cause, connect variability and forcing with response, and vastly improve national capabilities to predict climate, weather, natural hazards, and conditions in the space environment. NASA's Earth science portfolio addresses six focus areas:

1. Climate Variability and change;
2. Atmospheric composition;
3. Carbon cycle, ecosystems, and biogeochemistry;
4. Water and energy cycles;
5. Weather; and
6. Earth surface and interior.

In each of these areas, NASA seeks the input of the Earth science community in universities and elsewhere to identify the scientific questions to be addressed and to define effective strategies to pursue the answers to those questions.

NASA answers these questions by:

1. conducting selected Earth science missions which extend our knowledge of Earth systems;
2. managing mission observation data so that it is widely available to the broader scientific community;
3. conducting and sponsoring research to answer fundamental science questions about observed changes in climate, weather, and natural hazards;
4. enabling partner organizations to apply NASA's science results to help improve the Nation's observational and forecasting systems; and
5. developing technologies that will improve future Earth measurement capabilities.

The NASA Earth Science Division (ESD) consists of seven programs: Earth Systematic Missions, Earth Science Pathfinder, Research, Applied Sciences, Multi-Mission Operations, Technology and Education and Outreach. ESD has 14 operational missions on orbit, 5 missions in implementation, and 2 missions in formulation.

NASA's Earth Science Program is dedicated to advancing Earth remote sensing and pioneering the scientific use of global satellite measurements to improve human understanding of our home planet in order to inform economic and policy decisions and improve operational service s of benefit to the nation. The program is responsive to several Congressional mandates and Presidential initiatives. Perhaps more than any other human activity, decades of progress in flight and advances in the space-related technology have steadily changed our perception of the Earth as a home planet. Satellite measurements of essential characteristics have enabled human understanding of the Earth as a system of tightly coupled parts. It is now clear for example that the characteristics of Earth's atmosphere so critical to human habitability are maintained by complex and tightly coupled circulation dynamics, chemistry, and interactions with the oceans, ice and land surface; all driven by solar radiation and gravitational forces. All these natural interactions and the human-induced changes require continuous and global observations. These observations detail the variability and change and enable us to analyze and document the forces involved, the nature of the underlying processes and how these are coupled within the Earth system. To inform resource management decisions and policies we need ongoing predictions derived from Earth observations to expose the responses that determine further change. All these observations and analysis are geared to solving the underlying fundamental question: "*How is the Earth changing and what are the consequences for life on Earth?*" NASA's mission in Earth science, as mandated by the Space Act, is to "*... conduct aeronautical and space activities so as to contribute materially to ...the expansion of human knowledge of the Earth and of phenomena in the atmosphere and space*". Thus, NASA's role is unique and highly complements those of other Federal agencies.

NASA's Earth science programs are essential to the implementation of three major Presidential initiatives: *Climate Change Research* (June 2001), *Global Earth Observation* (July 2003), and the *U.S. Ocean Action Plan* (December 2004). The first is the subject of the *U.S. Climate Change Science Policy (CCSP)*, combining the congressionally mandated Global Change Research Program (USGCRP) with the Climate Change Research Initiative. The second is related, and focuses on national and international coordination of Earth observing capabilities to enhance their use in meeting important societal needs. An Earth Observation Summit in Brussels, Belgium, in February 2005, adopted a 10-year plan for a Global Earth Observation system of systems. The third is

the U.S. Government response to the Congressional Commission on Ocean Policy of 2002, and its final recommendations report, *An Ocean Blueprint for the 21st Century*. NASA's unique role in these coordinated efforts is to advance remote sensing technology and computational modeling for scientific purposes, and facilitate the transition of mature observations and technologies to partner agencies that provide essential services using Earth science information. Earth Science at NASA contributes to the Presidents initiative *Vision for Space Exploration* (February 2004) by providing leverage of observing technologies and knowledge of Earth as a planet to aid in the Nation's exploration of worlds beyond. NASA will use the recently completed first decadal survey by National Research Council for Earth science and application from space to set priorities for future missions and research. The missions, programs and research objectives in this section are based on heritage roadmaps developed with the science community in each of the science focus areas defined below. The most recent Earth Science Research Plan can be found at http://science.hq.nasa.gov/ strategy/past.html.

From the 1960s through the 1980s, space and airborne observations allowed the first global view of the Earth and led to important discoveries such as the processes behind Antarctic ozone depletion, the Earth's response to incoming solar radiation, and the extent, causes, and impacts of land use and land cover change. In the 1980s and 1990s, NASA's comprehensive suite of global measurements together with the associated temporal scales of observation led to the development of the interdisciplinary field of Earth System Science. NASA deployed the first set of platforms in the Earth Observing System (EOS) and promoted research focused on the Earth as a system of dynamic set of interactions among continents, atmosphere, oceans, ice, and life. In this decade, NASA has begun to deploy new types of sensors to provide three-dimensional profiles of Earth's atmosphere and surface. Emphasis is placed into linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form coherent time series, and facilitating the use of the extensive data in the development of comprehensive Earth system models.

An example of the advantage of such framework is starting to emerge from the A-Train: a set of six satellites which are carefully choreographed by NASA ground controllers to observe the same portion of the Earth over the time span of twenty three minutes. The five satellites now in orbit include Aura, Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL), CALIPSO, Cloudsat, and Aqua. The instruments include spectrometers, radiometers, polarimeters, and lasers, which map or determine vertical distributions beneath the A-Train. A particular target is the composition of the Earth's atmosphere, which is being studied by a full range of A-Train instruments, resulting in tremendous synergy by combining datasets. For example, simultaneously measured cloud and trace gas properties can be studied to better understand the formation of clouds and aerosols and their interactions with gases from near the ground into the stratosphere. This will be valuable in understanding the connections between atmospheric chemistry and climate. The launch of Orbiting Carbon Observatory (OCO), the sixth satellite, in 2008, will complete the constellation and make the first global measurements of CO2 sources and sinks.

The complexity of the Earth system, in which spatial and temporal variability exists on a range of scales, requires that an organized scientific approach be developed for addressing the complex, interdisciplinary problems that exist, taking good care that in doing so there is a recognition of the objective to integrate science across the programmatic elements towards a comprehensive understanding of the Earth system. In the Earth system, these elements may be built around aspects of the Earth that emphasize the particular attributes that make it stand out among known planetary bodies. These include the presence of carbon-based life; water in multiple, interacting phases; a fluid atmosphere and ocean that redistribute heat over the planetary surface; an oxidizing and protective atmosphere, albeit one subject to a wide range of fluctuations in its physical properties (especially temperature, moisture, and winds); a solid but dynamically active surface that makes up a significant fraction of the planet's surface; and an external environment driven by a large and varying star whose magnetic field also serves to shield the Earth from the broader astronomical environment. The resulting structure is comprised of six interdisciplinary science Focus Areas: Atmospheric position, Carbon Cycle and Ecosystems, Water and Energy Cycle, Climate Variability and Change, Weather and Earth Surface and Interior. These six focus areas include research that not only addresses the challenging hierarchy of science questions but drives the development of an Earth observing capability and associated Earth system models as well.

NASA conducts Earth science research within a larger national and international context. This implies both opportunities for task sharing with partner agencies and the responsibility to seek optimal coordination of mutually supportive programs of these national and international partners. In particular, NASA has been actively seeking the cooperation of operational agencies in the US (DoD, NOAA, USGS) and elsewhere to ensure the

long-term continuity of key environmental measurements in the long term. To achieve this goal, NASA will promote the convergence of the operational observation requirements of partner agencies with its research data needs for systematic observations, share the cost of new developments, and develop precursor instruments and spacecraft technologies for future operational application missions. NASA will also encourage the continuing involvement of scientific investigators in the calibration and validation of operational measurements, the development of more advanced information retrieval algorithms, and the analysis of operational data records. From this perspective, the potential for serving operational needs or commercial-applications is a priority for NASA Earth science programs.

Focusing on partnerships with domestic Federal agencies and other international organizations, the Earth Science Enterprise also seeks to facilitate the assimilation of NASA's Earth science observations, measurements and model output into the decision support tools or systems of the partner organizations to provide essential services to society. The NASA ESE Applied Science Program has identified twelve elements of applications of national priority in: Agricultural Efficiency, Aviation, Air Quality, Carbon Management, Coastal Management, Disaster Management, Ecological Forecasting, Energy Management, Homeland Security, Invasive Species, Public Health, and Water Management. This program focuses on applications of national priority to expand and accelerate the use of knowledge, science, and technologies resulting from the NASA goal of improving predictions in the areas of weather, climate, and natural hazards. The intended outcome of the applications program is to serve the nation through the benefits of routine, sustained use of NASA Earth science observations, data products, Earth system model outputs, and technology in the decision support tools employed by national organizations and Federal agencies to meet their mandated policy and management responsibilities. The Earth Science Enterprise Applications Strategy, available online at http://science.hq.nasa.gov/earth-sun/applications/index.html, provides a detailed discussion of the systems approach that NASA takes to benchmark its partners' decision support tools and the linkages between the six science focus areas and the twelve elements of applications of national priority.

Interagency and international partnerships are also important for maximizing the scientific value of any research while minimizing costs. The need for partnerships in process-oriented field measurement activities is crucial, especially when investigators' access to particular regions of scientific interest is needed. For space-based measurements, partnerships provide the opportunity for leveraging additional contributions onto those that would be made by NASA, and allow for benefiting from the technological and scientific skills resident in other agencies and countries, as well as access to information needed for validation under a broad range of biological and geophysical conditions. Partnership opportunities will typically be encouraged in all relevant solicitations as long as they are consistent with national policy objectives such as export control of sensitive technology. Commercial partnerships also provide the opportunity for NASA to obtain needed data or services, and NASA has committed to working with the private sector to avoid duplicating capability that already exists in it.

NASA's Earth Science Program is an end-to-end program that starts with the development of observational techniques and the instrument technology needed to implement them; tests them in the laboratory and from an appropriate set of suborbital (surface, balloon, aircraft) and/or space-based platforms; uses the results to increase basic process knowledge; incorporates results into complex computational models that can be used to more fully characterize the present state and future evolution of the Earth system; and develops partnerships with other national and international agencies that can use the generated information in environmental forecasting and in policy and resource management. Since its inception, NASA has exploited satellite platforms to observe the Earth, providing a critical resource for Earth science research. As a result of growing research efforts, many measurements from space are now routine and essential. For example, satellite remote sensing has become indispensable for accurate weather forecasts and severe storm warnings.

TABLE 3.4 A BRIEF DESCRIPTION OF OPERATING NASA EARTH SCIENCE SATELLITES

Jason	Jason is an oceanography mission to monitor global ocean circulation, improve global climate predictions, and monitor events such as El Nino conditions and ocean eddies. The Jason satellite carries a radar altimeter and continues the precise sea surface height measurement record begun by the TOPEX/Poseidon mission in 1992. Jason measurements support the Climate Variability and Change science focus area. It is a collaboration with France. Jason was launched on December 7, 2001 and is in an extended mission having exceeded its 3 year design life.
ICESat	Ice, Clouds, and Land Elevation Satellite (ICESat): ICESat's primary objective is to quantify ice sheet mass balance and understand how changes in the Earth' atmosphere and climate affect polar ice masses and global sea level. It also measures the distribution of clouds and aerosols, as well as surveying land topography, sea ice, and vegetation cover. ICESat observations support the Climate Variability and Change, Earth Surface and Interior, and Water and Energy Cycle science focus areas. The primary instrument is a laser altimeter. ICESat was launched on January 12, 2003 and is in an extended mission having exceeded its 3 year design life.
Landsat 7	Landsat 7 systematically provides calibrated, multispectral, moderate resolution images of the Earth's continental and coastal areas with global coverage on a seasonal basis. It covers the United States every 16 days. These images form a unique resource for global change research and various applications. Landsat 7 measurements support the Carbon, Ecosystems and Biogeochemistry science focus area. Landsat 7 is a collaboration with the U.S. Geological Survey which took over spacecraft operations in the Fall of 2000. Landsat 7 was launched on April 15, 1999 and is in an extended mission having exceeded its 5 year design life.
EO-1	Earth Observing-1 (EO-1): EO-1 is an advanced land-imaging mission to demonstrate new instruments and spacecraft systems. EO-1 validated technologies contributing to the significant reduction in cost of follow-on Landsat missions. It supports the Carbon, Ecosystems and Biogeochemistry science focus area. EO-1 was launched on November 21, 2000 and is in an extended mission having exceeded its 2 year design life.
TRMM	Tropical Rainfall Measuring Mission (TRMM): TRMM monitors tropical and subtropical rainfall and the associated release of energy that helps to power the global atmospheric circulation shaping both weather and climate around the world. Its measurements support the Climate Variability and Change, Water and Energy Cycle, and Weather science focus areas. The TRMM satellite carries the first precipitation radar flown in space and several microwave and optical radiometers. It is a collaboration with Japan. TRMM was launched on November 27, 1997 is in an extended mission having exceeded its 3 year design life.
Terra	Terra, Latin for land, provides global data on the state of the atmosphere, land, and oceans, as well as their interactions with solar radiation and with one another. Its name reflects an emphasis on observations of terrestrial surface features although its measurements have a truly interdisciplinary character. Terra measurements support the Atmospheric Composition; Carbon, Ecosystems and Biogeochemistry; Climate Variability and Change; Earth Surface and Interior; Water and Energy Cycle; and Climate Variability and Change science focus areas. Terra employs five optical instruments on a single satellite. It is the first, of the series of large satellites devoted to characterizing the Earth system and identifying and tracking changes. It is a collaboration with Japan and Canada. Terra was launched on December 18, 1999 and is in an extended mission having exceeded its 5 year design life.
ACRIMSAT	The Active Cavity Radiometer Irradiance Monitor III (ACRIM III) instrument onboard ACRIMSAT monitors total radiant energy from the Sun. Measurements of total solar irradiance are directly relevant to the Climate Variability and Change science focus area. When combined with other scientific data, these measurements will help climatologists to improve their predictions of long-term climate. They extend the database initiated by ACRIM I in 1980. ACRIMSAT was launched on December 20, 1999 and is in an extended mission having exceeded its 5 year design life.

QuickSCAT	Quick Scatterometer (QuikSCAT): QuikSCAT records sea-surface wind speed and direction data for global climate research and operational weather forecasting and storm warning. These data support the Climate Variability and Change and Water and Weather science focus areas. It replaces the data lost by the failure of the Japanese Advanced Earth Observing Satellite (ADEOS) in 1997. SeaWinds, a radar scatterometer, is the main instrument on the QuikSCAT satellite. QuickSCAT was launched on June 19, 1999 and is in an extended mission having exceeded its 3 year design life.
GRACE	Gravity Recovery and Climate Experiment (GRACE): The primary goal of the GRACE mission is to accurately map variations in the Earth's gravity field. GRACE studies gravity changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges between ice sheets or glaciers and the oceans; and variations of mass within the earth. The tandem two satellite mission supports the Earth Surface and Interior, Climate Variability and Change, and Water and Energy Cycle science focus areas. GRACE maps the Earth's gravity fields by making accurate measurements of distance between the two satellites using high quality Global Positioning System (GPS) receivers and a microwave ranging
SORCE	SOlar Radiation and Climate Experiment (SORCE): SORCE provides data continuity with ACRIMSAT and operational successors to ensure long-term systematic measurement of total and spectral (1–2000 nm) solar irradiance, the dominant energy source in the Earth's atmosphere and one of its primary climate variables. Its measurements support the Climate Variability and Change science focus area. SORCE was launched on January 25, 2003 and is in its prime 5 year mission.
Aqua	Aqua, Latin for water, was named for the large amount of information that the mission collects about the Earth's water cycle, including evaporation from the oceans, water vapor in the atmosphere, clouds, precipitation, soil moisture, sea ice, land ice, and snow cover on the land and ice. In addition to the Water and Energy Cycle science focus area, its six optical and microwave sensors provide interdisciplinary measurements supporting the Climate Variability and Change; Weather; Carbon Cycle, Ecosystems and Biogeochemistry; and Atmospheric Composition science focus areas. It is the second, following Terra, of the series of large satellites devoted to characterizing the Earth system and identifying and tracking changes. It is a collaboration with Japan and Brazil. Aqua was launched on May 4, 2002 and is in its prime 6 year mission. Aqua was the first member launched of a group of satellites termed the Afternoon Constellation, or sometimes the A-Train. Envisioned to eventually comprise 6 satellites, the A-Train will provide synergistic measurements from multiple satellites that together will contain comprehensive information about key atmospheric components and processes related to climate change and atmospheric composition.
Aura	Aura, Latin for air, was named for the unique global view it provides of the Earth's atmosphere in direct support of the Atmospheric Composition science focus area. It additionally supports Climate Variability and Change science focus area. Aura's objective is to study the chemistry and dynamics of the Earth's atmosphere with emphasis on the upper troposphere and lower stratosphere by employing four optical and microwave instruments on a single satellite. It is the third, following Aqua, of the series of large satellites devoted to characterizing the Earth system and identifying and tracking changes. It is a collaboration with the UK, Netherlands, and Finland. Aura was launched on July 15, 2004 and is in its prime 6 year mission. Aura is the second member to joint the A-Train or Afternoon constellation of satellites.

CloudSat	CloudSat uses advanced radar to "slice" through clouds to see their vertical structure, providing a completely new observational capability from space. CloudSat is one of the first satellites to study clouds on a global basis. It will look at their structure, composition and effects in support of the Climate Change and Variability and Weather science focus areas. It is a collaboration with Canada. CloudSat was launched on April 28, 2006 with CALIPSO and is early in its prime 22 month mission. CloudSat maintains a close formation with Aqua and particularly CALIPSO, providing near-simultaneous and collocated observations with the instruments on these two A-Train satellites.
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO): CALIPSO will help answer significant questions about the effects of thin clouds and aerosols on changes in the Earth's climate. Understanding these components will provide the more comprehensive data set that is essential for better understanding the Earth's climatic processes in support of the Climate Change and Variability science focus area. CALIPSO combines a laser radar (backscatter lidar) with passive infrared and visible imagers to probe the vertical structure and properties of thin clouds and aerosols. It is a collaboration with France. CALIPSO was launched on April 28, 2006 with CloudSat and is early in its prime 3 year mission. It flies within seconds of CloudSat in the A-Train formation to take advantage of its complementary millimeter-wave radar measurements of clouds.