NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences -2023
NNH23ZDA001N-EMIT
A.32 Earth Surface Mineral Dust Source Investigation (EMIT) Science and Applications Team

The National Aeronautics and Space Administration (NASA), Science Mission Directorate, Earth Science Division has selected new projects from the 2023 Earth Surface Mineral Dust Source Investigation (EMIT) Science and Applications Team solicitation. EMIT's prime mission observation period is focused on measuring the mineral composition of Earth's arid land dust source regions with imaging spectroscopy. The 2023 supports basic research and analysis as well as applications activities associated with the production, validation, and utilization of EMIT products. These studies will support, but not duplicate prime mission research and utilize EMIT data to support new fields of research and application. NASA received a total of 51 proposals and has selected 16 for funding. The total funding from NASA anticipated for these investigations is approximately $8.3 million over three years. The selected investigations are listed below, including Principal Investigator, institution, title, and abstract. Co-Investigators are not listed here.

Yoseline Angel/University of Maryland, College Park
Mapping the Spectral Colors of Blooming Deserts with EMIT
23-EMIT23-0039

Despite the harsh conditions, the floristic composition of arid and semi-arid deserts is rich and diverse in endemic species, as evidenced by spectacular seasonal wildflower blooms. Resistant seeds, bulbs, and rhizomes can remain dormant under the dry soil for years, but after sufficient precipitation accumulates, an unusual and explosive development of ephemeral flowering plants occurs: a super bloom. Super blooms have been reported primarily in desert transitions towards Mediterranean ecoregions and are often triggered by climate-ocean conditions associated with El Niño. However, a detailed spatio-temporal assessment of the blooming desert" phenomenon in arid and semi-arid ecological regions worldwide (e.g., California/Arizona, South Africa, Australia, Chile, Peru) is still needed. Ephemeral flowering triggers relevant changes in the ecosystem, such as temporary fractional cover expansions, outbreaks of pollinators and predators, and microclimate changes: higher evapotranspiration and lower surface albedo. Monitoring such phenology dynamics across large scales can be performed by integrating remote sensing with field-based ecology.

The unique optical properties of flowers allow imaging spectroscopy to be used as a non-destructive tool to study flowers through space and time. The high spectral resolution and fidelity of imaging spectrometers like EMIT allow the retrieval of spectral signatures that comprise the weighted contribution of materials at smaller scales than the ground sampling distances (e.g., 60 m for EMIT). However, disentangling the mixed contributions of green leaves, flowers, non-photosynthetic canopy components, and background covers (e.g., soil, shadows) to spectroscopic reflectance measurements at different spatial resolutions is challenging. Moreover, most physical and hybrid modeling and mapping methods at canopy scales ignore flowers, which have different spectral signatures and phenological patterns.

We aim to study wildflower blooms in arid and semi-arid desert ecoregions overlapping the EMIT data coverage. First, we will develop and evaluate spectral unmixing methods for quantifying fractional flowering coverage relying on the unique optical properties of flowers (especially in the 380-1000 nm spectral range). We will build an open-access floral spectral library for endemic species in Mediterranean, arid, and semi-arid ecoregions, which, together with other available spectral libraries for soils, will be used as input for setting the unmixing framework to map the flowering abundance and their uncertainties based on the EMIT imagery. Informed by this spectral library, we will develop spectral unmixing techniques for mapping flowering areas and apply these techniques to EMIT scenes in these regions to identify and characterize blooming events. We will also evaluate whether blooms can be detected from other remote sensing measurements, including multispectral, thermal, and synthetic-aperture radar.
Our current understanding of flower blooming in diverse ecosystems hinges predominantly on phenological data collected by field experts and volunteer networks, which is geographically limited and primarily concentrated in developed nations. Consequently, the majority of blooming forecasting indices are established based on ground-based meteorological data, calibrated using phenological models of a select few flowering species. This lack of comprehensive, globally-inclusive data constitutes a significant gap in our understanding of desert flower blooms. After using the EMIT hyperspectral data to identify desert flower blooms, we will investigate the underlying atmospheric and surface conditions inducing these blooming events. For each blooming event identified using EMIT, we will analyze antecedent remote sensing/modeled data for variables such as rainfall and temperature to understand the drivers of blooming events and develop predictive models for anticipating future blooming events.

Alana Ayasse/Carbon Mapper, Inc.
Methane and Carbon Dioxide Point Source Emissions Validation and Analysis
23-EMIT23-0008

EMIT has shown initial capability for quantifying methane (CH_4) and CO_2 point source emissions. These capabilities have drawn strong public and scientific interest for a variety of carbon cycle research projects and applications. Key to adoption of these greenhouse gas products is robust and transparent validation of L2-L4 products, including retrieval concentration maps, individual plume images, emissions quantification, uncertainty estimates, and facility and sector attribution for point sources. For this project, we propose three main objectives. The first objective will be to execute a CH_4 and CO_2 point source emission validation program to quantify minimum detection limits and precision and bias of emission estimates derived from EMIT observations. The second objective will be to independently process all cloud-free EMIT observations over priority regions to detect and quantify emissions from CH_4 point sources, attribute them to key emission sectors, and integrate the resulting dataset with airborne point source data from AVIRIS-NG, GAO, and the upcoming Carbon Mapper satellites into Carbon Mapper's

Global Waste Sector Baseline, a core project under the Global Methane Pledge's Waste Pathway. The final objective will be to extend the impact of EMIT observations by infusing L2-L4 CH_4 and CO_2 products into Carbon Mapper's global open data platform and ongoing stakeholder engagement programs.

Successful validation of quantitative CH_4/CO_2 products means independent evaluation of retrieval concentration maps, CH_4/CO_2 plume detection and delineation, emission quantification and uncertainty estimates, and sectoral attribution. We propose a comprehensive validation program which will include controlled release experiments, simultaneous under flights with aircraft, and intercomparisons with emission estimates from other satellites and surface measurements. Most of the component systems and protocols are already funded and planned as part of the validation efforts for the Carbon Mapper mission which we propose to extend to include EMIT. This validation framework includes established Carbon Mapper collaborations with the US Environmental Protection Agency, the California Air Resources Board, University of California Berkeley, Stanford University, and Colorado State University. As we validate each product, we will share algorithms, benchmark data sets, and findings with the EMIT Science Data System team. With robust CH_4 and CO_2 products, we propose to use these data to analyze the global distribution of point sources. We plan to focus our CH_4 analysis on the global waste sector, a historically understudied source of methane and an area where Carbon Mapper has strong partnerships and expertise. We also plan to apply our Observing System Completeness metric which combines detection limits, spatial coverage and sample frequency to generate completeness heat maps for EMIT observations of emitting regions. This will help provide context for the observations, including objective, quantitative assessments of EMIT's observing system coverage and completeness of anthropogenic emissions including variable and intermittent sources. This proposal will directly address the solicitation by providing validation of an EMIT product of high interest. Additionally, this proposal will support the NASA science objectives to understand global carbon cycle and further the use of Earth system science research to inform decisions and provide benefits to society.

Jeff Dozier/University of California, Santa Barbara
The Role of EMIT and Thermal Infrared Remote Sensing in Addressing the Decadal Survey's Most Important Objectives for Snow in the Water Cycle
23-EMIT23-0032

Two Most Important objectives for the hydrologic cycle in the National Academies' Thriving on Our Changing Planet (2018) identify hyperspectral imagery in the visible and shortwave infrared and multispectral imagery in the thermal infrared as essential observables:
H-1a. Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components of the water and energy cycles & H-1c. Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.

A subset of Objective H-1a includes energy balance models of the snowpack, driven by measurements of snow albedo and snow surface temperatures. A subset of Object H-1c requires the ability to measure snow albedo and temperature and understand how and why they vary, especially in the world's mountains, which comprise a quarter of the world's land area but produce at least half of the runoff.

The Decadal Survey's traceability matrix (Table B.1) clarifies the specific need: Spectral albedo of subpixel snow and glaciers at weekly intervals to an accuracy to estimate absorption of solar radiation to 10%. Ice/snow surface temperature to ±1 K. At spatial resolution of 30 to 100 m."

EMIT's temporal and spatial coverage do not enable that mission to meet the Decadal Survey's needs, but its spectral capabilities match proposed designs for the VSWIR spectrometer on NASA's SBG and Europe's CHIME. The EMIT imagery therefore provides the opportunity to demonstrate retrieval of snow properties to meet the 10% criterion for the absorption of solar radiation. Similarly, currently available remotely sensed temperatures lack the combined spectral and spatial capability to estimate subpixel snow temperature at ±1 K accuracy, but the thermal infrared component of SBG will enable estimates of subpixel snow temperature. Current sensors can measure temperatures of fully snow-covered pixels.

The proposed investigation will address the following Questions that will use EMIT imagery to help develop appropriate Level 2 and Level 4 products for SBG and CHIME.
Q1. How accurately must we measure snow properties to estimate absorption of solar radiation to 10% accuracy?
Q2. How does sensitivity of imaging spectroscopy retrievals of snow and glacier properties in the mountains vary depending on the retrieval algorithms and the available ancillary data?
Q3. How can knowledge of snow albedo, along with surface temperature at two times in the diurnal cycle, constrain an energy balance model of the snowpack?
The corresponding Objectives are:
O1. Calculate the accuracy of snow properties needed to estimate absorption of solar radiation.
O2. Assess the sources of uncertainty in algorithms to retrieve snow properties.
O3. Determine whether retrieved snow properties from EMIT meet necessary accuracy, based on surface measurements of albedo that are already available.
O4. Examine whether snow energy balance models can be improved by knowledge of remotely sensed surface temperature.
O5. Compare available EMIT data and coincident temperature measurements to drive a snow energy balance model.

In most snow-dominated environments, net solar radiation drives melt and metamorphism of snow. Inaccuracy in the estimation of snow albedo constitutes the major source of uncertainty in calculating the snowpack's energy balance. Meeting the Decadal Survey's objectives requires improvement in spatially distributed models of snow melt and metamorphism, which the EMIT data provide a path to achieve.

Amato Evan/University of California, San Diego
Assessing the Impact of Dust from Ephemeral Lakes on Earth's Weather and Climate
23-EMIT23-0043

As Earth's climate continues to warm, the aridity of the planet's drylands increases, and human demands on water resources continues to grow, it is plausible, if not likely, that dust emission from ephemeral lakes will similarly increase over time. As such, in order to understand how the dust cycle and dust impacts on weather and climate will change in the future, there is a need to better characterize and understand dust from these sources. This project aims to address that need by investigating dust from ephemeral lakes and its effect on Earth's weather and climate by utilizing soil mineralogy products from the Earth surface Mineral dust source InvesTigation (EMIT) imaging spectrometer.
The main goal of this project is to use EMIT level 2b surface soil mineralogy data products to characterize the microphysical properties of dust from ephemeral lakes and evaluate how increasing emission such sources can feedback onto extreme weather events and impact Earth's climate through the dust direct radiative effect. In order to accomplish this goal we propose a series of studies ranging from the local to global scale that are designed to elucidate the role of dust from dry lakebeds on Earth's weather and climate:
1. Comparison of the dust direct radiative effect between desert and playa sources over a research site in the Salton Basin, a region in southeastern California prone to frequent dust storms. Dust microphysical properties will be obtained from EMIT and the direct radiative effect will be estimated using these data and observations of other relevant aerosol and atmospheric properties, with validation obtained via comparison to radiative flux measurements. Results will be compared to a similar analysis conducted with the Airborne Visible/Infrared Imaging Spectrometer in order to evaluate the differences in these surface soil mineralogy products.
2. Utilization of EMIT-based dust microphysical properties to evaluate the influence of dust direct radiative effect on extreme weather events associated with dust storms in the Salton Basin using the Weather Research and Forecasting Model with Chemistry. The investigation will explore how dust-driven feedbacks evolve as the Salton Sea, a large lake in the region, dries up and becomes emissive, such that an increasing fraction of the airborne dust is from playa sources.
3. Global-scale numerical experiments using the Geophysical Fluid Dynamics Laboratory Earth System Model to assess the current contribution of dust from ephemeral sources to the dust direct radiative effect. Additionally, the project aims to evaluate potential future changes in the dust cycle and the direct radiative effect due to continued drying of and thus emission of dust from lakebeds in arid regions.
The proposed project aligns closely with the EMIT science objectives by addressing dust radiative forcing and changes in dust sources under future climate scenarios. It also supports the RFP's focus on evaluating EMIT data products and advancing understanding of Earth's climate system and extreme weather events. Furthermore, increased dust emissions from playa sources may pose health risks, particularly impacting disadvantaged communities, emphasizing the project's relevance to environmental justice

concerns. Findings from this research have the potential to inform climate planning and adaptation strategies.

Hosein Foroutan/Virginia Polytechnic Institute & State University
From the Earth Surface to Atmospheric Aerosols: Understanding the Evolution of Dust Mineralogy and Geochemistry
23-EMIT23-0036

The NASA EMIT mission transforms our knowledge of the mineral composition of Earth's dust source regions using hyperspectral imaging. Nevertheless, little is known about the variations in the mineralogy of airborne dust aerosols due to atmospheric processes. We hypothesize that 1) atmospheric dust mineralogy can be different from the mineralogy of parent soil at emission sources and 2) atmospheric processes modulate the evolution of dust mineralogy from the Earth surface to aloft. To accomplish our objective and test these hypotheses, we propose to integrate the EMIT L2b data of surface mineralogy, in-situ analyses of dust aerosol mineralogy and geochemistry, multiplatform satellite and ground observations of atmospheric aerosols, and multiscale reanalysis and atmospheric simulation data to establish connections between changes in dust mineralogy and atmospheric processes. Specifically, this research project will address the following Science Questions:
SQ1. How is the mineralogy of dust aerosols associated with the mineralogy of different dust emission sources that contribute to a dust plume?
SQ2. How does the mineralogy of atmospheric dust vary due to atmospheric processes and environmental conditions endured by dust plumes?
SQ3. What is the time scale for the variation of the mineralogy and composition of atmospheric dust?
SQ4. What are the implications of mineralogy evolution for the regional radiative properties of dust aerosols?
These science questions will be addressed by pursuing the following tasks:
Task 1. Sampling of airborne dust aerosols in Tenerife, Spain. We will sample atmospheric dust aerosols simultaneously at two distinct locations within and above the planetary boundary layer in Tenerife, Spain. Sampling will be conducted continuously every week for two years.
Task 2. In-situ analysis of collected samples. The mineralogy of aerosol dust samples collected from Tenerife, Spain will be characterized using laboratory diffraction, spectroscopy, and electron imaging methods. The main objective is to identify and quantify the different types of minerals present in the samples and examine their basic physical and chemical characteristics.
Task 3. Investigation of the transport and deposition of dust aerosols. To capture the transport and evolution of dust plumes from source regions to the sampling sites, we will synergistically use data from various NASA platforms, including OMPS, VIIRS, CALIOP, and AERONET, as well as MERRA-2 reanalysis data. Specifically, we will focus on multi-source emissions, three-dimensional dust aerosols pathways, dust layer altitude, dust aerosols size distributions, and dust deposition fluxes as relevant to dust transport from North Africa to the sampling location.

Task 4. Characterization of the evolution of dust plumes mineralogy. By combining findings from the three preceding tasks and utilizing NASA EMIT mission level 2b mineralogy data, we will construct a comprehensive understanding of dust mineralogy and geochemistry variations.
Task 5. Exploring the impact of dust mineralogy evolution on radiative properties. In order to translate our findings about changes of dust aerosol mineralogy to its radiative properties, we will conduct radiative transfer calculations constrained by our observations from task 2.
This project will improve the state-of-the-science in understanding how the mineralogy of dust particles changes due to atmospheric processes in a regional scale, thereby directly advance science objectives of the NASA EMIT mission.

W Hively/Geological Survey, United States Department Of
Evaluating Spaceborne Hyperspectral Approaches for Monitoring the Performance of Climate Smart Agricultural Conservation Practices
23-EMIT23-0048

Our objective is to apply spaceborne imaging spectroscopy to map and evaluate two climate-smart agricultural (CSA) conservation practices: winter cover crops and conservation tillage, while providing ground control data and analysis to enhance validation of EMIT map products for green vegetation (GV) nd non-photosynthetic vegetation (NPV) in the agricultural setting. This work will advance our understanding of the distribution of winter cover crops (WCC); their associated biomass, ground cover, species composition, and biochemical traits (termed performance"); and the distribution and biochemical traits of crop residues remaining on the soil surface in conservation tillage systems, all of which have important implications for soil health, carbon sequestration, and climate change mitigation and adaptation. WCC are multifunctional biological tools that can provide a suite of agroecosystem services including improved water quality and soil health, increased carbon sequestration, reduced greenhouse gas emissions, and nutrient supply to cash crops. However, WCC performance varies substantially, impacting the magnitude of the agroecosystem services they provide. Similarly, maintaining NPV on the soil surface in the form of crop residues improves soil health and water balance and reduces soil erosion, but measuring NPV cover with broadband multispectral imagery is problematic. Imaging spectroscopy has been successfully applied to characterize plant species, quantify plant biochemistry, and estimate fractional cover of crop residues in agricultural systems. Development of resilient CSA production systems can be supported by use of spaceborne imaging spectroscopy to discriminate WCC from other wintertime GV, map WCC biochemical traits, and to quantify NPV characteristics associated with conservation tillage.
In the proposed project, we will employ spaceborne imaging spectroscopy from EMIT (5 scenes) and PRISMA (9 scenes) to quantify within-scene fractional cover of wintertime GV and NPV; classify GV types to accurately distinguish WCC fields from weeds and commodity cereal crops; and quantify WCC and NPV performance and biochemical traits. Our data will be made available to validate EMIT estimated fractional cover L3 products on agricultural lands. Furthermore, we will develop techniques to compensate

for in-scene surface moisture variability, which greatly influences the spectral assessment of GV and NPV cover and biochemical traits. Our research will focus on applications in temperate agricultural regions in Maryland and Mississippi, USA, and Aranjuez in the Community of Madrid, Spain. In these areas, we have collected abundant destructive vegetation samples (n = 546) as well as roadside field surveys (154 fields) and WCC conservation program enrollment data (15,751 fields and 1,772 terminated fields) which detail land cover type and cover crop species in temporal proximity to EMIT and PRISMA imagery acquisitions.

A key contribution of our proposed research will be the assessment of spaceborne imaging spectroscopy to quantify GV and NPV cover associated with the distribution and performance of CSA practices, which benefit Earth's climate system and carbon cycle. This work supports the application of EMIT to inform the development of the Surface Biology and Geology (SBG) mission," as our preliminary research indicates robust relationships for WCC and NPV cover and performance estimation using imaging spectroscopy. Taken together, these proposed activities will establish and validate EMIT-based imaging spectroscopy methodologies to classify agricultural land cover, and will estimate the performance of CSA practices and their impacts on nutrient dynamics and erosion control, thereby paving the way for integration of SBG imagery into decision support tools to provide management recommendations that aid farmers adaption to climate change.

Bingqing Liu/University of Louisiana at Lafayette
Exploring the Potential of Hyperspectral EMIT Data to Assess Phytoplankton Community Composition and Carbon Dynamics in the Wetland-Estuarine Systems of the Northern Gulf of Mexico
23-EMIT23-0047

The hyperspectral observation by the Earth Surface Mineral Dust Source Investigation (EMIT) instrument offers an untapped potential for monitoring water quality and biodiversity across diverse habitats, from estuaries and wetlands to coastal pelagic. We propose to explore the EMIT hyperspectral capabilities in studying biogeochemical processes in the wetland-estuarine system of the northern Gulf of Mexico (nGoM), which has experienced rapid changes due to multiple, pressing environmental stressors. In particular, we will test an advanced machine learning algorithm (mixture density networks) and refine a prior adaptive semi-analytical algorithm to fully utilize the hyperspectral information from EMIT Level 2 surface reflectance data to infer the inherent optical properties (IOPs, including phytoplankton absorption coefficient) and biogeochemical indicators including chlorophyll a (Chl a), phytoplankton community composition, and dissolved and particulate organic carbon (DOC and POC). The EMIT algorithms will be developed and validated using a comprehensive optical and biogeochemical dataset to be acquired through simulation, uncrewed autonomous observation and lab analysis.

Our overarching goal is to apply novel retrieval algorithms to enhance the prediction of biogeochemical variables using remotely sensed hyperspectral measurements. To achieve the goal, we propose to accomplish the following specific objectives:
Objective 1: Collect hyperspectral measurements for algorithm development and validation by deploying an autonomous optical system (AOS) and ground-based field experiment and lab analysis.
Objective 2: Develop and validate an MDN-based model for predicting phytoplankton absorption coefficient, Chl a, and phytoplankton community composition from hyperspectral reflectance.
Objective 3: Refine and validate an adaptive semi-analytical IOPs inversion algorithm to extract IOPs, DOC, and POC from hyperspectral reflectance.
Objective 4: Apply algorithms to EMIT Level 2 surface reflectance data to characterize spatial distributions of IOPs, phytoplankton community and carbon dynamics along with coastal habitats classification in different wetland-estuarine systems of the nGoM.
The research we propose directly addresses the application of EMIT data to advance our understanding of the carbon cycle, ecosystems, biodiversity, and extreme weather events. The proposed algorithms will not only extend the application of EMIT to coastal aquatic environment but also can be spectrally adapted to other current and upcoming hyperspectral missions, including PRISMA (Hyperspectral Precursor of the Application mission), DESIS (DLR Earth Sensing Imaging Spectrometer), SBG (Surface Biology and Geology mission), and PACE (Plankton, Aerosol, Clouds, and ocean Ecosystem mission). The proposed data collection using the autonomous optical system (AOS) will significantly enhance and expand the validation strategies, techniques, and data products of EMIT. Furthermore, our research aligns with one of the key potential applications of the EMIT mission, which is to monitor phytoplankton distribution, as well as harmful algal bloom biomass and composition. In addition, our proposed research contributes to the development of the Surface Biology and Geology (SBG) mission in area of surface biology and functional traits of inland and near-coastal aquatic ecosystems. The proposed work also closely aligns with the interests of NASA's Earth Science Division's Ocean Biology and Biogeochemistry program, which aims to understand, and predict the biological and biogeochemical processes in the upper ocean through ocean color remote sensing. The proposed algorithms have a mechanistic nature, which enables their seamless adaptation to NASA's next-generation ocean color sensor, such as the hyperspectral PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) mission.

Nima Pahlevan/Science Systems and Applications, Inc.
Enabling Interdisciplinary Aquatic Science Studies from the EMIT Archive
23-EMIT23-0017

Coastal and fresh water ecosystems are among the most productive ecosystems. They are highly vulnerable to the changing climate (e.g., hurricanes, wildfires, dust storms) and anthropogenic activities (e.g., agriculture, aquaculture) while supporting human lives through their services. For over two decades, satellite systems with ocean color (OC) capabilities have produced valuable science-quality aquatic products (e.g., chlorophyll-a; Chla, total suspended solids; TSS) for studying carbon and biogeochemical cycling in these optically complex aquatic environments. With future planned hyperspectral missions, like the Surface Biology and Geology (SBG) mission, the aquatic remote sensing community will have access to a broader suite of observations across the visible-shortwave infrared regions.

Despite all the recent advances in inversion models, retrieving consistent global in-water products in coastal and fresh waters using existing multispectral and hyperspectral remote sensors still presents major challenges. The Earth surface Mineral dust source InvesTigation (EMIT) imaging spectrometer provides an excellent opportunity for calibration and validation of recently developed novel algorithms to accelerate the uptake of SBG observations well in advance. Further, EMIT standard surface mineral maps, in conjunction with historical in-water products from Landsat and Sentinel-2, will enable innovative interdisciplinary case studies, such as assessing the effects of short- or long-term atmospheric dust deposition on high-altitude lakes.

By leveraging our existing NASA supports, we propose to refine and adapt our robust processing workflow for EMIT's hyperspectral observations, enabling the generation of a comprehensive product suite for optically deep inland and nearshore coastal waters. We will formulate, implement, and rigorously cross-validate our proven machine-learning (ML) model, termed Mixture Density Networks (MDN), with equivalent products from near-coincident Landsat and Sentinel-2 measurements. Our proposed workflow encompasses four main components. First, we will devise an atmospheric correction method to retrieve hyperspectral aquatic reflectance (rw) using an MDN model trained with in situ rw and simulated top-of-atmosphere reflectance/radiance spectra. Second, we will utilize the derived rw products to retrieve biogeochemical products (e.g., Chla) and hyperspectral inherent optical properties (IOPs), such as phytoplankton absorption spectra (aph). Third, our EMIT products, accompanied by their pixel-level uncertainties, will be extensively cross-validated with products from near-coincident Landsat-8/-9 and Sentinel-2 images. Lastly, we will demonstrate the use of EMIT surface mineral maps along with historical Landsat and Sentinel-2 aquatic products for assessing the impacts of dust deposition and water-level variability in a few lakes in the Western U.S. and the Swiss Alps.

This research directly addresses the objectives outlined in the EMIT SAT request for proposal, which requests submissions to advance the EMIT science objectives, evaluate, and improve existing EMIT data products, and contribute to the SBG mission. Supplemented by other NASA supports, our project will have several far-reaching consequences for future NASA imaging programs. Our products will demonstrate and validate SBG-like products and facilitate research for their synergistic use with those derived from other multispectral or hyperspectral missions in the 2030s. We will further enable advancements in interdisciplinary limnological/geological/atmospheric science via combined, novel use of EMIT's surface mineral maps and historical aquatic products concerning sensitive lake ecosystems.

Masanori Saito/The University of Wyoming
An ESM-Free Approach for Dust Direct Radiative Effect Estimations Based on EMIT, CALIPSO, and Mineralogy-Resolved Dust Optical Property Models
23-EMIT23-0026

Dust aerosol is one of the most dominant aerosol species by mass and is ubiquitous globally due to the intercontinental transport of its plume. Airborne dust plumes affect the radiation fields directly through scattering and absorbing solar radiation, emitting infrared radiation, and indirectly through modifying cloud microphysical and thermodynamic properties via ice-dust interactions. Additionally, dust plumes fertilize iron-rich dust particles for oceanic phytoplankton growth. The optical properties of dust aerosols vary substantially with their particle sizes, shapes, and mineralogical compositions, as suggested by rigorous electromagnetic theory and confirmed by laboratory measurements. These variations in dust optical properties lead to significant uncertainty in the estimation of the dust direct radiative effect (DDRE).

Many previous studies have attempted to estimate DDRE using spaceborne observations and Earth System Model (ESM) simulations. In general, DDRE estimations obtained from these studies rely on significantly simplified assumptions made for dust optical property models and dust plumes, such as the spherical particle assumption, the regionally invariant dust refractive index, a universal particle size distribution (PSD) across the globe, and/or a single homogeneous dust layer assumption. These assumptions are often inappropriate for typical dust plumes in the atmosphere. The latter two factors can be improved by an ESM-based approach. However, ESM-based approach may involve uncertainty due to dust emission/transport/microphysics schemes, and therefore the estimated DDRE could be ESM-dependent. Thus, the conventional assumptions made in dust aerosol studies create a substantial gap in our in-depth understanding of the role of mineralogical and microphysical properties in DDRE estimation, making the accurate estimation of climatological DDRE challenging based on observations.
To tackle this long-standing challenge, we propose a three-year project focused on better observational constraints of DDRE over arid and semi-arid regions using EMIT observations, CALIPSO observations, and state-of-the-art dust optical property models.

Our proposed three-year research project includes the following tasks:
1) Developing a mineralogically resolved dust optical property model and a dust radiative parameterization for EMIT Science and Application Team, as well as the numerical modeling communities.
2) Validating the dust optical property model with EMIT observations and other measurement datasets, with a focus on mineralogical compositions and PSDs.
3) Estimating DDRE over the Saharan desert region using EMIT, CALIOP, and the dust optical property model through an ESM-free approach.
One striking feature of our proposed project is that the dust optical property model will be developed based on realistic particle shape assumptions, a rigorous electromagnetic framework for various internal mixtures of mineralogical compositions, and various PSDs of dust aerosol particles. Another feature of this project is that the DDRE

evaluation is solely based on spaceborne observations, without the uncertainty introduced by ESM numerical schemes. With these proposed efforts, we will provide a 'benchmark' dust optical property model and observational DDRE estimations.

Suniti Sanghavi/California Institute of Technology
A Bigger Whole than the Sum of Its Parts: Joint Retrievals of Surface Albedo, Dust and Methane over Arid Regions and Coastal Oceans
23-EMIT23-0046

EMIT observations focus on determining the mineral composition of Earth's arid dust source regions by imaging spectroscopy. EMIT is also in the process of developing products for greenhouse gases, notably CH_4. The resulting data products will be used to refine Earth System Models (ESMs) and reduce uncertainty in radiative forcing caused by mineral dust.

Mineral dust is a principal contributor to direct radiative forcing over arid regions, impacting agriculture, precipitation, and desert encroachment around the globe. Dust storms are a substantial contributor to the global aerosol population, particularly in the dust belt region, and known to strongly influence the radiation budget due to their significant scattering and absorption properties. A combination of the vertical distribution of dust and the overall aerosol loading allows the computation of the complex balance among shortwave scattering and absorption and longwave absorption and emission, which determines the net impact of dust on the low-level tropospheric temperature profile. Methane is emitted from a variety of anthropogenic and natural sources. Anthropogenic emission sources include landfills, oil and natural gas systems, agricultural activities, coal mining, stationary and mobile combustion, wastewater treatment, and certain industrial processes. Methane, which accounts for 20% of all GHG emissions, is the second largest contributor to the warming of the Earth's atmosphere since the industrial revolution. However, this belies the fact that CH_4 is a source of the more long-lived CO_2, and has a 25 times stronger warming effect than CO_2. In view of its more localized occurrence, shorter lifetime, and potent greenhouse effect, spatially resolved CH_4 detections would provide valuable observational constraints to account for heat fluxes in ESMs.

We will use the full EMIT spectral range in a time series approach similar to Sanghavi et al. (2010, 2012) to obtain arid surface albedos and dust aerosol optical thickness, making it possible to distinguish between the spectral characteristics of the surface and the dust emitted from it. We will apply the retrieval method of Sanghavi et al. (2012) over coastal ocean soundings to determine the vertical distribution of lofted dust, providing observational constraints of dust height, which is a valuable initialization parameter for Earth System Models (ESMs). EMIT spectra include the strong 2.3 micron methane absorption band. We demonstrate that the inclusion of aerosols significantly improves the accuracy of methane retrievals from EMIT. Using the aforementioned aerosol retrieval methodology, we will develop a coupled dust-methane retrieval for reduced-bias retrievals from EMIT measurements.

Our work will deliver algorithmic data enhancements to support EMIT science objectives by providing key observational parameters - surface albedo, dust AOT, dust height, and methane concentration, to constrain the sign and magnitude of dust-related radiative forcing at regional and global scales in ESMs. Our time series approach will help detect seasonalities and trends in the activity of dust sources, allowing the validation of forecast model predictions of the increase or decrease of available dust sources under future climate scenarios.

Anna Schweiger/Montana State University
Remote Sensing of Biodiversity Across Trophic Levels
23-EMIT23-0052

Significance: Fostering healthy biodiversity is our strongest natural defense against the negative impacts of climate change, as diverse ecosystems sequester more CO2 and maintain ecosystem functions better than impoverished ones. However, most conservation, restoration, and ecosystem management projects rely on field surveys to track the progress of their efforts. This needs to change, as only consistent, continuous, and repeated information on biodiversity and ecosystem health will allow identifying the best conversation, restoration, and management practices and counteracting negative effects of ecosystem change in due time. Previous research has shown that biodiversity metrics developed from proximal and airborne imaging spectroscopy provide indicators for plant diversity at the individual and plant community scale. However, the degree to which these remotely sensed diversity metrics translate to satellite systems, and in how far they can capture the diversity of other trophic levels and at which scale remains underexplored. EMIT (the Earth Surface Mineral Dust Source Investigation) allows us to test and further develop algorithms for biodiversity assessments across ecosystems and trophic levels. Ultimately, this work will improve our understanding of Earth's ecosystems and biodiversity and will contribute to answering key questions, such as: Which aspects of biodiversity can be captured by which sensors and at which spatial scale? This information will be important for future NASA missions, including SBG (Surface Biology and Geomorphology).

Objectives: The proposed research focusses on developing and testing algorithms for biodiversity assessments based on EMIT data. We will concentrate our efforts on estimating plant, soil microbial, and bird diversity, which are interconnected and responsible for providing essential ecosystem services, including biomass production, seed distribution, soil fertility, carbon, and water storage. Geographically, our objective is to cover all major US ecosystems by working with auxiliary organismal and airborne remote sensing data collected by NEON (the National Ecological Observatory Network). In addition, we will combine EMIT imaging spectroscopy data with lidar data from GEDI (the Global Ecosystem Dynamics Investigation), because we expect that the information extracted from imaging spectroscopy and lidar will vary in their importance for predicting the diversity of different organism groups.

Methods: We will use trait diversity, calculated from radiative transfer model (RTM) inversion, and spectral diversity metrics to test the degree to which taxonomic, functional, and phylogenetic diversity of plants, soil microbes, and birds can be predicted across all NEON sites covered by EMIT. We will combine remotely sensed diversity metrics calculated from EMIT with structural diversity metrics calculated from GEDI data to test hypotheses including the assumption that soil microbial diversity depends more on plant chemical variation, whereas bird diversity depends more on plant structural variation. In addition, we will use NEON's airborne imaging spectroscopy and lidar data to compare algorithm performance when applied to remote sensing data with different spatial resolutions and over time. Overall, our project will provide critical information on the remote detectability of biodiversity across ecosystem, biological, spatial, and temporal scales, which is critical for global biodiversity assessments and for providing consistent indicators for biodiversity protection, restoration, and management.

William Smith/University of Arizona
Mapping Biocrust Community Composition and Functional Diversity Across Global Drylands
23-EMIT23-0003

Background and Objectives
Biological soil crusts (hereafter, biocrusts), are photosynthetic communities of cyanobacteria, lichens, and/or bryophytes that cover vast expanses of the terrestrial surface and play critical roles in soil stabilization, fertility, water cycling, and carbon exchange with the atmosphere. Biocrusts are found on all of Earth's continents and are ubiquitous and play keystone roles in global dryland ecosystem structure and function. Global estimates of biocrust distribution suggest that these photosynthetic soil communities make up 12% of Earth's land surface   roughly equivalent to the total extent of tropical and temperate forests combined. Biocrusts exude an exopolysaccharide glue" that binds mineral soils together and their tissues form an intact crust that dramatically increases soil stability and reduces erosion. Biocrusts also fix significant amounts of CO_2, including at times of year when many vascular plants are inactive (e.g., winter), and they are a major source of dryland nitrogen through their ability to fix N_2. Despite their global extent and importance, our quantitative understanding and spatially explicit estimates of biocrust community composition, coverage, function, and response to global change remains in their infancy compared to our understanding of vascular plants. In part this relatively poor spatial quantification comes from the fact that we cannot use many of our existing multispectral remote sensing tools for assessing biocrust communities to the same degree we can for vascular plants.

Here, we propose to address this critical knowledge gap by integrating Earth Surface Mineral Dust Source Investigation (EMIT) and other complementary satellite observation records with the larger goal of mapping biocrust community composition and functional diversity across global drylands. The EMIT mission provides full-range (400-2500nm) hyperspectral surface reflectance observations at high spatiotemporal resolution with the first-time potential to reveal the distinct role and function of biocrusts within dryland ecosystems. We will fully explore this unique opportunity by leveraging multiple unique long-term dryland climate manipulation experiments; assess soil stability and erodibility in the context of plant and biocrust stabilization; and acquire new C flux, stock, and soil microclimate data from an existing global network of dryland eddy covariance sites. We propose three main objectives: 1) Develop a biocrust hyperspectral library across multiple spatial scales; 2) Quantify critical biocrust functional traits through new measurements at core research sites; 3) Map biocrust community composition and function at the global scale utilizing a global network of dryland eddy covariance sites.

Significance and Relevance to NASA
Our proposed work fulfills a key focal area of the solicitation in representing new hypothesis-driven research and innovative analyses using EMIT data products alone or in combination with data products from other sensors & that advance the understanding of & the carbon cycle, ecosystems and their biodiversity&". We propose an interdisciplinary framework that incorporates multiple key focus areas within NASA's mission in Earth system science including Carbon Cycle and Ecosystems and Climate Variability and Change. Our core sites and high resolution remote sensing measurements will be invaluable for evaluation and calibration purposes, and for broader integrated analysis. Our proposed work is planned to complement and directly integrate data from multiple NASA Earth science data platforms including ECOSTRESS and GEDI. Our integrated data products will also have broad real-world utility including as potential key components of land management decision support frameworks that guide improved management of vulnerable dryland ecosystems.

Daniel Sousa/San Diego State University
Comparative Analysis of Spectroscopic Mixing Spaces: To what Extent Does Fine Particulate Cover Affect Impervious Surface Reflectance in Global Built Environments?
23-EMIT23-0015

Capturing diagnostic information about the composition of Earth's land surface is a fundamental goal of satellite imaging spectroscopy. But the majority of terrestrial photons observed only interact with the skin" (approx. surficial 1 micron) of the solid Earth. Fortunately, surficial properties can often be diagnostic of subsurface composition (e.g., in-situ physical weathering of autochthonous rock units).

But important circumstances may also exist where the compositional information of interest might be partially or completely masked by fine particulate coatings (e.g., dust). This problem has been noted in planetary spectroscopy for decades, and has helped motivate the development of iconic optical models. Particulate coatings on plant leaves can drive meaningful changes in physiology. Fine particulate coatings can be especially pervasive in and around human settlements, where both human (vehicle and industrial emissions) and natural (eolian geologic) sources can each be major sources especially in arid regions.

Reflectance spectra from high signal-to-noise spaceborne imaging spectrometers like EMIT can provide diagnostic information on the built environment. In particular, spectroscopic absorption features can clearly identify far more anthropogenic materials and particulate covers   than is possible with multispectral imaging. For problems relevant to mapping built environments, e.g. pervious versus impervious surface distinction for hydrological modeling, spectroscopic imagery may enable improvement in current products   but this question remains open. Specifically, the potential of fine particulate coatings to mask underlying material composition may (or may not) seriously limit mapping accuracy and precision.

Preliminary analysis of 30 EMIT subscenes from urban cores worldwide reveals geographically distinct and spectrally separable differences in both spectral continuum shape and SWIR absorption features of impervious substrates (https://arxiv.org/abs/2307.04716). Despite compositional heterogeneity of urban impervious substrates at the scale of the EMIT IFOV, this suggests that many combinations of impervious substrates may also be spectrally distinguishable from pervious substrates (e.g. soils) in peripheral non-built environments.
Further, this early analysis has found both remarkable geographic consistency in reflectance of geographically proximal cities, and intriguing within-city gradients.
But our early results leave many more questions than answers: What component is compositional versus surficial? To what extent do spectral consistencies generalize among biomes, climates and geologic settings? How do intra- versus inter-settlement gradients compare in both spectral amplitude and continuity? Can specific physical drivers of spectral gradients be identified?

The fundamental goals of this proposal are thus to:
1. Characterize geographic consistency and spatial gradients in spectral properties within & among a diverse global compilation of ~100 built environments.
2. For a subset of built environments with existing AVIRIS data, use airborne imaging spectroscopy for: a) multiscale comparison of urban dust cover; and b) partition dust among surfaces likely versus unlikely to accumulate (e.g., untrafficked roofs vs high-traffic roadways).
3. Investigate specific instances of spatial variations in suspected fine particulate cover across urban development density gradients, and validate with field and lab reflectance spectroscopy.

If funded, this research would provide fundamental physical constraints on important Earth surface properties while offering hands-on, intuition-building experience to a new generation of imaging spectroscopists   including many first-generation students with deep personal knowledge of the study area. Work would also be integrated into the NASA Student Airborne Research Program (SARP), for which the PI is the terrestrial spectroscopy faculty mentor.

Mohamed Sultan/Western Michigan University
EMIT for Lithologic Mapping, Mineral Exploration, and Tectonic Investigations in Arid Lands
23-EMIT23-0028

We propose to evaluate the lithologic mapping capabilities of EMIT, their application for identifying mineralization in arid and hyperarid crystalline terrains, and their potential contribution to our understanding of the accretionary and post-accretionary history of areas under investigation. We selected as our test sites, the once contiguous Eastern Desert of Egypt in the Nubian Shield and the Midyan Region in the Arabian Shield prior to the Red Sea opening. They were selected as test sites for the following reasons: (1) vegetation and cloud coverage is minimal to absent, (2) the test sites host the overwhelming majority of the lithologies of the Arabian Nubian Shield (ANS; ~2.5 M km2) and thus, the developed EMIT-based mapping capabilities could be readily applied elsewhere across the ANS, (3) we have already field checked, sampled, and analyzed many of those units within the test sites for their mineralogic, petrographic, and spectral characteristics, and (4) the test sites encompass multiple gold mineralization sites. We will investigate the extent to which EMIT data can be used to accomplish the following objectives: (1) improve existing geologic maps and Landsat TM-based lithologic maps, (2) use the generated regional maps to enhance our understanding of the accretionary history of the ANS, (3) correlate the lithologies and structures along the Red Sea coastlines and further investigate the validity of pre-Red Sea reconstructions including ours (pole: lat. 34.6°N, long. 18.1°E; rotation amount: 6.7°) and constrain the post-accretionary history of the ANS, (4) develop and test an exploration model that integrates observations from EMIT hyperspectral data with regional- and small-scale tectonic and geological controls to identify existing and previously unrecognized gold mineralization locations, and (5) share and distribute the project's data and findings with the scientific community. The objectives will be accomplished by applying an approach that integrates observations from EMIT hyperspectral data (e.g., mineral maps, supervised spectral angle mapping classifications), multispectral data (TM band ratio images), VNIR field spectrometer, petrographic (modal abundances, XRD), and geochemical data (XRF, SEM, gold assays).

Philip Townsend/University of Wisconsin-Madison
Foliar Functional Traits from EMIT
23-EMIT23-0022

EMIT is at the vanguard of a new generation of imaging spectrometers that are enabling the characterization of Earth and its ecosystems with unprecedented detail. EMIT imagery offers the opportunity to prototype data products expected for the forthcoming global Surface Biology and Geology (SBG) mission. Specifically, in the terrestrial ecology domain, EMIT provides the capacity to map foliar functional traits from space, a priority that was identified by the 2017-2027 Decadal Survey as very/most important for SBG. To date, most efforts to map foliar functional traits over large extents have utilized data from airborne imaging campaigns or via time-static upscaling of in-situ data. The broad spatial coverage of EMIT will enable characterization of foliar traits across large areas of Earth where limited in-situ or airborne imaging spectroscopy data currently exist. We propose to develop models to map foliar functional traits from EMIT by leveraging existing data sets for training and validation from a range of sources, including extensive mapped data sets from California, NEON, South Africa, India and other locations where EMIT imagery overlap with airborne-derived trait maps that can be used for training. In addition, we will leverage trait measurements from databases such as TRY, synthesis products such as sPlotOpen, and datasets recently compiled by collaborators to support efforts at global trait upscaling. Notably, we will link in-situ data from Central Asia (especially Mongolia) to EMIT imagery, a vast area of steppe ecosystems which are poorly represented in our current understanding of global traits.

Our primary focus will be on dry, semi-dry and seasonally-dry ecosystems that have been the focus of EMIT imaging to date, but we will develop and test our trait mapping models in all ecosystem types imaged by EMIT. Primary traits of interest are nitrogen and leaf mass per area (LMA, or its inverse, specific leaf area, SLA), although we will also test additional traits such as foliar phenolics, nonstructural carbohydrates, lignin, cellulose and others for which good in-situ data exist. Chlorophyll and leaf water content will not be directly assessed because we will use archived EMIT imagery; the short-term dynamic nature of these traits limits the availability of suitable training and validation data. One area of analysis will be the incorporation of vegetation fractional cover into the trait-modeling framework, since many areas (especially drylands) will exhibit substantial variation in the proportion of green vegetation within 60-m EMIT pixels. Vegetation fractional cover will be mapped using independent sources based on an existing framework developed and tested by co-Investigator Radeloff for Central Asia. This research will provide a first-cut approximation of models that can be used for forthcoming spaceborne sensors such as the imaging spectrometer planned for SBG. Finally, we will analyze patterns and drivers of traits derived from EMIT. In general, the study of foliar traits in dryland systems has received far less attention than temperate vegetation such as forests, so this effort will primarily address traits in the dry systems that comprise the bulk of current EMIT data. Our research questions will examine trait trade-offs in vegetation traits as related to environmental drivers such as temperature, soils and seasonality of rainfall.

Zhibo Zhang/University of Maryland Baltimore County
Retrieval of Spectrally-Resolved Dust Aerosol Direct Radiative Effect from EMIT Hyperspectral Observations
23-EMIT23-0005

Mineral dust is one of the most abundant types of atmospheric aerosols in terms of dry mass. Dust directly interacts with both solar shortwave (SW) and thermal infrared (IR) longwave (LW) radiation and thereby influences the Earth's radiative energy budget, which is known as the direct radiative effects (DRE) of dust. Despite significant progress made over the last few decades, there are still significant uncertainties in both model- and observation-based estimates of dust DRE, which are particularly large in the desert regions. NASA's Earth Surface Mineral Dust Source Investigation (EMIT) mission launched in 2022 provides unique hyperspectral observations that cover most of the solar spectrum (381 nm to 2493 nm) and corresponding surface reflectance retrievals over the dust source regions. The surface soil mineralogy retrievals from EMIT will soon help the Earth System Models (ESMs) improve their dust DRE simulations.

The proposed research is motivated to provide a unique observation-based, spectrally-resolved clear-sky SW dust DRE at the top of atmosphere (TOA) in the desert regions based on a novel method enabled by the hyperspectral observations of EMIT instrument. The retrieved dust DRESW will provide a valuable independent dataset for model evaluations and studies of dust's multifaceted roles in the climate systems. To achieve this objective, we propose a three-year research project with the following specific tasks:
" Improve the prototype retrieval method for estimating the spectrally-resolved SW dust DRE at TOA and implement it using the EMIT level-1 hyperspectral radiance observations and level-2 surface reflectance retrievals.
" Evaluate the retrieved DRE through comparisons with benchmark results derived based on Aerosol Robotic Network (AERONET) retrievals and carry out comprehensive sensitivity studies to understand and quantify the sources of uncertainties in our method.
" Apply the retrieval method to the dust dominant regions over land observed by EMIT mission.
" Use the retrievals to better understand the spectral signature and temporospatial variations of clear-sky dust DRE.

Although taking a different pathway, the proposed research is perfectly aligned with the primary scientific objective to constrain the sign and magnitude of dust-related radiative forcing at regional and global scales" of the EMIT mission. There is no doubt that the surface mineralogy retrievals from the EMIT mission will soon be used in many ESMs to improve their dust DRE simulations. In this regard, the proposed research is timely and necessary because the observation-based dust DRE from the proposed research provides a valuable independent data point for validating, evaluating, and understanding the dust simulations in models, thereby advancing the objective of the EMIT mission. From a broader perspective, the proposed method provides a novel alternative way enabled by the hyperspectral observations to derive the dust DRE in the desert regions, which has been a formidable challenge in the previous studies. The proposed project will allow this novel method to be tested, improved, and mature so it can be applied to future NASA missions.