A.28 INTERDISCIPLINARY RESEARCH IN EARTH SCIENCE

NOTICE: Amended November 14, 2022. This amendment delays the proposal due date for this program element due to Hurricane Nicole. Proposals are now due November 23, 2022.

This program element is participating in the Inclusion Plan Pilot Program, see Section 1.3. This Inclusion Plan will not be part of the adjectival ratings nor selection recommendations for this opportunity. Proposals that include developing new datasets must include a data management plan, see Section 2.

1. Scope of the Program

This opportunity is for new and successor interdisciplinary research investigations within NASA's Interdisciplinary Research in Earth Science (IDS) program. Proposed research investigations will meet the following criteria: a) offer a fundamental advance to our understanding of the Earth system; b) be based on remote sensing data, especially satellite observations, but including suborbital sensors as appropriate; c) go beyond correlation of data sets and seek to understand the underlying causality of change through determination of the specific physical, chemical, and/or biological processes involved; d) be truly interdisciplinary in scope by involving traditionally disparate disciplines of the Earth sciences; and e) address at least one of these specific themes:

- Analyzing the Nitrogen Cycle from Space: Integrating Atmospheric Observations and Biogeochemical Models ;
- Ocean-Atmosphere Gas Exchange and Particle Deposition;
- Wildfire Impacts on Ecosystems and Communities ;
- Environmental and Climate Justice Using Earth Observations;
- Processes Across the Land-Ocean Continuum;
- Ocean Worlds: Research at the Interface;
- Earth-Moon Connections in a Changing Climate.

The results of these investigations will improve our capability for both prognostic predictions and retrospective simulations of the Earth system. They will also advance our understanding of the vulnerabilities in human and biogeophysical systems and their relationships to climate extremes, thresholds, and tipping points. Meeting these goals requires approaches that integrate the traditional disciplines of the Earth sciences, as well as innovative and complementary use of models and data.

1.1 Context and History

Since its inception more than a decade ago, NASA's IDS program has advanced the goal of understanding the Earth system by promoting interdisciplinary research and exploiting the vast wealth of data from NASA satellite and airborne sensors. The program's focus has generally aligned with the goals of the U.S. Global Change Research Program (http://globalchange.gov/). Substantial contributions have also been made to Earth system model development, training the next generation of interdisciplinary scientists, and developing the necessary infrastructure to take full advantage of NASA satellite data.

The specific topics of the program have varied through time and this program element represents the development of new elements and the continuation of others. In its most recent prior incarnation IDS (ROSES 2019) these topics were:

- Volcanoes in the Earth System;
- Interactions Between Sea Ice and the Atmosphere;
- Polar Ocean/Biology/Biogeochemical Coupling;
- The Life Cycle of Snow;
- Impacts of urbanization on local and regional hydrometeorology;
- Space Archaeology: Using the Past to Inform the Present and Future;
- Exploring the Microbial Biodiversity of the Atmosphere.

One may see information about awards from IDS-2019 in this PDF under "Selections" on the NSPIRES pages for IDS 2019.

1.2 Potential for Acquisition of Additional Field Data as Part of IDS Investigations

Proposals are expected to utilize existing remote sensing and *in-situ* datasets. While NASA expects IDS investigations typically to be accomplished using publicly available data, NASA also recognizes that some additional data collection through small scale field work may add significantly to the proposed work. Thus, unless otherwise noted in the specific subelement, proposals may include some small-scale field work. The cost for such field work should not exceed 20% of the total project budget. Consistent with NASA Earth Science data policy, all data collected must be made freely and publicly available with no period of exclusive use beyond calibration and validation.

Proposals requiring data from airborne sensors must detail in their budget all costs for acquiring the new data sets, including costs for aircraft hours, deployment costs, mission peculiar costs, data processing costs, and other costs associated with deploying the sensors and aircraft (this includes NASA and non-NASA sensors and platforms). In addition, for any proposed activities requiring NASA aircraft or NASA facility sensors, proposers should submit a Placeholder Flight Request to the Airborne Science Flight Request system at https://airbornescience.nasa.gov/. If the instrument or aircraft are not NASA facilities, proposers must take responsibility for making all arrangements to secure the availability of the needed sensors and aircraft and explain these plans in the proposal.

1.3 Inclusion Plan

An Inclusion Plan, not to exceed two pages and immediately following the Data Management Plan, is required in all proposals. Inclusion is a core NASA value, and diversity and inclusion are prioritized in Strategy 4.1 from *A Vision for Scientific Excellence* (formerly known as the Science Plan). NASA defines diversity broadly as "The entire universe of differences and similarities" and inclusion as "the full participation, belonging, and contribution of organizations and individuals". SMD believes in the importance of diverse and inclusive teams to tackle strategic problems and maximize scientific return, and seeks to promote such opportunities and benefits across the solid-Earth science community. To this end, proposers are to use the 2-page inclusion plan to:

- identify barriers to creating a positive and inclusive working environment for those carrying out the proposed investigation;

- address ways in which the investigation team will work against these barriers to create and sustain such an environment, such as fostering communication and openness amongst the team, involving under-represented groups in proposal activities, etc.;
- discuss contributions the proposed investigation will make to the training and development of a diverse and inclusive scientific workforce, and clearly define roles and responsibilities for all team members towards pursuing those goals;
- consider involvement of organizations and institutions that support and serve under-represented groups including, but not limited to, Historically Black Colleges and Universities, Hispanic-Serving Institutions, Tribal Colleges, and Other Minority Universities. A resource that some proposers may find useful in this regard is the NASA MSI Exchange at https://msiexchange.nasa.gov/.
- identify and address other topics related to diversity, equity, accessibility, and inclusion that the proposing team has identified and seeks to resolve.

All efforts identified under the Inclusion Plan should have clearly stated goals, activities to achieve those goals, and metrics for measuring progress during the award period. If additional funding is needed to implement the plan, it should be included and justified in the budget. Feedback will be provided to the proposers as part of the panel review summaries, but will not contribute to the adjectival ratings or selection recommendations. Note that even though the assessment of the inclusion plan will not be part of the adjectival grade for the proposal and will not inform the selection of proposals, funding will be released to selected institutions only once a satisfactory inclusion plan is approved by the NASA Program Manager of his program element. If additional funding is needed to implement the inclusion plan, it should be stated and included and justified in the budget. SMD plans to invite comments regarding this pilot program from reviewers and proposers after the review is completed. SMD plans to invite comments regarding this pilot program from reviewers and proposers after the review is completed.

2. Interdisciplinary Research Themes, Proposal Details, and Review information

Specific scientific topics and questions are identified as separate subelements within any given year's program element. These topics and questions constitute the complete set of scientific research topics solicited by the IDS program, and no priority should be construed from their relative order. Proposals submitted in response to this element MUST address at least one of these subelements, and proposals MUST identify clearly which subelement or subelements are addressed. Proposed research investigations must also meet all of the following criteria, and each of these should be specifically addressed in the proposal:

- offer a fundamental advance to our understanding of the Earth system;
- be based on remote sensing data, especially satellite observations, but including suborbital sensors as appropriate;
- go beyond correlation of data sets and seek to understand the underlying causality of change through determination of the specific physical, chemical, and/or biological processes involved;

- be truly interdisciplinary in scope by involving traditionally disparate disciplines of the Earth sciences; and
- address at least one of the specific subelements listed in the program element.

Proposals that include developing new datasets must include a data management plan, see Section 1.1 of A.1 The Earth Science Research Overview.

NASA is leading the implementation of Open Source Science (OSS) and proposers should incorporate the principles of OSS to the maximum extent possible in developing their proposals. Details on this may be found at https://science.nasa.gov/open-science-overview.

Proposals should advance our knowledge of interdisciplinary Earth System Science and advance the capability of models in a way that will contribute to the analysis of data from currently-operating and future NASA Earth Science satellites, including those that will constitute the forthcoming Earth System Observatory https://science.nasa.gov/earth-science/earth-system-observatory.

NASA expects to have separate peer review panels for each subelement, and proposals will be assigned to one or more panels based on the proposer's identification of the appropriate subelement, as well as NASA's assessment of proposal content. While NASA expects to select proposals in each of the subelements, NASA reserves the right to select proposals in none, some, or all of these depending on the nature and distribution of proposals received and the outcome of the peer review process.

In this program element, there are two classes of elements – Subelements 1-5 are "large," each with total funding of ~$2M/year contemplated, while Subelements 6-7 are "small," each with total funding of ~$750K/year contemplated.

Note that for these subelements, numerous potential topics are included. Given the number of such topics and the funding limitations, no commitment is made to fund proposals related to each of the subtopics listed. Balance among these potential topics will be considered as part of the programmatic considerations being made during the selection process.

2.1 Subelement 1: Analyzing the Nitrogen Cycle from Space: Integrating Atmospheric Observations and Biogeochemical Models

Over the past century, human activities such as fossil fuel combustion, and chemical fertilizer production/application have dramatically impacted the natural nitrogen (N) cycle. Reactive nitrogen (N_r) emitted to the atmosphere by human activities is eventually returned to the Earth's surface though either wet or dry deposition. Excessive N deposition can negatively impact terrestrial, estuarine and coastal ecosystems. Ammonia (NH_3) and nitrogen dioxide (NO_2) are important to atmospheric chemistry and are primary components of atmospheric aerosols. In addition, ammonium (NH_4^+) and nitrate (NO_3^-) are often the nutrients limiting the growth of many ecosystems and can result in eutrophication, toxic algal blooms, hypoxic, or anoxic conditions in estuarine and coastal aquatic environments if found in excess. The methods of estimating atmospheric N_r emissions and subsequent deposition include a combination of ground-based monitoring, atmospheric chemical transport monitoring, and constraints from satellite atmospheric composition column observations. Modeling approaches have also been useful to determine N sources, sinks, and local and global distribution, though uncertainties persist regarding sources and sinks in terrestrial and aquatic environments.

The OMI and TROPOMI instruments have provided multiple years of high quality NO_2 observations from space, helping to observe large point sources of NO_2 emissions and constrain the NOx budget. The recent advancements in NH_3 retrievals from the Cross-track Infrared Sounder (CrIS), Atmospheric Infrared Sounder (AIRS), and Infrared Atmospheric Sounding Interferometer (IASI) infrared sounder satellite instruments can be used to help constrain NH_3 emissions from various sources. Using satellite observations to provide top-down constraints on NO_2 and NH_3 emissions (both anthropogenic and natural) should help improve our understanding of the reactive N and reduce model uncertainties. With satellite N_r observations, atmospheric and ecological communities have a unique new opportunity to examine N budgets and fluxes as well as the source/receptor impacts on various terrestrial and aquatic ecosystems.

We solicit studies that can advance our understanding of:

- The influence of land surface processes, land cover and land use, or marine outgassing of N_r on the atmosphere;
- Detection and understanding of hot spots on the land surface for emissions of Nr at local, regional and global scales;
- Improved understanding of the impacts of agricultural, industrial, and forest management activities on the nitrogen cycle;
- The movement of reactive nitrogen in the atmosphere and deposition to ecosystems at regional to global scales.
- Improved biogeochemical modeling of impacts of N_r deposition on terrestrial and aquatic ecosystems using atmospheric satellite observations of N_r; and
- Improved understanding of the impact of atmospheric N_r deposition on ecosystem services and subsequent impacts on society.

Note that the number of proposals selected for the above topics may be zero, one, or more than one. The distribution of proposals selected will depend on the number and quality of proposals received in each of these topics. In addition, ecosystem services are defined as one or more of the direct or indirect benefits that humans derive from ecosystems, e.g., food, fiber, and water, regulating services such as flood/erosion/disease, cultural services such as spiritual, recreational and cultural benefits, and life support services such as nutrient cycling and maintenance of air quality.

In addressing this subelement, proposals shall:

- Make significant use of space based NO_2 and NH_3 products.
- Be interdisciplinary in scope and specifically address atmosphere-ecosystem connections; proposals that address only a single component of the Earth System will be considered non-responsive.
- Include both biological/ecological (terrestrial, aquatic and/or hydrological) and atmospheric scientist investigators.

- Go beyond correlation of datasets and, wherever possible, gain new insight into the physical processes and underlying causality; and
- Address weaknesses in existing atmospheric and ecosystem models.

2.2 Subelement 2: Ocean-Atmosphere Gas Exchange and Particle Deposition

The ocean encompasses over 70% of the Earth's surface, and the exchange of gases across the air-sea interface is fundamental to the processes that influence weather and regulate climate. While a substantial amount of research has been focused on air-sea gas exchange and its environmental controls, there remain significant knowledge gaps pertaining to the flux of climate-relevant gases between the ocean and atmosphere that must be addressed to better predict future climate scenarios. Physical oceanographic conditions are critical drivers and regulators of air-sea gas exchange, which, in turn, has significant impacts on ocean carbon biogeochemistry and ocean ecosystem health.

The magnitude of air-sea gas exchange varies on a wide range of temporal scales, including seasonal and multi-decadal variations. Large-scale oscillations, such as the El Niño Southern Oscillation (ENSO) and Atlantic Multidecadal Oscillation (AMO), impact the lower atmosphere and surface ocean exchange across scales that are largely not well understood. Improving the understanding of gas exchange processes across the air-sea interface, as well as the response of surface ocean biology and biogeochemistry to changes in atmospheric forcing, has direct impacts on our capacity to manage ecosystems, and to develop and support a sustainable blue economy. Further constraining surface physical processes and air-sea fluxes will advance our understanding and predictive capabilities of oceanic biogeochemical processes and of the ocean/atmosphere state, enabling reduced uncertainty in our predictions of gas exchange and climate variability. Satellite observations of atmospheric greenhouse gases (GHGs; i.e., carbon dioxide, methane, nitrous oxide, etc.), trace gases (volatile organic compounds (VOCs) including halogenated VOCs); sea-surface temperature, vector winds, ocean salinity, sea ice age and extent, biogeochemistry, and biology are all critical to understanding and monitoring of ocean/atmosphere gas fluxes, complementing the often sparse *in-situ* measurements and enabling synoptic atlases and other synthetic data products to be developed. Coupled ocean-atmosphere models are also instrumental for quantifying air-sea gas exchange and advancing the understanding of atmospheric nutrient deposition in the oceans and the corresponding ecosystem impacts.

This subelement aligns with the goals of the US SOLAS Science Plan and contributes to advancing SOLAS science within the U.S. research community. It also takes into consideration the recommendations of the NASEM Report "*A Research Strategy for Ocean Carbon Dioxide Removal and Sequestration*," and contributes toward the goals of the Ocean Policy Committee. The subelement specifically solicits research that would further advance our understanding in the following areas: (1) Greenhouse gases and reactive trace gases emitted by the ocean (e.g., surface ocean exchange processes, feedback mechanisms, etc.) and (2) Atmospheric deposition of particles and ocean biogeochemistry.

2.2.1 *Trace gas exchange to/from the ocean*

Atmospheric GHG and reactive trace gas fluxes and concentrations are mainly regulated by physical and biogeochemical processes in the upper ocean. This research topic seeks to address topics such as better constraining surface ocean exchange processes and sources of natural variability in air-sea gas exchange, resolving temporal variability in regional air-sea fluxes, and identifying environmental feedbacks on varying timescales associated with physical and biological responses. In addition to GHGs, many VOCs that influence regional atmospheric chemistry and global climate are emitted from the ocean and their source is often associated with phytoplankton, macroalgae, and/or chromophoric dissolved organic matter (CDOM). Examples of reactive VOCs emitted from the ocean include: dimethyl sulfide (CH_3SCH_3), acetaldehyde (CH_3CHO), acetone (CH_3COCH_3), bromoform ($CHBr_3$), dibromomethane (CH_2Br_2), dibromochloromethane ($CHClBr_2$), and bromodichloromethane ($CHBrCl_2$).

2.2.2 *Atmospheric deposition of particles and ocean biogeochemistry*

Dust events, volcanic eruptions and biomass burning can inject in the atmosphere nutrient-containing particles that subsequently precipitate into the marine environment, potentially altering ocean primary production and carbon uptake. This research topic seeks to further understand processes involved in atmospheric deposition and its impacts on ocean biology and biogeochemistry, addressing issues such as better understanding deposition processes as they pertain to potential future climate-induced changes and feedbacks.

2.3 Subelement 3: Wildfire Impacts on Ecosystems and Communities

Wildfire is a complex process that spans multiple components of the Earth System. Increasing trends in the frequency and intensity of wildfires are occurring, particularly with notable severe fire seasons in the western United States and elsewhere across the globe in recent years. These increases in uncharacteristically large and severe wildfires have profound effects on ecosystems and thus on the human communities both adjacent to and far removed from the burned area. Ecosystem impacts include alteration of biogeochemical cycles, impacts on vegetation community composition, structure, and function as well as alteration of the hydrological cycle, among others. Impacts on human communities such as degraded water and air quality as well as increased risks of landslides and flooding events, may ultimately have severe negative impacts on human health and livelihoods. Increases in the frequency, size, and severity of wildfires is expected to continue under climate change. Understanding the changing characteristics of these wildfires and associated impacts on ecosystem biogeochemistry, hydrology, vegetation community composition and structure, wildlife, atmospheric feedbacks, and human communities is a critical challenge in Earth system science.

Over the last decade significant advances have been made in the remote sensing and modelling of wildfire and associated impacts. Earth Observation data and models are routinely used to assess the pre-, active, and post-fire environments, for example, to detect, track, and predict wildfire spread, map burned areas and fire severity, and characterize smoke transport and impacts on air quality. However, despite these advances, there are still significant gaps in fire related observations and modelling. Data from many new NASA satellites (e.g., ECOSTRESS, GEDI, ICESat-2, etc.), commercial satellites, suborbital, aircraft (e.g., AVIRIS/AVIRIS-ng, HyTES, LVIS), and ground-based sensors are now available that could start to fill important observational gaps in the pre-, active, and post-fire environments, with advancements continuing through the development and execution of NASA's Earth System Observatory missions (e.g., Surface Biology and Geology; Atmosphere Observing System; https://science.nasa.gov/earth-science/earth-system-observatory).

NASA seeks proposals for interdisciplinary studies of wildfire impacts on terrestrial ecosystems, feedbacks to the atmosphere and consequences to human communities. It is mandatory that proposals satisfy the requirements of IDS investigations by proposing a fundamental scientific advance, remote-sensing based, process-focused, and truly interdisciplinary research. Potential topics include (note that the selection of proposals may include none, one, or more than one for each of the indicated topics, with the distribution of proposals selected dependent on the distribution and quality of proposals received in these areas):

- Integrated observational and modeling studies of wildfire processes including detailed treatment of land, vegetation, atmospheric and radiative effects, to advance our understanding of extreme fire impacts on ecosystems, biogeochemical cycles, atmospheric composition, water quality, and air quality.
- Enhanced use of existing and/or new observations to provide the key inputs for improving models of fire spread, smoke transport, and greenhouse gas emissions.
- Improved understanding of the impacts of climate change on wildfire properties (e.g., frequency, intensity, severity) and associated impacts on ecosystems and human communities.
- Improved understanding of the role that wildfire behavior plays in the post-fire environment including long-term recovery of vegetation composition and structure and ecosystem function over multidecadal time spans.
- Integrated remote sensing and modeling to predict post-fire erosion including landslide risk and hazard and related impacts to water quality.

2.4 Subelement 4: Environmental and Climate Justice using Earth Observations

The NASA Earth Science Division (ESD) recognizes that the world's poorest and marginalized communities are disproportionately influenced by environmental exposures and vulnerabilities. This is also notably the case for impacts related to climate change, referred to as climate justice. NASA ESD's commitment to environmental justice (EJ) and climate justice (CJ) is aligned with Executive Orders 13985 and 14008 and is based on the understanding that the use of NASA data, products, and personnel can and should inform the just treatment and meaningful involvement of all people – regardless of race, color, national origin, income, or ability – with respect to development, implementation, and evaluation of programs, practices, and activities that affect human health and the environment.

We extend the White House Environmental Justice Advisory Council (WHEJAC) definition for EJ communities (WHEJAC Interim Final Recommendations, May 13, 2021, page 79) to include CJ. In this subelement, we use EJ and CJ communities to mean geographic locations around the globe with significant representation of minoritized populations, low-income persons, and/or indigenous persons or members of Tribal nations, where such individuals experience, or are at risk of experiencing, more adverse human health, environmental, and/or climate change impacts.

NASA ESD not only aims to diversify Earth science research and applications communities with representation from all backgrounds but also to support EJ and CJ communities by expanding awareness, accessibility, and use of Earth data. ESD activities that focus on EJ/CJ merge NASA's Earth observations with socioeconomic data and, when combined with external social science data and expertise, can help better serve the needs of EJ and CJ communities.

NASA Earth Science can play an important role in addressing questions at the intersection of Earth observations and EJ/CJ. This subelement supports opportunities for the research and applications communities to work with colleagues in social science disciplines to address complex and challenging problems that are relevant to EJ communities worldwide.

In this subelement, proposed investigator teams must include an end-user who is part of or who works directly with underserved communities, as a funded co-investigator on the project.

NASA encourages proposals that address high priority EJ/CJ needs (as defined above) through the following topics:

- Air pollution impacts on human health
- Urbanization impacts on heat islands effects and/or changes in precipitation
- Land cover/use change impacts on food, energy, and/or water
- Impacts of upstream activities on coastal communities
- Exposure and vulnerability to geohazards (e.g., infrastructure and flooding, landslides, etc.)

All proposals must directly address the interfaces between the Earth processes of interest and human factors (e.g., decisions, cultures, policies, geographic disparities, etc.). Proposals must use remotely sensed data integrated with socio-economic data as a critical component of the proposal. Preference will be given to proposals that use satellite-based remote sensing; however, other NASA data products from airborne campaigns, ground-based stations, or model output may be used for the proposed research

2.5 Subelement 5: Processes Across the Land-Ocean Continuum

This sub-element solicits proposals to study processes across the land-ocean interface to better understand how the ecosystems are interconnected and how changes in one may cascade into or impact the other. Traditionally, fluxes of material from land to inland water bodies (e.g., rivers, freshwater wetlands) and coasts (coastal marshlands, mangrove forests) have been partitioned into, and studied as, its individual components (e.g., agriculture, natural grassland, urban, forest, inland water and coastal ocean), which precludes observing this continuum as a holistic entity. Understanding the interconnection between ecosystems requires an integrated and interdisciplinary approach, considering hydrologic and nutrients cycles across land, freshwater, and marine environments. This subelement is focused on the impacts of fast (yearly scale) natural and human-induced processes. Proposals on slow processes (decadal scale), such as sea-level rise impact in the coastal zone, are beyond the scope of this subelement (proposers interested in this time scale may may want to examine Element A.52, Earth System Science for Building Coastal Reslience).

Some examples of land-cover and land-use change and its impacts on aquatic ecosystem components are provided below; these topics require an interdisciplinary approach to advance our understanding of the impacts by natural processes and human-induced alterations across the land-ocean continuum, both now and in the future. Note that the selection of proposals may include none, one, or more than one for each of the indicated topics, with the distribution of proposals selected dependent on the distribution and quality of proposals received in these areas):

Agricultural expansion and intensification: Tillage of the land and deforestation for agricultural expansion alter infiltration and runoff characteristics affecting other surface hydrology variables, e.g., groundwater recharge, sediment and water yield, and evapotranspiration. The removal of surface water and groundwater for irrigation affects ecosystems that depend upon natural water distribution. The use of fertilizers, with excess of nutrients or pesticides lead to contamination of inland waters, which may further propagate to coastal marine habitats, resulting in a degradation of water quality including eutrophication, toxic algal blooms, and hypoxic conditions. On the other hand, climate change-induced reduction in precipitation may lead to increases in crop irrigation, where excess runoff, affects streamflow, groundwater, and ultimately reaches wetlands and marshlands. Extreme rainfall events cause a major increase in runoff of sediment and nutrients impacting water quality and challenging effective water management.

Urbanization: Removal of water from streams and groundwater systems to supply the residential water and agricultural irrigation needs of growing cities and surrounding areas can impact surface and groundwater reservoirs. Many urban areas are located in the coastal zone, where extraction of freshwater can lead to increasing ground water salinization. As vegetation is replaced by the built environment, water infiltration decreases and runoff from impervious surfaces, such as highways, parking lots and buildings, increases, often leading to flooding. Intensifying climate stressors affect hydrologic changes, and more frequent extreme events (floods, droughts and fires) may further compound the anthropogenic effects.

Wetland conversion: Urban development and agricultural land conversion in coastal regions are often accomplished by draining wetlands. This leads to reduced groundwater recharge and increases the risk of flooding. Also, draining wetlands, which are among the most biologically productive ecosystems on Earth, adversely impacts biodiversity and often has cascading effects on nearby coastal ecosystems.

Proposers to this subelement should state how their proposal advances the interdisciplinary science of land-ocean process interactions in the context of previous research and highlight the novel aspects of the proposed research.

Elemental cycling and transformation across the land-ocean continuum: Changes within terrestrial ecosystems affect how elements flow from the land through inland aquatic systems and to the coastal ocean. These changes in the movement and cycling of elements across the land-ocean continuum have the power to impact the structure and function of both terrestrial and aquatic ecosystems. Waterways, including rivers, lakes, and dams, serve as conduits that transport these elements. Increasing climate stressors adds a layer of complexity when it comes to predicting how water quality and availability are impacted by future changes in land use. The quantification of these changes is a challenge, requiring temporally and spatially concurrent observations of, but not limited to, the composition of aquatic and terrestrial ecosystems, land-use/land-cover change (including natural and human-induced disturbance), pre- and post-disturbance patterns of temperature and precipitation, and consequences of hazards, such as flood, drought, and fire.

2.6 Subelement 6: Ocean Worlds: Research at the Interface

In ocean worlds, including our own Earth, important physical and biogeochemical processes occur at interfaces; on Earth, processes occurring at interfaces between the solid Earth, water, ice, soil, and air significantly influence and control chemical cycling, energy flows, and the availability of resources that are necessary for life. Processes at interfaces take place across a wide range of temporal and spatial scales. These regions are critical for life, yet, because of the challenges that exist in capturing the wide range of processes and drivers that occur at those interfaces, these areas remain poorly described even on Earth. For example, there still remains a wide range of rates of transformation, and biogeochemical and biological constituents and processes at interfaces, including phytoplankton and microbes, that have not been adequately characterized on Earth. In addition, models that can capture interface workings on Earth and on ocean worlds on other planets and moons are important; however, many challenges such as inadequate characterization of smaller scale processes. As most ocean worlds are frozen, linking Earth's ocean-ice interactions (for example geochemical cycling and climate response of ice shelves) with those that likely also operate on other ocean worlds means that exploring these physical processes on Earth also provides context for exploring other ocean worlds.

This particular topic seeks investigations that better characterize processes that take place at the ocean-ice interface, with an eye towards improved characterization of interfaces through satellite remote sensing and modeling, to better understand critical physical processes that happen at those interfaces (radiation, thermal, salinity, mixing, etc.) and how these in turn affect biochemistry and biology, what essential parameters govern these ocean-ice interface processes, how these dynamics change spatially and temporally, and how biology (or biosignatures) can be linked to environmental conditions and processes. These studies are expected to advance our understanding of biogeochemistry and life on Earth in the face of climate change, and further the understanding of dynamics of habitable worlds. Characterizing processes that occur at interfaces on Earth and other ocean worlds will require a multidisciplinary framework and an interdisciplinary approach that draws on multiple fields of expertise. Terrestrial and extraterrestrial ocean and ice scientists are expected to work collaboratively to measure and model spatial and temporal dynamics, determine essential parameters that govern interface processes, and evaluate new and existing technologies to access and study dynamics of habitable worlds.

Note that the selection of proposals within this subelement may include none, one, or more than one for each of the indicated topics, with the distribution of proposals selected dependent on the distribution and quality of proposals received in these areas.

2.7 Subelement 7: Earth-Moon Connections in a Changing Climate

Understanding and predicting Earth's climate change and preparing for human exploration of the Moon in Artemis are among the top priorities for NASA. While each of those priorities is addressed by dedicated programs at NASA, an obvious physical connection between the Earth and its moon warrants a joint look at both missions through investigation of the effects of climate change on the Earth-Moon system. As humanity is influencing Earth's climate system, do our actions have far-reaching consequences beyond our home planet?

The Earth and the Moon are directly connected through their gravitational interaction and shared angular momentum. The magnitude of the gravitational pull varies with distance between the two objects and the gradient in the Moon's gravitational field generates tides in Earth's oceans as well as solid body tides in the solid Earth and Moon. Bound by the conservation of the angular momentum of the Earth-Moon system, Earth's orbital changes are offset by those of the Moon. This conservation and transfer of angular momentum between the Earth and Moon explains the observation that the Moon is gradually moving farther away from Earth, resulting in slowing of the Earth's rotation rate and an increase in the length of its day.

Lesser-studied variations in the Earth-Moon system are those induced by the ongoing and projected changes in the Earth's climate system, including rising sea level, changes in ocean tides impacted by local coastal processes, and redistribution of mass due to cryospheric and hydrological changes. Per the recent science consensus of the International Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), an additional global mean sea level increase of 0.5 m towards the end of the century is inevitable, with a likely increase of up to a meter depending on the future that humanity chooses. With the two celestial bodies being intimately and directly linked, are there any measurable feedbacks to the Earth-Moon systems with the changes on Earth as a result of climate change, now or in the future?

The intent of this sub-element is to determine to what extent there is linkage between the physics of the Earth's ocean-climate processes and the parameters of the lunar orbit (distance, libration magnitude, etc.) and to identify any potential feedbacks between the lunar orbit and Earth's ocean processes. In particular, we seek investigations answering a two-part question about the Earth-Moon system changes and feedback responses:

1. Are there any changes to lunar orbital parameters that can be attributed to Earth's changing climate that occurred over the past decades? What are the magnitudes of these changes? What are the expected changes to lunar orbital parameters related to projected climate scenarios, as provided by the IPCC AR6? Do projected future changes in sea level, ocean circulation, and mass redistribution produce measurable impacts on the Earth-Moon system?
2. Do the climate-induced changes to the Earth-Moon system result in any observable feedback loop responses that could modulate Earth's ocean changes, e.g., through modified tidal forcing, ocean tides, and sea level rise? What is the

magnitude of those expected feedback processes? Are these effects significant enough that they should be incorporated into current climate and ocean models, e.g., ocean tides and sea level response?

Proposal teams are expected to be interdisciplinary with expertise to investigate potential connections between Earth ocean climate processes and lunar orbital mechanics. Proposers are encouraged to use a wide range of NASA data and models, including (but not limited to) satellite altimetry (TOPEX/Poseidon, Jason-1, 2, 3, Sentinel-6 MF) and gravity missions (GRACE, GRACE-FO), tide gauge records, data from Lunar Laser Ranging (LLR) available on the CDDIS, APOLLO (Apache point lunar laser), GRAIL (gravity field of the Moon; Gravity Recovery and Interior Laboratory), LRO (Lunar Reconnaissance Orbiter) data, as well as theoretical, numerical and climate simulations if appropriate.

As the first science collaboration between the Physical Oceanography Program of the Earth Science Division and Planetary Science Division, this subelement is to advance the priorities of both divisions through the investigation of coupled processes impacting both Earth's ocean physics and the lunar orbit, thus jointly advancing both NASA's climate change and Artemis missions.

3. Summary of Key Information

Expected program budget for new awards	~ $11.5M Total ~$2.0M/year each for subelements 1-5; ~$0.75 M/year each for subelements 6 and 7
Number of awards anticipated	~ 4-5 each for subelements 1-5; 2-5 each for subelements 6 and 7
Maximum duration of awards	3 years
Due date for Notice of Intent to propose (NOI)	See Tables 2 and 3 of this ROSES NRA
Due date for proposals	See Tables 2 and 3 of this ROSES NRA
Planning date for start of investigation	No earlier than 6 months after the proposal due date.
Page limit for the central Science/Technical/Management section of proposal	15 pp; see also Table 1 of *ROSES*-2022 and the *Guidebook for Proposers*
Relevance	This program is relevant to the Earth Science questions and goals in the NASA Science Plan. Proposals that are relevant to this program are, by definition, relevant to NASA.
General information and overview of this solicitation	See the *ROSES-2022 Summary of Solicitation*
General requirements for content of proposals	See A.1 the Earth Science Research Program Overview, and Section IV and Table 1 of *ROSES*-2022.
Detailed instructions for the preparation and submission of proposals	See NSPIRES Online Help, the *NASA Guidebook for Proposers* and Section IV(b) of the *ROSES Summary of Solicitation*.

Submission medium	Electronic proposal submission is required; no hard copy is permitted.
Web site for submission of proposal via NSPIRES	http://nspires.nasaprs.com/ (help desk available at nspires-help@nasaprs.com or (202) 479-9376)
Web site for submission of proposal via Grants.gov	http://grants.gov/ (help desk available at support@grants.gov or (800) 518-4726)
Funding opportunity number for downloading an application package from Grants.gov	NNH22ZDA001N-IDS
Main point of contact concerning this program. See POCs for specific subelements below.	Kathy Hibbard Earth Science Division Science Mission Directorate National Aeronautics and Space Administration Washington, DC 20546-0001 Telephone: (202) 358-0682 Email: Kathleen.A.Hibbard@nasa.gov

General questions about the IDS Program should be directed to the point of contact above. Questions about specific subelements should be directed to those listed below, all of whom share the same mailing address given above.

NAME	PROGRAM RESPONSIBILITY	TELEPHONE	EMAIL
Barry Lefer	Subelement 1	202-358-3857	Barry.Lefer@nasa.gov
Laura Lorenzoni	Subelement 2	202-358-0917	Laura.Lorenzoni@nasa.gov
Mike Falkowski	Subelement 3	202-358-1431	Michael.Falkowski@nasa.gov
Jared Entin	Subelement 4	202-358-0275	Jared.K.Entin@nasa.gov
Garik Gutman	Subelement 5	202.358.0260	Garik.Gutman@nasa.gov
Thorsten Markus[1]	Subelement 6	202-358-3860	Thorsten.Markus@nasa.gov
Nadya Vinogradova Shiffer[2]	Subelement 7	202-358-0976	nadya@nasa.gov

1. Questions regarding planetary aspects of Subelement 6 may be addressed to Mary Voytek (Mary.Voytek-1@nasa.gov, 202-358-1577) of the Planetary Sciences Division.

2. Questions regarding specific lunar aspects of Subelement 7 may be addressed to Amanda Nahm (Amanda.L.Nahm@nasa.gov, 202-281-5326) of the Planetary Sciences Division.