NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2016
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The National Aeronautics and Space Administration (NASA) solicited proposals for the Arctic-Boreal Vulnerability Experiment (ABoVE) Airborne Campaign. ABoVE is a large-scale study in western North America's Arctic - Boreal Zone of ecosystem responses to environmental change and the implications of these changes for social-ecological systems. The research for the ABoVE Airborne Campaign will link data provided by state-of-the-art airborne sensors to both field-based studies and to satellite sensors. The effort will build a foundation for improving the analysis and modeling capabilities needed to understand and predict ecosystem responses and consequent societal implications and to help develop the next generation of satellite sensors for monitoring ecosystem properties and processes in northern regions. It is envisioned that a successful ABoVE Airborne Campaign will (1) contribute to greater scientific understanding of the vulnerability and resilience of ecosystems and societies to environmental change in western North America, and (2) provide the scientific basis for informed decision-making at local-to-international levels. The funded proposals address the following research objectives:

(a) Improve understanding of active-layer thickness and permafrost state characterization and the impacts of variations in permafrost on ecosystems at local to regional scales;

(b) Advance our ability to characterize the type, structure, and function of vegetation during the peak of the growing season and its relationship to ecological disturbance;

(c) Improve understanding of the drivers and impacts of variations in surface hydrology (soil moisture and inundation) at local to regional scales.

(d) Understand how the magnitudes, fates, and land-atmosphere exchanges of carbon pools are responding to environmental change, and what are the biogeochemical mechanisms driving these changes?".

NASA received a total of 34 compliant proposals in response to this NRA and will recommended 8 or 9 for funding. The total funding to be provided by NASA for these investigations is approximately $8.25 million over three years. The investigations recommended are listed below. The Principal Investigator, institution, investigation title, and a project summary are provided. Co-investigators are not listed here.

Abhishek Chatterjee/Goddard Space Flight Center
GEOS-5 Forecasting and Modeling in Support of ABoVE Airborne Research
16-TE16-0016

The ABoVE field campaign will improve our understanding of one of the most dynamic regions on the planet â€“ the Arctic-Boreal region (ABR), where changes in climate are progressing most rapidly and are already triggering changes to ecosystem carbon storage.

While the importance of the ABR in the global carbon cycle is well established, our fundamental understanding of the magnitude, behavior and fate of carbon pools in this domain remains incomplete. The first ABoVE airborne campaign will provide critical observations needed to understand permafrost carbon dynamics. These unique datasets complement existing monitoring networks that are limited in spatial coverage (ground) or spatial resolution (satellite). Strategically integrating the information collected during the ABoVE campaign into a high-resolution, scalable and global land-atmosphere model is a vital step towards achieving the science objectives of the mission.

We propose to deliver a highly integrated modeling framework using NASA's GEOS-5 system that will rely on multi-scale data streams from ABoVE to inform and improve process-based representation of permafrost-carbon dynamics. We will adopt a three-pronged approach, which includes: (a) analyzing and interpreting the airborne (primarily the Foundational) measurements that will be collected during the 2017 ABoVE airborne campaign, (b) integrating the airborne information into a dynamic vegetation modeling framework (LPJ-wsl) tailored for the ABoVE study domain, and (c) using the coupled high-resolution GEOS-5-LPJ-wsl framework to improve our understanding of the permafrost carbon (both CO2 and CH4) emissions, and associated feedbacks at a variety of spatiotemporal scales. In order to maximize the scientific return of the early mission data from the 2017 campaign, we will also leverage data from existing remote-sensing missions (e.g., SMAP, Landsat -7/8, OCO-2, etc.), previous airborne campaigns (e.g., CARVE) and ground-based measurements, as applicable.

During the airborne campaign, we will use GEOS-5 to produce high-resolution forecasts of meteorology, aerosols and trace gases in near real-time and support flight planning. We will also provide statistical analyses of clear-sky conditions and trace gas plumes to the ABoVE team to guide planning of the optical (for e.g., AVIRIS-NG, LVIS) sensors in advance of deployment. The GEOS-5 model has contributed to numerous field campaigns and the inclusion of trace gas and aerosol fields can inform mission planning by representing emissions processes being targeted or factors that can confound measurements.

Ongoing and recent developments within the GEOS-5-LPJ-wsl framework are uniquely suited to address the science goals of ABoVE. Its ability to run at spatial resolutions of 12.5-50 km is comparable to resolutions used by regional models, but because it is a global model it can readily extend lessons learned to the pan-Arctic scale to realistically simulate carbon-climate interactions in the present and future. By performing rigorous comparisons between airborne and satellite observations, this effort will also help inform observing strategies and maximize the use of satellite data in this complex region. The proposed study thus addresses both the conceptual basis for ABoVE as well as NASA Earth Science's strategic goal to quantify and document changes to the carbon cycle in the high-latitudes.

Karl Huemmrich/University of Maryland Baltimore County
Causes and Consequences of Arctic Greening: the Importance of Plant Functional Types

16-TE16-0003

Long-term satellite data records show greening of high latitude terrestrial ecosystems based on change in NDVI with strong trends in the coastal arctic. This proposal is directed at investigating how changes in biodiversity and tundra carbon and energy balance are related to the change in NDVI. Tundra vegetation groups into several different plant functional types (PFT) such as vascular plants, lichens, and mosses. These PFT have very different physiological responses and thus lead to differential growth rates, carbon fluxes (GPP), and energy balance under varying environmental conditions. The distribution of these PFTs over the arctic landscape is key to describing patterns of biodiversity and carbon fluxes and understanding responses to climate change. Spatial distributions of vegetation functional types are strongly related to surface microtopography with surface hydrology being a significant controlling factor. Warming and melting permafrost alter surface hydrology (wetting or drying), with moisture affecting surface-atmosphere fluxes and albedo.
Resulting changes in PFT distribution and surface hydrology impact ecosystem function, which will, in turn, require changes in how these systems are modeled as well as the interpretation of remotely sensed signals. Key drivers for remotely sensed spectral reflectance are vegetation structure, physiology, and phenology, which are all factors that describe plant functional traits thus providing physical links between remote sensing and plant physiology. We will utilize small-plot measurements of spectral reflectance and carbon fluxes to describe the spectral characteristics and light use efficiency of different PFTs. These data will be used to develop spectral unmixing approaches for describing the fractional coverage of the tundra PFT that will be applied to the AVIRIS and other aircraft imagery from the ABoVE airborne data collection. We will use the PFT information to parameterize models of carbon and energy fluxes, testing the results against flux tower measurements. The spatial change encountered along the flight lines will be used to examine how relationships between NDVI and carbon fluxes vary to evaluate how a greening NDVI signal relates to changing tundra biodiversity and carbon fluxes.

Go Iwahana/University of Alaska Fairbanks
Quantification of Thermokarst and Carbon Release in Ice-Rich Permafrost Regions
16-TE16-0004

I. Introduction and objectives

Carbon release from permafrost regions upon degradation is one of the greatest uncertainties for projections of future climate. Lack of knowledge about rate of permafrost degradation, its spatial variation, and carbon storage in the permafrost represents a major source of uncertainty for the future climate projection. Permafrost thaw and degradation promotes the mobilization of organic matter, water and greenhouse gases (GHG). It is of great scientific interest and social concern to know where and to what extent permafrost degradation may occur, especially in ice-rich permafrost, as consequential subsidence by thaw (thermokarst) will cause large changes in surface ecology, landscape evolution, and hydrological processes, and will also affect local life and subsistence.

Objectives in these case studies are to:

1. Measure the spatial variation of thermokarst subsidence, using InSAR and LiDAR differencing techniques;
2. Improve uncertainty in the thermokarst quantification by remote sensing;
3. Estimate GHG and organic matter contents in permafrost, including in the ground ice body; and
4. Evaluate the rates of potential release of carbon upon thermokarst development

II. Methods

We propose conducting an investigation to determine subsided volume due to thermokarst, combining remote sensing techniques and field surveys. We will employ a DInSAR (Differential Interferometry Synthetic Aperture Radar) technique, using data from the past and new NASA airborne campaigns and L-band SAR (ALOS (2) / PALSAR (2)) to measure the rate of thermokarst subsidence and its spatial variation in wide areas of permafrost regions. ABoVE airborne operations with LIDAR and RADAR over targeted areas are expected to provide ranges of seasonal surface movement and active layer thickness, which are critical information to reduce uncertainty for quantification of inter-annual subsidence due to thermokarst development. Optical space-borne sensors capable of capturing ground objects in sub-meter spatial resolution will be used to detect thermokarst development through land surface texture changes. In-situ, high-accuracy GPS mapping, UAV topographical survey, and geocryological analysis support the thermokarst measurements by airborne and satellite remote sensing. We will further sample permafrost sediments and ground ice in the selected target areas to analyze the concentration of greenhouse gases and the amount of organic matter. Drill-core and surface soil samples will be kept frozen for laboratory measurement of greenhouse gas concentration and volume.

III. Significance of the proposed study

Our goal is to greatly increase our knowledge about the conditions and disturbances that lead to thermokarst and permafrost thaw in Arctic ice-rich permafrost regions. Thawing of permafrost whether by human disturbance, fire, or climate change will have direct and indirect consequences for local societies by way of effects on infrastructure, changes in water availability and quality, nutrient cycles and habitat. In addition, the potentially very large release of GHG from permafrost thaw could have catastrophic consequences for the global climate. We therefore believe this proposed study will not only increase our scientific understanding of permafrost dynamics in the Arctic, but will also generate further understanding about Arctic ecosystem carbon exchange dynamics that are of crucial importance for the well-being of all societies on earth. This project relates particularly to the future NASA L-band SAR program NISAR, and our proposed method for quantification of thermokarst in permafrost regions represents a promising application of NISAR, while also serving as an important carbon-monitoring task for future projects.

Charles Miller/Jet Propulsion Laboratory
Imaging Arctic Methane Plumes
16-TE16-0031

Active biogeochemical processes create intense, localized methane (CH4) emissions sources across Arctic-boreal landscapes, but their contribution to the northern high latitude CH4 budget is uncertain and their spatial and temporal distributions are uncharacterized at the regional scale.

Our research is driven by the questions: What are the dominant landscape and biogeochemical features associated with large CH4 source plumes in the ABoVE domain? and How do these characteristics differ in tundra vs boreal ecosystems? In Alaskan vs Canadian ecosystems? We test the hypothesis that CH4 emissions from geologic seeps contribute significantly to the permafrost carbon feedback.

We will exploit recent breakthroughs in high-resolution (1-3m) CH4 imaging to identify, geolocate and quantify CH4 plumes from all imagery acquired with the Next Generation Airborne Visible Infrared Imaging Spectrometer (AVIRIS-NG) during the 2017 ABoVE Airborne campaign. We estimate that AVIRIS-NG surveys will detect >250 CH4 plumes from sub-permafrost (geologic) ebullition seeps and hundreds more plumes from a combination of aboveground seeps, wetlands hotspots, thermokarst slumps, energy exploration and infrastructure. The operational AVIRIS-NG On-board Real-Time Detection System and cluster-matched filter (CMF) retrieval algorithm enable us to deliver Quicklook CH4 plume products within 24 hours of acquisition and CMF CH4 plume products within 2 weeks of Level 1 data processing.

We will follow up AVIRIS-NG CH4 plume detections with ground-truth field studies of selected sources near Noorvik, AK and Bethel, AK to validate the AVIRIS-NG observations and characterize the source process using isotopic analyses of collected gas samples. We will characterize the spatiotemporal variability of observed CH4 sources by analyzing high-resolution optical and synthetic aperture radar images of thermokarst lake ebullition seeps acquired during the cold season. Our use of isotope geochemistry, year-round flux sampling, and surveys of concentrated energy exploration and infrastructure will enable us to separate geologic and energy sector CH4 sources from ecologic sources, providing critical insight into the CH4 component of the permafrost carbon feedback.

We will deliver maps of CH4 sources for the ABoVE domain and compare these to CH4 flux maps estimated from CARVE, AIRMETH, other measurements and models.
The resulting data set will transform our understanding of the spatial distribution and magnitude of CH4 sources in the varied ecosystems of the ABoVE domain.

Our investigation leverages collaboration with and significant investments from the NANA Regional Corporation (NANA). NANA will provide at no cost to our investigation:
1) Logistics for four team members to conduct ground-truth fieldwork on gas seeps in the Kobuk Delta region and near Kotzebue.
2) Permits for access to NANA land
3) Accommodation, transportation and local guides to explore gas seep sites in rural lakes near villages

Additionally, NANA will provide a two-year graduate fellowship (stipend and related benefits) at the University of Alaska Fairbanks to Janelle Sharp, a native Alaskan and NANA Shareholder, who will use the results from this research as the basis of her thesis. NANA will also identify a resident researcher whom we will train to monitor seeps in the Noorvik-Kotzebue area year-round over multiple years.

Our research addresses the ABoVE Tier 2 Science Question How are the magnitudes, fates, and land-atmosphere exchanges of carbon pools responding to environmental change, and what are the biogeochemical mechanisms driving these changes? Our expected findings of CH4 sources related to energy exploration will guide DOE and NRCanada as energy commerce evolves in the North. Our study of geologic thaw lake seeps links ABoVE to research in the Earth Science Directorate's Atmospheric Composition, Cryosphere Science, Hydrology and Solid Earth programs.

Kevin Schaefer/University of Colorado, Boulder
The Airborne InSAR and PolSAR Permafrost Dynamics Observatory
16-TE16-0014

The Airborne Interferometric and Polarimetric Synthetic Aperture Radar Permafrost Dynamics Observatory (PDO) will combine data from the AirMOSS and UAVSAR instruments to simultaneously measure seasonal subsidence, Active Layer Thickness (ALT) and soil moisture. The PDO combines proven techniques to measure ALT and soil moisture: Remotely Sensed Active Layer Thickness (ReSALT) and the polarimetric retrieval from AirMOSS. ReSALT uses the Interferometric Synthetic Aperture Radar (InSAR) technique to measure ALT and the polarimetric retrieval uses backscatter observations to measure soil moisture and ALT. PDO will use backscatter measurements from both the P-band AirMOSS and L-band UAVSAR instruments to measure soil moisture. PDO will apply the InSAR technique to both P-band and L-band data to measure surface subsidence and ALT.

The combined PDO retrieval will measure seasonal subsidence, ALT and soil moisture using four distinct observations from two instruments at two frequencies. The team will use Ground Penetrating Radar to collect in situ measurements of ALT and soil moisture along the ABoVE flight path to validate the PDO retrieval. The team will perform several statistical analyses between PDO data and data from other foundation instruments to quantify statistical relationships between vegetation conditions, ALT, and soil moisture that cut across spatial scales. These include scaling PDO ALT up to the entire permafrost domain and scaling SMAP data down to the 10-meter resolution of the flight data.

PDO is the first to combine InSAR and polarimetric backscatter observations from two instruments at two frequencies, resulting in a retrieval that is much more powerful than the individual techniques alone. The PDO project makes maximum use of ABoVE airborne data by using all of the UAVSAR and AirMOSS data and a large portion of data from the remaining foundational instruments. The PDO products will complement currently funded ABoVE science projects, many of which have already requested ReSALT and AirMOSS data for their study areas. PDO directly addresses three of the

six ABoVE science questions and will remotely sense five of the twenty high priority parameters. Permafrost influences all other hydrological, ecological, and disturbance processes, making the PDO data and statistical analyses applicable to ABoVE science questions. The PDO techniques readily transfer to the planned NASA-ISRO Synthetic Aperture Radar (NISAR) mission and fulfill its requirement to study permafrost dynamics. The PDO provides validation data for SMAP and a simpler, data-driven technique to downscale SMAP data. PDO represents a bridge in spatial scales necessary for the development of a successful satellite product: in situ ALT measurements linked with intermediate spatial scales from airborne measurements flowing up to global satellite measurements.

The team is uniquely qualified to meet PDO objectives. The University of Colorado and Stanford teams jointly developed the ReSALT retrieval of ALT. The University of California team developed the polarimetric retrieval and served as PI on the original AirMOSS project. The University of Wyoming team has used GPR to measure ALT and soil moisture across the Arctic.

Laurence Smith/University of California, Los Angeles
Sensitivity of Arctic-Boreal Surface Water to Permafrost State
16-TE16-0032

Nearly ~50% of Canada and ~80% of Alaska are underlain by permafrost (perennially frozen ground), but are precluded from field study owing to logistical difficulty, short field seasons, and high cost. The presence of this permafrost exerts feedbacks on surface water ecosystems and the Arctic-Boreal landscape, most observably in the form of millions of lakes, ponds, wetlands, and saturated soils, with associated impacts on vegetation cover, greenhouse gas emissions, soil carbon sequestration, landscape disturbance, wildlife habitat and traditional subsistence economies. The proposed project will study the resilience of these surface water features in response to thawing permafrost, capitalizing on the long flight lines of the NASA Arctic-Boreal Vulnerability Experiment (ABoVE) which will span a full spectrum of permafrost conditions (permafrost-free to continuous permafrost, low to high ground ice content), ecosystems, climatic regions, topographic relief, and geological substrates. At the heart of the proposal is acquisition and study of new airborne data from AirSWOT, an experimental radar interferometer specifically designed for surface water studies including precise determination of water surface elevations (WSEs) for thousands of lakes, ponds, rivers and wetlands occurring along planned ABoVE flight lines.

The overarching science question to be answered is can permafrost presence and/or disturbance be identified from remote sensing of surface water lake and wetland ecosystems? Two scientific hypotheses relating water surface elevations and extents to permafrost and associated landscape disturbance will be tested. To isolate the influence of permafrost from regional water balance variations, the Variable Infiltration Capacity (VIC) water balance model will be calibrated along the ABoVE flight paths for use by this and other ABoVE projects. Remotely sensed surface water elevations and areal extents, and mapping of visible manifestations of permafrost (e.g. thermokarst) are key

targets of study and will be obtained using the AirSWOT Ka-band interferometric radar and Digital Cirrus Camera (DCC) optical camera imagery, as well as planned ABoVE UAVSAR, AirMOSS and LVIS airborne acquisitions and ancillary data products (permafrost maps, ArcticDEM high-resolution digital elevation model). Anticipated outcomes of the project include 1) fundamentally new scientific understanding of the interaction between permafrost and lake/wetland water surface elevations in the Arctic-Boreal Zone (ABZ); 2) identification of forest/ecosystem disturbance locations attributed to permafrost thaw along ABoVE flight lines; 3) assessment of the potential for using remotely sensed WSE and/or WSE changes to infer the presence/absence of subsurface permafrost and/or attributing ecosystem disturbance to permafrost thaw; 4) new synergies between ABoVE and AirSWOT/SWOT datasets; and 5) new science and data-sharing collaborations among the ABoVE Science Team.

PI Larry Smith and Co-I Tamlin Pavelsky have career-long expertise in remote sensing and field studies of Arctic-Boreal hydrology and carbon cycles and in planning airborne campaigns in remote northern environments, including extensive field experience inside the ABoVE Study Domain. Co-Investigator Dennis Lettenmaier developed the VIC water balance model and brings decades of NASA Science Team experience to ABoVE. The proposal is highly responsive to specific priorities of ABoVE, NASA and numerous federal entities, and offers mentorship of graduate and undergraduate students, and community outreach through scientific engagement with elementary and secondary schools in Alaska and northern Canada.

Colm Sweeney/University of Colorado, Boulder
Airborne Seasonal Survey of CO2 and CH4 Across ABoVE Domain
16-TE16-0024

Large changes in surface air temperature, sea ice cover and permafrost in the Arctic Boreal Ecosystems (ABE) are likely to have significant impact on the critical ecosystem services and the human societies that are dependent on the ABE. In order to predict the outcome of continued change to the climate system in the ABE, it is necessary to understand the vulnerabilities of the underlying ABE ecosystems by understanding what processes drive both spatial variability and interannual variability.

The proposed study entitled airborne seasonal survey of CO2 and CH4 across the ABoVE Domain focuses on improving our understanding and predictive capabilities for modeling the land-atmospheric exchange of CO2 and CH4 to better understand the feedbacks that these greenhouse gases will have on the ABE. We will perform this task in the following way:

1. Airborne measurements a multi-ecosystem/seasonal aircraft survey of the ABoVE study area is proposed which will provide both in situ and flask measurements over seven ecosystems during six surveys between April and November of the 2017 field season. The in situ measurements will include CO2, CH4, CO, O3, H2O, temperature and wind; the flask measurements will include more than 50 different species including CO2, CH4, CO, SF6, and a variety of hydrocarbons, halocarbons and isotopes of carbon.

2. Analysis of airborne measurements the data collected during the Multi-Ecosystem/Seasonal Aircraft Survey will be combined with two intensive airborne studies of the North Slope in 2015 and 2016; Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE); CARVE-CAN and NOAA aircraft sampling sites to summarize the findings of all of these flight missions and understand their unique contribution.

3. Inverse modeling analysis leveraging ground-based data collected from the ABE gathered as part of the Phase 1 ABoVE project of Co-PI Miller (JPL) and a pre-ABoVE project led by Munger (Harvard), we will create a spatially explicit estimate of the CO2 and CH4 fluxes from 2012-2017 for the ABE. The multi-year product over the Alaskan domain will provide a baseline estimate of interannual variability and spatial variability throughout the ABoVE domain.

4. Evaluation of OCO-2 retrievals during the summer months the Orbiting Carbon Observatory-2 (OCO-2) offers valuable data that will augment the available CO2 measurements made from ground and aircraft sites as well as add solar-induced chlorophyll fluorescence data that has had a dramatic influence on the prior model that we will be using for our inverse modeling analysis.

Our results will significantly reduce uncertainties in estimates of the current carbon balance of ABoVE ABE and model projections as the climate continues to change. Our research: 1) Provides a baseline record of atmospheric observations, carbon flux patterns and magnitudes that can be used to document change in the future, 2) Improves our ability to estimate regional-scale carbon fluxes and their drivers, and 3) Informs decision making and ecosystem services management through reduced uncertainty in projections of long-term change in ABE carbon balance.

The study seeks to answer the Tier 2 Science Questions defined in the ABoVE Concise Experiment Plan: "How are the magnitudes, fates, and land-atmosphere exchanges of carbon pools responding to environmental change, and what are the biogeochemical mechanisms driving these changes?"

Alireza Tabatabaeenejad/University of Southern California
Estimation of Belowground Biomass and Permafrost Active Layer Properties Using Radar and Lidar Measurements
16-TE16-0028
We propose to advance methods of retrieving belowground biomass and permafrost active layer properties by developing accurate radar scattering and inverse scattering models of layered ground that include a combination of organic and mineral soils, overlain by vegetation, and containing vegetation roots. We will use the radar forward scattering models to develop corresponding methods of simultaneously retrieving root biomass, permafrost active layer thickness, and soil moisture profiles for both organic and mineral layers using the ABoVE Foundational Airborne Measurements, particularly P-band (70 cm) and L-band (24 cm) measurements from the AirMOSS and UAVSAR instruments, respectively.

The proposed study will benefit the ABoVE campaign by providing foundational datasets supporting regional investigations. This work takes advantage of the baseline set of data and products established by an ongoing Interdisciplinary Research in Earth Science (IDS) Program project that has aimed to estimate the active layer thickness along a 2500 km-long transect in Alaska, covered by 6 AirMOSS flights in two years (2014, 2016). The work proposed here, however, will develop substantially more sophisticated radar scattering model, retrieval algorithm, and geospatial data products for the permafrost regions, including modeling of vegetation roots, which has not been addressed before.

A limited set of ground measurements are also planned to support radar scattering model parameterization as well as the validation of retrieved products; these data will be used with other biophysical data collections enabled by ABoVE including vegetation parameters derived from NASA's Laser Vegetation Imaging Sensor (LVIS) measurements"for regional calibration and refinement of radar models and retrieval algorithms, leading to improved monitoring of soil processes in Alaskan and Canadian permafrost landscapes.

This proposal directly responds to the Terrestrial Ecology Program's seeking to strengthen the theoretical and scientific basis for measuring Earth surface properties using reflected, emitted, and scattered electromagnetic radiation. By providing accurate estimate of spatiotemporal distribution of permafrost active layer properties, this work addresses Question 3 and Question 4 of Tier 2 Science Questions, that is â€œWhat processes are controlling changes in the distribution and properties of permafrost and what are the impacts of these changes? and What are the causes and consequences of changes in the hydrologic system, particularly the amount, temporal distribution, and discharge of surface and subsurface water? This study also indirectly helps address How are environmental changes affecting critical ecosystem services and how are human societies responding?

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