APPENDIX A. EARTH SCIENCE RESEARCH PROGRAM

A.1 EARTH SCIENCE RESEARCH 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 organizations that can use the generated information in environmental forecasting and in policy, business, and management decisions.

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 2.1 to "Advance Earth System Science to meet the challenges of climate and environmental change." (See the most recent *NASA Strategic Plan* (see http://nasascience.nasa.gov/about-us/science-strategy/)). In particular, it addresses the more specific Science Goals (see the *Science Plan for NASA's Science Mission Directorate* (hereafter the *NASA Science Plan*), also available at http://nasascience.nasa.gov/about-us/science-strategy/), which are to:

- Advance the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition;
- Improve the capability to predict weather and extreme weather events;
- Detect and predict changes in Earth's ecological and chemical cycles, including land cover, biodiversity, and the global carbon cycle;
- Enable better assessment and management of water quality and quantity to accurately predict how the global water cycle evolves in response to climate change;
- Improve the ability to predict climate changes by better understanding the roles and interactions of the oceans, atmosphere, land, and ice;
- Characterize the dynamics of the Earth's surface and interior, improving the capability to assess and respond to natural hazards and extreme events; and
- Further the use of Earth system science research to inform decisions and provide benefits to society.

The most up-to-date description of the Earth Science Research Program may be found in Section 4.2 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; more recently, NAS released a midterm assessment of NASA's implementation of the Decadal Survey (http://www.nap.edu/catalog.php?record_id=13405). A description of the most recent plans by the Earth Science Division to implement a series of climate-oriented missions beyond those suggested by the decadal survey (*Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space*) was released in June 2010, and may be found at http://science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf). An earlier 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/Report/Earth-Observations-from-Space-First/11991.

NASA's Earth Science Research Program is a major contributor to several interagency efforts within the U.S. Government, most notably the U.S. Global Change Research Program (USGCRP, see http://www.globalchange.gov), to which NASA is the major contributor. This program released its strategic plan in 2012, the *National Global Change Research Plan 2012-2021: A Strategic Plan for the U. S. Global Change Research Program* (http://www.globalchange.gov/browse/reports/national-global-change-research-plan-2012%E2%80%932021-strategic-plan-us-global-change). Similarly, there are interagency programs related to Oceans and the Arctic. In particular, the Implementation Plan (http://www.whitehouse.gov//sites/default/files/national_ocean_policy_implementation_plan.pdf) for the National Ocean Policy (http://www.whitehouse.gov/administration/eop/oceans), the Research Plan (http://www.whitehouse.gov/sites/default/files/microsites/ostp/2013_arctic_research_plan.pdf) for the Interagency Arctic Policy Research Council (IARPC, see http://www.nsf.gov/od/opp/arctic/iarpc/start.jsp), and the National Strategy for the Arctic Region (http://www.whitehouse.gov/sites/default/files/docs/nat_arctic_strategy.pdf) with its associated implementation plan (http://www.whitehouse.gov/sites/default/files/docs/implementation_plan_for_the_national_strategy_for_the_arctic_region_-_fi....pdf). In addition, there are several other subgroups of the Committee on the Environment, Natural Resources and Sustainability (CENRS, see http://www.whitehouse.gov/administration/eop/ostp/nstc/committees/cenrs) that serve to provide interagency coordination in areas covered by NASA's Earth Science Research Program. In addition, the NASA Earth Science Research Program has focused bilateral efforts with other Federal agencies on transitioning knowledge and approaches from research to operations, most notably with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS).

Research is solicited in four major areas for the Earth Science Research Program: research and analysis, satellite 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. The applied sciences area supports efforts to discover and demonstrate innovative and practical uses of NASA Earth science observations and research through applications projects carried out in partnership with end user organizations (http://AppliedSciences.nasa.gov/). Applied sciences, thus, serves as a bridge between the data, modeling, and knowledge generated by NASA Earth science and the information required by Government agencies, companies, and organizations to improve their products, services, and decision making.

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).

Most proposals to ROSES will require a data management plan (DMP) or an explanation of why one is not necessary given the nature of the work proposed. Proposers will satisfy this requirement by responding to the compulsory NSPIRES cover page question about the DMP. The kinds of proposals that require a data management plan are described in the NASA Plan for increasing access to results of Federally funded research and in the SARA FAQs for ROSES. Proposals to instrument development programs (Advanced Information Systems Technology, The Instrument Incubator Program, Advanced Component Technology and In-Space Validation of Earth Science Technologies) do not require a DMP. Moreover, select calls, such as Making Earth System data records for Use in Research Environments (MEaSUREs) and Advancing Collaborative Connections for Earth System Science (ACCESS) include data requirements in the text that make redundant the cover page DMP.

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 also sought, 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. These can contribute to scientific advances in several areas, 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, most notably one that solicits proposals that address rapid response to significant Earth system events, as well as allowing for work that doesn't easily fit into standard ROSES elements (Rapid Response and Novel Research in Earth Science – Program Element A.26).

Several elements solicited in prior years are not being solicited this year, but have program-specific ROSES-2015 elements for completeness, as well as to provide potential proposers with plans about the anticipated dates of the next solicitation. Elements for which it has not yet been decided whether or not to solicit during the period of applicability of ROSES-2015 are not included in this list, but are included by focus area and/or program component later in Appendix A. Note that not all elements which have been solicited in previous ROSES are included this year; some will reappear in future solicitations at an appropriate time that should allow for smooth transition between the currently funded tasks and those that would come out of the next solicitation.

- Terrestrial Ecology (Element A.4);
- Carbon Cycle Science (Element A.5);
- Carbon Monitoring System (Element A.7);
- Ocean Salinity Science Team (Element A.9);
- Ocean Surface Topography Science Team (Element A.11);
- Ocean Vector Winds Science Team (Element A.12);
- Upper Atmosphere Research/Aura Science Team (Element A.16);
- Radiation Science (Element A.17);
- Atmospheric Composition: Modeling and Analysis (Element A.18)
- Terrestrial Hydrology (Element A.20);

- NASA Energy and Water Cycle Study (Element A.21);
- Weather Focus Area (Element A.24);
- Airborne Instrument Technology Transition (Element A.29);
- U.S. Participating Investigator (Element A.30);
- Interdisciplinary Research in Earth Science (Element A.31);
- NASA Data for Operation and Assessment (Element A.32);
- Making Earth System data records for Use in Research Environments (Element A.37);
- Computational Modeling Algorithms and Cyberinfrastructure (Element A.38);
- Advanced Information Systems Technology (Element A.39);
- Instrument Incubator Program (Element A.40); and
- Advanced Component Technology (Element A.41).

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 goal of the Carbon Cycle and Ecosystems Focus Area is to:

- Quantify, understand, and predict changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

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 that are or may be soliciting proposals in ROSES-2015 are:

- Land Cover and Land Use Change (Program Element A.2); and
- Ocean Biology and Biogeochemistry (Program Element A.3).

Topics relevant to the Carbon Cycle and Ecosystems Focus Area that are actively or potentially soliciting this fiscal year include the following program elements:

- Biodiversity (Program Element A.6);
- Science Utilization of the Soil Moisture Active-Passive Mission (Element A.22);
- Rapid Response and Novel Research in Earth Science (Element A.26);
- Satellite Calibration Interconsistency Studies (Element A.34);
- New (Early Career) Investigator Program in Earth Science (Element A.35);
- Advancing Collaborative Connections for Earth System Science (Element A.36).

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 that are or may be soliciting proposals in ROSES-2015 are:

- Physical Oceanography (Program Element A.8);
- Surface Water and Ocean Topography (SWOT) Science Team (Element A.10);
- Modeling, Analysis, and Prediction (Program Element A.13);
- Cryospheric Science (Program Element A.14);
- IceBridge Observations (Program Element A.15).

Topics relevant to the Climate Variability and Change Focus Area that are actively or potentially soliciting this fiscal year include the following program elements:

- Science Utilization of the Soil Moisture Active-Passive Mission (Element A.22);
- Precipitation Measurement Missions Science Team (Element A.23);
- Rapid Response and Novel Research in Earth Science (Element A.26);
- GRACE and GRACE-FO Science Team (Element A.27);
- Space Archaeology (Element A.28);
- Cloudsat/CALIPSO Science Team (Element A.33);
- Satellite Calibration Interconsistency Studies (Element A.34);
- New (Early Career) Investigator Program in Earth Science (Element A.35);
- Advancing Collaborative Connections for Earth System Science (Element A.36)

2.3 Atmospheric Composition

Atmospheric composition changes affect air quality, weather, climate, and critical constituents, such as ozone and aerosols. Atmospheric exchange links 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 composition is central to Earth system dynamics, since the atmosphere integrates surface emissions globally on time scales from weeks to years and 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 aerosols and tropospheric ozone 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 composition and solar radiation are driving global climate?
- How does atmospheric composition respond to and affect global environmental change?
- What are the effects of global atmospheric composition 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 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, as well as aerosol interaction with clouds. 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 that are or may be soliciting for proposals in ROSES-2015 are:

- Atmospheric Composition: KORUS-AQ: An International Cooperative Air Quality Field Study in Korea (Element A.19)

Topics relevant to the Atmospheric Composition Focus Area are also included in the following program elements that are actively or potentially soliciting this fiscal year include the following program elements:

- Rapid Response and Novel Research in Earth Science (Element A.26);
- Cloudsat/CALIPSO Science Team (Element A.33)
- Satellite Calibration Interconsistency Studies (Element A.34);
- New (Early Career) Investigator Program in Earth Science (Element A.35);
- Advancing Collaborative Connections for Earth System Science (Element A.36)

2.4 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://nasa-news.org/. 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://nasa-news.org/. 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 cycles.

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 prediction 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, disasters, and ecological forecasting (see Section 3 for more details on the Applied Sciences Program). 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 that are or may be soliciting for proposals in ROSES-2015 are:

- Science Utilization of the Soil Moisture Active-Passive Mission (Element A.22).

Topics relevant to the Water and Energy Cycle Focus Area are included in the following program elements that are actively or potentially soliciting this fiscal year include the following program elements:

- Surface Water and Ocean Topography (SWOT) Science Team (Element A.10);
- Precipitation Measurement Missions Science Team (Element A.23);
- Rapid Response and Novel Research in Earth Science (Element A.26);
- GRACE and GRACE-FO Science Team (Element A.27);
- Cloudsat/CALIPSO Science Team (Element A.33)
- Satellite Calibration Interconsistency Studies (Element A.34);
- New (Early Career) Investigator Program in Earth Science (Element A.35);
- Advancing Collaborative Connections for Earth System Science (Element A.36)

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 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 coordination with other U.S. agencies' programs and it is guided by the question from the 2003 Earth Science Enterprise Strategy:

- How can weather forecast duration and reliability be improved?

NASA sponsored research continues to gain new insight into weather and extreme-weather events by the utilization of data obtained from a variety of NASA- and partner satellite platforms and hurricane field experiments. Major numerical weather prediction (NWP) centers both outside (European Centre for Medium Range Weather Forecasts (ECMWF) and in the U.S. – NOAA/National Centers for Environmental Prediction (NCEP), NASA Global Modeling and Assimilation Office (GMAO), and the U.S. Navy – have shown notable improvements from the assimilation of Atmospheric Infrared Sounder (AIRS) data into their operational forecast systems.

An extra benefit of AIRS data assimilation at NWP centers is its use in establishing readiness to assimilate data from other current and future operational instruments, as has been demonstrated for the Crosstrack Infrared Sounder (CrIS) l on the Suomi National Polar-orbiting Partnership (NPP) satellite launched in October 2011.

Through collaborations in the Joint Center for Satellite Data Assimilation (JCSDA) (http://www.jcsda.noaa.gov/), observations from Suomi-NPP were assimilated into the operational weather forecast systems in a record seven months after the satellite launch. Observation impact analyses conducted with NASA Goddard Earth Observing System model, version 5 (GEOS-5) in the NASA Global Modeling and Assimilation Office, showed that, in concert with other observations, the Advanced Technology Microwave Sounder (ATMS) makes a significant impact on a global integrated forecast metric. Preparatory work and channel selection for the assimilation of the CrIS data and tests of the impact of that sensor have been completed. The preparations involved modifications to the Community Radiative Transfer model, passive monitoring of systematic and random errors in the CrIS data products, observation minus forecast residuals, and finally preoperational data assimilation/forecast experiments.

The NASA Short-term Prediction Research and Transition (SPoRT) (http://weather.msfc.nasa.gov/sport/) program is an end-to-end research-to-operations (R2O) activity focused on improving short-term weather forecasts through the use of unique high-resolution, multispectral observations from NASA and NOAA satellites, nowcasting tools, and advanced modeling and data assimilation techniques. The SPoRT program has established a successful R2O paradigm in which the end-users (mainly forecasters at NOAA/NWS forecast offices and National Centers) are involved in the entire process. SPoRT also partners with universities and other Government agencies to develop new products that are transitioned to applicable end user decision support systems. SPoRT has recently succeeded in broadening its activities to other National Weather Service (NWS) Regions and its active participation in NOAA Proving Ground activities and Testbeds.

NASA periodically provides opportunities for participation in the JCSDA and SPoRT programs. The most recent such activity was ROSES 13 element A.33 (NASA Data for Operation and Assessment (http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={649CE75A-9095-4146-CD72-2427D2071D10}&path=closedPast).

NASA also has a long history of conducting airborne field campaigns in support of hurricane research (http://airbornescience.nsstc.nasa.gov/field/). Most recently, the Hurricane and Severe Storm Sentinel (HS3) Mission, a five-year Earth Venture Class Suborbital mission that was awarded in 2010, has been obtaining data from its base at the Wallops Flight Facility (WFF) on the coastline of Virginia during the hurricane seasons of 2012-2014 (https://espo.nasa.gov/missions/hs3/). This campaign uses two Global Hawk (GH) unmanned aircraft systems (UAS) with distinct payloads to address both over-storm and near-storm environmental issues. The HS3 Mission is designed to investigate some basic questions regarding changes in hurricane intensity:

1. What impact does the large-scale environment, particularly the Saharan Air Layer (SAL), have on intensity change?
2. What is the role of storm internal processes such as deep convective towers?
3. To what extent are these intensification processes predictable?

In June 2012, NASA selected the Cyclone Global Navigation Satellite System (CYGNSS) satellite mission under its Earth Venture program. CYGNSS data will enable scientists, for the first time, to probe key air-sea interaction processes that take place near the inner core of the storms, which are rapidly changing and play large roles in the genesis and intensification of hurricanes. The CYGNSS Mission satellites are expected to launch in 2016. While this is a Principal-Investigator led mission, NASA provided an opportunity for community members not part of the original proposal to be involved with the mission in ROSES13 (Appendix A.22 – Weather; see http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={6E74C972-BD4C-2286-AF21-D6B43CF3BA4C}&path=closedPast).

The ROSES elements most closely directed towards the Weather Focus Area that are or may be soliciting for proposals in ROSES-2015 are:

- Precipitation Measurement Missions Science Team (Appendix A.23).

Topics relevant to the Weather Focus Area are included in the following program elements that are actively or potentially soliciting this fiscal year include the following program elements:

- Rapid Response and Novel Research in Earth Science (Element A.26);
- Cloudsat/CALIPSO Science Team (Element A.33)
- Satellite Calibration Interconsistency Studies (Element A.34);
- New (Early Career) Investigator Program in Earth Science (Element A.35);
- Advancing Collaborative Connections for Earth System Science (Element A.36).

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.

The ROSES elements most closely directed towards the Earth Surface and Interior Focus Area that are or may be soliciting for proposals in ROSES-2015 are:

- Earth Surface and Interior (Element A.25)
- Space Archaeology (Element A.28)

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

- Rapid Response and Novel Research in Earth Science (Element A.26);
- Satellite Calibration Interconsistency Studies (Element A.34);
- New (Early Career) Investigator Program in Earth Science (Element A.35);
- Advancing Collaborative Connections for Earth System Science (Element A.36).

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

There are several cross-cutting and interdisciplinary elements in ROSES-2015, all of which have been identified as related elements to specific research focus areas in Sections 2.1 through 2.6 (and also briefly summarized in the overview to Section 2). These elements, all of which are being actively solicited in ROSES-2015 or are being evaluated for possible solicitation, are:

- Rapid Response and Novel Research in Earth Science (Element A.26) – This solicitation allows for two types of proposals not normally solicited through ROSES – (a) immediate research activity to take advantage of a target of opportunity due to an unforeseen event in the Earth system, and (b) exceptionally novel and innovative ideas to advance Earth remote sensing that do not fit within ESD's current slate of solicitations and or programs;
- GRACE and GRACE-FO Science Team (Element A.27) - This ROSES element seeks proposals that will advance the development of new methods, algorithms, and models for the exploitation of gravity field observations to be made by GRACE, GRACE-Follow on (FO), and future space based gravity field missions for the broad spectrum of Earth system science challenges. This solicitation also seeks the development of techniques and algorithms capable of bridging gravity field observation across different gravity missions.

- Space Archaeology (Element A.28) - This potential ROSES element will, if actively solicited this year, allow for proposals to use the unique vantage point of space to improve our understanding of past human settlement patterns and the relationships between the natural environment and cultural adaptations as functions of time and space.
  Cloudsat/CALIPSO Science Team (Element A.33) – This ROSES element allows for proposals to enhance the state of atmospheric and climate science through the substantive utilization of CloudSat and CALIPSO data products. These can be taken alone, but preferably will be used in conjunction with data from other satellites (e.g., others in the A-Train), suborbital campaigns, ground-based networks, and/or model-produced results. The inventive combination of CloudSat and CALIPSO data with other sensors (such as other A-Train sensors or the CATS lidar on ISS) is encouraged.
- Satellite Calibration Interconsistency Studies (Element A.34) – This ROSES element provides an opportunity for the research community to participate in the quantitative comparison of multiple satellite data products to facilitate the development of multi-instrument/multi-platform data sets involving satellites from multiple providers. Proposals responsive to this call MUST address interconsistency issues of two or more satellites, at least one of which must be one currently supported through NASA's Earth Science Program, and at least one of which must be supported by some other organization (U.S. or foreign).

3. Applied Sciences

The Applied Sciences Program supports efforts to discover and demonstrate innovative and practical uses of NASA Earth science data, knowledge, and technology. The program (http://AppliedSciences.NASA.gov/) develops applications knowledge and understanding of how Earth science can be applied to serve society, increasing the benefits of the nation's investments in NASA Earth science. The Program funds applied science research and applications projects to enable near-term uses of Earth science, transition applied knowledge to public and private organizations, and integrate Earth science and satellite observations as inputs to organizations' decision-making and services. The projects are carried out in partnership with end user organizations. The Program, thus, serves as a bridge between the data and knowledge generated by NASA Earth science and the information needs and decision making of Government agencies, companies, regional associations, international organizations, not-for-profit organizations, and others.

The Program's applications themes align with the U.S. Group on Earth Observations (USGEO) Societal Benefit Areas, with current emphasis on Water Resources, Health and Air Quality, Disasters, Weather, and Ecological Forecasting. Applied Sciences projects leverage products, knowledge, and outcomes of Research and Analysis activities described in Section 2.

Applied Sciences plans to solicit activities in ROSES-2015, and the final text will be released as an amendment(s) to ROSES. In addition, topics relevant to the Applied Sciences Program that are actively or potentially soliciting this fiscal year include the following program elements:

- Precipitation Measurements Missions Science Team (Element A.23);
- Earth Surface and Interior (Element A.25);

- GRACE and GRACE-FO Science Team (Element A.27);
- Space Archaeology (Element A.28);
- Cloudsat/CALIPSO Science Team (Element A.33);
- New (Early Career) Investigator Program in Earth Science (Element A.35);
- Advancing Collaborative Connections for Earth System Science (Element A.36).

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. 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).

4.1 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 early 2015, SMD announced – through the release of a Science Education Cooperative Agreement Notice – an opportunity for the submission of proposals to collaborate with SMD in the execution of its science education efforts. The desired outcome of this CAN is to increase the overall coherence of the SMD science education program leading to more effective, sustainable, and efficient utilization of SMD science discoveries and learning experiences to meet overall SMD science education objectives. Fundamental to achieving this outcome is to enable NASA scientists and engineers to engage more effectively with learners of all ages. In addition, SMD is moving away from mission-by-mission products and services and towards aggregating efforts into science-based disciplines aligned with SMD Divisions.

While the NASA science education efforts embedded in SMD missions undergo the transition in 2015, the Earth Science Research Program will continue its management of the Global Learning and Observations to Benefit the Environment (GLOBE) Program and oversight of the GLOBE Implementation Office that is responsible for the coordination of the worldwide community in relation to GLOBE science, education, evaluation, communication, and other common functions.

4.2 Graduate and Early-Career Research

With a 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 (Early Career) Investigator Program in Earth Science (Appendix A.35), which is directed towards scientists and/or engineers within five years of their receipt of a Ph.D. degree, is solicited every two years, and is included in ROSES-2015.

4.3 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 volumes 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.

Two program elements have been solicited periodically by the Data and Information Management programs of the Earth Science Division – The Advancing Collaborative Connections for Earth System Science (ACCESS) and the Making Earth System Data Records for Use in Research Environments (MEaSUREs). In ROSES 2015, only the ACCESS program (Appendix A. 36) is being solicited.

Unless otherwise specified, any data proposed to be analyzed in response to Appendix A solicitations from any source, including NASA and other satellite data, ancillary data, and data from commercial sources, must use publicly available data, in the sense that they are openly accessible. Commercial data need not be free, but it must be purchasable by all potential investigators. Proposals that utilize any data that is not, or not yet, publicly available will *not* be considered unless permitted by the call for proposals or associated Frequently Asked Questions. Please read the individual appendices and associated amendments to ROSES carefully and contact the program officers if you have any questions regarding whether a restricted dataset is permissible for a given call.

4.4 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.

In ROSES-2015 no program elements specifically targeted towards High End Computing, Networking, and Storage will be solicited. A relevant ROSES element, Computational Modeling Algorithms and Cyberinfrastructure, was last solicited in ROSES-2013 (see Appendix A.38). This element provides research opportunities for new or improved computational modeling algorithms; the exploitation of new computing, storage, and networking architectures; or the development of programming and analysis environments relevant to NASA's modeling and data assimilation systems.

4.5 NASA Earth Exchange

For large-scale global high resolution Earth science data analysis and modeling projects, especially in areas of land surface hydrology, land cover, land use, carbon management, and terrestrial ecosystems, NASA encourages using the new NASA Earth Exchange (NEX) collaboration facility. The NEX facility includes a state-of-the-art Earth system modeling and data analytics system for the use of remote sensing data from NASA and other agencies. It is supported by a world-class supercomputing and data storage system. Much of the global Landsat, MODIS, AVHRR and related data have been staged online for easy access. NEX (http://nex.nasa.gov) represents a scientific collaboration platform to deliver a complete work environment in which users can explore and analyze large Earth science data sets, run modeling codes, collaborate on new or existing projects, and share results.

Since it is a unique platform for large-scale data analyses that cannot be easily accommodated by a single Principal Investigator (PI) or small research group-based data analysis system, PIs who require the use of such a system are encouraged to register on the NEX Website at https://nex.nasa.gov/nex/auth/register/. Proposals should include a section that justifies the need for using NEX, specifies the data storage and processing needs, and includes a data management plan. The resource availability will be considered during the proposal review and selection process.

Proposals that involve the use of NEX must be submitted to the appropriate ROSES program element depending on the science addressed by the proposed investigation. Additional constraints and requirements for proposals to use NEX are available at https://nex.nasa.gov/nex/resource_updates.

4.6 Airborne Science

The Earth Science Research Program airborne science program provides access to airborne platforms that can be used to obtain measurements of the Earth. Airborne 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 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, G-III, ER-2, P-3B, and Global Hawk, as well as several independently owned aircraft, including, but not limited to, those operated by other Federal agencies. 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 2016 Call Letter for Flight Requests supporting approved investigations is expected to be released in April 2015. Proposals that require the acquisition of new airborne data may be submitted in response to other active ROSES elements unless otherwise specified in the element. In any such cases, proposers are encouraged to contact the program manager indicated prior to submitting such proposals.

The NASA Headquarters science concurrence is provided by the manager of the NASA Research Program under which the grant or contract is issued. User fees are paid by the investigator's funding source's research program or directly from the investigator's grant funds.

Any airborne science experiment using NASA assets, personnel, instruments, or funds, must be in compliance with NASA Policy Directive 7900 and NASA Procedural Requirement Series 7900. It is NASA policy that when utilizing other than NASA aircraft, including foreign owned or leased aircraft, those aircraft are subject to the same compliance requirements.

4.7 Technology

Advanced technology plays a major role in enabling Earth research and applications. The Earth Science Technology Program (ESTP) enables previously infeasible science investigations, improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments.

As the implementer of the ESTP, the Earth Science Technology Office (ESTO) performs strategic technology planning and manages the development of a range of advanced technologies to enable new science observations or reduce the cost of current observations. ESTO employs an open, flexible, science-driven strategy that relies on competitive solicitations and peer-review to produce a portfolio of cutting-edge technologies for NASA Earth science endeavors. This is done through:

- Planning investments by careful analyses of science requirements
- Selecting and funding technologies through competitive solicitations and partnership opportunities
- Actively managing the progress of funded projects
- Facilitating the infusion of mature technologies into science measurements

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* (http://nasascience.nasa.gov/about-us/science-strategy), the 2010 NASA plan for climate-centric observations: *Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations from Space* (http://science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf), and the 2007 *Earth Science Decadal Survey: Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* by the National Research Council (NRC) of the National Academies (http://www.nap.edu/catalog.php?record_id=11820).

The Earth Science Technology Office (http://esto.nasa.gov/) maintains several program lines through which technology investments are regularly competed through ROSES, and that cover a range of technology readiness levels (TRLs). Currently, only the In Space Validation of Earth Science Technologies (InVEST) program (Element A.42) will be solicited in ROSES-2015:

- InVEST (Element A.42): The In-Space Validation of Earth Science Technologies program provides a path for some new technologies to be validated in space prior to use in science mission.

Other ESTO programs that are periodically solicited are NOT being solicited in ROSES 2015:

- AIST (Element A.39): The Advanced Information Systems Technology program advances information systems that are used to process, archive, access, visualize, and communicate science data;
- IIP (Element A.40): The Instrument Incubator Program funds technology development that leads directly to new Earth observing instruments, sensors, and systems. From concept through field demonstrations and infusion, IIP developments yield smaller, less resource intensive, and easier-to-build flight instruments; and
- ACT (Element A.41): The Advanced Component Technology program develops a broad array of components and subsystems for instruments and observing systems.