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 and seek to characterize its properties on a broad range of spatial and temporal scales, to understand the naturally occurring and human-induced processes that drive the Earth system, 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 *in-situ,* surface-, ship-, 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 solicited here. The Research Program addresses NASA's Strategic Goal 1.1 to "Understand The Sun, Earth, Solar System, and Universe". (See the most recent *NASA Strategic Plan:* *https://www.nasa.gov/sites/default/files/atoms/files/nasa_2018_strategic_plan.pdf*). In particular, it addresses the more specific Science Goals, see *SCIENCE 2020-2024: A Vision for Scientific Excellence* (hereinafter the *NASA Science Plan*), 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 ecosystems and biogeochemical 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 in the climate system;
- 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://science.nasa.gov/about-us/science-strategy. The most recent Decadal Survey covering NASA's Earth science activities, *Thriving on our Changing Planet: A Decadal Strategy for Earth Observation from Space*, was released on January 5, 2018 by the National Academies of Science, Engineering, and Medicine (see https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth). This 2018 Decadal Survey now serves as a foundational document for NASA's Earth Science Division (ESD), and includes recommendations for the scopes, foci, and relative budgetary magnitudes of the Research and Analysis (R&A), Applications, and Technology portions of the ESD program. In addition, the Decadal Survey includes a specific endorsement of the NASA missions making up the 2017 Program of Record (comprehensively defined in the Survey's Appendix A).

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-2012–2021-strategic-plan-us-global-change). This plan is updated triennially; the most recent such update may be found at https://downloads.globalchange.gov/strategic-plan/2016/usgcrp-strategic-plan-2016.pdf. Similarly, there are interagency programs related to Earth System Predictability, Weather, Oceans and the Arctic. In addition, there are several other subgroups of the National Science and Technology Council (NSTC) Committee on the Environment that serve to provide interagency coordination in areas covered by NASA's Earth Science Research Program. NASA's 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 (R&A), satellite missions, applied sciences, and enabling capabilities, with R&A containing the bulk of the solicited research. 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 (activities which are very focused towards a single scientific area of the Earth Science Research Program will be solicited through the R&A area).

The overarching goal of NASA's Earth Science program is to develop a scientific understanding of Earth as a system. Scientific knowledge is most robust and actionable when resulting from transparent, traceable, and reproducible methods. This requires open access to not only to the data used in scientific analysis, but also to the software used to arrive at results as well. Additionally, software developed to be openly accessible, without restrictions on modification and distribution, enables reuse across Federal agencies, reduces overall costs to the Government, removes barriers to innovation, ensures consistency through the application of uniform standards, and facilitates collaboration between agencies and non-Federal institutions. NASA addresses these goals by encouraging the open development, access, and distribution of the source code used to generate, manipulate, and analyze science data and results.

Program elements will give preference to proposals that include a plan for committing software as Open Source Software (OSS), beginning at the inception of the proposed work. This plan will include the identification of software components developed as part of the proposed work, and the designation of a permissive, widely accepted OSS license and a public repository hosting service for these components. Please read the individual appendices and associated amendments carefully and contact the program officers if you have any questions regarding OSS development for a given call.

Contracts will not be issued in response to proposals submitted to the research program elements in Appendix A, unless otherwise noted. Instead, awards to non-governmental organizations will be made in the forms of grants or cooperative agreements, as appropriate given the nature of the work solicited. For more about award types see Section II.(a) of the *ROSES Summary of Solicitation*. Awards internal to the Government will be made through the usual Agency processes.

Earth Science Division Templates for the Table of Work Effort and Current and Pending Support are now required for a number of program elements in Appendix A, including Biodiversity (A.7), Cyrospheric Science (A.15), Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (A.17), Earth Surface and Interior (A.23), and Precipitation Measurement Missions Science Team (A.24).

1.1 Data Management Plans and Archiving

Starting with ROSES-2020 the data management plan (DMP) was evaluated as part of the Intrinsic Merit of the proposal and must be included in a special section of the proposal (see below).

To broaden access to the results of NASA-funded research, most proposals to ROSES require a data management plan (DMP) or an explanation of why one is not necessary given the nature of the work proposed. The philosophy behind this requirement is that all relevant taxpayer-supported data should be made publicly available (i.e., without fee or restriction of use) at the time of publication, or at the earliest practical time thereafter, through a stable and long-term supported public data repository. If proposals do not generate or otherwise produce data suitable for deposition in a public repository, then that should be explicitly justified in the DMP. Individual program elements may provide instructions that amplify the following requirements, but the requirements stated below are the minimum.

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 DMP Frequently Asked Questions (FAQs) for ROSES. Proposals to instrument development programs (e.g., 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, selected calls include data requirements in the text that supercede the standard guidance. Any proposal intending to submit data products for archival and public distribution by a NASA Distributed Active Archive Center (DAAC) should review guidelines on the Earthdata web site.

For some program elements, the nature of the work is inexorably linked to the handling of data so a DMP is part of the page limit for the Scientific/Technical/Management (S/T/M) section of the proposal. With the exception of those elements where instructions explicitly say otherwise, all proposals to any of the ROSES elements that require DMPs must place it in a special section of the proposal, not to exceed two pages in length entitled "Data Management Plan" immediately following the references and citations for the S/T/M portion of the proposal. The two-page DMP section does not count against the 15-page limit of the S/T/M section. Formatting requirements for DMPs are the same as for the S/T/M section.

The DMP must cover any data needed to validate the scientific conclusions of peer-reviewed publications, particularly data underlying figures, maps, and tables. It also needs to cover any other data and software that would enable the replication/reproduction of published results and any future research building on those results.

"Data" does not include preliminary and other unpublished data, data in prepublication documents, private communications, or certain other types of information that have been specifically exempted from the DMP requirement.

In the case of a project that would produce no data, as defined above, or only data specifically exempted, the DMP must state that no data preservation or data sharing is needed, and must also explain why. In a case where no appropriate archive exists for a particular data set, the DMP should discuss alternative methods for making the data publicly available.

The DMP must contain the following elements, as appropriate to the project, in adequate detail for review:

- A description of data types, volume, formats, and (where relevant) standards;
- A description of the schedule for data archiving and sharing;
- A description of the intended repositories for archived data, including mechanisms for public access and distribution;
- A discussion of how the plan enables long-term preservation of data;

- A discussion of roles and responsibilities of team members in accomplishing the DMP. If funds are required for data management activities, these should be covered in the normal budget and budget justification sections of the proposal.

Software, whether a stand-alone program, an enhancement to existing code, or a module that interfaces with existing codes, created as part of a ROSES award, should be made publicly available when it is practical and feasible to do so, and when there is scientific utility in doing so. Stand-alone code that is not straightforward to implement, or whose utility is significantly outweighed by the costs to share it, is not expected to be made available. This expectation extends to three types of software, defined as follows:

Short Name	Name	Description	Examples
Libraries	Libraries and toolkits	Generic tools implementing well-known algorithms, providing statistical analysis or visualization, and so on, that are incorporated in other software categories.	Numerical Recipes, NumPy, general FFTs, LAPACK, scikit-learn, AstroPy, GDAL
Analysis software	Analysis, post-processing, or visualization software	Generalized software (not low-level libraries) used to manipulate measurements or model results to visualize or gain understanding.	Stand-alone image processing, topology analysis, vector-field analysis, satellite analysis tools, and so on
Frameworks	Modeling frameworks	Multicomponent software systems that incorporate a variety of models and couple them together in a complex way.	Community Earth System Model (CESM) is a collection of coupled models including atmospheric, oceanographic, sea ice, land surface, and other models

NASA expects that the source code, with associated documentation sufficient to enable use of the code, will be made publicly available as Open Source Software (OSS). This includes all software developed with ESD funding used in the production of data products, as well as software developed to discover, access, visualize, and transform NASA data. OSS is defined as software that can be accessed, used, modified, and shared by anyone. The definition of OSS, along with examples of OSS licensing and public code repositories, can be found on the Earthdata web site. Some elements require a separate Software Development Plan. Please read the program elements carefully.

General statement about model results or any derived data products: Whether derived products and model output should be archived is determined by the scientific utility and need on a case-by-case basis. When these types of data/output are considered for long-term archive and availability at a DAAC the utility or archiving the data set is evaluated by the DAAC User Working Group (UWG) and the DAAC program scientist. If it is determined there is sufficient scientific justification and budget a DAAC will then archive the data. Any proposal intending to submit data products for archival and public distribution by a NASA Distributed Active Archive Center (DAAC) should review guidelines on the Earthdata web site. See this web page for details: https://earthdata.nasa.gov/collaborate/new-missions/adding-competitive-other. If a dataset is selected for archival, the DAAC may require updates to the DMP including information about data processing and quality.

Proposals that include non-mission data (e.g., laboratory results, Earth-based observations) not publicly available (e.g., in a publicly accessible archive, in the literature, etc.) are expected to describe plans to make the data available following the Data Management Plan guidelines.

The sufficiency of the data management plan (DMP) will be evaluated as part of Merit and thus may have a bearing on whether or not the proposal is selected. Proposals that do not address each of these items in their DMP, even if determined to be selected or selectable for funding, may not be funded until an adequate DMP is submitted. Funded researchers, research institutions, and NASA centers are responsible for ensuring and demonstrating compliance with the approved DMPs as part of their awards. Awardees who do not fulfill the intent of their DMPs may have continuing funds withheld and this may be considered in the evaluation of future proposals.

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 and their associated ecology; 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 and interior that drive changes in the Earth’s shape, orientation, rotation, gravity, and surface and atmospheric composition; 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 Atmospheric Dynamics, 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 some of 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 truly novel work that doesn't easily fit the active ROSES elements this year or in the recent past (Rapid Response and Novel Research in Earth Science – program element A.27).

Several elements solicited in prior years are not being solicited this year, but have program-specific ROSES elements for completeness, as well as to provide potential proposers with plans about the anticipated dates of the next solicitation.

- Ocean Biology and Biogeochemistry (program element A.3);
- Carbon Cycle Science (program element A.5);
- Physical Oceanography (program element A.8);
- Sea Level Change Team (program element A.10);
- SWOT Science Team (program element A.11);
- Ocean Surface Topography Science Team (program element A.12);
- Ocean Vector Winds Science Team (program element A.13);
- Modeling, Analysis, and Prediction (program element A.14);
- Atmospheric Composition: Upper Atmospheric Composition Observations (program element A.16);
- Atmospheric Composition: Modeling and Analysis (program element A.18);
- Atmospheric Composition: Tropospheric Composition Program (program element A.19);
- Terrestrial Hydrology (program element A.20);
- Weather and Atmospheric Dynamics (program element A.21);
- Airborne Instrument Technology Transition (program element A.28);
- U.S. Participating Investigator (program element A.29);
- Interdisciplinary Research (program element A.30);
- New (Early Career) Investigator Program in Earth Science (program element A.31);
- The Science of Terra, Aqua, and Suomi-NPP (program element A.32);
- ICESat-2 Research (program element A.33);
- Earth Science Applications: Disaster Risk Reduction and Resilience (program element A.36);

- Advancing Collaborative Connections for Earth System Science (program element A.39);
- Citizen Science for Earth Systems Program (program element A.40);
- Advanced Component Technology (program element A.42);
- In-space Validation of Earth Sciences Technologies (program element A.43); and
- Sustainable Land Imaging – Technology (program element A.44).

Elements for which it has not yet been decided whether or not to solicit during the period of applicability of this year's ROSES 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.

2.1 Carbon Cycle and Ecosystems

The carbon cycle, which encompasses the flow and transformation of carbon between reservoirs, is the backbone that sustains life on planet Earth. The cycling of carbon dioxide and methane into the atmosphere contributes to the planetary greenhouse effect and global climate. Organic and inorganic carbon flow through ecosystems as part of food webs, and interact with the climate system. Earth's carbon cycle and ecosystems are subject to human intervention and environmental changes on an unprecedented scale, in both rate and geographical extent. This has the potential to impact ecosystem services, which provide a wide variety of essential goods to human societies. 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 focus area is directly related to the "Ecosystem Change" topic identified in the NASA Science Plan.

The Carbon Cycle and Ecosystems Focus Area addresses: (1) the distribution and cycling of carbon among the active terrestrial, marine, and atmospheric reservoirs and (2) 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;
- Identification of factors that determine the distribution and abundance of elements of biodiversity as well as how biodiversity acts as a driver on the wider Earth System;
- 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 and Atmospheric Dynamics 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 this year are:

- Land-Cover and Land-Use Change (program element A.2);
- Terrestrial Ecology (program element A.4);
- Carbon Monitoring System (program element A.6); and
- Biodiversity: Marine, Freshwater, and Terrestrial Biodiversity Survey of the Cape (BioSCape) Airborne Campaign Science Team (program element A.7).

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

- Remote Sensing of Water Quality (program element A.21);
- Rapid Response and Novel Research in Earth Science (program element A.27);
- Earth Science Applications: Water Resources (program element A.34);
- SERVIR Applied Sciences Team (program element A.35);
- Earth Science Applications: Health and Air Quality Applications (program element A.37);
- Instrument Incubator Program (program element A.41);
- Decadal Survey Incubation (program element A.45);
- Advanced Information Systems Technology (program element A.46); and
- Topical Workshops, Symposia, and Conferences (program element F.2).

2.2 Climate Variability and Change

Climate change is one of the major themes guiding Earth System Science today, and NASA is at the forefront of quantifying forcings and feedbacks of recent and future climate change. To address the challenging questions associated with Climate Variability and Change, NASA implements a comprehensive end-to-end program which ranges from global high-resolution observations to data assimilation and model predictions. The focus area is most closely related to the "Reducing climate uncertainty and informing societal response" and "Sea-level rise" topics identified in the NASA Science Plan. Recently, the Climate Variability and Change Focus Area has directed its research toward addressing five specific questions:

- How and why is global ocean circulation varying on interannual, decadal, and longer time scales?
- What changes are occurring in the mass and extent of the Earth’s ice cover, and what drives them?
- How is global sea level affected by natural variability and human-induced change in the Earth system?
- What are the climate-relevant land, atmosphere, ocean, cryosphere and biospheric processes, and how do they interact?
- How can predictions of climate variability and change be improved?

NASA provides near-global coverage of key observations for studying the climate system. This includes selected ocean properties every two to ten days as well as observations of the vast expanses of polar land and sea ice. Importantly, these observations are provided at the temporal and spatial scales necessary to detect change. 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. By combining these observations with other NASA space-based measurements, the ocean and cryosphere can be linked to other components of the Earth System, such as cloud distribution, snow cover, surface temperatures, humidity characteristics and others. In addition to investments in space-based observations, 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.

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 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 this year are:

- Ocean Salinity Science Team (program element A.9); and
- Cryospheric Science (program element A.15).

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

- Carbon Monitoring System (program element A.6);
- Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (program element A.17);
- Precipitation Measurement Missions (PMM) Science Team (program element A.24);
- DSCOVR Science Team (program element A.25);
- CloudSat and CALIPSO Science Team Recompete (program element A.26);
- Rapid Response and Novel Research in Earth Science (program element A.27);
- Earth Science Applications: Water Resources (program element A.34);
- SERVIR Applied Sciences Team (program element A.35);
- Instrument Incubator Program (program element A.41);
- Decadal Survey Incubation (program element A.45);
- Advanced Information Systems Technology (program element A.46); and

- Topical Workshops, Symposia, and Conferences (program element F.2).

2.3 Atmospheric Composition

Changes in atmospheric composition affect air quality, weather, climate, and critical constituents, such as ozone and aerosol particles. 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, in turn, affects incoming solar and outgoing long wave radiation. 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, the impact of clouds and aerosol particles on the Earth's energy budget and the evolution of aerosols and tropospheric ozone and their impacts on climate and air quality). The focus area is most closely related to the "Reducing climate uncertainty and informing societal response" and "Extending and improving weather and air quality forecasts", topics identified in the NASA Science Plan. 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 aerosol particles in the Earth's troposphere and stratosphere, as well as aerosol particle 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 proposals in ROSES this year are:

- Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (program element A.17).

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

- Terrestrial Ecology (program element A.4);
- Carbon Monitoring System (program element A.6);
- DSCOVR Science Team (program element A.25);
- CloudSat and CALIPSO Science Team Recompete (program element A.26);
- Rapid Response and Novel Research in Earth Science (program element A.27);
- SERVIR Applied Sciences Team (program element A.35);
- Earth Science Applications: Health and Air Quality Applications (program element A.37);
- Instrument Incubator Program (program element A.41);
- Decadal Survey Incubation (program element A.45);
- Advanced Information Systems Technology (program element A.46); and
- Topical Workshops, Symposia, and Conferences (program element F.2).

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 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 focus area is most closely related to the "Coupling of the water and energy cycles" topic identified in the NASA Science Plan.

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. For example, increased exposure and density of human settlements in vulnerable areas 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 global prediction systems and effective decision-support tools applicable to local conditions.

The Terrestrial Hydrology Program resides exclusively within the Water and Energy Cycle Focus Area. Other programs (Radiation Sciences, Weather and Atmospheric Dynamics, and Land-Cover Land-Use Change) which contribute to this focus area are shared with other focus areas (Atmospheric Composition, Weather and Atmospheric Dynamics, and Carbon Cycle and Ecosystems, respectively). 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 Focus Area's 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.

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 https://wec.gsfc.nasa.gov. NEWS has been established to create a mechanism to export and import information, results, and technology to and from other U.S. agencies and international partners concerned with the study and observation of water and energy cycles, such as the Global Energy and Water Cycle Exchanges project (GEWEX; http://www.gewex.org/).

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 this year are:

- Remote Sensing of Water Quality (program element A.21).

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

- Terrestrial Ecology (program element A.4);
- Precipitation Measurement Missions (PMM) Science Team (program element A.24);
- CloudSat and CALIPSO Science Team Recompete (program element A.26);
- Rapid Response and Novel Research in Earth Science (program element A.27);
- Earth Science Applications: Water Resources (program element A.34);
- SERVIR Applied Sciences Team (program element A.35);
- Instrument Incubator Program (program element A.41);
- Decadal Survey Incubation (program element A.45);
- Advanced Information Systems Technology (program element A.46); and
- Topical Workshops, Symposia, and Conferences (program element F.2).

2.5 Weather and Atmospheric Dynamics

The Weather and Atmospheric Dynamics 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 and Atmospheric Dynamics 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 use of these measurements in retrievals, research, and weather forecast models in order to both enhance our understanding of weather systems and their role(s) in the Earth system, as well as to improve and extend U.S. and global weather prediction. This Focus Area is implemented in coordination with other U.S. agencies' programs and helps address the topic described in the NASA Science Plan "Extending and improving weather and air quality forecasts"

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) on the Suomi

National Polar-orbiting Partnership (NPP) and Joint Polar Satellite System-1 satellites launched in October 2011 and November, 2017, respectively. Recent advancement in the Nation's operational geostationary capability, especially the Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM) on the Geostationary Operational Environmental Satellite (GOES) – R series are of interest to the Weather and Atmospheric Dynamics Focus Area. Currently NASA is prioritizing assimilating all-sky radiance into GEOS-5 to take advantage of the GPM data.

The study and analysis of the dynamics of the atmosphere and its interaction with the oceans and land is also an important component of the Weather and Atmospheric Dynamics Focus Area. Improvement of our knowledge of weather processes and related phenomena is crucial in gaining a better understanding of the Earth system. Applying NASA Scientific remote sensing data such as from the Global Precipitation Measurement (GPM) mission, GOES, ATMS, SMAP, and CYGNSS could lead to improved retrieval algorithms, increased knowledge of atmospheric dynamical processes, and assimilation of these measurements into NASA's research investigations, cloud and climate models, and quasi-operational weather models should improve global weather prediction, climate change studies, and information on the interactions within the Earth System.

Two major investments in the Weather and Atmospheric Dynamics Focus Area form the integrator and transition centers of research results in this area. Through collaborations in the Joint Center for Satellite Data Assimilation (JCSDA) (https://www.jcsda.org), 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) and CrIS have made positive impacts on a global integrated forecast metric.

On the short time scale, 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 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.

There are no ROSES element directly focused towards the Weather and Atmospheric Dynamics Focus Area soliciting for proposals in ROSES this year.

Topics relevant to the Weather and Atmospheric Dynamics Focus Area that are actively or potentially soliciting in ROSES this year include the following program elements:

- Carbon Monitoring System (program element A.6);

- Precipitation Measurement Missions (PMM) Science Team (program element A.24);
- DSCOVR Science Team (program element A.25);
- CloudSat and CALIPSO Science Team Recompete (program element A.26);
- Rapid Response and Novel Research in Earth Science (program element A.27);
- Earth Science Applications: Water Resources (program element A.34);
- SERVIR Applied Sciences Team (program element A.35);
- Earth Science Applications: Health and Air Quality Applications (program element A.37);
- Instrument Incubator Program (program element A.41);
- Decadal Survey Incubation (program element A.45);
- Advanced Information Systems Technology (program element A.46); and
- Topical Workshops, Symposia, and Conferences (program element F.2).

2.6 Earth Surface and Interior

The Earth Surface and Interior Focus Area promotes the development and application of remote sensing to better understand core, mantle, and lithospheric structure and dynamics, and interactions between these processes and Earth's fluid envelopes. ESI studies provide the basic understanding and data products needed to inform the assessment, mitigation, and forecasting of natural hazards, including phenomena such as earthquakes, tsunamis, landslides, and volcanic eruptions. These investigations also exploit the time-variable signals associated with other natural and anthropogenic perturbations to the Earth system, including those associated with the production and management of natural resources. The focus area is most closely related to the "Surface dynamics, geological hazards and disasters" topic identified in the NASA Science Plan. 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. ESI seeks to address the questions:

1. What is the nature of deformation associated with plate boundaries and what are the implications for earthquakes, tsunamis, and other related natural hazards?
2. How do tectonic processes and climate variability interact to shape Earth's surface and create natural hazards?
3. How does the solid Earth respond to climate-driven exchange of water among Earth systems and what are the implications for sea-level change?
4. How do magmatic systems evolve, under what conditions do volcanoes erupt, and how do eruptions and volcano hazards develop?
5. What are the dynamics of Earth's deep interior and how does Earth's surface respond?
6. What are the dynamics of Earth's magnetic field and its interactions with the rest of Earth's systems?
7. How do human activities impact and interact with Earth's surface and interior?

ESI's Space Geodesy Program (SGP) produces observations that refine our knowledge of Earth's shape, rotation, orientation, and gravity, advancing our understanding of the motion and rotation of tectonic plates, elastic properties of the crust and mantle, mantle-core interactions, solid Earth tides, and the effects of surface loading resulting from surface water, ground water, glaciers, and ice sheets. SGP infrastructure enables the establishment and maintenance of a precise terrestrial reference frame that is foundational to many Earth missions and location-based observations.

Modeling, calibration, and validation are essential components in advancing the above solid-Earth science objectives. ESI views natural laboratories as a critical component for the validation and verification of remote sensing algorithms. For example, NASA joins with the National Science Foundation (NSF) in support of the Geodetic Facility for the Advancement of Geoscience (GAGE) initiative to maintain and operate a set of foundational geodetic capabilities that are essential for current research efforts to measure Earth changes with unprecedented spatial and temporal resolution, enabling advances in our understanding of tectonic processes; earthquakes and tsunami; magmatic processes; landslide hazards; continental water storage; atmospheric, ice sheet and glacier dynamics; and interactions among these components of the Earth system.

Among the many activities carried out by ESI are the following:

- Geodetic and thermal imaging of the precise metrology of Earth's surface and its changes through GNSS, 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 forecasts and early warnings for earthquakes, tsunamis, landslides, and volcanic eruptions through the use of a broad range of Earth surface remote sensing and space geodesy approaches.

The ROSES element most closely directed towards the Earth Surface and Interior Focus Area that are or may be soliciting for proposals in ROSES this year is:

- Earth Surface and Interior (program element A.23).

Topics relevant to the Earth Surface and Interior Focus Area that are actively or potentially soliciting in ROSES this year include the following program elements:

- Rapid Response and Novel Research in Earth Science (program element A.27);
- SERVIR Applied Sciences Team (program element A.35);
- Instrument Incubator Program (program element A.41);
- Decadal Survey Incubation (program element A.45);
- Advanced Information Systems Technology (program element A.46); and
- Topical Workshops, Symposia, and Conferences (program element F.2).

2.7 Cross-Cutting and Interdisciplinary

There are several cross-cutting and interdisciplinary elements in ROSES this year, 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 this year or are being evaluated for possible solicitation, are:

- Rapid Response and Novel Research in Earth Science (program element A.27) - This program element 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;
- Precipitation Measurement Missions Science Team (program element A.24) - The Precipitation Measurement Missions (PMM) science team seeks investigations related to satellite observations of precipitation using measurements from, but not limited to, the Global Precipitation Measurement (GPM) Core Observatory (2014-present), GPM mission constellation partner spacecraft, and the Tropical Rainfall Measuring Mission (TRMM, 1997-2015);
- DSCOVR Science Team (program element A.25) – This program element emphasizes the analysis and validation of geophysical measurements and other derived quantities using available DSCOVR products. Science exploitation proposals in response to this program element must address explicit hypotheses, primarily using standard, currently available DSCOVR data products. NASA will also consider proposals for algorithm maintenance, algorithm enhancement, and new product development, as well as science exploitation proposals that address explicit hypotheses, using standard, currently available DSCOVR data products; and
- Cloudsat and CALIPSO Science Team Recompete (program element A.26) – This program element requests proposals for the CloudSat/CALIPSO science team that draw on the results of the 14 years of operation of the two satellites, and take advantage of both their particular results and the synergies of their flying for most of their period of operation in the A-Train constellation which allowed for nearly-simultaneous measurements with other NASA satellites (e.g., Aqua, Aura, OCO-2) and those of NASA’s international partners (PARASOL, GCOM-W1).

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, and Ecological Forecasting. Applied Sciences projects leverage products, knowledge, and outcomes of Research and Analysis activities described in Section 2.

The ROSES elements most closely directed towards Applied Sciences that are or may be soliciting for proposals in ROSES this year are:

- Earth Science Applications: Water Resources (program element A.34);
- SERVIR Applied Sciences Team (program element A.35); and
- Earth Science Applications: Health and Air Quality Applications (program element A.37).

Topics relevant to the Applied Sciences Program that are actively or potentially soliciting in ROSES this year include the following program elements:

- Carbon Monitoring System (program element A.6);
- Rapid Response and Novel Research in Earth Science (program element A.27);
- Decadal Survey Incubation (program element A.45);
- Advanced Information Systems Technology (program element A.46); and
- Topical Workshops, Symposia, and Conferences (program element F.2).

4. 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 the NASA Science Plan and the most recent Decadal Survey covering NASA's Earth science activities, *Thriving on our Changing Planet: A Decadal Strategy for Earth Observation from Space*, which was released on

1/5/2018 by the National Academies of Science, Engineering, and Medicine (see https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth). This 2018 Decadal Survey now serves as a foundational document for NASA's Earth Science Division (ESD), and includes recommendations for the scopes, foci, and relative budgetary magnitudes of the R&A, Applications, and Technology portions of the ESD program.

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, the Instrument Incubator Program, Decadal Survey Incubation, and Advanced Information Systems Technology Program will be solicited in ROSES this year:

- Instrument Incubator Program (program element A.41): The Instrument Incubator Program (IIP) 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;
- Decadal Survey Incubation (program element A.45): The Decadal Survey Incubation program develops and matures observing systems, instrument technology, and measurement concepts for Planetary Boundary Layer and Surface Topography and Vegetation observables through technology development, modeling/system design, analysis activities, and small-scale pilot demonstrations; and
- Advanced Information Systems Technology (program element A.46): The Advanced Information Systems Technology (AIST) program advances technologies that enable: unique measurement collection capabilities through distributed sensing; optimizing Science missions return on investment through flexible information integration; and agile Science investigations through data analytics and artificial intelligence tools and algorithms.

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

- ACT (program element A.42): The Advanced Component Technology program develops a broad array of components and subsystems for instruments and observing systems;
- InVEST (program element A.43): 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; and
- SLI-T (program element A.44): The Sustainable Land Imaging Technology Program - The Sustainable Land Imaging Technology program develops technologies leading to new SLI instruments, sensors, systems, components, data systems, measurement concepts, and architectures in support of the nation's future SLI activities.

5. Enabling Capability

Enabling capabilities include those programmatic elements that are of sufficient breadth that they contribute to a broad range of activities within the Earth Science Research

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

5.1 Education

The Earth Science Research Program 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 2015, SMD announced selections from the Science Education Cooperative Agreement Notice. These projects collaborated with SMD in the execution of its science education efforts 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 2020, the program, now known as Science Activation, selected 18 organizations from the original cohort to continue their effort. Nine additional projects were selected to enhance processes that incorporated subject matter experts and broadened participation of under-represented and under-served learners.

The Earth Science Research Program will continue its management of the Global Learning and Observations to Benefit the Environment (GLOBE) Program (https://www.globe.gov/) 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. It will also continue to oversee the GLOBE Data and Information System. ESD welcomes proposals that incorporate the use of GLOBE observations, where appropriate. Observations can be accessed via the GLOBE Visualization System (https://vis.globe.gov/GLOBE/) and the GLOBE Advanced Data Access Tool (ADAT; https://datasearch.globe.gov/). Data can also now be accessed via the GLOBE Application Programming Interface (API; https://www.globe.gov/globe-data/globe-api).

5.2 Graduate and Early-Career Research

The NASA Earth Science Division recognizes the importance of workforce enrichment. To this end, the Earth Science Division sponsors the Earth science component of the Future Investigators in NASA Earth and Space Science and Technology (FINESST) program, that replaced the NASA Earth and Space Science Fellowship (NESSF) program. FINESST supports graduate student-designed research projects that contribute to SMD's science, technology, and exploration goals.

The opportunity to propose for the next school year was in ROSES-2020 and proposals were due February 4, 2021. The opportunity to propose for the 2022/2023 school year will be in program element F.5 of ROSES this year. It is anticipated that FINESST final text will be released in November 2021, with proposals due in February 2022. Those currently holding FINESST awards do not submit renewal proposals for their next year of funding; rather they submit annual progress reports due in March.

The New (Early Career) Investigator Program in Earth Science (program element A.31), which is directed towards scientists and/or engineers within six years of their receipt of a Ph.D. degree, is solicited every three years. It is not being solicited in ROSES this year; the next anticipated solicitation will be in ROSES-2023.

5.3 <u>Data and Information Management</u>

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.

Three program elements related to Data and Information Management have been solicited periodically by the Earth Science Division in recent years – The Advancing Collaborative Connections for Earth System Science (ACCESS, program element A.39), the Making Earth System Data Records for Use in Research Environments (MEaSUREs, most recently solicited in ROSES-2017 as program element A.43), and Citizen Science for Earth Systems Program (program element A.40), none of which are solicited in ROSES this year.

Unless otherwise specified, any data proposed to be analyzed in response to Appendix A program elements 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 these data 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 specifically 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.

Data, model results and other information created with NASA funding are subject to NASA's Earth Science Data policy (see http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/ for the policy). All data will be released along with the source code for algorithm software, coefficients, and ancillary data used to generate products.

Proposers are encouraged to utilize data acquired by the Commercial SmallSat Data Acquisition Program (CSDAP). The CSDAP program evaluates and procures data from commercial vendors that advance NASA's Earth science research and applications activities. The scientific community may use data that have been previously acquired by NASA for scientific purposes in adherence to vendor-specific terms and conditions. Currently, data acquired during the evaluations of Planet, Maxar (Digital Globe) and Spire Global are available, as are data from the Teledyne Brown Engineering DLR Earth Sensing Imaging Spectrometer (DESIS). These products are available at no cost to PIs and are subject to scientific use licenses. Please check the link that follows regularly, for new data being added to the list as evaluations and procurements are completed. For an up-to-date list of available data and associated licenses please visit https://earthdata.nasa.gov/csdap.

5.4 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. Over the past several years, computational resources have become significantly constrained. Since 2016 SMD has implemented a more rigorous resource allocation process. Proposals that would make use of NASA's High-End Computing (HEC) Resources must follow the instructions given in Section I(e) of the *ROSES Summary of Solicitation* generating and submitting a request via the HEC Request Management System (RMS) at https://request.hec.nasa.gov. Save a PDF copy of your request after submitting it using the button provided in RMS and then attach that (as a separate file as type "Appendix") to your ROSES proposal (this is not counted against the technical proposal page limit). The form includes a written justification of how the computational resources would support the investigation and this will be used during the proposal evaluation and selection processes. This justification should include how the computational resources may support the investigation and a multiyear resource-phasing plan, in annual increments, identifying the computing system and facility location where the computational project will be accomplished for the duration of the proposed award period. Proposers to this NRA must follow the instructions in Section I(e) of the *Summary of Solicitation* of this NRA to request computing resources, including explicit descriptions of computing resource needs.

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 this year, no program elements specifically targeted towards High End Computing, Networking, and Storage will be solicited.

5.5 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 are staged online for easy access. Recently, NEX also includes a partial collection of data from operational geostationary satellite systems. This sub-system is called GeoNEX (https://www.nasa.gov/geonex). NEX (https://nasa.gov/nex) 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, proposals that require the utilization of NEX should include a section to justify the need for using NEX, specify the data storage and processing needs, and includes a data management plan as described above in Section 1. 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 recommended information to include in proposals to use NEX is available at https://nasa.gov/nex/access/.

In ROSES this year, no program elements directed towards the enhancement of NEX are being solicited.

5.6 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 students can be engaged in all aspects of scientific investigations, 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 NASA-owned and supported aircraft including the DC-8, multiple G-III's, a G-V, two ER-2's, and a P-3B. NASA also owns several other aircraft (i.e WB-57's) which may be available but are not ESD supported. In addition, several independently owned aircraft, including, but not limited to, those operated by other Federal agencies and commercial aircraft providers have been utilized in the past to support ESD airborne activities. Proposers that utilize commercial aircraft service providers must ensure real time position tracking of the aircraft and provide flight reports after the completion of flights. Information regarding the utilization and reporting requirements of airborne assets to support proposals can be found at https://airbornescience.nasa.gov/.

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.

All participants in ESD Airborne activities will comply with all appropriate NASA Procedural Requirements including medical qualifications for Qualified Non-Crewmembers (QNC). Participants will be screened (in a timely fashion) by the appropriate Center medical personnel to determine their readiness for QNC duties.
