NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WEATHER PROGRAMS

The National Aeronautics and Space Administration (NASA) supports weather operations through the Space Operations Mission Directorate (SOMD), weather and climate research through the Science Mission Directorate's (SMD) Earth Science Division, and space weather research through SMD's Heliophysics Division. The SOMD objective is weather-related safety of manned spacecraft, satellites, scientific instruments, and launch vehicles. The greatest challenge is to accurately measure and forecast mesoscale weather events that strongly impact ground processing, launch, and landing operations. The SMD objective is to improve accuracy of operational numerical weather prediction of severe storms through understanding of severe storm formation and subsequent trajectory and intensity. The greatest challenge is to observe the continuum of weather-to-climate processes and produce models verifiable with observations. The SMD objective in space weather research is to develop the scientific foundation that will enable space weather forecasters to predict the extreme and dynamic conditions in space in order to maximize the safety and productivity of human and robotic explorers.

OPERATIONS

Kennedy Space Center Weather Office

The SOMD Weather Office at NASA Kennedy Space Center (KSCWO) has oversight responsibility for operation and maintenance of the weather information infrastructure required for NASA's Space Shuttle, Constellation, and Expendable Launch Vehicles (ELV) programs. The infrastructure is a multi-agency partnership of KSCWO, NASA Marshall Space Flight Center (MSFC), Department of Defense (DoD) U.S. (US) Air Force (USAF) 45th Space Wing, and Department of Commerce (DoC) National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Spaceflight Meteorology Group (SMG).

Manned flights launch and land at the Kennedy Space Center (KSC) adjacent to USAF Cape Canaveral Air Force Station (CCAFS) in Florida and also land at USAF Edwards Air Force Base (EAFB) in California. KSCWO provides daily staff meteorological support to KSC and the Space Shuttle and Constellation programs.

The ELV program operates from many locations, including CCAFS, USAF Vandenberg Air Force Base in California, NASA Wallops Flight Facility in Virginia, and the U.S. Army Ronald Reagan Ballistic Missile Defense Test Site on Kwajalein Island. KSCWO ensures that DoD weather support at DoD sites meets NASA requirements through training, technology, and tools.

KSCWO is the NASA lead for the joint NASA and USAF Lightning Advisory Panel (LAP), which provides independent scientific assessments of changes to the lightning launch commit criteria (LLCC) and technical guidance about lightning-related issues on facilities and ground operations. The U.S. Department of Transportation (DoT) Federal Aviation Administration (FAA) utilizes the same LLCC at commercial spaceports.

In FY 2008, the KSCWO:

- Supported four Space Shuttle missions: STS-120, STS-122, STS-123 and STS-124;
- Helped develop and deploy a new system to detect lightning at KSC Launch Complex-39;
- Supported the Constellation program through infrastructure and requirements concept studies of Ares 1 and Ares 1-X rockets and Orion Crew Exploration Vehicle (CEV);
- Prepared first draft of a weather operations plan for Constellation Ground Operations;
- Developed an analytical tool to provide the probability of exceeding operational peak wind thresholds of hurricanes and tropical storms at landfall.

In FY 2009, the KSCWO will:

- Support the Space Shuttle and ELV programs;
- Expand its support for the Constellation program through increased meteorological activities for the Ares 1-X test flight in 2009 and for planning Ares and Orion programs;
- Prepare and recommend LLCC revisions to the LAP to improve launch operation;
- Increase capability of the hurricane peak wind analysis tool.

Applied Meteorology Unit

The Applied Meteorology Unit (AMU) is a joint venture of KSCWO, USAF 45th Space Wing, and NOAA NWS. The AMU is co-located with the 45th Weather Squadron located at CCAFS. The AMU develops, evaluates, and transitions weather technology into operations.

In FY 2008, the AMU:

- Completed an objective cost-benefit analysis of the impact on forecast skill of local numerical weather prediction models through elimination of selected weather towers at CCAFS and one of the daily radiosonde soundings from CCAFS;
- Developed optimal scan strategies for the new 5-cm Doppler dual-polarization weather radar, which will be deployed for use at CCAFS in 2009;
- Updated its Anvil Forecast Tool for the SMG-operated Advanced Weather Interactive Processing System (AWIPS) to improve evaluation of the threat from natural and triggered lightning during a returning Space Shuttle in the presence of an anvil cloud;
- Created composite soundings to display in AWIPS so that they could be overlaid on current observed soundings allowing forecasters to compare the current state of the atmosphere with climatology;
- Developed a tool to help the 45th Space Wing forecast the average wind speed and the speed and timing of the daily peak wind from the surface to 300 feet at KSC and CCAFS for the cool season October – April and provide the probability of the expected peak wind speed equal to or greater than each of the wind warning thresholds;
- Supported launch operations for four Space Shuttle, three Atlas V, three Delta II and one Delta IV.

In 2009, the AMU will:

- Conduct cost-benefit analysis of automating the calculation of the Volume Averaged Height Integrated Radar Reflectivity (VAHIRR), which is used in LLCC;
- Complete statistical wind guidance tool for Space Shuttle landings at Edwards Air Force Base (EAFB), which displays monthly-mean wind speed and probabilities of exceeding peak wind thresholds at EAFB;
- Determine the skill of different high-resolution Weather Research and Forecasting numerical weather prediction model configurations in forecasting wind cycling at EAFB to help SMG forecasters support Space Shuttle landings at EAFB;
- Update the probabilities of lightning climatologies for nine airfields in the NWS Melbourne County Warning Area using individual lightning strike data to improve the accuracy of the climatologies to support Space Shuttle landings and daily ground operations;
- Configure the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to provide guidance to SMG and NWS Melbourne in the event of incidents involving the significant release of harmful chemicals, radiation, and smoke from fires;
- Support Space Shuttle landings with HYSPLIT to track cumulus cloud development and visibility from smoke;
- Migrate the capabilities of the AMU-developed Severe Weather Tool and 45th Space Wing-developed Weak Waterspout Checklist into the 45th Space Wing Meteorological Interactive Data Display System (MIDDS) to support warm season May – September daily and launch operations at KSC and CCAFS.

Spaceflight Meteorology Group

Spaceflight Meteorology Group (SMG) is located at NASA Johnson Space Center (JSC).

In FY 2008, the SMG:

- Supported four Space Shuttle missions: STS-120 (23 October – 7 November 2007), STS-122 (7 – 20 February 2008), STS-123 (11 - 26 March 2008) and STS-124 (31 May – 14 June 2008);
- Provided an average of 32 unscheduled in-person weather briefings per Space Shuttle flight, in addition to normal activities;
- Coordinated with NWS and the Spanish and French weather services for weather radar data support to improve SMG assessments of Space Shuttle transoceanic abort landing site weather at Istres Air Base in France and Zaragoza or Moron air bases in Spain;
- Supported the Constellation Program with weather requirements for landing and recovery of the new Orion spacecraft and its crew;
- Provided extensive meteorological support to JSC during Tropical Storm Edouard and Hurricanes Gustav and Ike, including continued support from SMG staff members' homes after JSC had been evacuated;
- Hosted the 7th NASA Weather Users Forum in June 2008;
- Collaborated with AMU on technology development;
- Upgraded AWIPS workstation;
- Supported several educational outreach events.

In FY 2009, the SMG will:

- Support Space Shuttle mission;
- Support Constellation program, including upper air wind forecasts for the Ares 1-X launch scheduled for late summer 2009;
- Host the Range Commanders Council meeting in May 2009;
- Enable final agreement with the French weather service for access to real-time radar, lightning, wind and other observations.

Marshall Space Flight Center

The Natural Environments Branch (NEB) develops and implements weather support requirements for the Space Shuttle and Constellation programs, including development and evaluation of launch constraints.

In FY 2008, the NEB:

- Supported four Space Shuttle missions: STS-120 (23 October – 7 November 2007), STS-122 (7 – 20 February 2008), STS-123 (11 - 26 March 2008) and STS-124 (31 May – 14 June 2008);
- Performed day-of-launch analyses of upper air winds for evaluation of vehicle ascent loads;
- Developed or improved wind climatological data sets for safety margin analyses and day-of-launch procedures relating to upper air wind requirements;
- Prepared Program Requirements Document for the Ares 1-X test flight in 2009.

In FY 2009, MSFC will:

- Support the Space Shuttle program;
- Develop weather support architecture for Constellation program.

The Earth Sciences Branch in FY 2008 developed scan strategies and operations concepts for the new Doppler, dual polarization 5-cm weather radar at CCAFS. This work will continue in FY 2009.

RESEARCH

Earth Science Division

NASA's Science Mission Directorate Earth Science Division (ESD) conducts a program of breakthrough research to advance fundamental knowledge on the most important scientific questions on the global and regional integrated Earth system. ESD research encompasses the global atmosphere; the global oceans including sea ice; land surfaces including snow and ice; ecosystems; and interactions between the atmosphere, oceans, land, and ecosystems, including humans. ESD's vision is to understand the changing climate, including weather, and, in association with national and international partners, apply this understanding for the well-being of society.

In FY 2008, NASA operated fifteen on-orbit satellites: ACRIMSAT, Aqua, Aura, CALIPSO, CloudSat, EO, GRACE, ICESat, Jason, Landsat-7, OSTM, QuikSCAT, SORCE, Terra, and TRMM. Acronyms are defined in at the end of the section, which lists

primary weather and climate themes of on-orbit missions. On 24 February 2009, NASA's Orbiting Carbon Observatory (OCO) satellite did not reach orbit when the launch vehicle malfunctioned. NASA has six missions in development for launch in FY 2010 and later (refer to listing at the end of the section).

For missions beyond those currently in formulation and development, the principal determinant of the priority of NASA's Earth Science satellite science missions is described in the National Research Council report, entitled "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," which was released in 2007. Many Decadal Survey missions will contribute to weather and climate research, such as the 3-D Winds mission to measure the three-dimensional tropospheric wind vector profile to improve weather prediction capability. The Decadal Survey recommended six satellite missions to develop longer-term reliable weather forecasts.

NASA aircraft- and surface-based instruments are used to calibrate and enhance interpretation of high accuracy, climate quality, and stable satellite measurements. NASA supports state-of-the-art computing capability and capacity for extensive global integrated Earth system modeling. NASA, in recording approximately 4 terabytes of data every day, maintains the world's largest scientific data and information system for collecting, processing, archiving, and distributing Earth system data to worldwide users.

Weather and climate are part of a continuum spanning all time and space scales. A core objective of ESD is to improve severe weather forecast duration and climate projection through analyses of global observations from satellites, process studies combining orbital and suborbital measurements, and assimilation of satellite measurements into research and operational weather and climate models. NASA is working on climate change models with spatial and temporal resolutions to contain severe weather phenomena.

The NASA Tropical Rainfall Measuring Mission (TRMM) satellite directly measures rainfall with a Japanese Precipitation Radar (PR), an active microwave instrument and the only such instrument in space; and indirectly with the NASA TRMM Microwave Imager (TMI), a passive microwave instrument. The National Oceanic and Atmospheric Administration (NOAA) and the US Navy utilize TMI data in their weather forecasts. In addition to operational utility of TRMM data to improve weather forecasts, ongoing research studies illustrate the complexity of the dynamics and thermodynamics of rainfall because of the strong influence of aerosols. The lack of knowledge about the interaction of clouds and aerosols represent a large uncertainty in climate models. Two examples show this research finding.

Bell et al. (Journal of Geophysical Research, vol. 113, D02209, doi:10.1029/2007JD008623, 2008) used TRMM to show that rainfall over the southeast US was significantly higher during the middle of the week than on weekends. Afternoon storms intensified in the midweek. Apparently, air pollution, which is more extensive during the week than on weekends, suppresses cloud-drop coalescence and early rainout from clouds, allowing more cloud liquid water to be carried aloft to produce an overall increase in rainfall.

Berg et al. (Journal of Geophysical Research, vol. 113, D14S23, doi: 10.1029/2007/JD009649, 2008) showed that rainfall estimated from the PR, an active instrument, and TMI, a passive instrument, exhibited large differences off the coast of China and extending east across the North Pacific storm track. The area is rich in sulfate aerosols, which produce high liquid water content clouds with either no precipitation or light rain or drizzle with small drops that were not detected by the PR because of the PR's lack of sensitivity. Measurements from NASA's Cloudsat helped solve the mystery.

In-situ measurements at island and continental stations have demonstrated conclusively that rainfall has a diurnal-period oscillation, especially in the tropics where most rainfall occurs over the Earth. The geographical distribution of the time of day of maximum rainfall remained a mystery until sustained high accuracy well calibrated tropical rainfall data were acquired by satellite. Liu and Zipser (Geophysical Research Letters, vol. 35, L04819, doi:10.1029/2007GL032437, 2008) used TRMM measurements to describe diurnal-period oscillations of surface rainfall, vertical structure of precipitation, and deep intense convection reaching the top of the troposphere. This breakthrough study could be achieved only with the TRMM PR instrument and

will guide the sampling strategy for the Global Precipitation Measurement (GPM) mission in development for launch in 2013.

Assimilation of satellite data in models is an important theme throughout ESD's programs. Investigations are primarily supported through annual solicitations of competitive peer-refereed proposals. Institutionally, ESD supports the NASA Global Modeling and Analysis Office (GMAO), located at NASA's Goddard Space Flight Center, and the interagency Joint Center for Satellite Data Assimilation (JCSDA), located at the National Oceanic and Atmospheric Administration (NOAA) World Weather Building. Several years ago, JCSDA demonstrated an increase in NOAA's National Centers for Environmental Prediction (NCEP) global weather forecast skill produced by the assimilation of measurements recorded by NASA's Atmospheric Infrared Sounder (AIRS) instrument on NASA's Aqua satellite. In FY 2009, the JCSDA Management Oversight Board decided to adopt the overarching short-term goal to contribute to making the forecast skill of the operational numerical weather prediction systems of the JCSDA partners internationally competitive by assimilating the largest possible number of satellite observations in the most effective way.

NASA airborne campaigns improve understanding of atmospheric processes and provide calibration and validation instruments for NASA satellites. The series of CAMEX airborne campaigns (CAMEX-3, 1998; CAMEX-4, 2001; Tropical Cloud Systems and Processes (TCSP), 2005; NASA African Monsoon Multidisciplinary Analyses (NAMMA), 2006) provided a wealth of new research findings into the genesis, intensity change, and three-dimensional multi-scale structure of tropical cyclones in the Atlantic Ocean, Gulf of Mexico, and eastern Pacific Ocean. In addition, the CAMEX airborne campaigns were a test-bed for new remote sensing technologies for satellite and aircraft platforms, retrieval algorithms, and predictive models. The recent scientific focus on tropical storm intensity change is particularly timely with the recent strengthened cyclone intensity in the Atlantic Ocean storm activity and the continuing challenge of accurately forecasting tropical cyclone intensity. As part of the NASA annual omnibus solicitation, called Research Opportunities in Space and Earth Science (ROSES), in 2008 NASA selected a science team to use NASA satellite and field campaign data on problems related to the formation and intensification of hurricanes.

NASA is planning the Genesis and Rapid Intensification Processes (GRIP) airborne campaign for summer 2010 to better understand how tropical storms form and develop into major hurricanes. NASA plans to use the DC-8 aircraft and the Global Hawk Unmanned Airborne System (UAS) and is soliciting proposals through ROSES 2009 for instrument teams that can achieve the required measurements. GRIP deployment is planned in Miami, Florida, for the DC-8, and Edwards, California (or Wallops Island, Virginia), for the Global Hawk. The Global Hawk will fly in the upper troposphere and stratosphere, and, with 30-hour flight duration, can easily reach all regions of the Atlantic, Caribbean, and Gulf of Mexico. It is anticipated that the NOAA Hurricane Research Division will participate and deploy one or two low-altitude P3 turboprops and possibly a Gulfstream IV jet for the upper troposphere.

The global water cycle represents the transport and transformation of water within the Earth system, and, as such, distributes fresh water over the Earth's surface. The water cycle operates on a continuum of time and space scales and exchanges large amounts of energy as water undergoes phase changes and is moved from one part of the Earth system to another. Through latent heat release from condensation and sublimation, the water cycle is a major driving agent of global atmospheric circulation. Clouds play a critical role in modulating the flow of energy into and out of the Earth system, while at the same time modulating the continuous supply of solar energy that keeps the water cycle in motion. So while the water cycle delivers the hydrologic consequences of climate changes, the global water cycle is both a consequence of, and influence on, the global energy cycle. Weather and the global water and energy cycles are intimately entwined. Inherent to the topic of storm formation and intensification are questions related to the structure and evolution of clouds and precipitation and their links to the kinematic and thermodynamic characteristics of the initial disturbance, the more mature wind system, and the surrounding environment. Of particular relevance to NASA are remotely sensed estimates of wind, temperature, and water (in all of its phases)

and their validation via direct measurements of their distributions.

Heliophysics Division

The Earth, our home planet, in embedded in the outer atmosphere of a magnetic variable star, our Sun. As a consequence the Earth, and the planets of the solar system, are constantly influenced by the magnetic evolution of the Sun that produces a dynamic environment.

The Heliophysics Division of the SMD is organized to discover and communicate new scientific knowledge concerning the magnetic variability of the Sun, the effect of this variability on the planets of the solar system including the Earth, and the dynamic structure of the particle and field configuration of interplanetary space. The three areas of concentration in the Heliophysics Division's research program are theory, data, and modeling.

To support the effort of collection of data that characterizes the heliophysical environment, the Division operates a fleet of 15 missions involving 26 spacecraft. The region of space characterized is huge, extending from the Sun itself to the outer edges of the solar system and the heliosphere. To extend the research effort, new missions are under development, including the first two missions of the NASA Living with a Star program, the Solar Dynamics Observatory (SDO) and the Radiation Belt Storm Probes (RBSP).

Currently three NASA research missions contribute data to the national space weather community. This is done by either direct broadcast from the satellite to a combination of NASA and non-NASA ground stations, or by near real-time level zero data processing from the satellite and rapid, periodic updates of NASA data bases that are accessible to the public or other governmental agencies via internet. The Advanced Composition Explorer (ACE) spacecraft, an Explorer program research activity in extended mission status, provides data on the condition of the solar wind outside of the Earth's magnetic field. The ongoing success of the use of ACE data concerning the characteristics of the solar wind flowing toward the Earth has made this research mission a vital resource for the nation. Other such missions are Solar and Heliophysics Observatory (SOHO), a joint program with the European Space Agency, and the Solar Terrestrial Relations Observatory (STEREO), a Solar Terrestrial Probes Program mission. The successful use of the direct broadcast modes of ACE and STEREO has lead to the inclusion of this type of mode into the RBSP project. SDO has a separate, high speed, data link that will make near real-time solar data from this mission available to interested users with a few minutes delay between collection and delivery to Internet customers.

NASA also supports the development of models and new theories both with the research and analysis program and the Targeted Research and Technology portion of the Living with a Star Program. As a quality assurance activity to validate the national research community model development, the agency operates the Combined Community Modeling Center, an interagency collaborative activity involving the NSF, NOAA, and DOD, which is located at the Goddard Space Flight Center. The output of standard and requested computations using community provided models is available in near real-time via the Internet. A yearly conference entitled R2O (Research to Operations) is held to ensure the effective utilization of the supported models within the broad range of national space weather activities.

Brief summary of the correlation of NASA operating satellite missions with OFCM themes. *Acronyms: ACE, Advanced Composition Explorer; ACRIMSAT, Activity Cavity Radiometer Irradiance Monitor SATellite; CALIPSO, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation; CloudSat, Cloud Satellite; EO, Earth Observer; GRACE, Gravity Recovery and Climate Experiment; ICESat, Ice, Cloud, and land Elevation Satellite; OSTM, Ocean Surface Topography Mission; QuikSCAT, Quick Scatterometer; SORCE, Solar Radiation and Climate Experiment; STEREO, Solar Terrestrial Relations Observatory; TRMM, Tropical Rainfall Measuring Mission.*

Satellite	**Launch Date**	**Themes**
ACE	Aug 1997	Solar wind composition
ACRIMSAT	Dec 1999	Climate variability and change

Aqua	May 2002	Air quality; carbon cycle; climate variability and change; ecosystems; water cycle; weather
Aura	Jul 2004	Air quality
CALIPSO	Apr 2006	Atmospheric composition; water cycle
CloudSat	Apr 2006	Climate variability and change; water cycle; weather
EO	Nov 2000	Carbon cycle; ecosystems
GRACE	Mar 2002	Climate variability and change; water cycle
ICESat	Jan 2003	Climate variability and change; water cycle
Jason	Dec 2001	Climate variability and change; water cycle
Landsat-7	Apr 1999	Carbon cycle; ecosystems
OSTM	Jun 2008	Climate variability and change; water cycle
QuikSCAT	Jun 1999	Climate variability and change; weather
SORCE	Jan 2003	Climate variability and change
STEREO	Oct 2006	Solar coronal mass ejections
Terra	Dec 1999	Air quality; carbon cycle; climate variability and change; ecosystems; water cycle
TRMM	Nov 1997	Climate variability and change; water cycle

Brief summary of the correlation of NASA missions in development with OFCM themes.
Acronyms: LRD is launch readiness date. Acronyms are: NPP, National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project; LDCM, Landsat Data Continuity Mission; RBSP; Radiation Belt Storm Probes; SDO, Solar Dynamics Observatory; SMAP, Soil Moisture Active and Passive; GPM, Global Precipitation Measurement.

Satellite	**Planned Launch**	**Theme**
SDO	Nov 2009	Solar interior and atmospheric processes
Glory	Dec 2009	Air quality
Aquarius	May 2010	Climate variability and change; water cycle
NPP	Jan 2011	Climate variability and change; ecosystems
LDCM	Dec 2012	Carbon cycle; ecosystems
RBSP	May 2012	Solar influence on Earth and near-Earth space
SMAP	Mar 2013	Climate variability and change; water cycle; weather
GPM	Jul 2013	Climate variability and change