APPENDIX A. EARTH SCIENCE RESEARCH PROGRAM

A.1 EARTH SCIENCE RESEARCH OVERVIEW ROSES-2024

1. What's New for 2024 and Introduction

NASA's Earth Science Division (ESD) is encouraging proposers to consider its emerging Earth-Science-to-Action (ES2A) strategy in proposal development, especially by considering how the proposed project connects to other funded activities of the division.

ES2A is a new, ten-year strategy for ESD expected to be released in late FY2024. This strategy development is in response to many recent documents (including the most recent Decadal Survey, *Thriving on our Changing Planet: A Decadal Strategy for Earth Observation from Space*), calling for ESD to increase the impact of Earth science in response to the urgency of the changes taking place on Earth. The Decadal Survey and other recent strategic documents are discussed further below.

ESD has developed a graphic to convey the strategy and illustrate the ways in which our activities work together (Figure A.1-1). Scientific knowledge and data, Earth system models, technology innovation, and Earth observations from surface-based, airborne, and space-based platforms, are the foundation from which arises understanding of the Earth's systems. That understanding is used to improve our predictive capability, while also delivering actionable information and applications to inform decisions about societal challenges. In turn, new challenges and needs are revealed that can inform development of the next cycle of activities.

Figure A.1-1. The layers of the pyramid show the intent of the Earth Science to Action Strategy (currently in development).

Proposers are encouraged to consider the pyramid in developing their proposals by stating which layer or layers the proposal addresses. While some program elements of ROSES-2024 may be focused on a single layer, ESD aims to reduce the barriers associated with translating information across layers in projects selected under ROSES-

2024. To this aim, proposers are encouraged to identify connections of their project to adjacent layers or state how their proposal could inform future activities in another layer.

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* at https://science.nasa.gov/about-us/science-strategy. 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.

In 2023, NASA issued the document, *Advancing NASA's Climate Strategy*, see https://www.nasa.gov/wp-content/uploads/2023/04/advancing-nasas-climate-strategy-2023.pdf. This document lays out four key priorities to achieve NASA's climate mission:

innovate, inform, inspire, and partner. More detail about each of these priorities and needs are detailed in the document.

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 (now part of Earth Action), 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).

ESD's development of the ES2A Strategy is in response the Decadal Survey's recommendation that NASA increase its focus on addressing societal challenges. ESD will use the new ES2A strategy to drive the next iteration of programs, missions and initiatives, as well as to define the budget structure and inform employees' performance expectations.

While the ES2A Strategy is being finalized, proposers are encouraged to consider what layer or layers of the pyramid shown in Figure A.1-1 are most relevant to their proposal.

In addition to NASA's strategic plans, 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 2022, the *U.S. Global Change 2022-2031 Strategic* (https://downloads.globalchange.gov/strategic-plan/2022/USGCRP_2022-2031_Decadal_Strategic_Plan.pdf). NASA has additionally contributed to the *Federal Framework and Action Plan for Climate Services*, which highlights the critical need of enabling effective climate action through providing climate services to the public (https://www.whitehouse.gov/wp-content/uploads/2023/03/FTAC_Report_03222023_508.pdf). Similarly, there are interagency programs related to Meteorological Services, Oceans, Earth Observations, 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).

NASA contributes to both the National Climate Assessment (NCA) and the development of reports for the United Nations Intergovernmental Panel on Climate Change (IPCC). The most recent NCA (NCA5) (https://nca2023.globalchange.gov/), explains that "effects of human-caused climate change are already far-reaching and worsening across every region of the United States." The most recent IPCC synthesis report, AR6,

includes several warning statements regarding the impacts of taking (or not taking) decisive actions in the near term and the importance of adaptation in the long term (https://www.ipcc.ch/report/ar6/syr/).

Research is solicited in three major areas for the Earth Science Research Program: Research and Analysis (R&A), Earth Action (EA), and enabling capabilities. 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 teams that support developing, newly launched and currently operating satellite missions, interdisciplinary science, and calibration/validation activities.

The Earth Action area supports efforts to discover and demonstrate innovative and practical uses of NASA Earth science observations and research through applied research and applications projects carried out in partnership with end user organizations (http://appliedsciences.nasa.gov/). Earth Action, 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).

Open scientific practices are critical for facilitating transparency of the scientific process, reproducibility of results, and information sharing in the scientific community and beyond. Scientific knowledge is most robust and actionable when resulting from transparent, traceable, and reproducible methods. SMD is committed to encouraging and enabling openness and transparency in the scientific process. This requires open access to the data used in scientific analysis, to scientific publications, and to software used to arrive at results. 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. Thus, consistent with SMD's updated Scientific Information policy (SPD-41A), most program elements require an "Open Science and Data Management Plan", (formerly called the Data Management Plan) or an explanation of why one is not necessary given the nature of the work proposed, see Section 1.1, below.

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.

Use of the Earth Science Division Templates for the Table of Work Effort and Current and Pending Support is strongly recommended for a number of program elements in Appendix A.

Proposals aiming to use award funds for litigation against any local, state, or federal government agency are not permitted and will be deemed non-responsive.

1.1 Increasing Access to the Results of Federally Funded Research

The requirements regarding archiving of data, code, and publications were strengthened in the past year. In particular: 1) As-accepted manuscript versions of publications that derive from ROSES awards must be publicly available at the time of publication 2) Data and software developed using ROSES funding in support of a peer-reviewed publication shall be made publicly available at the time of publication, 3) Scientifically useful data and software developed during the award that was not already published must be made publicly available by the end of the award, and 4) To be eligible to receive funding, PIs and Co-Is must provide their digital persistent identifier (e.g., ORCID) via NSPIRES under Account Management → Personal Profile.

To broaden access to the results of NASA-funded research, most proposals require an "Open Science and Data Management Plan" (formerly called a data management plan) or an explanation of why one is not necessary given the nature of the work proposed. This Open Science and Data Management Plan (OSDMP) must address how publications, data, and software will be made available, see below.

Unless otherwise stated, when an OSDMP is required, its sufficiency will be evaluated as part of Merit and thus may have a bearing on whether or not the proposal is selected. OSDMPs that do not adequately address the three items in Sections 1.1.1-1.1.3 below may be declined or the awards delayed until an adequate OSDMP is provided.

The budget for the proposal should include any costs needed to implement the OSDMP**.**

Unless otherwise stated, the OSDMP will be placed in a 2-page section in the proposal PDF immediately following the references and citations for the Scientific/Technical/Management (S/T/M) section of the proposal and does not count against the page limit for the S/T/M Section.

Program elements that do not conform to the default approach for OSDMPs described above will say so explicitly. For example, 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) may not require an OSDMP at all. However, even if an OSDMP is not required with the proposal, the standard requirements regarding release of data, software and publications (see below) still apply to any ROSES award.

Any given program element may supersede this standard guidance, clarifying or adding to the requirements laid out here. For example, some elements may require a software

development or management plan in addition to or instead of the OSDMP and/or have separate additional requirements e.g., specifying preferred repositories, that the software must be made available under a certain kind of license, or may otherwise require more than is outlined here.

The OSDMP must cover data, software, and publications that result from ROSES awards. These three are separately addressed below for the convenience of proposers. After reading the subsections below, proposers are encouraged to review the new SMD Open-Source Science Guidance. Proposers may also refer to Scientific Information policy (SPD-41a) for definitions and background information on the sharing of publications, data, and software produced as part of SMD-funded awards.

The OSDMP should explain the roles and responsibilities of team members in accomplishing the plan. If funds are required for information management activities, these should be covered in the normal budget and budget justification sections of the proposal.

For programs participating in Dual-Anonymous Peer Review, the OSDMP must be anonymized.

1.1.1 *Data*

Data needed to validate the scientific conclusions of a peer-reviewed publication resulting from an award, e.g., data underlying figures, maps, and tables in a publication, must be made available at the time of publication. The remaining scientifically useful data must be made available at the end of the award, consistent with the OSDMP. “Made available” means publicly and electronically in a place where it can be found and it is likely to persist, e.g., in the supplemental material of the article, a community-endorsed repository, a NASA repository such as http://data.nasa.gov/, a repository supported by a division, or a combination of different resources as would be most appropriate to the data being shared. When shared, the data must include robust metadata and be made available for access, download, or export in non-proprietary, modifiable, open, and machine-readable formats consistent with standards used in the disciplines. Publicly shared data must receive a persistent identifier, such as a Digital Object Identifier, to support citation. The data should be released with an open license such as Creative Commons Zero. Any limitations to the sharing of data should be described as part of the OSDMP. "Data" does not include laboratory notebooks, preliminary analyses, private communications, or certain other types of information that have been excluded from the definition in SPD-41a. In the case of a project that would produce no "data", or only data specifically exempted, the OSDMP must state that no data preservation or data sharing is needed and explain why. In a case where no appropriate archive exists for a particular data set, the OSDMP must discuss alternative methods for making the data publicly available.

ESD-funded projects are required to comply with the NASA ESD Open Data, Services, and Software Policy https://earthdata.nasa.gov/collaborate/open-data-services-and-software. For project data, these requirements include:

a. Making data available in machine readable formats consistent with ESD standards with no period of exclusive access.
b. Making data available with robust, standard-compliant meta-data.

c. Making the data collection available with a digital object identifier to support citation.
d. Conforming to approved community standards for data formats, interfaces, and metadata, see https://www.earthdata.nasa.gov/esdis/esco/standards-and-practices.

Additional requirements related to Earth Science data can be found in Section 5.

The OSDMP 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;

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.

Whether derived products and model output should be archived is determined by the scientific utility and need on a case-by-case basis. The approach for the sharing and archival of such data must be described in the OSDMP. When these types of data/output are considered for long-term archive and availability at a DAAC, the utility of 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 archiving the DAAC may require updates to the OSDMP including information about data processing and quality.

For more information about meeting these requirements, see 'Data Management and Sharing' in the SMD Open-Source Science Guidance. No later than 2025, SMD plans to provide additional options for the long-term hosting of data produced from SMD ROSES awards. This may include hosting at NASA or Federal data repositories, community-based repositories, or other instructions for how the data should be archived. Thus, researchers need not include the cost of public access to their data or storing their data beyond the end of the period of performance of their award in their budgets. Future guidance and instructions related to how to publicly share the data will be made available via the Scientific Information Policy website.

1.1.2 *Software*

Software needed to validate the scientific conclusions of a peer-reviewed publication resulting from an award, must be made available at the time of publication. The remaining scientifically useful software must be made available by the end of the award, consistent with the OSDMP.

The software section of the OSDMP must cover the management and development of software necessary to complete the scientific research. The OSDMP must include what software development is needed, how the software will be managed and, if applicable, where the software will be shared.

For project software, requirements include:

a. Software should be developed openly in a publicly accessible, version-controlled platform that allows for community contributions using a permissive software license (https://earthdata.nasa.gov/collaborate/open-data-services-and-software/esds-open-source-policy#license).
b. Making product documentation (Algorithm Theoretical Basis Documents, user's guide, data quality information, etc.) publicly available.
c. All calibration information and simulated products supporting development and validation of algorithms should be made available.

NASA expects that the source software, with associated documentation sufficient to enable use of the software, 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.

For more information, see 'Software Management and Sharing' in the SMD Open-Source Science Guidance. The method of archiving software will not result in a weakness for proposals to ROSES-2024. No later than 2025, SMD plans to provide additional options for the long-term archiving of software produced from SMD ROSES awards. Thus, researchers need not include the cost of public access to their software, maintaining their software, or storing their software beyond the end of the period of performance of their award in their budgets. Future guidance and instructions related to how to publicly share software will be made available via the Scientific Information Policy website. Guidance on how to share software including providing a DOI is described in the SMD Open-Source Science Guidance**.**

Some program elements may require a separate Software Development/Management Plan. Please read the program elements carefully.

1.1.3 *Publications*

As-accepted manuscript or the version of record of peer-reviewed publications must be made publicly available at the time of publication. There are two options for how to comply with this requirement: Either (1) the manuscript may be individually uploaded to NASA PubSpace by the time of publication, or (2) it may be published in a journal indexed by either CHORUS, ADS, or NASA Science Explorer (scixplorer.org), and that makes it openly available at the time of publication. For more information about meeting the requirements on published papers, see "How to Share Publications" at https://science.nasa.gov/researchers/sara/faqs/OSDMP, or in the SMD Open-Source Science Guidance. SMD encourages publications to be published Open Access, and any cost to do so may be included in the budget. SMD also encourages publications to be posted on community appropriate preprint servers.

Conference presentations and technical documents resulting from ROSES awards must be made publicly available. As with data and software, this does not include material that would be excluded from the definitions in Scientific Information policy (SPD-41a).

Moreover, recipients of ESD funding are also encouraged to:

a. Publish manuscripts as open access. The costs for publishing as open access should be included in the proposed budget.
b. Make as-accepted manuscripts available on preprint services.

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.26).

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:

- Carbon Monitoring System (program element A.6);
- Ocean Salinity Science Team (program element A.9);
- Sea Level Change Team (program element A.10);
- SWOT Science Team (program element A.11);
- Ocean Vector Winds Science Team (program element A.31);
- Atmospheric Composition: Radiation Sciences Program (program element A.18);
- Atmospheric Composition: Tropospheric Composition (program element A.20);
- EMIT Science and Applications Team (program element A.29);
- Airborne Instrument Technology Transition (program element A.33);
- Interdisciplinary Research in Earth Science (program element A.35);
- DSCOVR Science Team (program element A.37);
- Early Career Investigator Program in Earth Science (program element A.38);
- Earth Action: Water Resources (program element A.39);
- Earth Action: Agriculture (program element A.40);
- Earth Action: Community Action for Equity and Environmental Justice (program element A.46);
- Commercial Smallsat Data Scientific Analysis (program element A.49);
- Instrument Incubator Program (program element A.51);
- Advanced Component Technology (program element A.52);
- In-space Validation of Earth Sciences Technology (program element A.53);
- Sustainable Land Imaging – Technology (program element A.54);
- Advanced Information Systems Technology (program element A.56); and
- Technology Development for Support of Wildfire Science, Management, and Disaster Mitigation (program element A.57).

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 element 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 carbon cycle and ecosystem 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);
- Ocean Biology & Biogeochemistry (program element A.3);
- Terrestrial Ecology (program element A.4);
- Carbon Cycle Science (program element A.5); and
- Biodiversity (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:

- Rapid Response and Novel Research in Earth Science (program element A.26);

- NASA ISRO Synthetic Aperture Radar (NISAR) Mission Research and Applications Science Team (program element A.27);
- Remote Sensing Theory (program element A.28);
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31);
- U.S. Participating Investigator (program element A.34);
- The Science of PACE (program element A.36);
- SERVIR Applied Sciences Team (program element A.41);
- Earth Action: Ecological Conservation Impact Assessment (program element A.45);
- Earth Action: Wildland Fires (program element A.47);
- Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (program element A.48);
- Decadal Survey Incubation (program element A.55);
- Increasing Participation of Minority Serving Institutions in Earth Science Surface-Based Measurement Networks (program element A.58); and
- New or Modified GLOBE Protocols (program element A.59).

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 biosphere 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:

- Physical Oceanography (program element A.8);
- Ocean Surface Topography Science Team (OSTST) (program element A.12);
- Integrated SWOT Water Field Campaign (program element A.14);
- Modeling, Analysis, and Prediction (program element A.15); and
- Cryospheric Science (program element A.16).

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:

- Rapid Response and Novel Research in Earth Science (program element A.26);
- NASA ISRO Synthetic Aperture Radar (NISAR) Mission Research and Applications Science Team (program element A.27);
- Remote Sensing Theory (program element A.28);
- Understanding Changes in High Mountain Asia (program element A.30);
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31);
- Precipitation Measurements Mission and CloudSat and CALIPSO Science Team Recompete (program element A.32);
- U.S. Participating Investigator (program element A.34);
- The Science of PACE (program element A.36);
- SERVIR Applied Sciences Team (program element A.41);

- Earth Action: Ecological Conservation Impact Assessment (program element A.45);
- Earth Action: Wildland Fires (program element A.47);
- Commercial Smallsat Data Acquisition: New Vendor Onramp Evaluation (program element A.48);
- Decadal Survey Incubation (program element A.55); and
- New or Modified GLOBE Protocols (program element A.59).

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:

- Atmospheric Composition Upper Atmosphere Observations (program element A.17);
- Atmospheric Composition: Atmospheric Composition Modeling and Analysis Program (program element A.19); and
- TEMPO Science Team (program element A.21).

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

- Carbon Cycle Science (program element A.5);
- Rapid Response and Novel Research in Earth Science (program element A.26);
- Remote Sensing Theory (program element A.28);
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31);
- Precipitation Measurements Mission and CloudSat and CALIPSO Science Team Recompete (program element A.32);
- U.S. Participating Investigator (program element A.34);
- The Science of PACE (program element A.36);
- SERVIR Applied Sciences Team (program element A.41);
- Earth Action: Health and Air Quality (program element A.43);
- Earth Action: Health and Air Quality Applied Science Team (program element A.44);
- Earth Action: Wildland Fires (program element A.47);
- Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (program element A.48);
- Decadal Survey Incubation (program element A.55);
- Increasing Participation of Minority Serving Institutions in Earth Science Surface-Based Measurement Networks (program element A.58); and
- New or Modified GLOBE Protocols (program element A.59).

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, 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 priority on integrating these components in a coherent fashion, as previously pursued by the NASA Energy and Water Cycle Study (NEWS). The Focus Area is committed to continuing coherent study of the two cycles and exchange information of such with other U.S. agencies, international partners, and especially the Global Energy and Water 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 Earth Action Program, in particular, the areas of water resources, agriculture, disasters, and ecological conservation (see Section 3 for more details on the Earth Action 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 is soliciting for proposals in ROSES this year are:

- NASA Energy and Water System (NEWS) (program element A.22); and
- Terrestrial Hydrology (program element A.23).

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:

- Carbon Cycle Science (program element A.5);
- Ocean Surface Topography Science Team (OSTST) (program element A.12);
- Rapid Response and Novel Research in Earth Science (program element A.26);
- NASA ISRO Synthetic Aperture Radar (NISAR) Mission Research and Applications Science Team (program element A.27);
- Remote Sensing Theory (program element A.28);
- Understanding Changes in High Mountain Asia (program element A.30);
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31);
- Precipitation Measurements Mission and CloudSat and CALIPSO Science Team Recompete (program element A.32);
- U.S. Participating Investigator (program element A.34);
- The Science of PACE (program element A.36);
- SERVIR Applied Sciences Team (program element A.41);
- Earth Action: Wildland Fires (program element A.47);
- Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (program element A.48);
- Decadal Survey Incubation (program element A.55); and
- New or Modified GLOBE Protocols (program element A.59).

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, Water and Energy Cycle, and Atmospheric Composition. It also has supporting links to Carbon Cycle and Ecosystems and Earth Surface and Interior.

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."

Recent investment in the Weather and Atmospheric Dynamics Focus Area is focusing on answering the following science questions:

- How can sub-seasonal to seasonal weather forecast duration and reliability be improved?
- How can we improve predictive capability for weather, including extreme events?
- What is the role of deep convective towers and precipitation on a tropical storm's life cycle?
- To what extent are storm intensification processes predictable?
- How can we use NASA, NOAA and other countries' satellite observations innovatively and transition new algorithms, data, and tools to weather forecast operations at our partner agencies?

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 NASA observations into their operational forecast systems, including the Atmospheric Infrared Sounder (AIRS) and the Global Precipitation Mission (GPM) Core Observatory data.

A key consideration of research within the focus area is to consider how NASA observations can be leveraged to develop new and advanced methods to exploit NASA data, but also how those methods can be translated to follow-on observatories from domestic and international partners. An example of this is how AIRS data assimilation at NWP centers was established a 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 satellites. The focus area continually considers how current and future

satellites within the NASA program of record can continue to advance the broader science as a whole by providing new and innovating observing strategies that complement the operational backbone observatories.

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.

The focus area continues to consider the role of new and future observatories in the context of its scientific objectives. The recent launch of the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) continues the approach of considering the potential utility of constellation approaches, particularly as the temporal resolution relates to the physical processes being observed. Focus area objectives continue to evolve and align with the slate of future mission that maintain relevance to the focus area. This includes the INVestigation of Convective UpdraftS (INCUS), the Polarized Submillimeter Ice-cloud Radiometer (PolSIR), and Atmospheric Observing System (AOS) missions.

As such, the focus area continues to advocate for both planned and advancing technologies and capabilities to measure the atmosphere, particularly as it relates to weather. This includes the four-dimensional atmospheric characterization of temperature, moisture (vapor, liquid, and solid), winds, density, and pressure. Similarly, physical processes that tie to these variables, including atmospheric dynamics, precipitation science, and lightning science, are included as part of the focus area. Relevant observations in this have included microwave and infrared nadir sounding, microwave imaging, active limb sounding via GNSS radio occultation, GNSS reflectometry, spaceborne and airborne radar and lidar measurements. Nascent technologies (e.g. sub-millimeter microwave imaging, active vertical sounding approaches, differential absorption radar methods) are of particular interest to the focus area.

With the 2017 NASEM Earth Science Decadal Survey, NASA considers the Planetary Boundary Layer (PBL) as a future spaceborne observable, as designated by its status as an Incubation-class observable (https://science.nasa.gov/earth-science/decadal-surveys/decadal-pbl/). The PBL is both considered from a scientific and technological perspective as part of the Decadal Survey Incubation (DSI) program. Scientifically, the PBL is considered a programmatic priority within the focus area. From a physical meteorological perspective, the PBL serves as the interface between the surface (i.e. land, sea, ice) and the free troposphere. From an observational perspective, it is the linkage of numerous observation methodologies – active/passive, spaceborne/suborbital, nadir/limb (i.e. fusion of nadir passive sounders and occultation methods), observation/modeling – that have all been identified as paths forward towards generating exploitable PBL science capabilities in-line with NASA agency capabilities and priorities.

Along with the PBL as an incubation-class observable, the scientific study and analysis of the dynamics of the atmosphere and its interaction with the oceans and land continues to be important component of the Weather and Atmospheric Dynamics Focus

Area. As the science continues to improve the coupled interactions across the spheres of the earth system, the improved knowledge of weather processes and related phenomena across these boundaries is crucial in gaining a better understanding of the Earth system. Applying NASA Scientific remote sensing data to understand and constrain these interfaces, such as those from GPM, GOES, SMAP, and CYGNSS will lead to improved retrieval algorithms, increased knowledge of atmospheric dynamical processes, and advanced assimilation of these measurements into NASA's research. These investigations directly tie to the advancement of agency-supported modeling capabilities, and these should tie to advances in 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. NASA GMAO has worked closely with JCSDA to transition to the Joint Effort for Data assimilation Integration (JEDI; https://www.jcsda.org/jcsda-project-jedi) data assimilation system in the 2024-2025 time frame. Observation impact analyses conducted with NASA Goddard Earth Observing System model(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.

The ROSES element most closely directed towards the Weather and Atmospheric Dynamics Focus Area that is or may be soliciting for proposals in ROSES this year is:

- Weather and Atmospheric Dynamics (program element A.24).

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:

- Ocean Surface Topography Science Team (OSTST) (program element A.12);
- Rapid Response and Novel Research in Earth Science (program element A.26);
- Remote Sensing Theory (program element A.28);
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31);

- Precipitation Measurements Mission and CloudSat and CALIPSO Science Team Recompete (program element A.32);
- U.S. Participating Investigator (program element A.34);
- SERVIR Applied Sciences Team (program element A.41);
- Earth Action: Disaster Risk Reduction, Recovery and Resilience (program element A.42);
- Earth Action: Wildland Fires (program element A.47);
- Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (program element A.48);
- Decadal Survey Incubation (program element A.55); and
- New or Modified GLOBE Protocols (program element A.59).

2.6 Earth Surface and Interior

The Earth Surface and Interior (ESI) 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 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;
- Spectral and thermal imaging of Earth's surface properties, including mineral composition and high-temperature features; as well as volcanic gas and ash emissions;
- 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 is soliciting for proposals in ROSES this year is:

- Earth Surface and Interior (program element A.25).

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.26);
- NASA ISRO Synthetic Aperture Radar (NISAR) Mission Research and Applications Science Team (program element A.27);
- Remote Sensing Theory (program element A.28);
- Understanding Changes in High Mountain Asia (program element A.30);
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31);

- U.S. Participating Investigator (program element A.34);
- Earth Action: Disaster Risk Reduction, Recovery, and Resilience (program element A.42);
- Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (program element A.48);
- Decadal Survey Incubation (program element A.55); and
- New or Modified GLOBE Protocols (program element A.59).

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.26 - 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;
- NASA ISRO Synthetic Aperture Radar (NISAR) Mission Research and Applications Science Team (program element A.27) – This solicitation seeks proposals for membership on the NISAR Post Launch Competed Science Team. The team will enable new and innovative research science spanning the research and applied science communities including: solid Earth, ecosystems, cryospheric sciences, hydrology, wetlands and coastal processes. NISAR data will support urgent response efforts when feasible. NISAR is expected to launch by spring 2024 and the solicitation will open up once data are broadly available to the community;
- Remote Sensing Theory (RST; program element A.28) - The RST program provides funding for the development of improved algorithmic and theoretical approaches for space-based remote sensing of the Earth and its components (atmosphere, ocean, biosphere, cryosphere, land surface, and/or Earth interior). It is designed to foster general advances of a fundamental nature not specifically tied to an existing or planned sensor;
- Understanding Changes in High Mountain Asia (program element A.30) – This solicitation funds investigations into High Mountain Asia's (HMA's) glaciers, snow, permafrost, and precipitation to improve our understanding of regional changes, water resources, and induced impacts, while furthering NASA's strategic goals in Earth system science and societal applications. Through expanded knowledge of the processes controlling change in HMA, the program intends to improve regional forecasts and address vulnerabilities in human and biogeophysical systems;
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31) – This solicitation funds the analysis of data from the Terra and Aqua platforms as well as the Suomi-National

Polar Orbiting Partnership (S-NPP) and NOAA's Joint Polar Satellite System (JPSS) products, with special focus on the imaging and sounding products. It can also include support for continuing production of NASA-generated products from these missions that are not included under the funding for those missions. Since the Terra and Aqua missions are due to complete their operation during the time period for which these awards would be in place, proposers are encouraged to analyze data and create products with full awareness of other relevant data sources from NASA, NOAA, and their international partners, and may include efforts that look to transition from the current satellites to the future ones to be launched by NASA as part of the Earth System Observatory;

- Precipitation Measurements Mission and CloudSat and CALIPSO Science Team Recompete (program element A.32) – This solicitation funds proposals to analyze and interpret data, as well as provide additional data sets not currently provided, from NASA's prior and current active remote sensing satellites for aerosols, clouds, and precipitation (TRMM, Cloudsat, and CALIPSO), combining as needed with active and/or passive data from the full suite of NASA and/or its interagency/international partners. There is particular interest in scientific studies that will help in the transition from the past/current generation of NASA active remote sensing missions for these parameters to those that will be available in the future, including NASA's Atmospheric Observing System (AOS) mission that is part of the Earth System Observatory, as well as the planned European Space Agency/Japan Aerospace Exploration Agency (ESAJAXA) EarthCare mission scheduled for launch in spring 2024; and
- The Science of PACE (program element A.36) – This announcement solicits for a science team to analyze and interpret data from the planned Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE) mission, which is anticipated to launch in early 2024. Its measurements will directly address scientific and application needs to better understand the state of ecosystems and their potential change under future climate scenarios The solicitation will open up once the data are publicly available.

3. Earth Action

The Earth Action (EA) element of ESD supports applied research and applications development projects that enable the use of NASA Earth science information for decision-making.

EA is a new element of ESD, created in FY2023 by combining the Applied Sciences Program with related other end user-centered activities within ESD, including the Greenhouse Gas Center and the Earth Information Center. All components of the Applied Sciences Program (http://appliedsciences.nasa.gov/) are now a part of EA.

EA is strongly aligned with the ES2A Strategy (Section 1) and the top three layers of the pyramid shown in Figure 1: public understanding and exchange, solutions and societal value, and Earth system science and applied research. EA aims to address the strategy by 1) scaling, 2) building bridges, and 3) conducting work in a user-centered way. Each of these items is described in more detail below.

- Scaling: The Applied Sciences Program historically incubated many successful

applied research and applications projects. EA aims to scale the impact of those investments by expanding these projects to support new, additional end-users.

- Building Bridges: EA projects should bridge between the knowledge generated by NASA Earth science and the relevant needs of public and private sector organizations. EA aims to work with R&A (Section 2) to accelerate the cycle between the development of new Earth science research outcomes, the application of that information by end-users, and the identification of new user-driven research needs. To this end, EA projects should leverage developments from across the NASA Earth Science Research Program.
- User-Centered: Projects are expected to have specific public or private sector end-users identified from the project's beginning and involved throughout the lifecycle. A key measure of project-success is the extent to which Earth science information positively impacts the end-users, whether for their decisions, activities, or the communities they support. Many projects aim to ultimately transition capabilities to the end-user for sustainability.

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

- SERVIR Applied Sciences Team (program element A.41);
- Earth Action: Disaster Risk Reduction, Recovery, and Resilience (program element A.42);
- Earth Action: Health and Air Quality (program element A.43);
- Earth Action: Health and Air Quality Applied Sciences Team (program element A.44);
- Earth Action: Ecological Conservation Impact Assessment (program element A.45);
- Earth Action: Wildland Fires (program element A.47); and
- Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (program element A.48).

Topics that may be relevant to Earth Action 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.26);
- NASA ISRO Synthetic Aperture Radar (NISAR) Mission Research and Applications Science Team (program element A.27);
- Remote Sensing Theory (program element A.28);
- Understanding Changes in High Mountain Asia (program element A.30);
- Earth Science Imaging/Sounding Data Analysis from Earth Observing System to Earth System Observatory (program element A.31);
- Precipitation Measurements Mission and CloudSat and CALIPSO Science Team Recompete (program element A.32);
- U.S. Participating Investigator (program element A.34);
- The Science of PACE (program element A.36);
- Decadal Survey Incubation (program element A.55);
- Increasing Participation of Minority Serving Institutions in Earth Science Surface-Based Measurement Networks (program element A.58); and

- New or Modified GLOBE Protocols (program element A.59).

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.

ESTO (http://esto.nasa.gov) maintains a number of program lines through which technology investments are regularly competed through ROSES, and that cover a range of technology readiness levels (TRLs). The following program will be solicited this year:

- Decadal Survey Incubation (program element A.55): 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.

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

- Instrument Incubator Program (program element A.51): 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;

- Advanced Component Technology (ACT) (program element A.52): The ACT program develops a broad array of components and subsystems for instruments and observing systems;
- In-space Validation of Earth Science Technologies (InVEST) (program element A.53): The InVEST program provides a path for some new technologies to be validated in space prior to use in science missions; and
- Sustainable Land Imaging - Technology (SLI-T) (program element A.54): The SLI-T 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;
- Advanced Information Systems Technology (program element A.56): The Advanced Information Systems Technology (AIST) program advances technologies that enable: unique measurement collection capabilities through distributed sensing; optimizing science mission's return on investment through flexible information integration; and agile science investigations through data analytics and artificial intelligence tools and algorithms;
- Technology Development for Support of Wildfire Science, Management, and Disaster Mitigation (program element A.57) – This program enhances the capabilities for existing science instruments for monitoring pre-fire, active-fire, and post-fire situations, reduces the power and mass of these instruments, and enables unprecedented observations in support of wildfire science through distributed observing systems and the information technologies needed for their support.

5. Earth Science Data Systems

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.

The ROSES elements most closely associated with the Earth Surface and Interior Focus Area that are soliciting for proposals in ROSES this year are: A.25 Earth Surface and Interior and A.50 Citizen Science for Earth Systems Program.

Topics relevant to the Earth Science Data Systems Program 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.26); and
- Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (program element A.48).

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 https://www.earthdata.nasa.gov/engage/open-data-services-and-software/data-and-information-policy for the policy). Data needed to validate the scientific conclusions of a peer-reviewed publication resulting from an award (e.g., data underlying figures, maps, and tables in a publication) must be made available at the time of publication. The remaining scientifically useful data, source code for algorithm software, coefficients, calibration and validation data, and ancillary data used to generate products must be made available no later than at the end of the award, consistent with the Open Science and Data Management Plan. Proposers are encouraged to utilize data acquired by the Commercial Smallsat Data Acquisition Program (CSDAP). The CSDAP 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. For an up-to-date list of available data and associated licenses please visit https://earthdata.nasa.gov/csdap. Please check this link regularly, for new data being added to the list as evaluations and procurements are completed.

6. Cross-Divisional Activities

Two elements being solicited in ROSES-24 span the interests of multiple components of the Earth Science Division, so they are called out separately to make clear the way they may engage all the components of the Earth Science Division. There are two such elements this year:

- Increasing Participation of Minority Serving Institutions in Earth Science Surface-Based Measurement Networks program element A.58) – This solicitation funds investigators at Minority Serving Institutions (MSIs) to request installation and

then support analysis and interpretation of resulting data from remote sensing instruments that quantify greenhouse gases (GHGs), such as carbon dioxide and methane, through infrared measurements, such as the EM27/Sun instruments, to complement existing *in situ* sites. This is part of an effort of the U.S. GHG Center to improve data quality and interagency coordination of calibration/validation and data standard, by establishing and expanding a network of ground-based, remote sensing instruments to complement existing *in situ* sites.

Emerging collaborative networks like the COllaborative Carbon Column Observing Network (CoCCON), which NASA partially supports, use similar methodology and provide access to open-source retrieval software to aid in coordination. Data analysis and interpretation should integrate information from the surface-based measurements together with satellite data from NASA and its interagency and international partners. NASA will procure the instruments and provide them to the selected institutions and assure that data will be an integral part of the U.S. GHG Center Measurement Network and shared with the research and applications communities.

- New or Modified GLOBE Protocols (program element A.59) – This solicitation funds proposals for new measurement protocols and modification of existing protocols for the Global Observing Network for the Environment (GLOBE) program, as well as associated training, education, and public engagement materials and evaluation. Protocol proposals that advance Earth system science, connect with existing or emerging cutting-edge Earth system research and application communities, and designed to maximize learning for GLOBE participants are welcome. Protocol proposals that are designed to yield complementary data to advance science and/or application with clear links to past, present, or future NASA Earth science data and/or models are strongly encouraged, including space-, balloon-, airborne-, surface-based remote sensing observations, field expeditions (coastal marine and land), and NASA-funded modeling efforts.

7. 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).

7.1 Education

The Earth Science Division recognizes its essential role in NASA's mission to build capacity and 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.

Since 2016, the SMD Science Engagement and Partnerships Division has supported the Science Activation Program (SciAct) to further enable NASA science experts and content into the learning environment more effectively and efficiently with learners of all ages. Proposers interested in this topic should look at F.6 SciAct for more information.

The Earth Science Division continues 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 of students, educators, scientists, citizen scientists, and partners in relation to GLOBE community engagement and support, science, training, education, and public engagement. It will also continue to oversee the GLOBE Data and Information System.

ESD will potentially solicit new or modified GLOBE measurement protocols in ROSES this year (program element A.59). ESD also continues to welcome proposals in any program element in Earth Science Research Program that incorporate the use of existing GLOBE observational data in conjunction with new data collection and/or modeling to advance understanding in all aspects of Earth system science. Proposers are encouraged to submit to the Citizen Science for Earth Systems Program (program element A.50) if the project's primary goal is to leverage GLOBE Program's capabilities and data to augment and enhance NASA scientific data and capacity through direct participation by members of the general public, including the GLOBE community, to advance understanding of the Earth as a system. Researchers are encouraged to review the latest version of the GLOBE Data User Guide to understand available GLOBE data (https://www.globe.gov/globe-data/globe-data-user-guide). GLOBE 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).

7.2 Early Career Research Program Opportunities

The NASA Earth Science Division recognizes the importance of workforce enrichment. To this end, the Early Career Research Program strives for excellent in Earth Science by empowering the next generation of Earth science researchers to create a diverse and inclusive workforce that enables solutions to benefit society, to respond to changes in the Earth's system, and to support the Earth Science to Action strategy.

The program sponsors the Earth science component of the Future Investigators in NASA Earth and Space Science and Technology (FINESST). FINESST Earth supports graduate student-designed research projects that vary in topic from looking at data systems and technology, putting Earth science research into action, and understanding components of the Earth system. 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 Early Career Investigator Program in Earth Science is not solicited in ROSES this year (program element A.38). This program welcomes innovative research initiatives and seeks to cultivate diverse scientific leadership in Earth System Science., specifically for those just having received their PhD. Projects focus across ESD priorities such the investigator's ability to promote and increase the use of space-based remote sensing, the integration of space-based remote sensing data with other datasets (e.g., surface, air) and into models, and the delivery of actionable Earth science — making Earth science data more usable and impactful for the benefit of humanity. It is solicited every three years; the next solicitation for this is tentatively planned for ROSES-26.

7.3 High-End Computing, Networking, and Storage

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

SMD recognizes the need of such an enabling capability and maintains appropriate high-end computing, networking, and storage for use by the SMD funded investigators. Computing resources are provided through various ROSES 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 use NASA High-End Computing (HEC) resources must follow the instructions given in Section I(e) of the *ROSES Summary of Solicitation* for 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 or link provided in RMS and then attach that (as a separate file of 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 facility location and resource type (central processing units, graphics processing units, commercial cloud, etc.) 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. Charges associated with commercial cloud use will be the responsibility of the project. On-premises resources are provided at no extra cost to the project.

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.

7.4 NASA Earth Exchange

For large-scale high-resolution Earth science data analysis and modeling projects, especially in areas of land surface hydrology, land cover, land use, carbon monitoring and management, terrestrial ecosystems, Earth system digital twins, wildfire science, climate change resilience and assessment, atmospheric chemistry modeling and data assimilation, high-resolution Earth system modeling, research data product generation, and large-scale data analysis, NASA encourages proposing teams to use the NASA Earth Exchange (NEX; https://nasa.gov/nex). NEX is a collaborative supercomputing and data analytics platform that enhances the availability and use of Earth science data from NASA missions and other sources, including models, analysis tools and research results. NEX is an environment that fosters, facilitates, and enables open-source science, knowledge sharing, collaboration, and innovation.

NEX uses the High-End Computing Capability (HECC) facility at NASA Ames Research Center (https://nas.nasa.gov/hecc) and commercial cloud providers. The HEC facility maintains an exascale mass-storage system that allows users to archive and retrieve significant results quickly, reliably, and securely. Any large remote sensing datasets may be staged in the NEX data pools for easy and performant user access. Pre-staged datasets include data from low Earth orbit (Landsat, MODIS, AVHRR and VIIRS) and operational geostationary (GOES 16/17/18, Himawari8, and GEO-KOMPSAT-2) satellites. Ancillary datasets, including high resolution topography, downscaled climate model outputs (NEX-GDDP-CMIP6) and the Ames Global Hyperspectral Synthetic Dataset (AGHSD), and gridded hypertemporal global geostationary (GeoNEX) data are also available in the NEX datapools. GeoNEX global products, generated from the constellation of operational geostationary satellites at a 10-minute time frequency, can be leveraged to address many of the Earth System science questions described in the 2017 Decadal Strategy for Earth Observation from Space.

For atmospheric composition and air quality research, NEX has recently staged WRF-Chem/DART, a regional, ensemble, atmospheric composition (AC) forecast/assimilation/emissions estimation system based on integrating the Weather Research and Forecast (WRF) model with online chemistry (WRF-Chem) into the ensemble Kalman filter based Data Assimilation Research Testbed (DART). The facility also maintains an exascale mass-storage system that allows users to archive and retrieve important results quickly, reliably, and securely.

Proposing teams that desire to use NEX should include a section in their proposal that describes their need for NEX and specifies their data storage and processing needs. Proposers are highly encouraged to contact the NEX team (https://nasa.gov/nex) when developing this section of their proposal. Proposers must also include an Open Science and Data Management Plan as described in Section 1.1 of this overview. 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://www.nasa.gov/nasa-earth-exchange-nex/accessing-nex/.

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

7.5 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 a B777, multiple G-III's, a G-V, a GIV, 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 necessarily 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 (https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=7900&s=4D) and NASA Procedural Requirement Series 7900 (https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7900&s=3D) . 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.