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 suborbital (surface, balloon, aircraft) and/or space-based platforms; uses the results to increase basic process knowledge; incorporates results into complex computational models that can be used to more fully characterize the present state and future evolution of the Earth system; and develops partnerships with other national and international agencies that can use the generated information in environmental forecasting and in policy and resource management. 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-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 3.1 to study planet Earth from space to advance scientific understanding and meet societal needs (see the *2006 NASA Strategic Plan*)**.** In particular, it addresses the more specific Science Outcomes, 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
- Progress in expanding and accelerating the realization of societal benefits from Earth system science

The Earth Science Research Program is a continuation of the research program managed by the Office of Earth Science (OES) at NASA that was merged into the unified Science Mission Directorate created at NASA in 2004. As part of this merger, the former OES research program was combined with the former Sun-Earth Connection (SEC) research program of the former Office of Space Science into a single Earth-Sun System Research Program. In this ROSES-2006 NRA, these are being split into separate Earth Science and Heliophysics Research Programs. As a result, science in most areas related to solar physics, which were included in Appendix A of ROSES 2005 (which covered the then Earth-Sun System Research Program), are treated separately in the Heliophysics Research Program described in Appendix B of this NRA.

The 2003 Earth Science Enterprise Strategy may be found at http://earth.nasa.gov/visions/ESE_Strategy2003.pdf. A decadal study for the satellite component of NASA's Earth science activities is currently being carried out by the National Academy of Sciences. An interim report of this study, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, is available from the NAS at http://www.nap.edu/catalog/11281.html.

Research is solicited in three major areas for the Earth Science Research Program: research and analysis, 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 that were supported by OES. Applied science emphasizes the development of partnerships with other organizational entities, most notably other agencies of the U.S. Government, to facilitate the use of NASA-produced science data products into their decision support systems in order to improve the quality of forecasts and/or policy and/or resource management that they produce. 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 Earth Science Research Program's future. These include focused activities in support of education; data, information, and management; suborbital science; and also 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 an 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 (Interdisciplinary Research in Earth Science, see Appendix A.14), the refinement of algorithms for scientific data products from the Terra, Aqua, and ACRIMSAT satellites as well as scientific analysis using these data to address a broad range of scientific questions (Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites, see Appendix A.15), and science in support of the objectives of the International Polar Year (IPY; International Polar Year, see Appendix A.16). While NASA maintains a particular interest in other "years" taking place in the 2007-2008 time frame, IPY is the only one for which NASA is soliciting proposals for Earth science research through a separate ROSES element. Other such activities include the International Heliophysical Year (http://ihy.gsfc.nasa.gov/), the International Year of Planet Earth (http://www.esfs.org/), and the Electronic Geophysical Year (http://www.egy.org/). While no separate solicitation of proposals associated with these areas is included in this appendix, proposers are free to identify any connection between their proposed activities and these coordination activities for consideration by the reviewers. In particular, it is noted that there is specific mention of these other programs made in three elements in this announcement (Earth Surface and Interior, see Appendix A.11; Recompetition of the GRACE Science Team, see Appendix A.12; GNSS Remote Sensing Science Team, see Appendix A.13)

The linkage between the Earth and the Sun is a critically important one, as well, and most of the scientific research related to that coupling is carried out within the Heliophysics Research Program (see Appendix B of this solicitation). However, there are some areas where solar variations and their environmental impacts are studied within the Earth Science Research Program. Scientists interested in all potential opportunities at NASA concerning Sun-Earth coupling should also read through this appendix including the Climate Variability and Change section (Section 2.2) for any opportunities about variations in total solar irradiance and their environmental impacts; the Atmospheric Composition section (Section 2.4) for any opportunities related to the impacts of variations in spectrally resolved solar irradiance and particle precipitation rates and their impacts on atmospheric composition; and the Earth Surface and Interior section (Section 2.6) for any opportunities related to both the connection between the origins of the Earth's magnetic field in its interior and its manifestations in the ionosphere and the connection between the ionosphere and neutral atmosphere that affects environmental remote sensing, especially that associated with the use of Global Positioning System.

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. Programs in Land-Cover and Land-Use Change (Appendix A.2), Terrestrial Ecology and Biodiversity (Appendix A.3), and Ocean Biology and Biogeochemistry (Appendix A.4), comprise the Carbon Cycle and Ecosystems Focus Area.

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
- coordination with the Earth Surface and Interior Focus Area to advance and/or exploit radar, lidar, and hyperspectral remote sensing technologies for surface properties.

Topics relevant to the Carbon Cycle and Ecosystems Focus Area are included in the following program elements solicited in this NRA:

- Interdisciplinary Research in Earth Science (Appendix A.14);
- Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites (Appendix A.15); and
- International Polar Year (Appendix A.16).

The three program elements most closely associated with the carbon cycle and ecosystems focus areas (Appendices A.2–A.4) are not soliciting proposals this year.

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 may have global impacts. 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 2 to 10 days. Additionally, NASA provides observations of the vast expanses of polar 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, as well as 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.

In order to understand the full impact of the coupled Earth-Sun System on the Climate System, the Climate Variability and Change Focus Area will expand its role in coupling the Earth System, including the Earth’s atmosphere, ionosphere, magnetosphere, and the interplanetary medium to and including the Sun. This component of the Climate Variability and Change Focus Area will be tightly coupled with research within the Heliophysics Research Program (see Appendix B).

Topics relevant to the Climate Variability and Change Focus Area are included in the following program elements solicited in this NRA:

- Recompetition of the GRACE Science Team (Appendix A.12);

- GNSS Remote Sensing Science Team (Appendix A.13);
- Interdisciplinary Research in Earth Science (Appendix A.14);
- Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites (Appendix A.15); and
- International Polar Year (Appendix A.16).

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 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, the 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; Appendix A.6), for which more information can be found at http://gwec.gsfc.nasa.gov/, and specific research projects are sought as a separate program element. NEWS will also 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 Science Program, in particular, the National Applications areas of Water Management, Disaster Management, and Agricultural Efficiency. 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."

Three program elements in this NRA directly support the water and energy cycle Focus Area:

- NASA Energy and Water Cycle Study (NEWS) (Appendix A.6);
- Terrestrial Hydrology (Appendix A.7); and
- Precipitation Science (Appendix A.8).

Of these, only Precipitation Science (Appendix A.8) solicits proposals this year.

Topics relevant to the Water and Energy Cycle Focus Area are also included in the following program elements solicited in this NRA:

- Recompetition of the GRACE Science Team (Appendix A.12)
- Interdisciplinary Research in Earth Science (Appendix A.14);
- Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites (Appendix A.15); and
- International Polar Year (Appendix A.16).

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. The ability of the atmosphere to integrate surface emissions globally on time scales from weeks to years couples several environmental issues, including global ozone depletion and recovery and its impact on surface ultraviolet radiation, climate forcing by radiatively active gases and aerosols, and global air quality. Thus, atmospheric chemistry and associated composition are a central aspect of Earth system dynamics.

NASA's research for furthering our understanding of atmospheric composition is geared to providing an improved prognostic capability for 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 suborbital 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 suborbital 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 Atmospheric Composition program elements solicited in this NRA, Atmospheric Composition: Tropical Composition, Cloud and Climate Coupling Experiment (Appendix A.9) and Atmospheric Composition: Research and Modeling (Appendix A.10), seek field measurements on the structure, properties, and processes in the tropopause transition layer of the tropical Western Pacific, global ground-based trace gas and aerosol measurements, analysis of field data from field studies in the area of radiation science, measurements of atmospheric radiation along with aerosol and/or cloud properties, and the creation, enhancement, and analysis of satellite remote-sensing data sets that enable our research in the area of tropospheric aerosols and trace gases and their impacts on climate and air quality.

Topics relevant to the Atmospheric Composition Focus Area are also included in the following program elements solicited in this NRA:

- Interdisciplinary Research in Earth Science (Appendix A.14);
- Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites (Appendix A.15); and
- International Polar Year (Appendix A.16).

2.5 Weather

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, Water and Energy Cycle, and 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 the National Oceanic and Atmospheric Administration (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), Multi-Angle Imaging Spectroradiometer (MISR), and Advanced Microwave Scanning Radiometer (AMSR-E) sensors on the 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 Convection and Moisture Experiments (CAMEX) 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 suborbital 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.

No program elements are soliciting proposals specifically for the Weather Focus Area during the current fiscal year. Topics relevant to the Weather Focus Area are also included in the following program elements solicited in this NRA:

- Interdisciplinary Research in Earth Science (Appendix A.14);
- Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites (Appendix A.15); and
- International Polar Year (Appendix A.16).

2.6 Earth Surface and Interior

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.

One program element is solicited in this NRA this is directed specifically towards the Earth Surface and Interior Focus Area (Earth Surface and Interior, see Appendix A.11).

Topics relevant to the Earth Surface and Interior Focus Area are also included in the following program elements solicited in this NRA:

- Recompetition of the GRACE Science Team (Appendix A.12)
- GNSS Remote Sensing Science Team (Appendix A.13)
- Interdisciplinary Research in Earth Science (Appendix A.14);
- Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites (Appendix A.15); and
- International Polar Year (Appendix A.16).

3. Applied Sciences

The primary goal of the NASA Applied Sciences Program is to extend the use of Earth Science Research Program results to serve society by informing decision support with enhanced knowledge, information, and technology. NASA forms partnerships with public, academic, and private organizations to pursue innovative approaches for benchmarking the use of Earth Science Research Program results in decision-support tools. The Applied Sciences Program focuses on facilitating the integration of observations from Earth-observing systems and predictions and forecasts from Earth System and Earth-Sun science models into the decision-making processes of partnering agency and national organizations. Additional information is accessible at http://science.hq.nasa.gov/earth-sun/applications.

NASA employs a systems engineering approach—involving evaluation, validation and verification, and benchmarking—to identify science results of value to partner organizations (e.g., Government, not-for-profit, and private-sector companies), develop prototype products, address systems integration issues with the partners, and document the capacity of integrated system solutions to be adopted or adapted for operational use. Outcomes for partner organizations include the use of project results, such as prototypes and benchmark reports, to enable expanded use of Earth science products and enhance their decision-support capabilities. The program's impacts include enhanced decision-support tools that have economic and environmental security benefits. Through the process of benchmarking beneficial uses and applications of Earth science measurements and technology, the Applied Sciences Program enables significant scientific and technological returns on the Federal investments in NASA research and development of aerospace science and technology.

NASA focuses on 12 application topics of national priority: Agricultural Efficiency, Air Quality, Aviation, Carbon Management, Coastal Management; Disaster Management, Ecological Forecasting, Energy Management, Homeland Security, Invasive Species, Public Health, and Water Management.

NASA works with organizations that have decision-support tools and policy and management responsibilities associated with the 12 application topics. Activities are underway in each of the applications of national priority. For example, in Disaster Management, NASA works with the National Oceanographic and Atmospheric Administration (NOAA) to integrate innovative scientific knowledge and technologies to improve warnings and predictions of hurricanes, tornadoes, and other severe weather events.

The Applied Sciences Program solicits proposals through the Decision Support through Earth Science Research Results Program (Appendix A.17). No proposals are solicited this year.

4. 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 and 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 and information management, suborbital science, and also 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).

4.1 Education

The Earth Science Research Program also recognizes its essential role in NASA's mission to inspire the next generation of explorers. 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.

The SMD Education and Public Outreach (E/PO) Program is designed to utilize NASA's unique capabilities and information technology to support NASA's educational goals in elementary/secondary, higher, and informal education. The E/PO Program works collaboratively with educators, as well as educational institutions and organizations to catalyze action at a scale great enough to ensure impact nationally and internationally. The E/PO Program also ensures the alignment of all endeavors in education and outreach with the NASA Education operating principles for Customer Focus, Content, Pipeline, Diversity, Evaluation, and Partnership/Sustainability. The NASA Education Strategy at http://www.education.nasa.gov/about/strategy and the Science Mission Directorate E/PO program at http://science.hq.nasa.gov/education provide further information and describe the considerable resources in Earth and space science education.

While some of the Earth Science Research Program education and outreach activities are embedded in and competitively selected as part of the flight and research programs, others issue program announcements periodically. The Earth System Science Fellowship Program for graduate research receives applications on an annual basis in coordination with the NASA Graduate Student Researchers Program. The New Investigator Program in Earth System Science (Appendix A.25) will be offered next year in ROSES-2007.

4.2 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 cover multiple temporal and spatial scales, and the large and diverse user community place stringent requirements on NASA for its data processing, archival, and data dissemination activities, and emphasize the need for having a range of data products. These products and services will be variously useful to multiple classes of users, going all the way from sophisticated scientific users, through other Government and private sector entities that use NASA's information for policy and resource management decisions, all the way to 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://science.hq.nasa.gov/strategy.

One program element in the area of data and information management is included in this NRA: the Research, Education, Applications and Solutions Network (REASoN; Appendix A.20). Another program element that is described in draft form and will be solicited later this year is entitled Advancing Collaborative Connections for Earth System Science (ACCESS; Appendix A.19).

4.3 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.

The Science Mission Directorate recognizes the need of such an enabling capability and strategically 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 description in Section I(d) of the *Summary of Solicitation* of this NRA to request computing resources.

NASA also supports computational science research and development for the advancement of Earth system modeling and data assimilation. No program elements for computational science are solicited in this NRA, however.

4.4 Suborbital Science

The Earth Science Research Program suborbital science program provides access to airborne and balloon-based platforms that can be used to obtain measurements of the Earth. Suborbital 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. Suborbital 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 2006 to the Aerosonde and Altair 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 suborbital missions that capitalize on NASA's unique expertise in platforms, sensors, and aeronautical operations.

The FY 2007 Call Letter for Flight Requests supporting approved investigations is expected to be released in April 2006. ROSES-2006 program elements that solicit suborbital-platform-based research include Atmospheric Composition: Tropical Composition, Cloud, and Climate Coupling Experiment (Appendix A.9), Earth System Science Research using Data and Products from Terra, Aqua, and ACRIMSAT Satellites (Appendix A.15), and International Polar Year (Appendix A.16).

4.5 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. Requirements for advanced technology development are based on requirements articulated in the 2003 Earth Science Enterprise

Strategy at http://science.hq.nasa.gov/strategy (in particular, see pages 43-45 of this document for appreciable detail).

The Earth Science Research Program identified technology requirements using a collaborative process of dialog between scientists, engineers, and technology experts, which is recorded and made available through a highly accessible data base (http://estips.gsfc.nasa.gov/). This data base provides a basis for the management of the Earth Science technology investment portfolio.

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 facilitated to establish connections between developers of maturing technologies and scientific investigators proposing new observing or modeling approaches, and also in response to open solicitations. 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 maintains several program lines through which technology investments are competed and that cover a range of technology readiness levels (TRLs):

- Advanced Technology Initiative,
- Advanced Information Systems Technology Program, and
- Instrument Incubator Program.

Two technology program elements, the Advanced Information Systems Technology Program (AIST; Appendix A.21) and Advanced Component Technology Program (ACT; Appendix A.22), are included but are not solicited this year.