APPENDIX A. EARTH SCIENCE RESEARCH PROGRAM

A.1 OVERVIEW

1. Introduction

NASA's Earth Science Research Program supports research activities that address the Earth system to characterize its properties on a broad range of spatial and temporal scales, to understand the naturally occurring and human-induced processes that drive them, and to improve our capability for predicting its future evolution. The focus of the Earth Science Research Program is the use of space-based measurements to provide information not available by other means. NASA's program is an end-to-end one that starts with the development of observational techniques and the instrument technology needed to implement them; tests them in the laboratory and from an appropriate set of surface-, balloon-, aircraft-, and/or space-based platforms; uses the results to increase basic process knowledge; incorporates results into complex computational models that can be used to more fully characterize the present state and future evolution of the Earth system; and develops partnerships with other national and international agencies that can use the generated information in environmental forecasting and in policy and resource management. The Earth Science Research Program is designed to leverage NASA's unique capabilities in the context of related research carried out by other Federal agencies, especially that conducted as part of organized interagency activities (including those coordinated through the Committee on Environment and Natural Resources under the National Science and Technology Council), such as the U.S. Climate Change Science and Technology Programs, the U.S. Group on Earth Observations, the Ocean Action Plan, the U.S. Weather Research Program, the EarthScope Program, and NASA-National Oceanic and Atmospheric Administration (NOAA) efforts to support the transition between research and operations.

The scientific documentation underlying the Earth Science Research Program provides a comprehensive background for the science addressing its objectives. The science carried out addresses NASA's Strategic Goal 4A to study planet Earth from space to advance scientific understanding and meet societal needs (see the *2009 NASA Strategic Plan*)**.** In particular, it addresses the more specific Science Outcomes (see the *NASA Science Plan*), which are to achieve:

- Progress in understanding and improving predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition;
- Progress in enabling improved predictive capability for weather and extreme weather events;
- Progress in quantifying global land cover change and terrestrial and marine productivity and in improving carbon cycle and ecosystem models;
- Progress in quantifying the key reservoirs and fluxes in the global water cycle and in improving models of water cycle change and fresh water availability;

- Progress in understanding the role of oceans, atmosphere, and ice in the climate system and in improving predictive capability for its future evolution;
- Progress in characterizing and understanding Earth surface changes and variability of the Earth's gravitational and magnetic fields; and
- Progress in expanding and accelerating the realization of societal benefits from Earth system science.

The most recent comprehensive description of the research goals of NASA's Earth Science Research Program was in the *2003 Earth Science Enterprise Strategy* at http://nasascience.nasa.gov/about-us/science-strategy. The most up-to-date description of the Earth Science Research Program may be found in Chapter 4 of the *NASA Science Plan* at http://nasascience.nasa.gov/about-us/science-strategy. A decadal study for the satellite component of NASA's Earth science activities has been carried out by the National Academy of Sciences (NAS); the report *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* is available at http://www.nap.edu/catalog.php?record_id=11820. A study by the NAS documenting the advances in the study of Earth from space, which draws significantly on NASA-produced results, was also released recently and is available at http://dels.nas.edu/dels/viewreport.cgi?id=4675.

Research is solicited in four major areas for the Earth Science Research Program: research and analysis, decadal survey missions, applied sciences, and enabling capabilities, with the bulk of the solicited research coming in the first of these. Research and analysis (R&A) emphasizes the development of new scientific knowledge, including the analysis of data from NASA satellite missions and the development and application of complex models that assimilate these science data products and/or use them for improving predictive capabilities. Within the Earth Science Research Program, the research and analysis activities include those historically coming under R&A, mission science team, interdisciplinary science, and calibration/validation activities. For decadal survey missions, science definition teams (SDTs) and preparatory activity are solicited. The applied sciences area develops and demonstrates innovative and practicable applications of NASA Earth science observations and research through demonstration projects carried out in partnership with end user organizations. Applied Sciences thus serves as a bridge between the knowledge generated by R&A (and research satellite measurements) and the information required by mission agencies and organizations to manage resources, to forecast and respond to events, such as disasters or infectious disease outbreaks, and to develop and implement policies.

Enabling capabilities include those programmatic elements with sufficient breadth to contribute to a broad range of activities within the Earth Science Research Program and typically involve the development of some kind of capability whose sustained availability is considered to be important for the Program's future. These include focused activities in support of education; data, information, and management; and airborne science, as well as some broadly based technology-related elements (others which are very focused towards a single scientific area of the Earth Science Research Program will be solicited through the research and analysis area).

2. Earth Science Research and Analysis Focus Areas

The Earth Science R&A activity is built around the creation of new scientific knowledge about the Earth system. The analysis and interpretation of data from NASA's satellites form the heart of the R&A program in the Earth Science Research Program, although a full range of underlying scientific activity needed to establish a rigorous base for the satellite data and their use in computational models, including those for assimilation and forecasting, is also included. 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:

- Carbon Cycle and Ecosystems,
- Water and Energy Cycle,
- Climate Variability and Change,
- Atmospheric Composition,
- Weather, and
- Earth Surface and Interior.

These Focus Areas form the basis around which R&A activity is solicited for the Earth Science Research Program. Given the interconnectedness of these science Focus Areas, research that crosses individual Focus Areas is sought after, and a number of specific cases of such connectivity will be identified in the specific research opportunities identified below. In particular, several instrument science teams for NASA satellite missions are solicited through this NRA; while these are identified under a single science Focus Area, most can contribute to scientific advances in several, and potential investigators may want to look carefully at all such teams for opportunities that may be relevant to them. In addition, there are several cross-cutting elements included within this appendix. They involve data analysis and modeling activities that involve scientific activities normally associated with multiple focus areas being carried out together as part of a single unified activity (Appendix A.22: Interdisciplinary Research in Earth Science), one cross-cutting element on technology transfer between focused technology and research programs for airborne instruments (Appendix A.23: Airborne Instrument Technology Transition), and one cross-cutting element on remote sensing theory (Appendix A.24: Remote Sensing Theory). There is also one additional element (Appendix A.25: Space Archaeology) which does not fit neatly into the Focus Area structure, but which represents a unique opportunity for utilizing NASA data for novel activities.

2.1 Carbon Cycle and Ecosystems

The carbon cycle is the basis for the food, fiber, and energy that sustain life on planet Earth. The cycling of carbon dioxide and methane into the atmosphere contributes to the planetary greenhouse effect and global climate. Ecosystems provide a wide variety of essential goods and services to humans and also affect the climate system by exchanging energy, momentum, trace gases, and aerosols with the atmosphere. Earth's carbon cycle and ecosystems are being subjected to human intervention and environmental changes on an unprecedented scale, in both rate and geographical extent. Our ability to ameliorate, adapt to, or benefit from these rapid changes requires fundamental knowledge of the responses of the carbon cycle and terrestrial and marine ecosystems to global change. Also required is an understanding of the implications of these changes for food production, biodiversity, sustainable resource management, and the maintenance of a healthy, productive environment.

The Carbon Cycle and Ecosystems Focus Area addresses: (i) the distribution and cycling of carbon among the active terrestrial, oceanic, and atmospheric reservoirs and (ii) ecosystems as they are affected by human activity, as they change due to their own intrinsic biogeochemical dynamics, and as they respond to climatic variations and, in turn, affect climate. Research activities focus on providing data and information derived from remote sensing systems to answer the following science questions:

- How are global ecosystems changing?
- What changes are occurring in global land cover and land use, and what are their causes?
- How do ecosystems, land cover, and biogeochemical cycles respond to and affect global environmental change?
- What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?
- What are the consequences of climate change and increased human activities for coastal regions?
- How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?

Frequent, repeat observations from space, at both moderate and high spatial resolutions, are required to address the heterogeneity of living systems. Complementary airborne and *in situ* observations, intensive field campaigns and related process studies, fundamental research, data and information systems, and modeling are employed to interpret the satellite observations and answer the science questions.

The goals of the Carbon Cycle and Ecosystems Focus Area are to:

- Document and understand how the global carbon cycle, terrestrial and marine ecosystems, and land cover and use are changing;
- Quantify global productivity, biomass, carbon fluxes, and changes in land cover; and
- Provide useful projections of future changes in global carbon cycling, land cover and use, and terrestrial and marine ecosystems for use in ecological forecasting and in improving climate change predictions.

Anticipated products and payoffs include:

- Assessments of ecosystem response to climatic and other environmental changes and the effects on food, fiber, biodiversity, primary productivity, and other ecological goods and services;
- Quantitative carbon budgets for key ecosystems along with the identification of sources and sinks of carbon dioxide and other greenhouse gases;
- Documentation and prediction of land cover and land use change, as well as assessments of consequences to society and for resource sustainability;
- Understanding of ecosystem interactions with the atmosphere and hydrosphere leading to comprehensive modeling of the exchange of gases, aerosols, water, and energy among the components of the Earth system; and
- Improved representations of ecosystem and carbon cycling processes within global climate models leading to more credible predictions of climate and other Earth system functions.

Interdisciplinary collaborations with other Earth Science Research Program Focus Areas include:

- Work with the Water and Energy Cycle Focus Area on land-atmosphere exchanges of water and energy and the effects of land cover and land use change on water resources;
- Work with the Atmospheric Composition Focus Area on surface emissions and atmospheric transport of trace gases and aerosols and on measurement of carbon-containing greenhouse gases;
- Work with the Climate Variability and Change and Weather Focus Areas on air-sea CO_2 exchange and to share the observations of climate, weather, ecosystems, and land cover that are needed to drive Earth system models; and
- Coordinate with the Earth Surface and Interior Focus Area to advance and/or exploit radar, lidar, and hyperspectral remote sensing technologies for surface properties.

The ROSES elements most closely directed towards the Carbon Cycle and Ecosystems Focus Area are (* indicates program elements soliciting proposals in ROSES-2009):

- Land Cover/Land Use Change (Appendix A.2);

- Ocean Biology and Biogeochemistry (Appendix A.3);
- Terrestrial Ecology * (Appendix A.4); and
- Orbiting Carbon Observatory (OCO) Science Team * (Appendix A.5).

Topics relevant to the Carbon Cycle and Ecosystems Focus Area are included in the following program elements (* indicates program elements soliciting proposals in ROSES-2009):

- Studies with ICESat and CryoSat-2 * (Appendix A.6);
- Interdisciplinary Research in Earth Science * (Appendix A.22);
- Airborne Instrument Technology Transition * (Appendix A.23);
- Remote Sensing Theory * (Appendix A.24);
- Science Definition Team for the DESDynI Mission * (Appendix A.27); and
- HyspIRI Preparatory Activities Using Existing Imagery * (Appendix A.29).

2.2 Climate Variability and Change

Climate change is one of the major themes guiding Earth System Science today. NASA is at the forefront of quantifying forcings and feedbacks of recent and future climate change. Our comprehensive end-to-end program goes from global high-resolution observations to data assimilation and model predictions. Recently, the Climate Variability and Change Focus Area has directed its research toward addressing five specific questions:

- How is global ocean circulation varying on interannual, decadal, and longer time scales?
- What changes are occurring in the mass of the Earth's ice cover?
- How can climate variations induce changes in the global ocean circulation?
- How is global sea level affected by natural variability and human-induced change in the Earth system?
- How can predictions of climate variability and change be improved?

Climate-variability and change research is now not just a global issue, but also a research problem that directly impacts regional to local environments. In fact, local-to-regional anthropogenic-induced changes are having global impacts whose magnitudes are expected to increase in the future. Climate models have moved toward higher and higher spatial resolution as computer resources have improved. During the next decade, climate models are expected to approach the spatial resolution of weather and regional models as more details of Earth System processes are incorporated.

The oceans are a major part of the climate system, and a unique NASA contribution to climate science is the near-global coverage of observations from space of selected ocean properties every two to ten days. Additionally, NASA provides observations of the vast expanses of polar ice, including both ice sheets and sea ice, on the temporal and spatial scales necessary to detect change and sampling of the other critical elements of the climate system that link climate to other Focus Areas, such as cloud distribution, snow cover, surface temperatures, humidity characteristics, etc.

NASA makes substantial investments to characterize and understand the nature and variability of the climate system. As part of those investments, NASA maintains an active research program to utilize data from satellites to both improve our understanding of these components of the Earth system and the interactions between them and to assess how satellite observations can be used to improve predictive capability. Current capabilities include global measurements of sea-surface topography, ocean-vector winds, ice topography and motion, and mass movements of the Earth's fluid envelope and cryosphere.

Understanding interactions within the climate system also requires strong modeling and analysis efforts. The climate system is dynamic and complex, and modeling is the only way we can effectively integrate the observations and current knowledge of individual components fully to characterize current conditions and underlying mechanisms, as well as to project the future states of the climate system. This modeling requires a concerted effort both to improve the representation of physical, chemical, and biological processes and to incorporate observations into climate models through data assimilation and other techniques. The ultimate objective is to enable a predictive capability of climate change on time scales ranging from seasonal to multidecadal.

The ROSES elements most closely directed towards the Climate Variability and Change Focus Area are (* indicates program elements soliciting proposals in ROSES-2009):

- Studies with ICESat and CryoSat-2 *(Appendix A.6);
- Physical Oceanography * (Appendix A.7);
- Ocean Vector Winds Science Team * (Appendix A.8);
- Ocean Surface Topography Science Team (Appendix A.9);
- Ocean Salinity Research Team (Appendix A.10); and
- Modeling, Analysis, and Prediction (Appendix A.11).

Topics relevant to the Climate Variability and Change Focus Area are included in the following program elements (* indicates program elements soliciting proposals in ROSES-2009):

- Ocean Biology and Biogeochemistry * (Appendix A.3);
- Precipitation Science * (Appendix A.14);
- CloudSat and CALIPSO Science Team Recompete * (Appendix A.18);
- Glory Science Team * (Appendix A.19);
- Interdisciplinary Research in Earth Science * (Appendix A.22);
- Airborne Instrument Technology Transition * (Appendix A.23);
- Remote Sensing Theory * (Appendix A.24);
- Space Archaeology * (Appendix A.25);
- Science Definition Team for the DESDynI Mission * (Appendix A.27); and

- Science Definition Team for the CLARREO Mission * (Appendix A.28).

2.3 Water and Energy Cycle

Earth is a unique, living planet in our Solar System due to the abundance of water and the vigorous cycling and replenishing of that water throughout its global environment. 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. The global water and energy cycles are intimately entwined.

The global water and energy cycles maintain a considerable influence upon the global pathways of biogeochemical cycles. The cycling of water and energy and nutrient exchanges among the atmosphere, ocean, and land help determine the Earth's climate and cause much of the climate's natural variability. Natural and human-induced changes to the water and energy cycle have major impacts on industry, agriculture, and other human activities. Increased exposure and density of human settlements in flood plains and coastal regions amplify the potential loss of life, property, and commodities that are at risk from intense precipitation events. Improved monitoring and prediction of the global water and energy cycle enable improved knowledge of the Earth system that must be nurtured to proactively mitigate future adversities. Current and forthcoming projections of such impacts will remain speculative unless fundamental understanding is assimilated into effective global prediction systems and effective decision-support tools applicable to local conditions. Predicting the consequences of global change — whether natural or human induced — and developing useful science-based applications of climate, weather, and hydrologic prediction systems are paramount challenges of NASA's Earth Science Research Program and specifically for its Water and Energy Cycle Focus Area.

Additional information on the Water and Energy Cycle Focus Area can be found at http://watercycle.gsfc.nasa.gov/. Within this Focus Area are the following R&A programs: Precipitation and Atmospheric Dynamics and Terrestrial Hydrology. Also, the Radiation Sciences and Land Cover Land Use Change programs are shared with, respectively, the Atmospheric Composition and Carbon Cycle and Ecosystems Focus Areas. In brief, the Water and Energy Cycle Focus Area seeks to address the topics discussed above by enhancing our understanding of the transfer and storage of water and energy in the Earth system. For the water cycle, the emphasis is on atmospheric and terrestrial stores, including seasonal snow cover. Permanent snow and ice, as well as ocean dynamics, are studied within the Climate Variability and Change Focus Area. The Water and Energy Cycle Focus Area aims to resolve all fluxes of water and the corresponding energy fluxes involved with the water changing phase. High priority is placed on understanding, observing, and modeling clouds and their interaction with energy fluxes, though this is done along with activities of three other Focus Areas (Atmospheric Composition, Climate, and Weather).

In addition to the study of the individual components of the water and energy cycle, this Focus Area places a high priority on integrating these components in a coherent fashion as is pursued by the NASA Energy and Water Cycle Study (NEWS), for which more information can be found at http://gwec.gsfc.nasa.gov/. NEWS has been established to create a mechanism to export and import information, results, and technology to and from other U.S. agencies and international partners concerned with the study and observation of water and energy cycle.

All of the Focus Area's activities should enhance the community's ability to answer these research questions:

- How are global precipitation, evaporation, and the cycling of water changing?
- What are the effects of clouds and surface hydrologic processes on Earth's climate?
- How are variations in local weather, precipitation, and water resources related to global climate variation?
- What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?
- How can weather forecast duration and reliability be improved?
- How can predication of climate variability and change be improved?
- How will water cycle dynamics change in the future?

Pursuit of answers to these questions should lead to research products, such as satellite data and model outputs, that are useful to activities sponsored by the Applied Sciences Program, in particular, the Applications areas of Water Resources, Disaster Management, and Agriculture. Ultimately, Water and Energy Cycle Focus Area-sponsored activities will lead to the fulfillment of its goal: "Models capable of predicting the water cycle, including floods and droughts, down to tens of kilometers resolution."

The ROSES elements most closely directed towards the Water and Energy Cycle Focus Area are (* indicates program elements soliciting proposals in ROSES-2009):

- NASA Energy and Water Cycle Study (Appendix A.12);
- Terrestrial Hydrology (Appendix A.13); and
- Precipitation Science * (Appendix A.14).

Topics relevant to the Water and Energy Cycle Focus Area are included in the following program elements (* indicates program elements soliciting proposals in ROSES-2009):

- CloudSat and CALIPSO Science Team Recompete * (Appendix A.18);
- Hurricane Field Experiment * (Appendix A.20);

- Interdisciplinary Research in Earth Science * (Appendix A.22);
- Airborne Instrument Technology Transition * (Appendix A.23); and
- Remote Sensing Theory * (Appendix A.24).

2.4 Atmospheric Composition

Atmospheric composition determines air quality and affects weather, climate, and critical constituents such as ozone. Exchanges with the atmosphere link terrestrial and oceanic pools within the carbon cycle and other biogeochemical cycles. Solar radiation affects atmospheric chemistry and is thus a critical factor in atmospheric composition. Atmospheric chemistry and associated composition are a central aspect of Earth system dynamics, since the ability of the atmosphere to integrate surface emissions globally on time scales from weeks to years couples several environmental issues. NASA's research for furthering our understanding of atmospheric composition is geared to providing an improved prognostic capability for such issues (e.g., the recovery of stratospheric ozone and its impacts on surface ultraviolet radiation, the evolution of greenhouse gases and their impacts on climate, and the evolution of tropospheric ozone and aerosols and their impacts on climate and air quality). Toward this end, research within the Atmospheric Composition Focus Area addresses the following science questions:

- How is atmospheric composition changing?
- What trends in atmospheric constituents and solar radiation are driving global climate?
- How do atmospheric trace constituents respond to and affect global environmental change?
- What are the effects of global atmospheric chemical and climate changes on regional air quality?
- How will future changes in atmospheric composition affect ozone, climate, and global air quality?

NASA expects to provide the necessary monitoring and evaluation tools to assess the effects of climate change on ozone recovery and future atmospheric composition, improved climate forecasts based on our understanding of the forcings of global environmental change, and air quality forecasts that take into account the feedbacks between regional air quality and global climate change. Achievements in these areas via advances in observations, data assimilation, and modeling enable improved predictive capabilities for describing how future changes in atmospheric composition affect ozone, climate, and air quality.

Drawing on global observations from space, augmented by airborne, balloon-, and ground-based measurements, NASA is uniquely poised to address these issues. This integrated observational strategy is furthered via studies of atmospheric processes using unique airborne platform-sensor combinations to investigate, for example: (1) the processes responsible for the emission, uptake, transport, and chemical transformation of ozone and precursor molecules associated with its production in the troposphere and its destruction in the stratosphere and (2) the formation, properties, and transport of aerosols in the Earth's troposphere and stratosphere. NASA's research strategy for atmospheric composition encompasses an end-to-end approach for instrument design, data collection, analysis, interpretation, and prognostic studies.

The ROSES elements most closely directed towards the Atmospheric Composition Focus Area are (* indicates program elements soliciting proposals in ROSES-2009):

- Atmospheric Composition: Modeling and Analysis * (Appendix A.15);
- Atmospheric Composition: Mid-Latitude Airborne Cirrus Properties Experiment * (Appendix A.16);
- Atmospheric Composition: Tropical Photochemistry and Aerosol Airborne Campaign * (Appendix A.17);
- CloudSat and CALIPSO Science Team Recompete * (Appendix A.18); and
- Glory Science Team * (Appendix A.19).

Topics relevant to the Atmospheric Composition Focus Area are also included in the following program elements (* indicates program elements soliciting proposals in ROSES-2009):

- Interdisciplinary Research in Earth Science * (Appendix A.22);
- Airborne Instrument Technology Transition * (Appendix A.23);
- Remote Sensing Theory * (Appendix A.24).; and
- Air Quality Applied Sciences Team * (Appendix A.32).

2.5 <u>Weather</u>

The Weather Focus Area represents the cooperation among NASA programs for Atmospheric Dynamics, Weather Forecast Improvement, and Ocean and Land Remote Sensing. It has strong ties to other Focus Areas, especially Climate Variability and Change and Water and Energy Cycle, and it has a supporting role in Carbon Cycle and Ecosystems and the Atmospheric Composition Focus Areas.

The Weather Focus Area is primarily designed to apply NASA scientific remote sensing expertise to the problem of obtaining accurate and globally distributed measurements of the atmosphere and the assimilation of these measurements into research and operational weather forecast models in order to improve and extend U.S. and global weather prediction. This Focus Area is implemented in close coordination with other U.S. agencies' programs under the U.S. Weather Research Program (USWRP), and it is guided by the question from the 2003 Earth Science Enterprise Strategy:

- How can weather forecast duration and reliability be improved?

A large effort in this Focus Area is concerned with the detection and quantification of rainfall rate, generally measured using microwave radiation. The first weather radar in space, on board the Tropical Rainfall Measuring Mission (TRMM) satellite, has enabled the global mapping of rainfall in the tropics and has contributed to the increased physical understanding of storm cloud characteristics accompanying various forms and levels of rainfall rates. Future planning involves the extension of the TRMM concept to a global constellation of active and passive sensors in the form of a Global Precipitation Measurement (GPM) mission.

Another key component of the current Weather Focus Area is a set of core efforts to assimilate new NASA satellite data into numerical forecast models and to assess the amount of forecast improvement. Two groups are currently working on this problem, the Joint Center for Satellite Data Assimilation (JCSDA), involving the NASA Goddard Space Flight Center (GSFC) and the National Center for Environmental Prediction (NCEP) at NOAA, and now including other agency participation, and NASA's Short-term Prediction Research and Transition Center (SPoRT). These centers allow studies of the most effective ways of assimilating new satellite data into global and regional numerical models.

NASA-funded researchers are working to use the many forms of new data from Earth Observing System sensors related to the atmosphere. The Moderate Resolution Imaging Spectroradiometer (MODIS), Atmospheric Infrared Sounder (AIRS), Multiangle Imaging Spectroradiometer (MISR), and Advanced Microwave Scanning Radiometer (AMSR-E) sensors on the Earth Observing System (EOS) satellites Terra and Aqua all contribute valuable information, such as land and sea surface temperatures, cloud characteristics, bidirectional reflectance for interpreting air pollution concentrations, surface wetness, and polar winds.

The weather forecast area has also contributed to a number of field programs, such as the Tropospheric Cloud System and Processes (TCSP) and NASA contribution to the Amazon Multidisciplinary Monsoon Analysis (AMMA) that serve to both improve our understanding of atmospheric processes and provide calibration and validation instruments for NASA's Earth-observing satellites. Not all of the satellite and airborne measurements are currently being assimilated into numerical forecast models to determine their potential forecast impacts. Research work will continue for improved modeling and computing, the development of Doppler wind lidars, and the development of geosynchronous and active sounding to meet the future objectives of the Weather Focus Area.

The ROSES element most closely directed towards the Weather Focus Area is
(* indicates program elements soliciting proposals in ROSES-2009):

- Hurricane Field Experiment * (Appendix A.20).

Topics relevant to the Weather Focus Area are included in the following program elements (* indicates program elements soliciting proposals in ROSES-2009):

- Ocean Vector Winds Science Team * (Appendix A.8);
- Precipitation Science * (Appendix A.14);
- Interdisciplinary Research in Earth Science * (Appendix A.22);

- Airborne Instrument Technology Transition * (Appendix A.23); and
- Remote Sensing Theory * (Appendix A.24).

2.6 <u>Earth Surface and Interior</u>

The Earth Surface and Interior Focus Area promotes the development and application of remote sensing to address the questions:

- How is the Earth's surface being transformed by naturally occurring tectonic and climatic processes?
- What are the motions of the Earth's interior, and how do they directly impact our environment?
- How can our knowledge of Earth surface change be used to predict and mitigate natural hazards?
- How is global sea level affected by natural variability and human induced change in the Earth System?

The overarching goal of the Focus Area is to assess, mitigate, and forecast natural hazards that affect society, including such phenomena as earthquakes, landslides, coastal and interior erosion, floods, and volcanic eruptions. The path to prediction includes comprehensively recording and understanding the variability of surface changes controlled by two types of forces: external forces, such as climate, and internal forces that are in turn driven by the dynamics of the Earth's interior. In order to develop a predictive capability, these observations of the Earth's transformation must be modeled, interpreted, and understood. Space-based remote sensing is vital to forecasting in the solid Earth sciences, providing a truly comprehensive perspective for monitoring the entire solid Earth system.

Modeling, calibration, and validation are essential components in the development of accurate forecasting capabilities. The Earth Surface and Interior Focus Area views natural laboratories as a critical component for the validation and verification of remote sensing algorithms. NASA joins with the National Science Foundation (NSF) and U.S. Geologic Survey (USGS) in support of the EarthScope initiative to apply modern observational, analytical, and telecommunications technologies to investigate the structure and evolution of the North American continent and the physical processes controlling Earthquakes and volcanic eruptions.

Among the many activities carried out by the Earth Surface and Interior Focus Area are the following:

- Geodetic and thermal imaging of the precise metrology of Earth's surface and its changes through lidar, radar constellations, and optical arrays, coupled with geopotential field measurements to understand the dynamics of the Earth's surface and interior;
- Development of a stable terrestrial reference frame, highly precise realization of topography and topographic change, and understanding of changes in the Earth's

angular momentum and gravity fields, which can be applied to issues such as sea-level change, polar mass balance, and land subsidence;

- Use of gravitational and magnetic observables for studying the inner dynamics of the Earth, as well as for studies of how the ionosphere responds to changes in the Earth's surface; and
- Improved predictions of Earthquakes and volcanic eruptions through the use of a broad range of Earth surface remote sensing and space geodesy approaches.

The ROSES element most closely directed towards the Earth Surface and Interior Focus Area is (* indicates program elements soliciting proposals in ROSES-2009):

- Earth Surface and Interior (Appendix A.21).

Topics relevant to the Earth Surface and Interior Focus Area are included in the following program elements (* indicates program elements soliciting proposals in ROSES-2009):

- Studies with ICESat and Cryosat-2 * (Appendix A.6);
- Interdisciplinary Research in Earth Science * (Appendix A.22);
- Airborne Instrument Technology Transition * (Appendix A.23);
- Remote Sensing Theory * (Appendix A.24);
- Science Definition Team for the DESDynI Mission * (Appendix A.27); and
- HyspIRI Preparatory Activities Using Existing Imagery (Appendix A.29).

2.7 <u>Cross-Cutting and Interdisciplinary</u>

A major element in Interdisciplinary Science (Appendix A.22: Interdisciplinary research in Earth Science) is included in this year's ROSES (the last such one was in ROSES 2006 – see http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={6EC9DA00-8405-2552-78CC-FD5FB5D988A2}&path=past and click on "Selection List"). This element is designed to allow scientists to address major Earth Science issues that do not fit neatly into any one of the six focus areas. This year's element contains five subelements:

- Integrated System Responses to Extreme Events;
- Impacts of Varying or Changing Climate, Local Weather, and Land Use on Watersheds and their Connected Coastal Environments;
- Hydrologic, Biological, Biogeochemical and Geological Impacts of Melting Ice;
- Sea Level Change; and
- Water and Energy Cycle Impacts of Biomass Burning.

In this element, proposers are encouraged to offer truly interdisciplinary approaches (and teams) to address these issues.

A cross-cutting element potentially supporting all of the Focus Areas and serving as a bridge to the technology program (see section 4.5 below) is an Airborne Instrument

Technology Transition (AITT) program (Appendix A.23). This element is designed to support the completion of airborne instruments whose development has begun and been largely, but not totally, completed under the Instrument Incubator Program (see section 4.5 and Appendix A.36) or other instrument-development activities. This solicitation has the potential to lead to funding in any of the program elements, so it is identified as a contributing element to all the Focus Areas. This call is the second such call for the AITT; the first was in ROSES 2007, from which several investigations were selected (http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={7541C87F-D30A-FAF2-D11F-C47C3FDB6767}&path=past and click on "Selection List"). Proposers to this element should review the selections from the previous call to avoid proposing research which overlaps with that which has been already selected.

Another potentially cross-cutting element is one on Remote Sensing Theory (Appendix A.24). This element is designed to give proposers the opportunity to propose more basic research in radiative transfer and retrieval algorithm development than is typically supported through the individual Research and Analysis programs. It is oriented towards the development of new remote sensing techniques, especially as may be required to implement the missions called for by the NAS in its Decadal Survey referenced earlier. Proposals to this element should not be focused on a single mission but rather to those common challenges and problems that must be surmounted for the next generation of remote sensing satellites. A particular, but not exclusive, interest is in the consideration of the treatment of high spatial variability in observed scenes, especially across sharp demarcations (e.g., coastal, aerosol/cloud boundaries, etc.).

One additional element that does not fit neatly into the Focus Area structure is one on Space Archaeology (Appendix A.25). This element follows a similar one included in ROSES 2007, from which several investigations were selected (http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={C5C42C9E-5101-CDB2-06D7-BBAAF187D723}&path=past and click on "Selection List"). This current opportunity allows for additional community participation in NASA's Space Archaeology research program. Its goals are to utilize space-based remote sensing data to help identify regions of interest for archaeological studies and to facilitate interactions between remote-sensing scientists and archaeologists so that they can better make use of available data, tools, and techniques to support research in archaeology. Proposers to this element should review the selections from the previous call to avoid proposing research which overlaps with that which has been already selected.

The cross-cutting element, Accelerating the Operational Use of Research Data (Appendix A.26) previously solicited in ROSES 2007, from which several investigations were selected (http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={01C61E75-EF9D-BCD2-AA74-947E48888A71}&path=past and click on "Selection List") is not being solicited this year.

3. Decadal Survey Missions

Three elements are solicited related to high priority missions identified in the NRC's Decadal Survey referenced above. Two are for Science Definition Teams (SDTs) while one is for preparatory work based on available airborne and/or satellite imagery. These elements, all of which are being solicited in 2009 are:

- Science Definition Team for the DESDynI Mission (Appendix A.27);
- Science Definition Team for the CLARREO Mission (Appendix A.28); and
- HyspIRI Prepatory Activities Using Existing Imagery (Appendix A.29).

4. Applied Sciences

The overarching purpose of the Applied Sciences Program is to discover and demonstrate innovative applications of NASA Earth science research and technology and to maximize the benefits to society of the nation's investments in the NASA Earth science research program. To this end, the program develops and demonstrates practical applications of NASA Earth science observations and research through demonstration projects carried out in partnership with operational or end-user organizations. The Applied Sciences Program supports projects that address topics that are of national or regional importance in eight application areas -- Agriculture, Air Quality, Climate, Disaster Management, Ecosystems, Public Health, Water Resources, and Weather. All Applied Science projects are direct outcomes of Research and Analysis activities described in Section 2.

The Applied Sciences Program employs an "end-to-end" approach to extend Earth science research results as inputs to decision-making activities. The Program works together with organizations that develop, own, and employ operational decision support tools, systems, assessments, etc. to serve their mandated responsibilities. These organizations include Federal, state, and local agencies and organizations. The program also works with international, national, and regional associations, such as the World Health Organization and the Red Cross, the American Water Resources Association, the Western Governors Association, and the Gulf of Mexico Alliance.

The Applied Sciences Program solicits proposals through the following ROSES elements (* indicates program elements soliciting proposals in ROSES-2009):

- Decision Support through Earth Science Research Results * (Appendix A.30);
- Earth Science Applications Feasibility Studies * (Appendix A.31); and
- Air Quality Applied Sciences Team * (Appendix A.32).

Topics relevant to the Applied Science Program are also included in the following program elements (* indicates program elements soliciting proposals in ROSES-2009):

- Interdisciplinary Research in Earth Science * (Appendix A.22); and
- HyspIRI Preparatory Activities Using Existing Imagery (Appendix A.29).

5. Enabling Capability

Enabling capabilities include those programmatic elements that are of sufficient breadth that they contribute to a broad range of activities within the Earth Science Research Program. They typically involve the development of some kind of capability whose sustained availability is considered to be important for the Earth Science Research Program's future. These include focused activities in support of education; data, information, and management; and airborne science, as well as some broadly based technology-related elements (others which are very focused towards a single scientific area of the Earth Science Research Program will be solicited through the research and analysis area).

5.1 Education

The Earth Science Research Program also recognizes its essential role in NASA's mission to inspire the scientists and engineers of tomorrow. The Earth system science concept pioneered by NASA is changing not only how science research is conducted, but also the way Earth and space science education is taught at elementary through postgraduate levels, as well as the way space exploration is presented to the public by the media and informal learning communities.

In addition to the education and outreach opportunities that are embedded in and competitively selected as part of the Earth Science flight and research programs, other program announcements are issued periodically to focus on continued workforce enrichment. The Earth Science component of the NASA Earth and Space Science Fellowship (NESSF) program, which supports the training of graduate students in Earth system science and/or remote sensing, is solicited outside of ROSES with new applications due February 1 of each year (NESSF is posted at http://nspires.nasaprs.com/ in November). The New Investigator Program in Earth Science (Appendix A.33), which is directed towards scientists and/or engineers within five years of their receipt of a terminal degree, is solicited every two years.

5.2 Data and Information Management

NASA's space observation capabilities are a central part of the Agency's contribution to Earth system science, along with the science information systems that compile and organize observations and related data for research purposes. The Earth Science Research Program has established a number of strategic principles for the development and deployment of its observing and information systems, recognizing the importance of providing active and informed stewardship for the large volume of data that are returned to Earth every day. The broad range of uses to which the data are put and the large and diverse user community require multiple temporal and spatial scales, emphasize the need for having a range of data products, and place stringent requirements on NASA for its data processing, archival, and data dissemination activities. These products and services will be variously useful to multiple classes of users, from sophisticated scientific users to other Government and private sector entities that use NASA's information for policy and resource management decisions and including scientifically attentive members of the public who utilize data and information for general information and recreation.

NASA's data and information management activities are described in NASA's *2003 Earth Science Strategy* at http://nasascience.nasa.gov/about-us/science-strategy/past-strategy-documents/earth-science-enterprise-plans.

Two program elements in the area of data and information management are included in this NRA: the Advancing Collaborative Connections for Earth System Science (ACCESS; Appendix A.34) program, which is being solicited this year, and the Making Earth System data records for Use in Research Environments (MEaSUREs) program (Appendix A.35); which is not being solicited this year.

5.3 High-End Computing, Networking, and Storage

High-end computing, networking, and storage are critical enabling capabilities for Earth system science. Satellite observations must be converted into scientific data products through retrieval and/or data assimilation processes. Long-term data sets must be synthesized together and become a physically consistent climate-research quality data set through reanalysis. These data products, in turn, provide initial and boundary conditions, validation and verification references, and internal and external constraints to the models that describe the behavior of the Earth system. None of the above will be possible without advanced techniques in high-end computing, networking, and storage.

SMD recognizes the need of such an enabling capability and maintains the high-end computing, networking, and storage within its programs. Computing resources are provided through various program elements. Proposers to this NRA must follow the instructions in Section I(d) of the *Summary of Solicitation* of this NRA to request computing resources.

NASA also supports computational science research and development, including parallelization of codes to an advanced computing architecture for the advancement of Earth system modeling and data assimilation. Those interested are encouraged to consult the Applied Information Systems Research (AISR) program element (Appendix E.2), which is not being solicited this year.

5.4 Airborne Science

The Earth Science Research Program airborne science program provides access to airborne and balloon-based platforms that can be used to obtain measurements of the Earth. Airborne and balloon-based platforms may be used to test new measurement approaches, collect detailed *in situ* and remote-sensing observations that are needed to better document and test models of Earth system processes, and/or provide calibration/validation information for satellites. Airborne and balloon-based platforms can also be an important part of training the next generation of scientists because of the fact that students can be engaged in all aspects of science, from sensor development, through utilization, to completing analysis of data obtained.

Aircraft have proven to be of significant value in Earth system science research, particularly for investigation into atmospheric processes. NASA makes use of several existing aircraft through an annual Call Letter process, most notably the NASA-owned DC-8, WB-57F, ER-2, and P-3B, as well as several independently owned aircraft, including but not limited to those operated by other Federal agencies. Current experiments with new platforms include access in FY 2009 to the Aerosonde and Global Hawk, unmanned aerial vehicles (UAVs), as well as the innovative Proteus platform. By working with the Aeronautics Mission Directorate of NASA, SMD hopes to pioneer new types of airborne missions that capitalize on NASA's unique expertise in platforms, sensors, and aeronautical operations.

The FY 2010 Call Letter for Flight Requests supporting approved investigations is expected to be released in April 2009. ROSES-2009 program elements that solicit airborne-platform-based research include (* indicates program elements soliciting proposals in ROSES-2009):

- Ocean Biology and Biogeochemistry * (Appendix A.3);
- Atmospheric Composition: Mid-Latitude Airborne Cirrus Properties Experiment * (Appendix A.16);
- Atmospheric Composition: Tropical Photochemistry and Aerosol Airborne Campaign * (Appendix A.17);
- Hurricane Field Experiment * (Appendix A.20);
- Airborne Instrument Technology Transition * (Appendix A.23); and
- HyspIRI Preparatory Activities Using Existing Imagery * (Appendix A.29).

5.5 Technology

The Earth Science Technology Program is designed to foster the creation and infusion of new technologies into space missions in order to enable new science observations or reduce the cost of current observations. Needs for advanced technology development are based on Earth science measurement and system requirements articulated in chapter 4 of the *Science Plan For NASA's Science Mission Directorate 2007-2016*, available at http://nasascience.nasa.gov/about-us/science-strategy, and also the National Research Council (NRC) report *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, available at http://www.nap.edu/catalog.php?record_id=11820.

The key components of the technology infusion process are dialog among experts and the programs spanning the technology readiness scale for remote sensing, computing, and communications. Open solicitations are used to attract the best ideas from universities, industry, and Government laboratories. Conferences and workshops are held to establish connections between developers of maturing technologies and scientific investigators proposing new observing or modeling approaches. Principal investigators and others responding to mission solicitations can then adopt these technologies, whose maturation and readiness is well documented, in their proposals.

The Earth Science Technology Office (http://esto.nasa.gov) maintains several program lines through which technology investments are competed and that cover a range of technology readiness levels (TRLs) (* indicates program elements soliciting proposals in ROSES-2009):

- Instrument Incubator Program * (Appendix A.36);
- Advanced Component Technology (Appendix A.37); and
- Advanced Information Systems Technology Program * (Appendix A.38).