EARTH SCIENCE DIVISION

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

Outcome 2.1: Advance Earth system science to meet the challenges of climate and environmental change.

Objective 2.1.1: Progress in understanding and improving predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition.

In the past year, NASA researchers conducted an airborne field campaign to improve the characterization of mid-latitude cirrus clouds. The Measurements from the Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) served multiple needs: improved our basic understanding of cirrus formation and evolution, provided improved characterization of cloud properties for Earth system models, and enhanced remote sensing retrieval algorithms. The NASA WB-57 aircraft was used for MACPEX and many of the flights were coordinated with CALIPSO/CloudSat over-passes or ground based instruments at the Department of Energy Southern Great Plains site.

A NASA Earth Venture-funded mission, the Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ), conducted its first targeted series of flights during the summer of 2011. NASA King Air and P-3B aircraft flew multiple flights over the Baltimore-Washington, D.C. area to improve the use of satellites to monitor air quality for public health and environmental benefit. Future flights of this four-year mission may include Houston and Sacramento.

The United Nations Environment Program (UNEP) organized an assessment to provide a scientifically credible basis for informed decision-making on black carbon issues. NASA scientists and funded researchers participated and served in leadership roles in this activity. The assessment, published this year, found that control of black carbon particles and tropospheric ozone through implementation of proven emission reduction measures would have multiple benefits for human well-being.

The UNEP-led International Ozone Assessment published its 2010 report this year. NASA scientists and funded researchers made major contributions to the 2010 WMO/UNEP Ozone assessment, serving as overall lead authors, chapter lead authors, chapter co-authors, and contributors. This assessment used data from NASA satellites (Aura and past satellites like TOMS, SAGE, and UARS), data from ground-based networks (AGAGE and NDACC), and models (e.g. GSFC CCM).

Measurements from multiple space-borne instruments, including SAGE II, CALIPSO, and sensors on European and Canadian platforms, have demonstrated that the observed

trend in stratospheric aerosols is driven mainly by a series of moderate but increasingly intense volcanic eruptions, principally at tropical latitudes. These measurements have also been used to assess the role of aerosols in radiative forcing and their impact to climate model calculations of global change. If these measured increasing trends were not taken into account, climate model projects would continue to overestimate radiative forcing and global warming in coming decades.

Measurements of hydrogen cyanide from the Microwave Limb Sounder (MLS) were used to characterize the transport of air masses from the surface, through the Asian monsoon, and deep into the stratosphere. The monsoon circulation provides an effective pathway for pollution from southern and southeast Asia to enter the global stratosphere.

Numerous studies across the Focus Area have assessed the predictive capability of models for changes in composition, climate forcing and air quality. For example, new measurements of precipitation frequency from CloudSat were used to assess the realism of global model predictions of precipitation. These measurements were compared with five state-of-the-art models. Differences between observed and modeled precipitation were larger than can be explained by observational retrieval errors or by the sampling differences between models and observations. However, it was shown that the time-integrated accumulations of precipitation produced by these models closely match observations when globally composited. These studies rigorously test the theoretical understanding of the atmosphere that is expressed in these models with an overall aim towards model improvement.

Analyses of observations from the ARCTAS aircraft mission provided new perspectives on the transport of pollution to the Arctic and its climate implications. They showed that the Arctic is subject to a complex combination of influences from Asian, European, and North American anthropogenic pollution, as well as Russian fires. Black carbon in the Arctic was found to have major contributions from both fossil fuel and biomass burning. ARCTAS revealed that the prominent satellite observations of BrO hotspots in polar spring are not due to boundary layer bromine, as previously thought, but to tropopause depressions combined with higher-than-expected inorganic bromine in the lower stratosphere. This elevated bromine has important consequences for ozone in the Arctic stratosphere and troposphere.

Direct and semi-direct aerosol radiative effects of biomass burning aerosols from southern African fires were investigated using global models and measurements of aerosol properties from MODIS and CALIPSO. Surface forcing was found to be strongly negative, leading to a reduction in precipitation and also a reduction in the sensible heat flux. These results highlight the importance of semi-direct radiative effects and precipitation responses for determining the climatic effects of aerosols in the African region.

FY 2011 Annual Performance Goal	FY 08	FY09	FY10	FY11
2.1.1.1: ES-11-1: Demonstrate planned progress in understanding and improving	Green	Green	Green	Green

predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.				

Objective 2.1.2: Progress in enabling improved predictive capability for weather and extreme weather events.

In August-September 2010, NASA conducted the Genesis and Rapid Intensification Processes (GRIP) field experiment. The major goals of GRIP were to better understand the physical processes that control hurricane formation and intensity change. NASA and NSF aircraft teamed up to perform coordinated flights for the genesis of Hurricane Karl and Tropical Storm Matthew and the non-development of the remnants of Tropical Storm Gaston. NASA and NOAA conducted coordinated flights to thoroughly describe the rapid intensification of Hurricanes Earl and Karl.

NASA's Short-term Prediction Research and Transition (SPoRT) program has transitioned experimental satellite data and forecast products to NOAA's weather forecast offices and National Centers around the country to improve situational awareness and short-term forecasts on a regional and local scale.

NASA sponsored research continued to gain new insight into weather and extreme-weather events by the utilization of data obtained from a variety of satellite platforms (GOES, TRMM, Aqua, Terra, CloudSat, and CALIPSO). For example, one study using AIRS/AMSU retrievals, demonstrates that information about dry air associated with the Saharan Air Layer (SAL) improves hurricane simulations and that the SAL contributes to hurricane formation but suppresses hurricane intensification. Several studies have examined the robust signatures of internal gravity waves in AIRS radiances and this data has been used to identify cases where gravity waves in the lee of the Antarctic Peninsula lead to formation of polar stratospheric clouds. The accuracy and lack of diurnal drift have combined to make the AMSR-E SSTs the current gold standard for climate modeling of global SST. Gentemann *et al*. (2010) systematically examine the accuracies of SST retrievals using the AMSR-E 7 GHz and 11 GHz channels, quantifying the fact that the errors are smaller in the 7 GHz retrievals. Liu *et al*. (2010) assess the impact of MODIS IR, MODIS near-infrared (NIR), and AIRS total precipitable water data on simulations of Hurricane Emily, which was a category 5 Atlantic hurricane in July 2005. The model simulations were markedly improved (better tracking, intensity, and 10-m wind fields) upon incorporating the MODIS IR total precipitable water. Over the past decade, TRMM TMI and PR data have been heavily used by the National Hurricane Center (NHC), and have played an important role in the monitoring and analysis of tropical cyclones (e.g., Blake and Pasch 2010; Kimberlain and Brennan 2011). The data have helped establish key characteristics of the distribution and variation of rainfall in

tropical cyclones as a function of intensity, stage of development, and environmental conditions. The ability of TRMM to see within cloud systems enables it to detect the clouds within the inner regions of tropical cyclones. It aids the analysis of clouds and precipitation associated with the different parts of tropical cyclones including the eyewall and the rainbands beyond the eyewall region (Houze 2010). NASA satellite and re-analyses data show that the two super-extreme weather events in the summer of 2010, *i.e*., the Russian heat wave and the Pakistan flood, were physically connected. The development of an atmospheric blocking high associated with Russian heat wave set off a large-scale atmospheric Rossby wave which was instrumental in triggering torrential rain over northern Pakistan (Lau and Kim, 2010).

Finally the use of satellite data to assess and quantify intensification of the water cycle and the changing nature of extremes has led to new understanding of how changes in sea surface temperature (SST) may affect the frequency of extreme storms around the world. Research on merging or downscaling multi-sensor precipitation data is advancing providing thus improved inputs for hydrologic and earth hazard predictions, especially in mountainous and remote regions of the globe. Ground validation sites for integrated atmospheric/hydrologic modeling assessment are under development in preparation for the upcoming GPM mission.

FY 2011 Annual Performance Goal	FY 08	FY09	FY10	FY11
2.1.2.1: ES-11-5: Demonstrate planned progress in enabling improved predictive capability for weather and extreme weather events. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.	Green	Green	Green	Green

<u>Objective 2.1.3</u>: Progress in quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

A large number of ongoing NASA studies is quantifying and predicting changes in Earth's ecosystems and biogeochemical cycles, as well as improving our understanding of the driving processes. A subset of these are highlighted below.

In the past year, NASA research has advanced in quantifying global land cover, analyzing interannual variability and trends in terrestrial and marine ecosystems, and elucidating the processes that control productivity and carbon cycling in Earth's ecosystems. Many peer reviewed journal articles, including a special issue of the *Journal of Geophysical Research* (JGR), have reported results from the interagency North American Carbon Program's (NACP) interim synthesis studies. The effects of differing types of disturbances, caused by natural phenomena as well as by human actions, on carbon sources and sinks have been characterized and, in several cases, quantified at continental scales. In one study, the publicly available data for the United States, Canada, and Mexico was integrated into a coherent North American continental view of

the effects of biomass extraction (i.e., forest conversion and harvest) on carbon dynamics in for 2000-2008. Results for this period showed that every year one percent of North America's forests experience some form of human-caused disturbance, however, forest recovery following harvest, afforestation, and reforestation balance these losses such that the total forest area on the continent has been fairly stable. Patterns of extractions varied, with U.S. and Canadian activity dominated by partial and clear-cut harvest, respectively, and Mexico dominated by forest conversion for agriculture. In another study, forest age, which is related to time since disturbance, was shown to be a useful surrogate variable for analyses of the impact of disturbance on the ability of forests to sequester and store carbon. These insights, along with the findings of an on-going NACP model intercomparison study, will be used to improve the accuracy with which terrestrial ecosystem models can quantify carbon fluxes.

New regional and global satellite data products and analyses thereof include national biomass and carbon maps at 30 m resolution based on NASA radar interferometry (SRTM), Landsat, topographic survey, and forest inventory data; a global, 30 m (Landsat-scale) surface reflectance product; a decadal analysis of global hot spots using MODIS measurements of land surface skin temperature; a new estimate of global mangrove ecosystem areal extent; and a new map estimating carbon storage in tropical forests based on ICESat lidar and using MODIS, QuikScat and SRTM data for spatial extrapolation.

Important progress has been made in identifying, characterizing, and/or quantifying processes critical to marine productivity and biodiversity around the world. For example, a first ever satellite-based analysis of primary production associated with major phytoplankton classes (micro-, nano-, and picophytoplankton) was reported. The analysis of interannual variations revealed large anomalies in class-specific primary production, driven primarily by variations in the largest phytoplankton class (microplankton), supporting theory on phytoplankton successional processes.

A number of NASA-supported projects have used remotely-sensed data and ecological models to define the habitats of organisms and how they change, or are likely to change, in response to physical, chemical, and biological variations in their surroundings. These studies have improved understanding of how organisms respond to land cover change and other changes in their environment, which has important implications for managing natural systems to promote the conservation of biodiversity. In one such study, researchers combined the more than twenty-five year record of Landsat imagery with data from extensive diver transects as well as climate and physical oceanography data to discern the drivers of giant kelp abundance off the coast of California. The large fronds of this alga extend vertically through the water column, providing critical habitat for a number of marine species. Kelps are known to experience large, dynamic changes from year to year but our understanding of the factors controlling the distribution and biomass of giant kelp and impacts on habitat has been limited. This study found that sea surface temperature and wave disturbance tended to be the major drivers of kelp distribution and abundance with winds predominant in exposed regions and surface temperatures playing a larger role in sheltered regions.

During the past year, additional special sections of JGR have reported on results of the Southern Ocean Gas Exchange Experiment (SO GasEx; JGR-oceans vol. 116) and on vegetation three-dimensional structure from space (JGR-biogeosciences vol.116 no.G2). NASA also made airborne observations of the 2010 Deepwater Horizon oil spill in the Gulf of Mexico in support of the broad national response to the oil spill and the assessment of it ecological impacts.

FY 2011 Annual Performance Goal	FY 08	FY09	FY10	FY11
2.1.3.1: ES-11-7: Demonstrate planned progress in quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.	Green	Green	Green	Green

Objective 2.1.4: Progress in quantifying the key reservoirs and fluxes in the global water cycle and assessing water cycle change and water quality.

Over the past year, NASA has continued its progress improving its description of the water cycle, including the size and movement between its stores. Coincident use of multiple satellite data sources (e.g. AMSR-E, TRMM, MODIS, etc), especially those of different but linked variables have led to improvement both in the quantification of the water cycle and the uncertainty estimates of its terms, with both groundwater and total storage two new variables being provided. Furthermore GRACE data has been used to provide large area estimates of the change in total water storage of the land that by definition has to equal the sum of precipitation, evaporation, and run-off. Refinement has been made globally, regionally, and on annual and monthly time scales. A major scientific discovery is the quantified ground water depletion in India and California's Sierra Nevada mountains. Leveraging linked observations of the energy cycle has further refined the water cycle only estimates and the uncertainty estimates of them. Shorter term remote sensing data sets (EOS era ~10 years) have been combined with longer term satellite records (e.g. snow covered area) and land surface model simulations to provide assessment capability to determine if, where, and how the water cycle might be changing. Different open ocean remote sensing capabilities to assess water properties are being tested against collected coastal and in-land water body samples to determine the feasibility and capability of the use of remote sensing observations to determine water quality aspects.

The Soil Moisture Active Passive mission project continues to make excellent progress on its way towards a launch in 2014. Algorithm Theoretical Basis Documents (ATDBs) have been generated for all official SMAP products and have under gone internal line by

line review. The ATBDs will go through formal review during the next fiscal year. Members of the science definition team have engaged with the international community to discuss aspects of the pre- and post-launch calibration and validation campaigns as well as methods to leverage international *in situ* observation networks. The project has generated an Applications plan to accelerate the use of SMAP data upon launch by members of the applied sciences community. NASA has also made significant progress developing the hydrological side of the Surface Water Ocean Topography (SWOT) mission. Science meetings have been held, along with partners from CNES, to discuss potential hydrological goals of the mission to estimate storage change along the reach of a river, as well as higher order products, never before accessible from satellites, such as river discharge and evaluation of Northern Latitude lakes (both seasonal and multi-annual). NASA has worked with ESA-sponsored colleagues to improve snow water equivalent algorithms in preparation for a mission concept under review (CoreH2O) by ESA as well as the Decadal Survey recommended Snow and Cold Land Processes (SCLP) mission, including conducting a small field campaign to test use of Ku-band radar in deeper snowpacks.

FY 2011 Annual Performance Goal	FY 08	FY09	FY10	FY11
2.1.4.1: ES-11-9: Demonstrate planned progress in quantifying the key reservoirs and fluxes in the global water cycle and assessing water cycle change and water quality. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.	Green	Green	Green	Green

Objective 2.1.5: Progress in understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving predictive capability for future evolution.

NASA continues to provide specialized support for research to better understand the interactions of the oceans, atmosphere and ice in the Earth climate system. Recent efforts have focused on the integration of data acquired from satellites, aircraft and ground networks into climate modeling, at global and regional scales. Over the past year, these observations continue to show higher than climatologically normal surface temperatures, indicative of a warming climate.

Analysis of the long-term series of satellite altimetry data showed that mean sea level continues to trend upward by an average 3.4 mm/yr, but also revealed an interannual variability strongly correlated with the El Niño-Southern Oscillation phenomenon, a reminder that short-term (2-5 year) changes in the long-term trend do not signify a change in global warming. Additional, separate studies of altimetry-derived sea surface heights characterized the distribution of kinetic energy in the World Ocean over a range

of spatial scales, and produced a global survey of eddies and their characteristics. Record highs in sea surface temperature, sea surface height, and ocean bottom pressure (from the Gravity Recovery and Climate Experiment) were discovered in the South Central Pacific, associated with anomalous wind patterns, which are likely originating with the new type of central Pacific El Niños. NASA also launched the Aquarius/SAC-D satellite in June 2011, which is designed to measure sea surface salinity, helping to quantify the link between the Earth's freshwater cycle and the circulation within its oceans.

Satellite data during the past year continued to show a decline in Arctic sea ice cover, both in extent and thickness. The predicted minimum extent for September 2011, if achieved, would surpass the record minimum established in 2007. Thinning of the Arctic sea ice and decreases in its extent have been shown to increase the net ocean-atmosphere heat output, and are now playing a role in increasing surface air temperatures in the Arctic. Vanishing sea ice has also been associated with an increase in cloudiness, which reduces the emission of longwave radiation from the Arctic, further increasing temperatures in the region. Various studies of the Greenland ice sheet highlight the profound ice loss that has occurred there since the 1990s, much of it through fast-flowing outlet glaciers. Furthermore, models suggest that Pine Island Glacier, in west Antarctica, is at risk of losing its ice shelf, which could lead to a dramatic increase in ice flow there. These changes, in all aspects of the cryosphere, emphasize the need for continued monitoring and improved modeling.

Over the past year, NASA's investments in both capacity and new capabilities in data processing have enabled scientists to transform the output from remote sensing and *in-situ* instruments into the scientific measurements needed to improve both our understanding and predictive capability of the oceans, atmosphere and ice. These tools have accelerated the process of scientific discovery by permitting the research community to assimilate the large quantities of data obtained and have ensured the stewardship of that data over the long periods of time needed to understand the climate system's behavior.

Predictive and diagnostic modeling continues to make significant contributions to our understanding of the Earth system. Facilitated by increases in supercomputing capabilities, NASA models were pushed to higher resolutions. Higher resolution simulations show improved fidelity to observations. Significant improvements have been made in coupling regional and global climate models, developing tools, such as the NASA Unified Weather Research Forecast (NU-WRF) model, that will improve understanding of regional climate change.

FY 2011 Annual Performance Goal	FY 08	FY09	FY10	FY11
2.1.5.1: ES-11-11: Demonstrate planned progress in understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving predictive capability for	Green	Green	Green	Green

future evolution. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.				

Objective 2.1.6: Progress in characterizing the dynamics of Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.

NASA's Earth Surface and Interior Focus Area (ESI) has prioritized strengthening of the **global geodetic network** infrastructure, as well as development of **geodesy** and **geodetic remote sensing and geopotential field measurement technology**. These technologies are used within NASA's Earth Science Division to understand the transport of mass within the Earth System in response to tectonic, climatic and anthropogenic forces, and to better understand, mitigate, and respond to natural hazards such as earthquakes, volcanic eruptions, tsunamis, landslides, and floods.

Geodetic Observing Network: The development of the Geodetic Network Infrastructure was supported by the National Research Council's report "*Precise Geodetic Infrastructure: National Requirements for a shared Resource"* (2010). The report echoes the Decadal Survey in its concern for the decay of the global geodetic infrastructure and makes recommendations to reverse that trend. In response, NASA ESD is investing in the development of a next-generation multi-technique geodetic observatory and is completing a prototype aimed at upgrading and expanding the global geodetic observing network in collaboration with international partners. NASA scientists and managers continue to occupy significant roles within the Global Geodetic Observing System (GGOS). NASA also provides about 40% support for the Global Geodetic Observing System and is leading a consortium of US agencies to place SLR retro reflectors on the GPSIII satellites. NASA/ESI supports the GGOS Networks and Communications Bureau and funded the editing and publication of the book *Global Geodetic Observing System*. ***ITRF 2008*** was released on May 31, 2010 (http://itrf.ensg.ign.fr/news.php). ESI supported scientists published an integrated analysis on the estimation of the accuracy of the ITRF, particularly the geocenter estimation accuracy, including the first geodetic bounds on the rate of earth expansion.

Following earlier investments, NASA has embarked upon the building of a new GNSS spaceborne receiver, the TriG, to replace the very successful BlackJack GPS receiver – with a prototype receiver available in 2013. The receiver will provide the needed positioning and timing capability required for the Decadal Survey missions of the next decade as well as GNSS remote sensing techniques of the occultation and reflection sounding.

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Geodetic Imaging: ESI is strongly focused on the development of the DESDynI mission a Tier-1 Decadal Survey Mission, it successfully passed MCR in March 2011, and the concept is currently being revised to make this mission more affordable as per the

instructions of the President's FY12 budget. The MCR mission concept carried level-1 requirements associated with the needs of the Earth Surface and Interior, Carbon Cycle and Terrestrial Ecosystems, and Cyrospheric portion of the Water and Energy Cycle programs. Many, but not all, of the SAR/InSAR related activities within ESD directly support preparations for DESDynI. The airborne UAVSAR on a Gulfstream-III and its current integration onto the Global Hawk provides a technology test bed and scientific data to complement what can be obtained from current spaceborne SAR. As a technology test bed, the Ka-band GLISTIN single pass interferometer is being integrated on the G-III under the AITT program, the P-band AirMOSS is also being developed for use on a second G-III made available in March 2011 under the Earth Ventures-1 program, and the SweepSAR technique was demonstrated in July 2011. UAVSAR has already provided important observations helping to constrain kinematics of faulting on the San Andreas Fault system, detect active slow moving landslides, constrain dynamics of ice caps in Greenland and Iceland, and track and characterize oil slicks in the Gulf coast disaster.

Other efforts focus on prototyping the ground segment for DESDynI capable of meeting high data volumes and support of a diverse set of scientific constituencies. These include a number of activities at both JPL and at the ASF-DAAC. NASA completed a successful collaboration with JAXA to downlink ALOS PALSAR data via TDRSS. ASF-DAAC is collaborating with WInSAR and UNAVCO on access to SAR/InSAR holdings in support of the InSAR component of EarthScope (a NSF, NASA and USGS partnership) and GEO and CEOS task on Geohazard Supersites and Natural Laboratories.

Geopotential Fields: The ESI leadership engaged a group of scholars for the development of the International Decade of Geopotential Field Research that witnessed a blossoming of satellite missions focused upon the gravity and geomagnetic fields. NASA ESI provided support to the SWARM mission development through the development and application of comprehensive field models. Research in geomagnetism at NASA has focused on the analysis of international data sets generated through collaborations with our European partners with the Oersted, Champ and upcoming SWARM missions. NASA is investing in the development of a self-calibrating vector helium magnetometer that will be suitable for small satellite constellations as called out in the ESI program plan (Living on a Restless Planet). NASA geomagnetic field research contributes to field models for navigation, core dynamics, crustal evolution, and natural hazards.

The ESI scientific community has led NASA's effort to develop time variable gravity as a technique to measure the transport of mass within the Earth System. The applications of GRACE time variable gravity measurements extend well beyond the bounds of Solid Earth Science to include hydrology and water resource monitoring, ocean circulation, climate change, the validation of the principals of general relativity. In 2011, the GRACE Science team demonstrated that temporal and spatial inversions of GRACE gravity measurements provide high quality monthly measurements of ground water aquifer charge that correlate strongly with in situ well data and GPS surface deformation measurements of aquifer water charge variability.

Advanced Rapid Imaging and Analysis (*ARIA*) Center is an emergency response project under development at JPL and Caltech utilizing NASA resources to design and implement a system to fully exploit space geodetic capabilities to aid the nation in responding to natural disasters (earthquakes, volcanic activity, landslides, etc). Initial efforts have focused on responding to significant earthquakes – in a subproject called ARIA-EQ - and will provide a prototype near real time global large earthquakes analysis system using a combination of seismological, geodetic, and tsunami observations. The March 11, 2011 Tohoku earthquake in Japan demonstrated the true potential of this team to generate rapid, accurate information based upon seismic and geodetic information. Products from this effort where used by the USGS and many other organizations to provide situational awareness for the event as well as to identify neighboring zones of concern with respect to similar future earthquakes. Resulting data products can be found at ***ftp://sideshow.jpl.nasa.gov/pub/usrs/ARIA/*.** ARIA will be a critical component to the ground segment of the DESDynI mission.

FY 2011 Annual Performance Goal	FY 08	FY09	FY10	FY11
2.1.6.1: ES-11-15: Demonstrate planned progress in characterizing the dynamics of Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.	Green	Green	Green	Green