A.32 INTERDISCIPLINARY RESEARCH IN EARTH SCIENCE

1. Scope of the Program

This solicitation 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 the specific themes listed this solicitation:

- 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.

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 (see prior program elements and awards at nspires.nasaprs.com), and this program element represents the development of new elements and the continuation of others. In its most recent prior incarnation IDS (ROSES 2016) these topics were:

- Understanding the Global Sources and Sinks of Methane;
- Ecology at Land/Water Interfaces – Human and Environmental Interfaces;
- Understanding the Linkages Among Fluvial and Solid Earth Hazards;
- Life in a Moving Ocean;
- Partitioning of Carbon Between the Atmosphere and Biosphere.

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.

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 developing significant new datasets must include a data management plan. 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 "large," each with a total selection of ~ $2M/year contemplated, while Subelements 6-7 are "small," each with a total selection 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 review process.

2.1 Subelement 1: Volcanoes in the Earth System

Volcanic emissions fundamentally connect processes in the Earth's interior and atmosphere. SO_2, CO_2, ash, and associated aerosols can provide telltale signs of magmatic processes and volcanic system evolution, state of unrest, and eruption characteristics; while delivering important atmospheric forcing with implications for radiative budget, cloud formation, ozone depletion and other changes to atmospheric composition, and short- to long-term climate variations. While advancements have been made on these topics through improved spectral imaging, lidar, radar, modeling, and other techniques, further exploring connections between near-source volcanic and atmospheric processes stands to yield a step change in understanding these coupled systems. This subelement seeks proposals from teams of volcanologists and atmospheric scientists that bridge top-down perspectives of atmospheric processes and properties with bottoms-up perspectives of magmatic systems and erupted products towards this goal.

SO_2 is the volcanic gas most readily measured from space, and it is also responsible for much of the impact of eruptions on climate. Satellite measurements of SO_2 are useful for detecting eruptions, estimating global volcanic fluxes and recycling of other volatile species, and tracking volcanic clouds that may be hazardous to aviation in near real time. Techniques for measuring volcanic CO_2 from space have been developed, especially for OCO-3, and could lead to earlier detection of pre-eruptive volcanic degassing. Since current satellite-based remote sensing observations of volcanic gases are dominated by SO_2, obtaining a complete volatile inventory for explosive eruptions required for a full chemistry simulation of volcanic plumes is still a major challenge.

Recommendations from the recent National Academies of Sciences, Engineering, and Medicine report *Volcanic Eruptions and Their Repose, Unrest, Precursors, and Timing* (ERUPT; NASEM, 2017; https://doi.org/10.17226/24650) and *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space* (Decadal Survey; NASEM, 2018; https://www.nap.edu/catalog/24938) identify a number of priorities for understanding volcanoes in the Earth system. The ERUPT report identified advances in experimental and computational models for volcanic processes, combined with enhanced monitoring (including spatially and temporally enhanced remote sensing of gas emissions), as the pathway to enable model-based forecasting, which would constitute a paradigm shift for volcano science. The largest-volume explosive eruptions have yet to be observed with modern instruments and characterized quantitatively. It remains uncertain how effectively observations of volcanic plumes from relatively small eruptions scale up to very large eruptions. For example, the rate and processes of radial spreading of large plumes in the atmosphere may vary with the scale of the eruption, and the role of transient behavior of emissions in the largest volcanic eruptions are uncertain. Most dispersal models treat fine volcanic particles and gases as passive tracers in the atmosphere such that the plume itself has no impact on atmospheric temperature and wind patterns, an assumption that may be violated in moderate to large eruptions. These challenges suggest physics-based modeling as a primary need. Retrospective analyses of well-known systems with sufficient observations could play a key role here. Volcanic aerosol and gas concentration measurements are a high priority. For the short-lived forcers in particular, the precursor emissions together with a self-consistent meteorology are needed to obtain accurate global distributions and thus the spatially-dependent forcings.

NASA has also developed a Major Volcanic Eruption Response Plan (NASA, 2018; https://acd-ext.gsfc.nasa.gov/Documents/NASA_reports/), to include satellite, airborne, balloon, and ground-based observations, together with modeling in order to capture and interpret scientifically relevant data as close to event initiation as possible. The paucity of well-observed large eruptions poses a number of challenges. There is only about a 1 percent chance that a Volcanic Explosivity Index (VEI) ≥ 6 event will happen in a given year. Though such events are relatively infrequent, the consequences of these large eruptions are significant, both from hazards and climate perspectives. Thus, it is critical that the science community prepare to make comprehensive and high-quality observations of the next major eruption, regardless of where on Earth it is located. It is likely that the next major eruption will occur at a completely unmonitored and poorly characterized volcano, because (1) instrumentally monitored volcanoes tend to be those which have erupted in recent history, and (2) long periods of repose may be directly correlated with erupted volume. Thus, the initial detection of precursory unrest prior to a major eruption is likely to be made via satellite. Developing observing and analysis practices applied to current passively degassing and erupting volcanoes could help establish best practices to leverage in the event of a major eruption.
A suite of spaceborne instruments are needed to observe various stages and components of erupted products. Example observations and their capabilities include:

- Hyperspectral UV, near infrared, and TIR data are used to measure SO_2, H_2S, CO_2, and ash emissions;
- Space-borne lidar and radar are used to estimate plume altitude;
- Multispectral TIR data from ASTER have been used to quantify passive SO_2 degassing at scales less than 1 km;
- MODIS and OMI data to calculate gas fluxes and lava-discharge rates;
- OCO-2 data to successfully identify point-source volcanic CO_2 plumes;
- MISR to retrieve gas and ash plume height and thickness;
- CALIPSO to detect volcanic ash plumes; CALIPSO is used in support of commercial aviation operation;
- Global Navigation Satellite System (GNSS) signal-to-noise ratio to detect the timing and height of ash-laden plumes;
- The 2017-2018 HyspIRI Hawaii preparatory airborne campaigns including data from the AVIRIS, MASTER, PRISM, and HyTES instruments onboard the NASA ER-2 aircraft to measure the Kilauea volcano SO_2 plumes; and

- ECOSTRESS, launched in June, 2018, which could provide an SO_2 imaging capability analogous to ASTER, but with a much shorter repeat interval.

Combined, these and other tools offer a range of possibilities to connect the observed volcanic and atmospheric processes.

In this subelement, NASA requests interdisciplinary proposals that pose connected scientific hypotheses addressing both magmatic and atmospheric processes and/or properties. Given the large number of relevant topics and the limited number of selections planned, NASA may not fund proposals addressing all areas of interest. Potential areas of consideration include, but are not limited to:

- Eruptive source distribution and transient behavior, and their impacts on the atmosphere;
- Large, persistent volcanic eruptions and their effect on local weather and precipitation patterns at scales of weeks to months;
- Refining fluxes of volcanic gases and aerosols for improved predictions from weather forecasting, climate, and air-traffic control models;
- Inter-annual and decadal variations of the natural radiative forcings of volcanic aerosols;
- Observing and analysis approaches applied to current passively degassing and erupting volcanoes that could help establish best practices to leverage in the event of a major eruption.

In addressing this subelement, proposals are expected to:

- Make significant use of space-based remote sensing;
- Be interdisciplinary in scope and specifically address magmatic system-atmosphere connections; proposals that address only a single component will be considered nonresponsive; and
- Include both volcanologist and atmospheric scientist investigators.

2.2 Subelement 2: Interactions Between Sea Ice and the Atmosphere

Conditions in the Earth’s polar regions are changing rapidly. While some of these changes are well-characterized by remote sensing, their drivers and subsequent impact on other components of the Earth system are poorly understood. Notz and Stroeve (2016) [see Notz, D. and J. Stroeve, 2016, *Observed Arctic sea-ice loss directly follows anthropogenic CO2 emission*, Science, 354(6313):747-750, DOI: 10.1126/science.aag2345.] observed a linear relationship between cumulative CO_2 emissions and September Arctic sea ice area. This empirical relationship depends on the persistence of the currently poorly understood processes and feedbacks in the Arctic sea ice-ocean-atmosphere system. Changes in the processes regulating the Arctic energy budget must be better understood to improve our predictive modeling capability.

Among the largest unknowns are the couplings between sea ice and different components of the atmospheric system. Some of the connections are straightforward. For example, atmospheric temperatures are the primary driver of sea ice formation and sea ice, in turn, moderates the flux of mass and energy between the atmosphere and ocean. Weather, especially clouds, wind, and precipitation affect sea ice characteristics directly while also driving sea ice motion, setting its extent, and affecting its seasonal survival. However, other critical processes are not well characterized. In particular, the relationships between fluxes of moisture, gases, and aerosols from sea ice leads and the impact on the local radiative energy balance through clouds, fog and other forcings.

Over the last decade, significant advances have been made in remote sensing of the polar regions. Observations from many satellite and suborbital sensors are now available that could help constrain the relationships between sea ice and the atmosphere. Sea ice concentration, motion, freeboard, and other properties are available from passive microwave (DMSP), radar (SAR and altimetry), imagery (MODIS and others), lidar (ICESat, ICESat-2 and IceBridge), and other products. Extensive atmospheric, radiation, cloud and other data sets are also available from a range of satellites and sensors, especially CloudSat, CALIPSO, TERRA and AQUA, as well as the ARISE suborbital mission and NASA's AERONET and MPLNET surface-based installations. Derived products (e.g. sea ice thickness, lead locations) and reanalyses (e.g. MERRA-2) are also available to infer other information about the Arctic system, such as precipitation, wind speeds, and temperatures.

Combined, these tools offer a range of possibilities to connect the observed changes in sea ice with the atmosphere.

In this subelement, NASA requests interdisciplinary proposals to study any aspect of the connection between the polar sea ice and the atmosphere. Potential areas of consideration include, but are not limited to:

- Causes of Arctic amplification;
- Flux of mass and energy to the atmosphere through ice;
- Atmospheric moistening and changes in sea ice;
- Interactions of sea ice, cloud properties, and the polar energy budget;
- Sea ice leads and boundary-layer and cloud processes;
- Aerosol particle impact on cloud properties and ice extent;
- Precipitating ice radiative effects;
- Impacts on polar weather on sea ice extent, growth and loss.

In addressing this subelement, proposals are expected to have the following characteristics:

- Make significant use of space-based remote sensing;
- Be interdisciplinary in scope and specifically address ice-atmosphere connections; proposals that address only a single component (e.g., changes in ice cover or ice dynamics) will be considered unresponsive; and
- Go beyond correlation of datasets and, wherever possible, gain new insight into the physical processes and underlying causality.

Strong preference will be given to proposals that:

- identify at least one testable hypothesis and describe the process and data to be used to test the hypothesis; and
- address weaknesses in existing models.

Oceanographic science will be considered only if specifically connected to ice-atmosphere interaction. Influences of sea ice change on global weather will be considered only if it is specifically connected to quantifying the mechanisms by which sea ice influences the polar atmosphere.

Proposals are expected to utilize existing remote sensing and *in situ* datasets. Major new fieldwork will not be considered (note the limitation on fieldwork expenses for the overall Interdisciplinary Science element in section 1.2 above). Utilization of observations collected by the *MOSAIC Observatory* (http://www.mosaicobservatory.org/) is appropriate.

2.3 Subelement 3: Oceans, Ice, Climate, and Life

The global economy depends upon polar regions for climate regulation and natural resources, as well as support for a range of ecosystems not only critical to Earth's biodiversity and overall health but to economics around the world. The Arctic region, including Greenland and Alaska, is at the forefront of rapid climate, environmental, and socio-economic changes that are testing the resilience and sustainability of its communities and ecosystems. Arctic and Antarctic sea ice, ice sheets, and their resultant changes due to climate pressures influence local ocean physics, ocean biology and biogeochemistry, and local ecosystems differently. The Southern Ocean and the Antarctic are subject to similar climate pressures but support different ecosystems than the Arctic, driven largely by differing geography and landmass effects. Research to increase fundamental understanding of changes in Arctic (including Greenland and Alaska) and Antarctic sea ice and ice sheets, and the influence of ocean dynamics (i.e., resulting ocean physics) on local biology, biogeochemistry and ecosystems, is needed to inform sound, science-based decision- and policy-making and to develop appropriate solutions to a changing climate in these regions. This program element welcomes small-scale, targeted and well-justified field observations and projects (proposed field observations must be consistent with the guidance provided in section 1.2), analyses of existing data sets, and/or modeling proposals to explore and understand the influence of climate and environmental changes on ice, ocean physics, and on life in Earth's polar regions. Studies must combine research on the cryosphere, ocean physics, and biology/biodiversity/ecosystems on the ice or in the ocean. Illustrative research questions can be found at the end of this program element.

Sea ice is one on the largest biomes on Earth. It is also a unique habitat for assemblages of biota within and under ice, from bacteria to vertebrates. In and around these habitats conditions are dominated by strong gradients in temperature, salinity, nutrients, and ultraviolet, visible, and short-wave radiation. Physiological adaptations allow these organisms to thrive in and around ice as a key component of polar ecosystems. Sea ice algae are an important component of the polar trophic structure, providing energy and a nutritional source for invertebrates such as krill. Sea-ice algae also support a significant component of primary and fuel secondary production in ice-covered waters. Algae, including phytoplankton, the ocean's primary producers, and zooplankton, the ocean's primary consumers and the larvae of many higher-level consumers, make up plankton. Plankton support all levels of marine life, including commercial fish species and protected marine mammals. Beyond the in-ice biota, changes in sea ice will alter the seasonal distributions, geographic ranges, patterns of migration, nutritional status, reproductive success, and ultimately the abundance and balance of species in polar regions. The Intergovernmental Panel on Climate Change Working Group 2 reports have identified climate change as likely to produce long-term changes in the physical oceanography and ecology of the Southern Ocean. Projected reductions in sea-ice extent will alter under-ice biota and spring blooms in the sea-ice marginal zone, impacting all levels of the food chain, from algae and primary production to krill, fisheries and whales. The proliferation of Arctic melt ponds has also impacted under ice production and ecosystem dynamics. Marine mammals and birds, which have life histories that tie them to specific breeding sites, will be severely affected by shifts in their foraging habitats and migration of prey species. Recent NASA-funded research, such as Oceans Melting Greenland (OMG, https://omg.jpl.nasa.gov/portal/), has focused on quantifying to what extent the oceans are melting ice masses such as Greenland from below, suggesting to what extent ocean dynamics contribute to changes in Antarctic ice masses and associated impacts to local ecosystems.

A combination of current and planned NASA satellite, field campaign, and other *in situ* data can be used to address the dynamics of climate change, ice sheets and sea ice, ocean physics and life in the ocean, including organisms on and within the ice, at Earth's poles. Proposals submitted to this subelement must involve interdisciplinary teams of satellite researchers, cryospheric scientists, oceanographers, and investigators with modeling expertise appropriate to the science questions proposed. Proposers must use NASA satellite data (non-NASA satellite data products—in addition to NASA satellite data products—are also welcome) as a primary research tool to provide observations and estimates used in answering the research questions posed. Datasets may include but are not limited to:

- ice properties from missions such as ICESat-2;
- ocean physics such as currents from satellite and/or airborne instruments, for example Advanced Very High Resolution Radiometer (AVHRR), the Jason series, QuikSCAT/SEAWINDS, and MODIS along with other satellite and airborne platforms;
- and properties of ocean biology, ecosystems, biogeochemistry, and biodiversity from missions/instruments such as CALIPSO, MODIS, Suomi-NPP, along with other satellite and airborne platforms.

Given the critical role of ocean salinity in controlling air-sea gas exchange in polar regions, the use of salinity data and data-derived products is also encouraged, including *in situ* and satellite observations from Argo, SMAP, Aquarius, and SMOS, as well as data-driven ocean/sea-ice state estimates such as SOSE (the Southern Ocean State Estimate) and ASTE (the Arctic Subpolar gyre sTate Estimate). Upcoming NASA missions (e.g., SWOT) will resolve energetic scales of motion in the ocean that have never been sampled globally. The planned Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission will make unprecedented observations of ocean ecology and biogeochemistry. These missions will provide an opportunity to make available global high-resolution observed ocean currents for co-registration with ocean ecosystem data. Studies that promote efforts to better understand measurements associated with these two missions, particularly with complex high latitude retrievals and observations are encouraged.

This subelement seeks proposals to address the following high-level question: How does climate and/or environmental variability and change affect Earth's polar systems, particularly through the interplay of ice, ocean physics, biogeochemistry and local ecosystems?

Notional examples of specific proposal topics—meant only to be exemplary and not definitive or exhaustive, include:

- What are the impacts of polar warming on ice extent and associated changes in ocean dynamics on local fisheries and/or primary production?
- How are shifts in climate affecting polar ocean dynamics and any feedbacks to air/sea carbon fluxes?
- What are the impacts of the increased freshwater transport by sea-ice and consequent freshening of the Antarctic waters on ocean's stratification, uptake of carbon dioxide by the Southern Ocean, and Antarctic ecosystem?
- What are the environmental drivers of harmful algal bloom (HAB) evolution in polar seas?
- Are there changing biogeographies of ice-dependent flora and fauna?
- Are impacts of climate change and associated changes in ice affecting the livelihoods of humans who rely on the use of polar ecosystems for subsistence?
- Can changes in polar currents affect local trophic dynamics and energy flows within high-latitude ecosystems, including connections from primary producers to primary and secondary consumers to top predators and megafauna?

2.4 Subelement 4: The Life Cycle of Snow

The lifecycle of snow from evaporation of water into the atmosphere, precipitation to the surface, surface snowpack evolution (e.g., snow grain metaporphism, melt and refreeze), and dissipation through evaporation or melting are important scientifically and societally for climate, geology, agriculture, ecosystems, and more. For example, snowpacks store freshwater, insulate and impact vegetation growth, reflect incoming radiant energy (until they may be covered with dark dust), and contribute to formation of glaciers. The transport and lifecycle of snow/water through precipitation, evaporation, winds, and melt also influences other components of the Earth system, and yet, the drivers and interactions of snow in these systems are poorly understood. The 2017 Decadal Survey for Earth Science and Applications from Space fully recognized the need to better understand snow.

Over the last decade, significant advances have been made in remote sensing and modeling of snow, and yet the retrieval uncertainties are still relatively large. Data from many satellite (e.g., GPM, CloudSat, AMSR, Aqua, LandSat, Terra ICESat-2), suborbital, aircraft, and ground-based sensors are now available that could help elucidate the lifecycle of snow. Field campaigns (e.g., SnowEx, GCPEX, etc.) have provided localized snow datasets. Extensive atmospheric, radiation, cloud, surface feature, and other data sets are also available from a range of satellites, sensors, and models. Combined, these observations offer a range of possibilities to connect the lifecycle of snow to interdisciplinary studies.

In this subelement, NASA requests interdisciplinary proposals to study the connections among and.or interactions between the different elements of the lifecycle of snow (e.g., proposals that address only ONE of the steps in the life cycle of snow will be considered non-responsive).

Topics of interest to this subelement include, but are not limited to:

- Snow's linkages to environmental, societal, and climate change;
- Relationships between snow depth and coverage as they impact terrestrial ecology, vegetation growth, food sources for animals, and/or ecosystem diversity;
- Consistent modeling of both falling and fallen snow at global, regional, and/or microphysical scales;
- Interactions of snow and the distribution, transport, and transformation of water and energy within the hydrological and/or energy budgets;
- Snow as it connects land cover/land use, boundary-layer, and cloud processes;
- Precipitating snow and snow pack radiative effects via albedo investigations;
- Interdisciplinary science to reduce uncertainties in falling snow and snowpack retrieval products;
- Snow's impact on the Earth surface and interior, the cryosphere, and/or the oceans, including the impact of melting snow on soil moisture;
- The role of aerosols, carbons, and pollution in instigating changes in snow precipitation patterns and their transport and surface pack metamorphism.

Strong preference will be given to proposals that identify at least one testable hypothesis and describe the process and data to be used to test the hypothesis.

2.5 Subelement 5: Impacts of urbanization on local and regional hydrometeorology

There is strong evidence that urban environments modify local microclimates, with implications for regional and global climate change. Urban systems affect various climate attributes, including temperature, rainfall intensity and frequency, winter precipitation (snowfall), and flooding. New observational capabilities, data sets and regional coupled land–surface–atmospheric modeling systems for urban systems have been used to evaluate how the urban environment impacts the seasonality and changes in the type of precipitation (rain or snow), the amount and distribution of precipitation, and the significance of the size of metropolitan areas in hydrometeorological studies. For instance, urban-induced wind convergence can determine storm initiation; aerosol concentrations and composition then influence the amount of cloud water and ice present in the clouds. Aerosols can also influence updraft and downdraft intensities, their life span, and surface precipitation totals. For more recent information on assessed research on this topic, see Chapter 2 of the *Climate Change and Cities* Second Assessment Report of the Urban Climate Change Research Network (https://doi.org/10.1017/9781316563878) and Chapter 10 of the *National Climate Change Assessment*, Volume I (https://science2017.globalchange.gov/chapter/10/).

Proposals submitted in response to this sub-element MUST make a connection between the properties of and/or changes in the properties of the land surface AND hydrometeorological impacts. It is expected that successful proposals will include explicit consideration of both of these components, and make use of quantitative models to connect variation and/or changes in the land surface with local hydrometeorology. Proposals that address only one aspect of this (i.e. either land cover or hydrometeorology) will be considered non-responsive.

Topics of interest to this subelement include, but are not limited to:

- Urban Heat Island (UHI) and surrounding environmental gradients (e.g., forests, shrublands, peri-urban, rural) ecosystem impacts on regional hydrometeorology;
- The fate of precipitation and how the fraction of, and/or spatial patterns of impervious surfaces influences overland runoff;
- Changes in the UHI diurnal cycle along settlement pattern gradients (e.g., urban to rural);
- Interactions between temporal/spatial patterns of urban settlements and climate system variables, including hydrologic, carbon cycle, and aerosols, insofar as how they affect hydrometeorological properties;
- Urban-induced winds and storms, aerosols, clouds and water/ice presence in clouds;
- Moisture convergence in urban areas and their impacts on storm initiation and precipitation dynamics.

Proposals for this subelement must focus on more than one urban system and include data/model based comparisons between these systems. Proposals that focus on a single urban system will be considered non-responsive to this sub-element.

2.6: Subelement 6: Space Archaeology: Using the Past to Inform the Present and Future

It is widely recognized that current Earth system changes are strongly associated with changes in the coupled human-environment system, making the integration of human history and Earth system history a timely and important task. The IDS Space Archaeology subelement seeks to utilize existing remote sensing observations and data sources to discover archaeological evidence of human settlements. A secondary goal is to produce an integrated account and attribution of how changes in relevant environmental processes (e.g., climate, atmospheric chemistry and composition, ecosystem distribution, material and water cycle dynamics, biodiversity) have impacted human system dynamics (e.g., land-use systems, historical and pre-historical human settlement patterns, technologies, patterns of disease, patterns of language and institutions, conflicts and alliances). To achieve this ambitious goal, it will be necessary to integrate innovative remote sensing observations with perspectives, theories, tools and knowledge from a variety of disciplines spanning the full spectrum of natural and social sciences.

Cultures have blossomed, flourished, and then faded, sometimes abruptly, as societies have sought to optimize exploitation of the natural environment (climate, weather, physiography, hydrology, and biotic and mineral resources). A better understanding of how these cultures have flourished or transformed in response to local, regional, and global change is of profound significance to the present as societies grapple with possible adaptations to our changing world. In addition, past cultural practices often had profound impacts on the landscape by altering land-cover through land-use and modifying the hydrologic regime with associated potential consequences for biodiversity and climate. Thus, a better understanding of our past and how interactions between human and environmental systems have impacted and fed back into new, transformed societies might better inform current and future human-environmental interactions.

Space-based and suborbital observations, coupled with advances in digital image analysis, Geographic Information Systems (GIS), Global Positioning System (GPS) technology, and computer modeling provide the opportunity for the archeologist to discover, understand, and protect the world's human legacy that is threatened by both accelerating land cover/land use changes and ongoing climate variability and change. Remote sensing has been used by archaeologists to survey potential archaeological sites and to better understand the spatial relationships of cultural features to each other and the natural environment. The traditional use of optical data acquired from aircraft or balloons is now supplemented by a vast quantity of data routinely provided by numerous satellites launched and operated by NASA, other international space agencies, and private industry. In addition, NASA archives contain large quantities of potentially useful data from specialized airborne campaigns. While private commercial satellites tend to provide high-resolution spaceborne surrogates for airborne optical data, the NASA research satellites (https://www.nasa.gov/content/earth-missions-list) and those of other international space agencies generally collect data over a very broad range of the electromagnetic spectrum and at a coarser spatial resolution covering a broader spatial extent (regional-scale). The aerial vantage point lays out the spatial organization of archeological sites within the context of their environmental settings and leads to the realization that everything in an ancient landscape has meaning and interconnection. These data sets and their derived products can be used at the regional level to: (1) identify and explore the extent and nature of historical and pre-historical human settlement patterns, (2) model the ecological context and dynamics of past settlements as cultures modified and reacted to changes in the natural environment, and (3) provide critical information for improved preservation and sustainable development of cultural heritage sites.

The NASA Space Archaeology subelement has the scientific objective to use the unique vantage point of space to improve our understanding of past human settlement patterns and the relationships between the natural environment and cultural adaptations as functions of time and space. Major research topics solicited are:

- To accelerate archaeological discovery and understanding through access to and analysis of remotely-sensed data obtained from space borne and airborne platforms;
- To facilitate the infusion of technological expertise and capacity in remote sensing into archaeological research by fostering multidisciplinary collaborative relationships;
- Regional landscape analysis and modeling relating historic and pre-historic human settlement patterns and subsistence strategies to environmental factors derived from remote sensing.

Additional topics from previous program elements are of additional interest:

- Identification and exploration of the extent and nature of past human settlement patterns;
- Protection and preservation of cultural heritage sites and/or planning for the sustainable development of cultural resources.

Substantive connection to remote sensing data is required in all proposals. Proposers are encouraged to utilize existing or planned ground, airborne, and space-based observational capabilities and their associated data sets. These resources include, but are not limited to the existing high-resolution SRTM dataset, ongoing satellite and airborne LIDAR, and spectral imaging such as ASTER and MODIS that provide structural and compositional models. Geodetic observations utilizing vegetation penetrating SAR (i.e. Sentinel-1, ALOS-2) including the airborne platform UAVSAR (L- and P- band: Pol-SAR and InSAR), provide insights in sub-canopy and sub-surface features. In addition, passive sensors, including thermal infrared and visible/shortwave data, such as the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), Landsat, MODIS/VIIRS that that provide images of current vegetation status (water stress, greening, browning, etc) and highlight anomalous productivity patterns lending insight into archaeological discovery and environmental processes (e.g., net primary productivity, etc) are encouraged.

Ongoing and future missions such as ALOS-2, Sentinel-1, TerraSAR-X, COSMO-SkyMed, SAOCOM, GEDI, OCO2/OCO3 and NISAR provide additional and upcoming opportunities in this realm. These and other NASA datasets are cataloged in the Earth Observing System Data and Information System (EOSIDS, https://earthdata.nasa.gov) and provided by the DAACs.

This subelement continues with and expands upon foci in past program elements for Space Archaeology. Information about the specifics of prior program elements released and proposals selected in response to previous NASA program elements may be found on NSPIRES by searching for "Archaeology" in "Closed/Past Selected" solicitations at https://nspires.nasaprs.com/external/solicitations/solicitations!closedPastInit.do.

This subelement may support limited fieldwork as needed to verify and validate remotely sensed results, but requests for extensive excavation are considered nonresponsive. See section 1.2 above for overall restriction on costs of fieldwork for this IDS ROSES element.

2.7: Subelement 7: Exploring the Microbial Biodiversity of the Atmosphere

Like Earth’s landmasses and oceans, the atmosphere teems with life. Much of this atmospheric life is microbial, making its detection and tracking difficult. An understanding of atmospheric microbial life’s interactions with and impacts upon the broader Earth system is similarly challenging. Atmospheric microorganisms are often physically associated with aerosol particles, e.g., dust. Thus, microorganisms can travel thousands of miles in winds aloft, launching from one continent with deposition on another. NASA has an extensive suite of observation tools for characterizing atmospheric aerosols and understanding their impacts on climate and other phenomena. These include surface-based, airborne, and satellite instruments.

This IDS sublement solicits proposals that integrate existing observations from NASA sensors (combining observations from surface-based, airborne, and satellite instruments) with microbiological tools (including culture-based, metagenomic, and other molecular approaches) to characterize the aerosolized microbial biodiversity of the atmosphere. The inspiration and some of the questions for this topic arose from a recently-concluded scoping study funded by the NASA Biological Diversity Program entitled *A Transoceanic Aerobiology Biodiversity Study (TABS) to Characterize Microorganisms in Asian and African Dust Plumes Reaching North America* and a recent associated publication (Schuerger, A.C., Smith, D.J., Griffin, D.W. et al. Aerobiologia (2018) 34: 425. https://doi.org/10.1007/s10453-018-9541-7).

Proposals must address one or more of the following questions while using the observations and tools noted above (these questions are not in priority order):

- Are transported microorganisms metabolically active during long-range (e.g., transoceanic) transport, (i.e., Is the atmosphere a superhighway or a functioning ecosystem or both?)?
- What factors influence the viability of microorganisms during long-range transport and their survival to the site of deposition?
- Can we determine the source regions of aerosolized microorganisms and also differentiate these microorganisms from extant microorganisms at deposition sites?
- With regard to atmospheric microbial biogeography, are microbial taxa global in distribution (i.e., is everything everywhere?) or are there biomes or ecoregions of the atmosphere, characterized by unique atmospheric microbial communities?
- What are the major atmospheric pathways for transporting microorganisms at continental to global scales?
- What are the ecological consequences of long-range transported microbial deposition on downwind terrestrial or marine ecoystems?
- Are viable human, animal, or plant pathogens transported in long-range (e.g., transoceanic) dust plumes?
- How can remote sensing measurements and models used to track atmospheric aerosols and their impacts be combined and leveraged to develop or improve models specifically focused on the global dispersal and survival of atmospheric microorganisms?
- What fraction of the organic and total aerosol loads are made up of living organisms?
- What is the upper (altitudinal) limit of the atmospheric biosphere?
- What are the radiative impacts of biological aerosol particles?
- How effective are bioaerosol microorganisms in serving as cloud condensation nuclei and as ice nuclei?

Proposers are reminded that this subelement is not seeking proposals for new observations of life in the atmosphere, but calls for the use of existing observations to address these questions. This restriction supercedes the limit for fieldwork expenses noted in section 1.2 above. Proposals for this subelement with expenses for data acquisition will be considered non-responsive.

Applications must use both a) NASA satellite remote sensing data and b) *in situ* assesments of aerosolized microbial biodiversity as integral components of their proposed work and, furthermore, proposers are asked to document how they are using these two data types on the cover page of the proposal. For the purposes of this subelement, "NASA satellite remote sensing data" includes data from NASA on-orbit satellites and simulated measurements from planned NASA satellites. In addition, the use of measurements from commercial, foreign, and other U.S. remote sensing data products in the overall mix of data products proposed is welcome, although proposals must include specific NASA satellite remote sensing data products in the overall mix of data products proposed. The use of outputs and predictive capabilities from models associated with NASA products, NASA algorithms, NASA visualizations, and other NASA geospatial products, including airborne products, is also welcome.

Since this topic is a subelement of the 2019 Interdisciplinary Research in Earth Science program element, proposals should bring together interdisciplinary teams of individuals working in the disciplines of aerosol remote sensing, aerosol modeling, and microbiology, and seek to use the full suite of tools available for understanding microbial life.

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 ROSES
Due date for proposals	See Tables 2 and 3 of ROSES
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 the ROSES *Summary of Solicitation* and the *Guidebook for Proposers*
Relevance to NASA	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 Summary of Solicitation*.
Detailed instructions for the preparation and submission of proposals	See the *Guidebook for Proposers* at http://www.hq.nasa.gov/office/procurement/nraguidebook/.
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	NNH19ZDA001N-IDS
Main point of contact concerning this program. See POCs for specific subelements below.	Jack A. Kaye Earth Science Division Science Mission Directorate National Aeronautics and Space Administration Washington, DC 20546-0001 Telephone: (202) 358-2559 Email: Jack.A.Kaye@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, listed below.

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