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

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), and by the NWS' Spaceflight Meteorology Group (SMG) at Johnson Space Center (JSC), to support NASA's Space Shuttle and Expendable Launch Vehicle (ELV) programs. Their 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 their many customers' 24/7 operations, in the mesoscale driven lightning capital of America, requires:

- A sophisticated weather infrastructure which includes systems normally found only in research field programs rather than operations;
- A dedicated capability to transition research and technology to support new or poorly satisfied operational requirements;
- Rigorous training to ensure the weather infrastructure, diverse customer requirements, and dynamic, mesoscale weather are thoroughly understood; and
- At least 2-3 years of on-site experience to adequately master the infrastructure, the weather, and the requirements sufficiently to provide timely, tailored, accurate support to the many weather sensitive daily operations.

The focal point for satisfying requirement 3 above and assisting with requirements 1 and 2 above 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 interests. 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 NWS Memorandum of Understanding.

Current AMU tasks include:

- Task: Objective Lightning Probability Forecast: Phase I.

Goal: Develop a set of statistical equations to forecast the probability of lightning occurrence for the day. This will aid forecasters in evaluating flight rules and determining the probability of launch commit criteria violations, as well as preparing forecasts for ground operations.

- Task: Severe Weather Forecast Decision Aid.

Goal: Create a new forecast aid to improve the severe weather watches and warnings meant for the protection of KSC and CCAFS personnel and property.

- Task: Shuttle Ascent Camera Cloud Obstruction Forecast.

Goal: Develop a model to forecast the probability that at least three Shuttle ascent imaging cameras can view the Shuttle launch vehicle (LV) unobstructed by cloud at any time from launch to Solid Rocket Booster (SRB) separation.

- Task: Stable Low Cloud Evaluation.

Goal: Examine archived data collected during rapid stable cloud development events resulting in cloud ceilings below 8000 ft at the Shuttle Landing Facility (SLF). Document the atmospheric conditions favoring this type of cloud development to improve the ceiling forecast issued by the Spaceflight Meteorology Group (SMG) for Shuttle landings at KSC.

- Task: Hail Index.

Goal: Evaluate current techniques used by the 45 Weather Squadron (45 WS) to forecast the probability of hail occurrence and size. Hail forecasts are required to protect personnel and material assets at KSC, CCAFS, Patrick Air Force Base and the Melbourne International Airport. The evaluation results will be used by the 45 WS to determine if a new technique is needed.

- Task: RSA and Legacy Wind Sensor Evaluation.

Goal: Compare wind speed and direction statistics from the legacy and RSA sensors on the Eastern (ER) and Western (WR) Ranges to determine the impact of the sensor changes on wind measurements. The 45 WS and 30 WS at Edwards AFB, CA, need to know of any differences in the measurements between the two systems as they use these winds to issue weather advisories for operations.

- Task: Volume Averaged Height Integrated Radar Reflectivity (VAHIRR).

Goal: Transition the VAHIRR algorithm into operations. The current lightning launch commit criteria (LLCC) for anvil clouds to avoid triggered lightning are overly conservative and lead to costly launch delays and scrubs. The VAHIRR algorithm was developed as a result of the Airborne Field Mill program to evaluate a new LLCC for anvil clouds. This algorithm will assist forecasters in providing fewer missed launch opportunities with no loss of safety compared with the current LLCC.

- Task: Mesoscale Model Phenomenological Verification Evaluation.

Goal: Find model weather-phenomena verification tools in the literature that could be transitioned into operations. Forecasters use models to aid in forecasting weather phenomena important to launch, landing, and daily ground operations. Methods that verify model performance are needed to help forecasters determine the model skill in predicting certain phenomena.

- Task: Advanced Regional Prediction System (ARPS) Optimization and Training Extension.

Goal: Provide assistance and support for upgrading and improving the operational ARPS and ARPS Data Analysis System (ADAS) that is used to make operational forecasts at the National Weather Service in Melbourne, FL (NWS MLB) and SMG forecast offices.

- Task: User Control Interface for ADAS Data Ingest.

Goal: Develop a GUI to help forecasters at NWS MLB and SMG manage the data sets assimilated into the operational ADAS.

- Task: Anvil Transparency Relationship to Radar Reflectivity.

Goal: Determine if the NWS MLB WSR-88D radar can be used to analyze anvil cloud transparency

- Task: Range Standardization and Automation (RSA) Support.

Goal: Help ER management evaluate proposed designs and implementations of the weather systems upgrade by the RSA and SLRSC contractors.

Additionally the KSC Weather Office continues to work with the ER to improve the KSC and ER weather infrastructure and improve operational processes and facilities in the following areas:

- 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. Working with colleagues from the National Center for Atmospheric Research (NCAR), Marshall Spaceflight Center (MSFC), the University of Arizona (U AZ), the Hurricane Research Division (NOAA/HRD), National Severe Storms Lab., Aerospace Corp. and others, KSC developed and applied software to perform a variety of analyses on the massive data set. These analyses included correlation and power spectral analyses, and extensive statistical examinations of the radar, cloud physics and electric field data.

KSC facilitated and participated in defining the new LLCC. To help the Lightning Advisory Panel (LAP) determine the threshold electric field aloft that poses a triggered lightning hazard, KSC acquired information from Shuttle and Titan about the length of the ionized plum from their solid rocket motors. From data obtained elsewhere on the likely potential difference required to trigger lightning, the LAP used the plume lengths to convert the triggering threat potential to a corresponding threshold electric field.

In order to automate processing of ABFM data for the determination of the decay of electric fields with distance from cloud edges, KSC developed an automated cloud edge detection algorithm. A paper describing the algorithm and its testing appeared in the May 2004 issue of the Journal of Atmospheric and Oceanic Technology. (Ward, J.G. and F.J. Merceret, 2004: *An Automated Cloud-Edge Detection Algorithm Using Cloud Physics and Radar Data,* J. Atm. & Ocean. Tech., 21(5), 762-765)

• Winds.

The KSC Weather Office (KSCWO) requested the Shuttle Program to re-examine its day of launch upper air winds procedures to ensure spatial and temporal variability are being optimally accounted for. The KSCWO presented several briefings on temporal wind persistence as a function of vertical feature size and related instrumentation matters to the Space Shuttle Natural Environments Panel challenging engineers from the Shuttle, Titan and new Expendable Launch Vehicle programs (Atlas V and Delta IV) to reconsider their assumptions and launch day procedures.

• Visibility Sensors.

In FY 2004, KSC began transmitting Visibility and Soil Moisture data to JSC/SMG from five suites of newly installed sensors west of KSC to aid in the forecast of morning fog that could impact Shuttle landings.

• Range Standardization and Automation (RSA).

The KSC Weather Office, SMG at JSC, and the AMU continue to actively participate in plans and proposals for projects managed by the RSA program. RSA is a major Air Force program to modernize the Eastern and Western Range infrastructure. Many issues remain with RSA's pending changes. Thus the Air Force and NASA weather communities continued to expend significant resources to solve potential major RSA deficiencies, since NASA KSC, JSC and MSFC depend heavily on this infrastructure for their weather support. A major success was the RSA contractor's decision to discard their proposed Control and Display (C&D) system, and instead partner with NOAA's Forecast Systems Lab to deliver a COTS AWIPS (Automated Weather Information System). This will provide Range Weather Operations with a very capable system that is cost effective, and compatible with both future AWIPS upgrades and with SMG. However, in FY 2003 and FY 2004, the Air Force budget redirection seriously threatened cancellation of the entire RSA weather system which would have seriously degraded long term weather support to the American Space Program. Fortunately, the program is still progressing. Although deliveries of some weather sensors, models, and control and display systems began in FY 2000, budget restrictions have delayed full operational capability and acceptance by the Eastern Range to FY 2007 (a decade plus delay from original schedule).

• Spacelift Range Systems Contract (SLRS-C).

In addition to the RSA Modernization programs, the new SLRS-C provides Sustaining Engineering for the legacy systems and also the systems RSA is delivering. SLRS-C is currently upgrading or replacing three systems currently owned by NASA Kennedy Space Center: the 50 MHz Doppler Radar Wind Profiler; the Shuttle Landing Facility Weather Tower and Sensor system; and the Lightning Detection and Ranging (4D total lightning) system. Upon completion of each program, the system will be turned over from NASA/KSC to the Eastern Range. Despite numerous logistical and programmatic hurdles all three programs will likely move forward to completion: SLF in FY 2006, 4D lightning in FY 2007, and 50 MHz profiler in FY 2007.

• 50 MHz Doppler Radar Wind Profiler (DRWP).

Replacement of the KSC DRWP and its electronic components began in FY 2004 and finished in FY 2005. Meanwhile, several antenna field issues were corrected. The Air Force funded a project to improve the drainage of the DRWP antenna field that flooded during very heavy rains. During droughts, the very dry antenna ground plane caused erroneous side lobe returns. The Profiler O&M contractor designed and a contractor installed a sprinkler system to wet the antenna field during droughts. The sprinkler system is now installed which solved the side-lobe problem during dry weather.

• Shuttle Landing Facility (SLF) Weather Sensors.

LRSC also contracted to replace and modernize all SLF weather instrumentation. SLRS-C chose the AF Weather Agency FMQ-19 (aka OS-21) as the basic system to ensure adequate logistics support. To meet special NASA requirements, the system has been modified to provide 1-second winds, additional ceilometers off both runway approaches, and a 120 minute (vs 30 minute) UPS backup. After several communication links are complete, the system will become operational and turned over to the AF expected by FY 2006.

• Lightning Detection and Ranging (LDAR) System.

Since LDAR was originally developed as a research system in the late 1980s, its components are increasingly subject to obsolescence, and thus costs and the risk of system failure are increasing.

KSC worked with the Range to justify raising the priority of a replacement LDAR in the AF Space Command priority list. The AF and KSC worked with SLRS-C to overcome numerous obstacles: electromagnetic interference; NASA and AF requirements vs. COTS capabilities; site selection for antenna towers; takeover of COTS contractor by Finish international company; etc. Major unresolved KSC issues: transmission of LDAR data to SMG and NWS Melbourne; and an expected requirement to perform environmental impact assessments (EIS) on all seven antenna sites because of the location of two towers in marshlands. The EISs will delay antenna installation until FY 2006; testing until FY 2006, and project completion until FY 2007.

• TAL Atmospheric Sounding System (TASS).

The Radio Automatic Theodolite System (RATS) was used to provide SMG with upper level winds, temperatures and humidity at the Shuttle Transatlantic Abort Landing (TAL) sites in Spain, Morocco, and Gambia. RATS became obsolete when the manufacturer announced cessation of sonde production. A replacement system called TASS, a Global Positioning System (GPS) based Sippican W9000, was selected, procured, integrated and tested with the help of the Eastern Range. The initial system is now installed and operational. The Eastern Range owns, operates and maintains the system for NASA. In order to improve TASS' user friendliness, reliability, and accuracy, NASA will funded the ER to upgrade the Operating System from DOS to Windows, and upgrade the sondes in FY 2005.

• Sonic Lightning Locator (SOLLO).

The KSC Weather Office funded development of a new lightning detection system capable of locating lightning strikes in 4D with an accuracy of less than 5 meters (a considerable improvement over the 250-300 meter accuracy of our current lightning location system). Called SOLLO, it uses a sensor to detect the time of arrival of the electromagnetic pulse from a lightning strike, and then one elevated detector and three surface based detectors to measure the time of arrival of thunder from the lightning, to very accurately calculate the location of the lightning strike. SOLLO also calculates the amperage, rise time, and polarity of the strike. During FY 2004, KSC replaced/upgraded SOLLO components to enhance its capability to operate reliably in the corrosive KSC/ER environment. During the 2004 and 2005 spring/summer lightning season, KSC installed SOLLO systems at the Shuttle Launch Complex and a new technology development and testing facility for further testing.

• KSC/CCAFS Weather Observation Site Relocation.

The 24/7 official KSC/CCAFS Weather Observation Site is located in a very aging structure with its view of Shuttle Landing Facility (SLF) runway totally obscured. We convinced architects and managers of a project to build a new SLF air traffic control tower to include two floors for weather observers and equipment. The Range Technical Service Contractor (CSR) provided detailed specifications to ensure the final design met strict observing requirements. Tower project is complete; and move in completed FY 2005. The tower enables observers to provide much more accurate weather depictions over SLF, especially during rapidly changing conditions, thus improving aircraft, Space Shuttle and future RLV safety.

• Lightning Launch Commit Criteria (LLCC) Revision.

During analyses of Airborne Field Mill (ABFM) Program data, the Lightning Advisory Panel (LAP) concluded the radar definition of cloud edge, top and base in the LLCC was not sufficiently conservative. Based on ABFM measurements of electric fields high enough to trigger lightning with radar reflectivities as low as 5 dBZ, the LAP concluded the radar threshold needed to be lowered from 10 dBZ to 0 dBZ. The conclusion was reached one week before the launch of first Mars Rover on board a Delta.

A new definition was quickly staffed from the LAP thru 45 WS. and 45th Space Wing Safety, and the revision recommended at the Delta/Mars Rover Launch Readiness Review, two days before launch. Although Launch and Program managers are normally reluctant to accept last minute changes to procedures, we emphasized the revision was a safety issue and they accepted the change exactly as proposed.

• Columbia Accident Investigation.

The entire NASA and ER weather communities (KSC, JSC/SMG, MSFC, GSFC, LRC, and 45 WS) were deeply involved supporting the Space Shuttle Columbia accident investigation. Weather analyses were crucial to: identifying likely debris impact locations over the western and central U.S.; characterizing the atmosphere during reentry, beginning in the very data sparse upper Mesosphere; identifying possible anomalous wind shears during launch ascent; analyzing Columbia's exposure to the atmosphere during the 39 days Columbia was on the launch pad; and numerous engineering studies. NOAA/NWS also provided considerable help.

• Helios Accident Investigation.

NASA's premier solar-powered research aircraft (Helios) crashed just west of Barking Sands, Kauai in late June 2003. The KSC Weather Office participated on the Mishap Board along with Dr. John Brown from NOAA/Forecast Systems Lab. Due to Helios' many unique design and power characteristics, it had many very complex stability and control physics and characteristics.

Initial research revealed little was known about the atmosphere's behavior west of Kauai, specifically the atmosphere's combined response to the wake turbulence from the Trade Wind flow over the island, shear lines from air flowing around Kauai, sea breezes, and the large scale pattern. Thus the Weather Office contracted with NCAR and the University of Hawaii to perform high resolution atmospheric numerical model simulations to try to understand the atmosphere Helios encountered. In addition, the University of Hawaii designed and implemented a very low budget, aircraft data gathering program offshore of Barking Sands, Kauai, to measure wind and temperature profiles, and turbulence features. The aircraft data was used to understand small-scale features and to validate results from NCAR's high resolution model simulations. The final Helios Mishap Board report was released to the public.

SUPPORTING RESEARCH

NASA's Earth Science program is dedicated to the utilization of space technology and the pioneering of the use of global satellite measurements to improve human understanding of our Home Planet and thus inform economic and policy decisions and advance operational services of benefit to the Nation. The program is responsive to several Congressional Mandates and Presidential Initiatives.

Perhaps more than any other human activity, several centuries 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. We live on a planet undergoing constant change due to natural phenomena and our own activities, and to maintain and improve quality of life on Earth, we need continuous global observations of variability and change analyzed to reveal 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. Thus, NASA's strategic goal: "study planet Earth from space to advance scientific understanding and meet societal needs" is expressed by the fundamental question: "How is the Earth changing and what are the consequences for life on Earth?"

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 Vision for Space Exploration (February 2004).

The first is the subject of the U.S. Climate Change Science Program (CCSP). 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 in February 2005, adopted a ten year plan for a Global Earth Observation system of systems. The third initiative uses NASA's observing technologies and knowledge of Earth as a planet to aid in the Nation's exploration of worlds beyond. 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.

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 criterion for NASA Earth science programs.

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.

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. But other important measurements require new concepts that take advantage of advancing technology-many observations remain difficult to interpret. Earth science research drives NASA satellite missions, and the focus area roadmaps indicate major requirements for developing or extending satellite remote sensing.

Beginning with the launch of the Terra satellite in December 1999, NASA began to deploy an Earth observing system with the objective of collecting systematic, well-calibrated and validated, long-term measurements to characterize and detect change in the Earth system. A suite of polar-orbiting and low-inclination satellites, each carrying multiple sensors, linked to a data system for acquisition, processing, and distribution, provides numerous science data products with global coverage and repeated measurements of sufficient frequency and accuracy to detect change. With the launch of Aura in July 2004, NASA completed the deployment of the observing system that now provides a core set of data products to characterize the Earth system and to identify and track changes. In the future, measurements whose scientific value demand a data continuity spanning multiple mission lifetimes will be provided by NASA satellites or operational satellites operated by other agencies. In addition, satellites like GRACE, launched in March 2002, probe key Earth processes globally for the first time. The CloudSat and CALIPSO satellites, launched in April 2006, are recent additions to these highly focused exploratory measurement missions. A brief description of all operating NASA Earth Science satellites is provided below:

<u>ACRIMSAT</u>

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.

<u>Aqua</u>

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 6-year prime 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.

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.

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.

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.

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 system. It is a collaboration with Germany. Grace was launched on March 17, 2002, and is in its prime 5 year mission.

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.

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.

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 U.S. 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.

Quick Scatterometer (QuikSCAT)

QuikSCAT records sea-surface wind speed and direction data for global climate research and operational weather forecasting and storm warning (Figure 3-NASA-1). 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.

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.

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.

Total Ozone Mapping Spectrometer (TOMS)-Earth Probe (EP)

TOMS-EP provides global measurements of atmospheric total column ozone and its variation on a daily basis. It continues a long-term data set of daily ozone of over two decades. Its measurements support the Atmospheric Composition science focus area. The single instrument, TOMS, is a second-generation backscatter ultraviolet sounder. TOMS-EP was launched on July 2, 1996, and is in an extended mission having exceeded its 2 year design life.

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

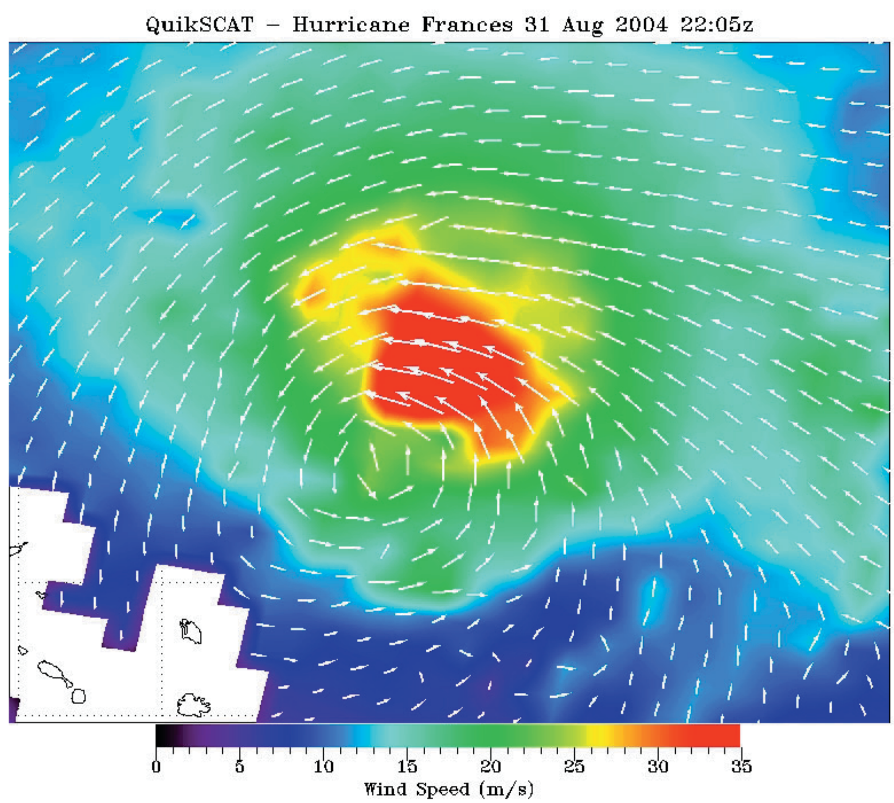

Figure 3-NASA-1. NASA QuickSCAT satellite view of Hurricane Frances (2004) in the Atlantic, showing structure of the low-level wind vortex.

around the world (Figure 3-NASA-2). 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.

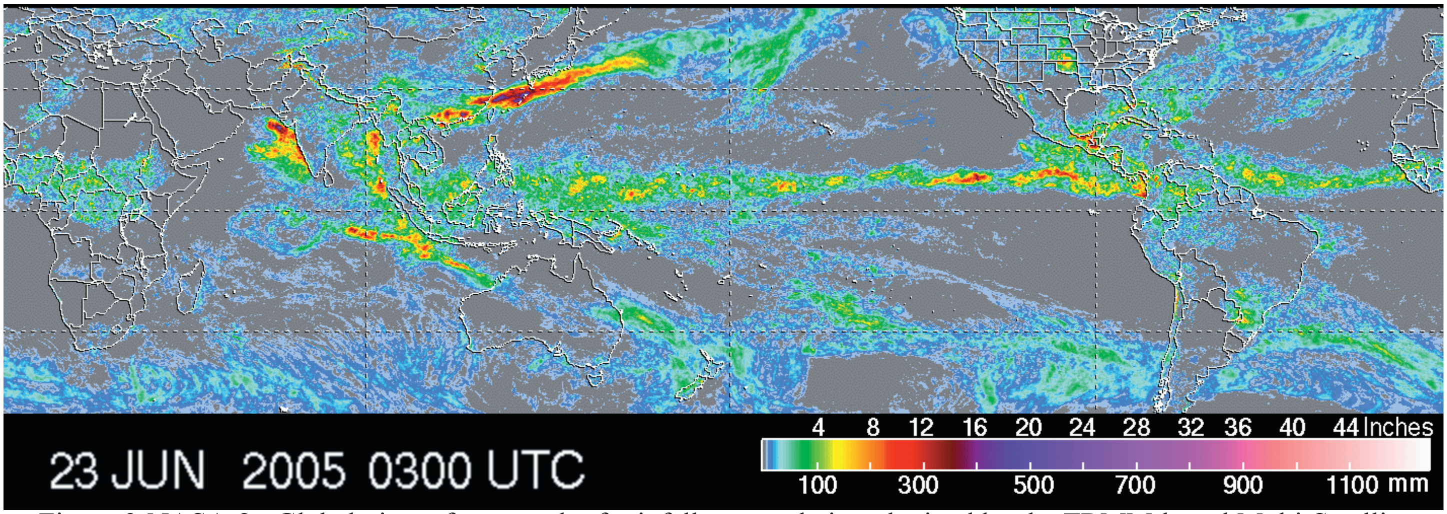

Figure 3-NASA-2. Global view of one week of rainfall accumulation obtained by the TRMM-based Multi-Satellite Precipitation Analysis.