NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2014
NNH14ZDA001N A.4
Updated March 22, 2016

The National Aeronautics and Space Administration (NASA) solicited proposals for the initial research investigations to begin the Arctic-Boreal Vulnerability Experiment (ABoVE) field campaign -- a large-scale study of ecosystem responses to environmental change in western North America's Arctic and boreal region and the implications for social-ecological systems. The Research for ABoVE will link field-based, process-level studies with geospatial data products derived from airborne and satellite sensors, building a foundation for improving the analysis and modeling capabilities needed to understand and predict ecosystem responses and societal implications. It is envisioned that a successful ABoVE 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. NASA requested proposals for the following types of research activities:

- Development and analysis of remote sensing data products;
- Collection and analysis of field-based (surface, in situ) data;
- Collection and analysis of socio-ecologic and -economic data;
- Modeling investigations;
- Synthesis investigations; and
- The Science Lead for the ABoVE Science Team.

NASA received a total of 101 compliant proposals in response to this NRA and recommended 22 for funding. The total funding to be provided by NASA for these investigations is approximately $18.1 million over four years. The investigations recommended by NASA are listed below. The Principal Investigator, institution, investigation title, and a project summary are provided. Co-investigators are not listed here.

Natalie Boelman/Columbia University
Animals on the Move: Remotely Based Determination of Key Drivers Influencing Movements and Habitat Selection of Highly Mobile Fauna Throughout the ABoVE Study Domain

Arctic-Boreal regions (ABRs) of North America are warming at a rate almost three times higher than the global average, and the biophysical responses are acute. Most regional scale studies to date have explored consequences on biogeochemical cycling and energy balance. Far less attention has been paid to the vulnerability and resilience of wildlife throughout the ABR, despite the fact that the region hosts the planet's most diverse neotropical migrant songbird communities, caribou which are among the most abundant long range migratory large herbivores in the Northern Hemisphere, and intact yet threatened mammalian trophic systems. Many ABR species play unique ecological roles and are of cultural and economic significance to indigenous people.

Many recent studies suggest that animal habitat throughout the ABR is undergoing rapid and profound change. For example, the region is undergoing altered vegetation productivity, phenology, composition, and bio-physical and -chemical structures; more extreme swings in seasonality of meteorological conditions; more frequent drought conditions; changes in snow and ice cover properties, dynamics and duration; enhancement of disturbance regimes, and; increasing human development. Each of these changes alters wildlife habitat in unique ways - very often overlapping and interacting with one another in time and space. In addition, there is high spatial heterogeneity in both the direction and magnitude of these changes across the ABR, yet little effort has been made to understand the ecological consequences. Highly mobile fauna of the ABR must navigate through an increasingly complex and dynamic mosaic of environmental and land surface conditions, but how vulnerable or resistant their long-term persistence is to the increasing spatiotemporal heterogeneity is unknown.

Although there has been some focus on how changing conditions in the ABR affect wildlife habitat quality and selection, the overwhelming majority of these studies have focused on how habitat selection by one species (or community of similar species) responds to a single extreme or disturbance event. Recent and emerging advances in space-based animal tracking technology allow direct measurement of wildlife movements across animal taxa, over vast and remote regions, and over multiple years. Importantly, these regional-scale and near-continuous descriptions of animal locations can be explicitly linked to remote sensing observations of dynamic environmental conditions, which enables examination of animal responses to a wide range of environmental conditions and extreme events that occur - often unpredictably - throughout their ranges and life histories.

Our overarching science goal is to understand how highly mobile terrestrial fauna navigate and select habitat in the rapidly changing ABoVE Study Domain. Facilitated by many data-sharing collaborations with US and Canadian government agencies, we will use space-based wildlife tracking technology to build an integrated dataset of regional-scale and near-continuous descriptions of passerine (American robins), raptor (Golden Eagles), ungulate (caribou, moose), and predator (wolf and brown bear) locations with both static and dynamic remote sensing products and other regional-scale geospatial datasets (Obj.1). We will use this data to build empirically-based statistical movement and habitat selection models for multiple groups of animals across the ABoVE Study Domain (Obj.2). The geospatial tools and products will be made accessible to natural resource agencies, wildlife managers, First Nations, Alaskan natives, and other stakeholders to aid them in management and adaptation decisions (Obj.3). Further, our

novel models and geospatial tools will be available for Phase 2 and 3 ABoVE studies in which future projections of animal movement and habitat selection will be made, and subsequently used to determine societal consequences and develop decision support products.

Laura Bourgeau-Chavez/Michigan Technological University
Understanding the Vulnerability and Resiliency of Boreal-Taiga Ecosystems to Wildfire in a Changing Climate:A study of the 2014 Northwest Territories Wildfires

Recent changes in climate including earlier springs, longer summers and changes in moisture patterns across the landscape, are affecting wildfire regimes of the Arctic-boreal region including intensity, severity and frequency of wildfires. During the summer of 2014, a record breaking year of wildfire occurred (3.4 million hectares) in the southern part of the Northwest Territories of Canada (NWT). The 2014 fires traversed gradients of ecozones, permafrost zones, ecosystem types, severity of burn and seasons of fire. The proposed project addresses questions about the vulnerability and resiliency of these NWT ecosystems to climate change including: 1) What are the controls on spatial and temporal variations in fire severity?; 2) Do fire effects (hydrology and revegetation) vary across different ecological zones and permafrost conditions?; and 3) Are pre-season fuel moisture patterns indicative of potential wildfire extent, severity and distribution? By studying a range of sites stratified across these gradients of biotic and abiotic factors we will improve our understanding of the vulnerability of a variety of ecosystems to wildfire, fire behavior, C consumption/emissions and the trajectories of succession that will ensue. This is particularly important for peatland ecosystems with deep organic soil profiles which are estimated to cover more than 75% of the southern NWT landscape, but also for determining thresholds that may change successional trajectories. Permafrost is the second most prevalent disturbance factor after wildfire in northern latitudes. There is evidence that climate change is exacerbating both wildfire and permafrost and the feedbacks between them. The diverse landscape of southern NWT allows us to evaluate the effects of both wildfire and permafrost thaw across 3 permafrost zones from sporadic to continuous.

The proposed work builds from two previous NASA TE projects, Grant #NNX09AM15G to consider the impacts of climate change on the vulnerability of boreal peatlands to fire and a one year NASA Rapid Response grant #NNX15AD58G that is focused on capturing the time critical field and remote sensing data in summer 2015, within 1 year of the NWT fires. The previous peatland project was focused on central Alberta where wildfires occurred only in spring during the period of study (2009-2014). This lack of seasonality of wildfire limited the analysis to conditions when water tables are typically high and burn severity typically low. Further, the previous project revealed important data gaps for understanding C emissions from peatlands. The proposed project will leverage these two previous projects to improve our understanding of the vulnerability and resiliency of boreal ecosystems to wildfire and the interaction with permfrost thaw. Field and remote sensing data will be collected for mapping peatlands, wetlands, uplands, burn severity to the surface organic layers, soil moisture pre- and post-fire, revegetation, fuel consumption, fire-progression, and permafrost condition to characterize the fire

effects and response in a cross section of these fire-disturbed sites. Time critical data will be collected in the summer of 2015, within one year of the events through the Rapid Response grant. Under the proposed ABoVE project, we plan to analyze the data collected in 2015 and continue the study through remote sensing and field analysis to monitor the longer term effects of wildfire on this diverse landscape through 2018. This proposed project will continue to develop a better understanding of our changing climate, the impacts it has on our boreal-taiga ecosystems and fire behavior. This proposal directly addresses the overarching science question for ABoVE on how vulnerable or resilient are ecosystems to environmental change in the Arctic-boreal region of western North America with a focus on wildfire, which is the most prevalent disturbance factor in the north.

Todd Brinkman/University of Alaska, Fairbanks
Biophysical Characteristics and Mechanisms of Environmental Disturbances Influencing Human Access to Ecosystem Services in Boreal Alaska

Increasingly, subsistence harvesters within the ABoVE domain have expressed concern that changes in the environment are influencing their ability to move across landscapes and access traditional hunting, fishing, and gathering areas. Few data have been collected on the biophysical characteristics and mechanisms of environmental disturbances influencing both human movement across landscapes and access to subsistence resources. In addition, the prevalence and spatial-temporal characteristics of subsistence-altering disturbances have not been quantified at a regional level. Approaches integrating participatory research, field data, remote sensing, and modeling are needed to analyze and interpret data on these consequential ecosystem dynamics. Our objectives are to: 1) Collaborate with subsistence harvesters to map travel networks and locate sites of ecosystem disturbances influencing access to subsistence resources in boreal Alaska; 2) Document traditional ecological knowledge on the relationships among environmental change, disturbance sites, and access to subsistence resources; 3) Document biophysical characteristics and the underlying mechanisms related to ecosystem disturbances identified by subsistence harvesters; 4) Use integrated modeling to expand the sample size of disturbance observations and determine spatial and temporal extent (frequency, duration, area, severity) of influential disturbances; and 5) Estimate uncertainty and error associated with generalizing findings beyond data-collection area. We will collaborate with tribal organizations in ~6 communities to recruit subsistence harvesters into a participatory research program. Using camera-equipped GPS units, harvesters will be asked to mark and photograph environmental disturbances influencing their access to subsistence resources for one calendar year. We will conduct semi-structured ethnographic interviews to document local perceptions of the prevalence, causes, and effects of disturbances identified. We will conduct field-based assessments of disturbance sites to document biophysical characteristics and quantify descriptive metrics that will facilitate identification of mechanisms causing disturbances. After we have mapped disturbances, we will use remote-sensing imagery (e.g., Landsat TM scenes, aerial photography) relevant to the study area to evaluate disturbances identified on the ground. Based on relationships among field, remote sensing, and disturbance variables, we will model travel networks and levels of access-related disturbances beyond our study area.

Our Phase I efforts will generate spatially- and temporally-explicit maps and models of human access to subsistence resources and an index of the extent of environmental disturbances influencing human movement in rural landscapes. Our research will quantify (with uncertainty) how interactions among environmental changes influence landscape connectivity between humans and provisional-cultural ecosystem services. Data collected and analyzed on ecosystem dynamics associated with subsistence-altering disturbances will facilitate Phase II efforts that assess the societal impact of and response (i.e., adaptation) to disturbances. Phase III will include scenario modeling to project the trajectory of future changes and the consequences of those changes. Our research will advance knowledge on human interaction with ecosystem change (ABoVE primary motivation). Our research also can contribute to other ABoVE projects by providing researchers with a direct connection to communities which may facilitate a better understanding of societal consequences of project findings. Lastly, our spatially-explicit findings may help prioritize Phase II areas for investigation of availability and change in ecosystem services.

Mark Chopping/Montclair State University
Changes in Shrub Abundance in Arctic Tundra from the Satellite High Resolution Record for the Arctic-Boreal Vulnerability Experiment and Impacts on Albedo

This project uses semi-automated interpretation of high resolution imagery to assess the direction and magnitude of changes in shrub cover and aboveground biomass in Alaskan and Canadian Arctic tundra over a 10- to 15-year period to provide data that can be used to validate lower spatial resolution ABoVE remote sensing data products, initiate, drive, calibrate and validate ecological models, and assess the impacts of these changed on tundra summer albedo. It exploits the availability of commercial satellite high spatial resolution imagery including the QuickBird record from 2002 onwards; GeoEye from 2012 onwards, and WorldView-3 imagery when this becomes available. MODIS NDVI and Fire maps and meteorological data will be used to ensure that imagery is not compromised by extreme weather events or fire. It will select sites that have cloud-free summer imagery, including existing or near-future ABoVE field campaign sites, and use the validated CANAPI method to measure shrub cover and where possible mean shrub crown radius and height; and use these estimates to quantify changes in shrub cover and biomass over the period 2002/3 to the near-present, and their impact on albedo, as estimated in MODIS, MISR, and VIIRS products. Replication allows quantification of uncertainty from user bias. Shrub canopy estimates will be calibrated using field data already collected for 26 sites on the North Slope of Alaska in 2010 and 2011 that are held in the North American Carbon Program data set "Woody Vegetation Characteristics of 1,039 Sites across the North Slope, Alaska". The output data will be stored on the ABoVE Science Cloud. They will not only provide a more precise picture of rates of change in shrub abundance and how this impacts summer tundra albedo but will also have utility for other ABoVE remote sensing initiatives that use imagery acquired at lower spatial resolutions (aerial acquisitions, Landsat, MODIS, MISR, VIIRS); and for other tundra researchers.

Bruce Cook/Goddard Space Flight Center

Fingerprinting Three Decades of Changes in Interior Alaska (1982-2014) Using Field Measurements, Stereo Air Photos, and G-LiHT Data

Climate change impacts on vegetation cover, composition, and productivity have been documented from field and satellite remote sensing studies for boreal forest regions such as interior Alaska, where temperature changes over the last three decades are significantly higher than in other terrestrial biomes. However, vegetation response to recent warming and disturbance (insects, fire) is highly variable, due in part to strong environmental gradients across a range of spatial scales. Not all resource environments are equally vulnerable to change, and drivers of ecosystem change differ along these gradients of topography, cover, and disturbance history. Fingerprinting changes in vegetation cover and composition over time is a critical step to characterize the vulnerability and likely future trajectories of these landscapes under projected warming and scenarios of future disturbances-two key goals of NASA's Arctic-Boreal Vulnerability Experiment (ABoVE).

Here, we propose to use a unique combination of field data, airborne remote sensing, and satellite time series to characterize the spatial heterogeneity of vegetation changes in interior Alaska since 1982. The proposed research emphasizes both temporal and spatial scaling; long time series of observations are needed to track slow changes in vegetation structure and composition in high-latitude systems, and detailed observations from field measurements and high-resolution airborne data (1 m) are critical to characterize the pattern and process of ecosystem responses in heterogeneous landscapes typical of the ABoVE study domain. This project specifically targets section 3.1.2.1 (Development and Analysis of Remote Sensing Data Products) using 2014 data from NASA Goddard's Lidar, Hyperspectral, and Thermal (G-LiHT) airborne imager to scale information from large (8 ha) field inventory plots measured in 1982 and re-measured during 2010 to 2017 and low-altitude air photos (1982-83 and 2012-14) on a 20 km grid for the Tanana Valley of interior Alaska (120,000 km2) to satellite spatial (30 m) and spectral resolutions (e.g., Landsat, HyspIRI). The multi-scale, multi-sensor approach will specifically target four types of changes listed in Table 4.2 of the ACEP using this unique combination of field and airborne remote sensing observations: 1) changes in surface water extent, including drying of wetlands and subsequent encroachment of woody vegetation, 2) post-disturbance vegetation recovery and burn severity, with an emphasis on post-fire succession, 3) biotic disturbances, including mortality and defoliation due to increased insect activity, and 4) forest cover change, emphasizing changes in tree growth (height, diameter) and expansion of woody vegetation at tree line. The complementary nature of these ground and airborne remote sensing observations offers the possibility to develop new, multi-sensor fusion approaches to quantify changes in composition, cover, and productivity for this critical region.

The scientific outputs of the proposed research include 1) an assessment of 30 years of vegetation change in a large, diverse and remote region of interior Alaska; 2) benchmark datasets from field data, air photos, and G-LiHT for contemporary topography, surface inundation, composition, and vegetation cover; and 3) an assessment of tradeoffs regarding spatial and spectral resolution for efforts to characterize fine-scale ecological

processes with moderate resolution satellite remote sensing data. Re-measurement for a subset of the 1982-83 field plots directly addresses Section 3.1.2.2 (Collection and Analysis of Field Data), and estimates of the rate and nature of vegetation changes during the 30+ year interval in this study will directly inform synthesis and study design elements for ABoVE (Section 3.1.2.5), including model parameterization and validation for ecosystem responses to warming conditions.

Jan Eitel/University of Idaho, Moscow
LiDAR, Passive Spectral, and Ecophysiological Approaches to Link Forest Tundra Ecotone Structure and Function

At 13,400 km in length, the Forest Tundra Ecotone (FTE) is the world's largest ecological transition zone. However, little is known about how the FTE - a critical component of the ABoVE study domain - will respond to ever-increasing environmental change. Remotely sensed information could play a key role in filling portions of this critical knowledge gap, yet relatively little remote sensing work has been conducted to link the current structural status of the FTE with dynamic changes in its ecological function. The overarching objective of the proposed study is to integrate LiDAR, passive spectral, and tree ecophysiological data to link biophysical structure to ecological function in the FTE. In so doing, we will be able to remotely assess the vulnerability and resilience of the FTE to environmental change. To characterize FTE structure, we will use LiDAR to create standardized baseline data at multiple locations within the FTE of the ABoVE study domain, and benchmark our results relative to the existing FTE-wide map developed by Ranson et al. (2011) using MODIS and Landsat. We will establish transects at FTE sites in Alaska and Canada to study how LiDAR-derived surface and canopy micro-structure affect: (1) air and soil temperature, (2) snowpack dynamics (via hyper-temporal terrestrial LiDAR), (3) net radiation throughout the FTE canopy and on the FTE floor (via a radiative transfer model parametrized using structural information from LiDAR), and (4) plant function (via the use of ground-based radiometers coupled with ecophysiological measurements). By using statistical modeling approaches, these datasets will allow us to determine mechanistic relationships among FTE structure, physical growth environment, and plant function at fine spatial scale, where critical changes in individual tree performance aggregate to drive overall long-term change trajectories of the FTE. Ultimately, this will allow us to determine the suitability of remotely sensed micro-structural information as a proxy for assessing the vulnerability and resilience of the FTE to environmental change while understanding the mechanisms that underlie such a remote sensing approach. The outcome of this study will advance our ability to remotely sense FTE structure and function, which in turn will be of key importance for accurately predicting impacts of environmental change on ecosystem services within the ABoVE study domain and beyond.

Joshua Fisher/Jet Propulsion Laboratory
A Model-Data Integration Framework (MoDIF) for ABoVE Phase I Research: Simulation, Scaling and Benchmarking for Key Indicators of Arctic-Boreal Ecosystem Dynamics

The Arctic-Boreal region (ABR) contributes among the largest uncertainties to terrestrial biosphere model (TBM) simulations for the entire planet. TBMs are orders of magnitude different from one another in ABR soil carbon, exhibit nearly every possible spatial configuration of net carbon fluxes across models, and, in general, are poorly parameterized with respect to cold/frozen environment sensitivities. This large spread among models defines the large uncertainty for the region, and there are few data with which to benchmark models to guide improvements and, ultimately, reductions in uncertainty. This presents a formidable challenge towards addressing the Overarching Science Question for ABoVE: how vulnerable or resilient are ecosystems and society to environmental change in the Arctic and boreal region of western North America?

Addressing the Ecosystem Dynamics Objectives, the focus of ABoVE Phase 1 research, requires an interdisciplinary but coordinated suite of modeling and scaling capabilities for studying the key indicators, namely: 1) disturbance, 2) flora / fauna and related ecosystem structure and function, 3) carbon pools and biogeochemistry, 4) permafrost properties, and 5) hydrology. To reduce this uncertainty, build integrated modeling capacity, and increase confidence in addressing the ABoVE Tier 2 Science Objectives, numerous coordinated activities must come together in Phase 1 research to evaluate and improve model performance in representing, simulating and scaling the key indicators of Arctic-boreal ecosystem dynamics. Given that IPCC-type uncertainties are commonly defined as multi-model variance, it is crucial that multiple TBMs both inform data collection and are improved from the data collected.

Here, we propose to coalesce a suite of modeling teams to provide a meta-synthesis of TBM requirements, parameter and structural uncertainties, and the associated data type, range, and co-variables necessary to improve ABR-specific simulations with respect to the Tier 2 science questions. The goals of this “team-of-teams” will be to: 1) exercise and inter-compare a suite of TBMs to identify critical data gaps for informing and prioritizing ABoVE remote sensing and field data collection, 2) develop and employ a flexible but consistent data integration, simulation and evaluation framework for ABoVE modeling research, and 3) build the foundational capacity of investigators, data sets, modeling tools and benchmarking targets for addressing the Ecosystem Services Objectives and other scaling research needed for Phase 2 research activities.

Gerald Frost/ABR, Inc.
Biophysical Drivers and Socio-Ecological Impacts of Environmental Change in the Yukon-Kuskokwim Delta Region, Western Alaska

The Yukon-Kuskokwim Delta (Y-K Delta) region of western Alaska is one of the most biologically productive areas of the tundra biome and supports one of the largest indigenous human populations in the circumpolar Arctic. Most of the region’s 57 Yup'ik communities are highly reliant on terrestrial subsistence resources, such as the Y-K Delta’s exceptional breeding populations of migratory geese and other waterbirds. The future sustainability of community infrastructure is uncertain due to changing dynamics of climate, coasts, rivers, and permafrost. Notably, large areas of the Y-K Delta lie very near sea-level, and much of the region is underlain by relatively warm permafrost that is

highly susceptible to thaw as temperatures warm. Sea-level rise, sea-ice loss, and expected changes in the frequency and intensity of storms make coastal ecosystems and infrastructure especially vulnerable. Satellite- and field-based observations on land and adjacent waters of the Bering Sea indicate that the Y-K Delta has already undergone widespread environmental change in recent decades. Satellite-observed trends of the Normalized Difference Vegetation Index (NDVI) in the Y-K Delta since the mid-1990s are highly idiosyncratic relative to circumpolar trends, with coarse-scale (12.5 km) time-series indicating strong declines in the productivity of tundra vegetation ("browning"). Regional browning in the Y-K Delta contrasts starkly with widespread "greening" trends observed in northern Alaska and elsewhere in the circumpolar Arctic. Yet, the changes to vegetation and their links to regional-scale climate drivers, and intensified landscape-scale disturbance regimes are poorly understood, despite the strong relationships between direct impacts of environmental change to ecosystem services and human well-being in the region.

The multi-disciplinary work proposed here integrates remote-sensing, field-based, and sociological approaches to address environmental change and socio-ecological impacts in the Y-K Delta region. Notably, all phases of the project will be informed by quantitative, repeat sampling of vegetation, soil, hydrology, and permafrost properties across a long-term monitoring plot network that was established in the mid-1990s and is well-suited for validating multi-temporal remote-sensing datasets. Specific objectives are to (1) elucidate links between the productivity of Y-K Delta ecosystems and regional-scale atmospheric and cryospheric climate drivers; (2) resolve the spatial extent and drivers of long-term changes in vegetation and physical landscape properties related to landscape-scale disturbance processes; (3) characterize changes in the composition and structure of tundra vegetation across a network of long-term monitoring plots; and (4) relate the observed changes to local observations and concerns regarding environmental change, impacts to ecosystem services, and community sustainability. The proposed work will occur in three phases over four years. In 2015, research activities will focus on analysis of multi-decadal remote-sensing data time-series, and retrospective studies of historical and contemporary high-resolution imagery. Results of the remote-sensing analysis will be used to design and implement a ground-based data collection effort focused on vegetation, soils, hydrology, and permafrost across environmental gradients near two Yup'ik population centers: the central coast region near Chevak (2017) and the Yukon Delta near Emmonak (2018). In 2018, work will focus on applying findings to address the concerns and needs for information identified by stakeholders and land managers. The project will leverage detailed long-term field datasets, as well as data products generated from recently-completed vegetation mapping and remote-sensing analysis efforts in western Alaska.

John Gamon/University of Nebraska, Lincoln
Evaluating Growing Season Length and Productivity Across the ABoVE Domain Using Novel Satellite Indices and A Ground Sensor Network

Objectives:
1) Using novel combinations of MODIS bands (including new chlorophyll:carotenoid indices, CCIs), we will develop a new light-use efficiency (LUE) model.
2) The new LUE model terms and products (e.g. gross primary productivity, GPP) will be compared to ground validation sites where flux and optical data are available.
3) We will compare the new LUE model to other models, including the benchmark MOD17 GPP products and emerging GPP products from solar-induced fluorescence (SIF) methods (OCO2 satellite sensor).
4) Using these methods, we will evaluate the relationship between growing season length and productivity to investigate reported "browning and greening" and their causes and implications for different ecosystems within the ABoVE domain.

Methods/Techniques: To accomplish these objectives, we will use satellite observations coupled with ground validation to investigate changing growing season length and its impact on the carbon budget of boreal and arctic regions. A primary approach will be to develop a new light-use efficiency (LUE) model of ecosystem productivity, based on a new combination of satellite indices provided by reprocessed MODIS prodects. In addition to standard MODIS products (e.g. NDVI) we will utilize newly available chlorophyll:carotenoid indices (CCIs, derived from novel combinations of MODIS terrestrial & ocean bands capable of "invisible" photosynthetic phenology in evergreens). Our initial geographic focus will be on boreal regions where photosynthetic downregulation restricts photosynthetic activity, which has been difficult to assess with conventional means. By the end of the project period, modeling will span the full range of ecosystems across the ABoVE domain, and validation will involve both ground networks and independent satellite-based productivity estimates.

To validate satellite sensor and LUE model products with ground observations, we will utilize existing data from an extensive network of ground stations, consisting of flux tower and optical phenology stations spanning the ABoVE domain and covering a range of conditions and ecosystem types. Validation will consider both satellite optical indices and their modeled flux products, and will evaluate the effects of spatial scale, sampling angle, spectral scale, and temporal aggregation on the interpretation of optical signals. Ground validation will also clarify the confounding effects of clouds, snow, ice, and standing water on key vegetation optical indices, including NDVI and CCIs. Additional validation will compare satellite products (e.g. GPP) to the standard MODIS GPP product (MOD17) with independent estimates from OCO2 fluorescence products and atmospheric inversions as these become available.

Significance: This study addresses the ABoVE topics of reported greening and browning of northern ecosystems, as previously reported in the satellite NDVI record. These satellite NDVI observations have suggested potentially large changes in boreal and arctic carbon budgets, biogeochemistry, surface-atmosphere feedbacks, and disturbance

regimes, but can also be subject to misinterpretation due to the over-determined nature of satellite indices. By utilizing the full range of information available from MODIS products, we will enhance our understanding of ecosystem processes beyond what is possible from exiting NDVI-based methods alone, and lay the foundation for future modeling efforts and satellite sensors having improved sensitivity to subtle vegetation change and its underlying functional significance. This improved assessment of ecosystem productivity and effective growing season length across the ABoVE domain will allow better understanding of the carbon balance and other ecosystem feedbacks to the atmosphere and climate for northern ecosystems. By linking to an extensive ground validation network, we will also enhance opportunities for outreach and community participation across the ABoVE domain.

Scott Goetz/Woods Hole Research Center Inc.
Mapping and Modeling Attributes of an Arctic-Boreal Biome Shift: Resource Management Implications within the ABoVE Domain

We propose to investigate the role of vegetation dynamics across the ABoVE study domain, building upon our extensive prior work documenting changes in arctic and boreal vegetation productivity over the past three decades using moderate and coarse resolution satellite data and related field measurements. We will expand past activities with the most recent satellite data sets as well as newer, higher resolution satellite data products and existing aircraft lidar and hyperspectral data (in anticipation of future aircraft campaigns for ABoVE). These analyses will be coupled with extensive field measurements and species-specific modeling to capture areas of documented boreal biome tree mortality and tundra vegetation changes across regional climate and environmental gradients. Our investigations will be in the context of exploring multiple lines of evidence for the progression of an arctic-boreal biome shift, where tree productivity decreases and mortality increases in the southern boreal while suitability for range expansion and densification of woody vegetation (e.g. shrubs) increases in the northern boreal and arctic tundra.

The investigative team has worked extensively on these topics and can leverage existing resources, focusing on aspects of boreal forest dynamics that make them particularly vulnerable to productivity declines and tree mortality, mapping those with multi-scale satellite imagery and modeling these processes using gap and forest demography models with a long history of well developed capabilities. We will also conduct more detailed regional analyses focused on faunal habitat changes associated with vegetation composition and structure changes in both biomes, with a focus on areas of interior Alaska and western Canada (boreal biome), and the Seward Peninsula and North Slope of Alaska and northwestern Canada (tundra biome). These regions include the winter range of the declining western arctic caribou herd as well as the Fortymile caribou herd historical range extending from the Yukon river north of Fairbanks to near Whitehorse. Thus the proposed activity focuses on some of the largest issues of concern to management agencies in the region. A substantial contingent of the team has unique insights into these land and wildlife management issues, as well as the fine scale heterogeneity of vegetation pattern and process that provides a solid basis for calibration

and validation of maps derived from satellite imagery, and thus the means to scale from field site to landscapes. Other members of our interdisciplinary team have considerable complementary expertise in remote sensing and in situ vegetation mensuration for mapping and monitoring vegetation dynamics, forest demography process modeling, and other relevant experience in arctic and boreal landscapes. PI Goetz is also applying to be Science Team Lead.

Our proposed activity addresses the Tier 2 science objective for ABoVE focused on ecosystem dynamics, specifically Q5 “Determine the causes of greening and browning trends and their impacts on ecosystem form and function.” It also has direct relevance to Q7 “Determine how the spatial and temporal dynamics in both faunal abundance and characteristics of fish and wildlife habitat co-vary across gradients of climate and disturbance.” The proposed activity will also establish a firm basis for addressing the overarching ABoVE phase 2 objective focused on ecosystem services, specifically Q4 “Analyze how changes to natural and cultural resources will impact local communities as well as influence land management policies and practices” and Q6 “Determine the degree to which changing environment and altered human activities result in synergistic or antagonistic changes in ecosystem services.” Finally, the activity will address several of the ABoVE science questions, particularly 3.1 “How are environmental changes affecting critical ecosystem services..?” and 3.5 “How are flora and fauna responding to changes..?”

Michael Goulden/University of California, Irvine
Shifting Patterns of Boreal Forest Succession and Browning Over the Last 30 Years

Climate and fire largely control the productivity (“greenness”) and biodiversity of boreal forests in North America. We propose research to better understand: 1) the patterns of, controls on, and recent changes in North American Boreal Forest "Browning" and the declining Normalized Difference Vegetation Index (NDVI) observed in satellite records, and 2) the patterns of, controls on, and recent changes in North American Boreal Forest fire recovery and succession. Our overarching goal is to systematically assess whether browning is indicative of an actual decline in forest productivity or of a change in the rate and, or trajectory of fire succession. Our core intellectual premise is that fire and recovery in boreal North America are so pervasive, and exert such as strong influence on ecosystem properties, including spectral reflectance, that investigations of browning and succession must be tackled in concert.

We will address six hypotheses and their associated alternatives:
Hypothesis 1 The NDVI browning trend is robust and consistent across independent satellite records; browning cannot be explained as an artifact of a satellite record or by "natural" patterns such as fire recovery.
Hypothesis 2 The NDVI browning is occurring across the boreal landscape regardless of drainage class or permafrost state; upland forest and nearby lowland areas, and north and south facing slopes, show similar browning.
Hypothesis 3 The NDVI browning trend is occurring across the boreal landscape regardless of stand age; young, middle age and old stands show similar browning.

Hypothesis 4 Browning reflects a year-round net loss of LAI and photosynthesizing surfaces including moss; this reduces NDVI by decreasing the amount of NIR-reflecting foliage.
Hypothesis 5 The rate of boreal forest post-fire succession has remained constant over the last 30 years.
Hypothesis 6 The mean trajectory of post-fire succession has not changed in the last 30 years.

Our core methodological premise is that the availability of high quality, homogenous, long-duration Landsat time series has reached the point that a more definitive exploration of boreal forest browning and succession is possible. Our strategy combines four building blocks: 1) Existing long-term remote sensing datasets, such as the newly created time series of TM and ETM+ surface reflectance processed using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) approach. 2) Existing in-situ datasets collected over the last 15 years in Canada and Alaska detailing the ecological and biogeophysical patterns of boreal forest succession. 3) New field measurements to better understand, improve, and validate the use of remotely-sensed reflectance and thermal emission to quantify boreal forest biogeophysical properties. 4) A systematic analysis of how climate, drainage, permafrost and fire regime impact the reflectance of North American Boreal Forests.

Our work on Boreal Forest "Browning" is responsive to ABoVE Tier 2 Science Objective #5 "Determine the causes of greening and browning trends and their impacts on ecosystem form and function". Our work on Boreal Forest fire recovery and succession is responsive to ABoVE Tier 2 Science Objectives #1, #2, #6, and especially # 3 "Understand how vegetation attributes and hydrologic conditions interact, and respond and feedback to disturbance." Our workplan makes heavy use of remote sensing imagery with an emphasis on the Landsat archive; this work is responsive to the call for improvements to "Satellite Remote Sensing Data Products" for "Post-disturbance vegetation recovery" in Table 4.2 of the ABoVE Concise Experimental Plan.

John Kimball/University of Montana, Missoula
Satellite Data Driven Model Assessment of Landscape Variability and Environmental Controls on the Arctic-Boreal Carbon Budget

We will apply a satellite data driven carbon model framework to improve understanding and quantification of carbon (CO2 and CH4) fluxes and environmental controls on the net ecosystem carbon budget (NECB) over the ABoVE domain. We will develop a foundational database to explore and quantify links between changing surface conditions, including freeze-thaw (FT) regimes, soil moisture and open water inundation, and Arctic-boreal carbon fluxes. These data will link local tower site observations with CARVE airborne atmospheric CO2 and CH4 measurements and other land parameters derived from satellite optical and microwave remote sensing to clarify surface moisture and thermal constraints to vegetation growth and soil carbon cycling. We will apply these data within a terrestrial carbon flux (TCF) model to quantify the NECB, component carbon fluxes and underlying environmental drivers. Model sensitivity studies will be

conducted at site, local and regional scales in context with remote sensing observations to document model uncertainties and scaling properties of critical drivers. These results will be used to improve model representations of sub-grid scale processes affecting carbon flux estimates, while incorporating regional model enhancements representing wildfire disturbance recovery and wetland CH4 emissions. Results will include verified NECB maps, component carbon fluxes and environmental drivers with daily temporal fidelity, 1-km spatial resolution and 14+ year (2003-2016) data records.

This study addresses several ABoVE science questions, including: "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?" We also address ABoVE objectives for "elucidating how climate change and disturbances interact and alter land-atmosphere carbon exchange." This study meets Phase I priorities for developing "a set of readily accessible, validated data products derived from multiple sensors that can be integrated to form the basis for investigations of ecosystem and societal response over the entire Study Domain." We will also contribute model sensitivity and validation activities supporting ABoVE Phase II and III activities, with direct applications to NASA SMAP and CARVE missions.

Tatiana Loboda/University of Maryland, College Park
Quantifying Long-Term Impacts of Single and Repeated Wildfire Burning in North American Tundra on Organic Soil Carbon Stocks and Ecosystem Functioning

The proposed project will focus on investigating and quantifying fire-induced changes in Alaskan tundra with a specific aim to assess the region's vulnerability to on-going and future environmental change and the changes to carbon cycling in this ecosystem. In particular we aim to address several specific ABoVE-identified research priority areas including: 1) What processes are contributing to changes in disturbance regimes and what are the impacts of these changes? 2) What processes are controlling changes in the distribution and properties of permafrost and what are the impacts of these changes? and 3) What are the causes and consequences of changes in the hydrologic system, specifically the amount, temporal distribution, and discharge of surface and subsurface water? While quite rare in Canada and Northern Eurasia, wildfire is a major disturbance agent in the tundra ecosystems of Alaska. Existing paleo records, fire management records, and satellite observations have shown that wildfire has been a prevalent and recurring disturbance agent across many tundra ecoregions of Alaska and constitutes an emerging threat in previously less impacted tundra zone of North Slope. With the apparent changes in climate of the region expressed in prolonged growing season, shrub encroachment, and increasing temperature affecting both fire weather and above ground biomass and subsequently fire fuels, there is a considerable potential for a substantial change in fire regimes within this region which is likely to lead to notable changes in carbon stocks and ecosystem functioning. Our previous results (NASA TE NNX10AF41G PI - French, Co-I- Loboda) indicate that immediately after burning fire-impacted areas are characterized by small but statistically significant differences in active layer depth, soil moisture levels, and soil temperature compared to the adjacent unburned areas. Other previous studies have shown persistence or an increase in differences in

active layer depth and soil moisture over a 3-5 year period after the fire event. However, at present very little is known about these impacts outside of a single extreme recent fire event or about the differences in ecosystem functioning in unburned (within the past 65 years), single-time burned and repeatedly burned areas and the extent to which burned area is susceptible to repeat burning. Within this project we propose to collect field measurements of fire impacts on tundra ecosystems to characterize variation in 1) active layer depth, 2) soil moisture, 3) soil temperature, 4) vegetative cover, and 5) soil organic layer thickness across a wide range of burn scars of different ages and characteristics and adjacent unburned areas. These measurements will deliver a comprehensive dataset that will support quantification of above and below ground carbon stocks, permafrost mapping, surface hydrology characterization, and susceptibility to future fire occurrence through changes to fuel loading and site conditions. We propose to conduct 3 intensive field campaigns in tundra ecoregions characterized by different fire regimes including: 1) the Noatak River valley (Brooks Ridge), 2) Seward Peninsula, and 3) foothills of the North Slope of Alaska. Our previous experience in data collection in tussock tundra and the established field support network in the region will allow us to deliver a large (over 300 sites) set of field measurements at very low cost. Our second major aim is to link these observations to optical, thermal, and active microwave satellite observations to improve our ability to characterize these properties at the regional scale. We propose development and statistical testing of a wide range of satellite-based metrics to establish and quantify the relationships and produce wall-to-wall maps for several ecosystem characteristics for each ecoregion through Random Forest modeling.

Michelle Mack/Northern Arizona University
Increasing Fire Severity and the Loss of Legacy Carbon from Forest and Tundra Ecosystems of Northwestern North America

Depth of burning of the soil organic layer (SOL) and resultant carbon (C) emissions from wildfire is an important component of net ecosystem C balance in the ABoVE Domain. The SOL sequesters the majority of ecosystem C in layers that can be hundreds to thousands of years old. Deeper burning could rapidly shift ecosystems across a C cycle threshold: from net accumulation of C from the atmosphere over multiple fire cycles, to net loss. Yet deeper burning must release C that escaped one or more previous fires-which we term legacy C-to shift ecosystems into the domain of accelerating feedback between warming climate and fire. The proposed research will combine widely used and scalable SOL consumption metrics with radiocarbon techniques for aging soil C to address the first key question: What are the ecosystem, landscape and regional controls over the combustion of legacy C in forest and tundra regions of the ABoVE Domain?

Combustion of legacy C indicates that a larger proportion of the SOL was combusted in the current fire than in the previous fire, providing historic context for the current fire's severity. New fires that are greater in severity than past fires are expected to be to push ecosystems across thresholds in permafrost and plant composition, rendering C cycling vulnerable to state change after fire. The proposed research will combine a mechanistic understanding of legacy C loss with observations of ecosystem response to address our

second key question: What are the consequences of legacy C loss for post-fire permafrost and vegetation dynamics?

Proposed research for the Field Campaign will address these key questions by linking field-based, process-level studies of legacy C combustion and post-fire responses with geospatial data products in two regions: moist acidic tundra near treeline on the North Slope of the Alaska Range, Alaska, and boreal conifer forest in the Taiga Plains and Shield ecoregions of Northwest Territories, Canada. These regions provide stark contrast in vegetation structure, yet both occur on warm permafrost soils that could be vulnerable to rapid change following fire. Recent extreme fire activity in both regions provides natural gradients in depth of burning across multiple, spatially independent burn scars, making them ideal for addressing these questions. Specific research objectives are to: (1) develop a mechanistic understanding of the ecosystem, landscape and fire characteristics that control legacy C loss from tundra and boreal forest wildfires in the ABoVE Domain; (2) examine the generality of the mechanistic understanding by synthesizing results with combustion and radiocarbon data collected in other regions; (3) estimate the magnitude of legacy C loss across landscapes within fire scars by linking the mechanistic understanding with geospatial data products; (4) determine ecosystem response to legacy C loss and fire severity, focusing on ecosystem vulnerability to state change in permafrost and vegetation; and (5) project ecosystem response to legacy C loss and fire severity across fire scars and identify the ecosystems, landscape positions, and regions at the greatest risk of state change under an intensifying fire regime.

The proposed research fits within the overarching focus of the Field Campaign because it focuses on the impacts of an environmental change-intensifying fire regime-on ecosystem function in the ABoVE Domain. The aim to define a novel dimension of fire disturbance, the combustion of legacy C, directly addresses Tier 2 Science Question 3.2 regarding processes contributing to changes in disturbance regimes. Focus on the ecosystem consequences of this loss contribute to other questions, including the direct contribution of emissions to long-term ecosystem C balance (Q 3.6), and how losses may indirectly alter physical and biological controls over C cycling (Q 3.6), permafrost state (Q 3.3), soil drainage (Q 3.4), and vegetation composition (Q 3.5).

Franz Meyer/University of Alaska, Fairbanks
Characterizing Methane Emission Response to the Past 60 Years of Permafrost Thaw in Thermokarst Lakes

The proposed research combines geospatial data products derived from airborne and spaceborne remote sensing (RS) data with targeted field observations and modeling in order to quantify ecosystem responses to Arctic and boreal environmental change. Specifically, we will quantify methane (CH4) ebullition (bubbling) emissions associated with 60 years of permafrost thaw in thousands of Alaskan and NW Canadian lakes by direct observation with RS systems.

Our objective is to develop regional, multi-scale and multi-temporal maps of western North America's boreal and Arctic lake area change and associated CH4 ebullition emissions using Synthetic Aperture Radar (SAR), high resolution optical RS,

field work, and numerical and GIS modeling in order to improve our understanding of the vulnerability and resilience of lake ecosystems to permafrost thaw with respect to the release of 14C-depleted (old) CH4-carbon from decomposition of permafrost soil organic carbon (SOC).

We will expand upon our predecessor NASA-funded projects #NNX08AJ37G and #NNX11AH20G which developed statistically-significant models using SAR, optical and infrared RS data to detect and quantify CH4 ebullition emissions at intra-, whole- and regional-lake scales. We also established a relationship between observed CH4ebullition and average annual SOC inputs to a handful of Alaskan lakes via thermokarst-margin expansion during recent decades using field data, radiocarbon dating and modeling.

Our next goals are to: (i) Quantify CH4 ebullition in thousands of thermokarst-affected lakes in Alaska and NW Canada, spanning a range of climate, Arctic/boreal, permafrost SOC (e.g. yedoma/non-yedoma) and lake-change regimes using established and cross-validated relationships between SAR and optical RS signals and field-observed CH4 ebullition; (ii) Formulate a mathematical relationship between SOC inputs to lakes during the past ~60 years and field- and RS-observed CH4 emissions; and (iii) As a stretch goal, invert the relationship in (ii) to produce experimental maps of permafrost SOC stocks, which are vulnerable to CH4 production upon thaw.

This multi-scale project will include: (1) Collection of new and synthesis of existing field data on CH4 ebullition, thaw-bulbs and SOC; (2) analysis of existing data from aerial surveys, SAR and optical RS of CH4 in lake ice; (3) orthorectification of historic aerial photos for comparison to high-resolution satellite imagery to produce fine-scale regional maps of lake area change, (4) model estimations of permafrost SOC quantities eroded into lakes; (5) radiocarbon dating CH4 and SOC, (6) GIS modeling to produce multi-temporal regional maps of historic lake area change, associated CH4 emissions, and permafrost SOC stocks; (7) outreach to stakeholders at Alaska village and rural community field sites; and (8) participation in ABoVE Science Team (ST) meetings and workshops.

Anticipated results include process-level data to aid understanding the effects of lake area change on regional lake CH4 ebullition emissions across diverse permafrost SOC regimes. We will also produce experimental high-resolution regional maps of estimated permafrost SOC stocks that are vulnerable to CH4 production and ebullition emission upon thaw. Other ancillary data products will include time-series of geocoded (ortho-type) remote sensing products from SAR and optical sensors as well as time-series of lake boundary data for extended areas of the ABoVE Study Domain ("Historical Hydro"). Data and maps will be staged to the ABoVE Science Cloud (ASC) for use by other ABoVE ST members, the CCEO and policy-makers who communicate with stakeholders, and partnering programs, such as the DOE's NGEE. Project goals will meet shared objectives of NASA's Terrestrial Ecology Research and the North American Carbon Program (NACP) for understanding and predicting changes in North American C pools (e.g. permafrost-stored C converted to CH4 in thermokarst lakes).

Charles Miller/Jet Propulsion Laboratory
Quantifying CO2 and CH4 Fluxes from Vulnerable Arctic-Boreal Ecosystems Across Spatial and Temporal Scales

Executive Summary

Vast stores of carbon are sequestered in the permafrost soils, peatlands and boreal forests of western North America. Dramatic increases in warming, permafrost thaw, fire severity and frequency, and other natural disturbances threaten to alter these Arctic-boreal ecosystems (ABEs) irreversibly, transforming the landscape and the ecosystem carbon balance as terrestrial carbon pools are released as atmospheric carbon dioxide (CO2) and methane (CH4).

Ecosystem dynamics in the ABR vary on meter scales due to microtopographic changes in permafrost, elevation, water table height, vegetation, microbial populations, etc., resulting in CO2 and CH4 fluxes that vary by orders of magnitude on these scales. It remains unclear how landscape scale processes and biogeochemical drivers impact meso- to regional scale C fluxes or how diurnal to interannual variability of C exchange impacts decadal scale ABE C balance. What is the C balance of the ABoVE domain now and in the future? Are C flux scaling properties constant across the ABoVE domain, or do they vary with ecosystem classification? What emergent properties or macroscopic variables characterize ABE C fluxes at intermediate space-time scales?

We will deliver accurate, validated atmospheric CO2, CH4 and CO observations for 2015 - 2019 from the critically located CRV tower in Fox AK, as well as geostatistical inverse model analyses that leverage recent atmospheric observations to evaluate the process-level representation of land-atmosphere carbon exchange inside terrestrial biospheric models (TBMs) and identify the environmental parameters that optimally explain the observed spatiotemporal variability in carbon flux patterns across the ABoVE domain. We will work directly with collaborators Potter (CASA), Kimball (TCF), Koven (CLM), Luus (PVPRM) and Bloom (CARDOMAM) to assist them in interpreting our evaluations to improve the performance of their TBMs for ABoVE ecosystems.

Our results will significantly reduce uncertainties in estimates of the current carbon balance of ABoVE ABEs and in TBM projections of its future trajectory. 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.

We address the ABoVE 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?

ABoVE Science Lead

I, Dr. Charles Miller (JPL), propose to be the ABoVE Science Lead (ASL). I commit to making ABoVE success my top priority for the full duration of the project. My vision is to make ABoVE the most prestigious and desirable career track for young scientists, while delivering major advances in Arctic-boreal ecosystems science. My unique combination of skills and experience make me the ideal ASL candidate: I have more than 15 years of experience successfully leading international science teams for NASA missions, including 5 years leading intensive airborne science studies in the ABoVE domain. I am a dynamic speaker, equally confortable communicating with the science community, stakeholders, government agencies, the general public or the international media. I am committed to creating a single, unified ABoVE team dedicated to answering the overarching science question: How vulnerable or resilient are ecosystems and society to environmental change in the Arctic and boreal region of western North America?

Sue Natali/Woods Hole Research Center Inc.
Winter Respiration in the Arctic: Constraining Current and Future Estimates of CO2 Emissions During the Non-Growing Season

This proposal addresses the Tier 2 Science Question (3.6) of the Terrestrial Ecology solicitation (A.4): "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?" Over the past decades, surface air temperatures in the Arctic have increased at approximately twice the global rate, and climate models project that this rate of warming will continue through the century, with the greatest warming occurring during the winter months. An increase in wintertime temperature may reduce belowground carbon storage due to enhanced microbial respiration during the snow-covered period. Carbon dioxide (CO2) emissions during the winter and shoulder seasons (fall and spring) are an important component of annual respiratory loss, yet there is large uncertainty in local and regional estimates of CO2 emissions during the non-growing season. Carbon losses during the snow covered period can be as great as or equal to net growing season carbon uptake, shifting tundra ecosystems from carbon sinks during the growing season to sources on an annual basis. Therefore, refining winter respiration estimates and understanding the drivers of winter respiration are critical for understanding current and future carbon emissions from the Arctic.

The objectives of this proposal are to 1.) measure winter respiration continuously at sites across the permafrost region, 2) examine the drivers of winter respiration, and 3) combine field measurements with remotely sensed data sets and products to estimate regional CO2 emissions during the non-growing season. We will instrument sites across the ABoVE study domain with newly-developed forced diffusion soil efflux sensors (FDs), a low-power technique with high temporal resolution and high reliability for harsh deployment environments. We will also collect continuous automated measurements of key environmental drivers (e.g., air temperature, snow cover, soil moisture, soil temperature) and measure vegetation and soil characteristics at the plot level, and we will extend plot-level measurements of respiration drivers to larger spatial scales consistent with satellite remote sensing data retrievals. Sites will be selected to span the range of permafrost regions from continuous to sporadic to allow us to address questions about winter

respiration under different thaw regimes, including those influenced by fire disturbance and related thermal erosion, changes in active layer depth, and thermokarst.

The site-level flux measurements will be used with a range of existing multi-scale satellite data sets and products, as well as newly generated products where needed (particularly outside the growing season), to scale the field measurements spatially and temporally, thereby estimating CO2 emissions from winter respiration across the landscape. Linking to satellite data sets will be done primarily via indirect proxies such as vegetation properties (cover, density, composition) and land surface temperature. Additional landscape variables such as topography, soil properties and surficial geology will also be used as predictor variables in spatially explicit statistical ensemble models (i.e. RandomForest). Image segmentation approaches will also be used as a means to associate field measurements with spatial data and scale to the landscape.

Walter Oechel/San Diego State University
Temporal and Spatial Patterns of and Controls on Arctic CO2 and CH4 Fluxes in the ABoVE Domain

Summary:
Arctic terrestrial regions are significant contributors to the global greenhouse gas (GHG) budget and, given their large soil organic stores in the upper soil and permafrost layers, have the potential for continued, substantial, climate feedbacks. Despite the importance of current GHG fluxes, and the possibility of very large GHG fluxes in the future, we lack sufficient information to confirm and characterize the current CO2 and CH4 fluxes from Arctic tundra. For example, our certainty of the current Arctic CH4 fluxes, or in fact of all wetland methane emissions, has changed little over the last 40 years (Christensen, 2014). Comparison of ten regional and global models showed disagreement on the response of CH4 loss to climate change, with up to an 80-fold difference in total wetland CH4 flux estimates (Melton et al., 2013). Long-term CO2 and CH4 data from the Arctic are sparse and spatial coverage is limited, which prevents understanding of how warming and increased atmospheric CO2 concentrations are affecting the C dynamics from these systems. This project will contribute to reducing the uncertainty of current CO2 and CH4 fluxes and to improving the accuracy of our predictions of future fluxes, by continuing and extending these GHG flux measurements, and combining them to larger scale investigation. To accomplish this, we will operate an established network of Arctic CO2 and CH4 flux eddy covariance towers across the North Slope of Alaska along a 300 km transect from Barrow to Ivotuk with the Barrow tower initiated in 1995 and the Atqasuk tower in 1997. We will also deploy portable towers to investigate the persistence of and the causes and controls on the GHG â€œhot spotsâ€ detected by NASA Ca
Arctic Reservoirs Vulnerability Experiment (CARVE) during 2012-2015. This network has been critical to informing top down and bottom up models and in verifying model output, and has been a key source of data to CARVE, SMAP, and AirMOSS. The proposed work will provide critical information and understanding to improve estimates of CH4 and CO2 fluxes over the ABoVE study domain and, will better define the processes involved and the controls on CO2 and CH4 fluxes in order to better predict future fluxes. In addition to parameterizing and verifying top down and bottom up models

and estimates of regional fluxes, this site-level network is also critical to establishing a firm baseline of changing patterns in CO2 and CH4 fluxes through time.

Laura Prugh/University of Alaska, Fairbanks
Assessing Alpine Ecosystem Vulnerability to Environmental Change Using Dall Sheep as an Iconic Indicator Species

Dall sheep are an emblem of the North. The global distribution of this iconic species is contained entirely within the Arctic and boreal region of northwestern North America, and the rapid changes associated with a warming climate throughout the ABoVE domain therefore have profound implications for this species and the ecosystem services it provides. Dall sheep are critical to the functioning of alpine ecosystems, provide valued subsistence harvest opportunities for residents, and draw tourists and trophy hunters from around the world. Alpine ecosystems are important reservoirs of biological diversity in the ABoVE domain, and high-elevation snowpack is a vital source of water for residents and wildlife throughout the region. Declines in Dall sheep populations throughout their range have led to emergency harvest closures and made sheep harvest by far the most contentious wildlife management issue in Alaska. Dall sheep likely function as bellwethers of alpine ecosystem health, and signs are pointing towards increasing ailment. Lack of knowledge about climate change impacts in alpine ecosystems represents a critical gap in our understanding of resilience and vulnerability to environmental change in the Arctic and boreal region of western North America. Our proposed project addresses this gap through a powerful combination of fieldwork, remote sensing, modeling, and synthesis at both region-wide and localized scales.

The overarching goal of our study is to address the question: How are vegetation and snow conditions changing in alpine ecosystems throughout the ABoVE domain, and how do these changes impact iconic northern wildlife and critical ecosystem services? We hypothesize that shrub expansion is reducing alpine habitat area and connectivity among sheep populations, but the productivity of alpine vegetation may be increasing. The extent of snow cover during the lambing season and snowpack characteristics over winter are expected to strongly impact Dall sheep recruitment and survival. To evaluate these and other hypotheses, we propose to: (1) produce time series of snow extent, NDVI, and shrub encroachment throughout alpine areas of the ABoVE domain, (2) evaluate how these factors affect Dall sheep movements, habitat selection, and population viability using empirical models that couple remote sensing products and geospatial data from radio-collared Dall sheep (>350,000 locations from at least 451 sheep in 7 populations from 1997-present), (3) improve a spatially-explicit snowpack evolution model to characterize snowpack (depth, hardness, icing) at a spatial resolution relevant to wildlife management (100-m), and (4) relate our improved understanding of alpine ecosystem dynamics to the societal implications of altered sheep harvest by developing harvest models and participating in a newly-formed Dall sheep working group.

Our interdisciplinary team has expertise in wildlife population dynamics and movements, remote sensing, northern social-ecological research, snow processes in mountainous regions, and land surface hydrology modeling. In addition, collaborations with an

extensive network of biologists from government agencies and tribal councils throughout the range of Dall sheep, including several major cost-sharing partnerships, make this ambitious project feasible.

Findings from our study will provide insight into the resilience and vulnerability of Dall sheep, indicators of alpine ecosystem functioning, across this iconic species' global range. In addition, our work will substantially improve the remote sensing of snowpack characteristics and may inform future NASA missions by identifying key sensor data needed to further improve models. These advances will improve the ability of scientists to both (1) understand how changes in snow characteristics affect wildlife, and (2) measure and predict changes in hydrological systems and freshwater dynamics in the ABoVE domain and beyond.

Brendan Rogers/Woods Hole Research Center Inc.
Developing a Spatially-Explicit Understanding of Fire-Climate Forcings and their Management Implications Across the ABoVE Domain

We propose a thorough investigation into the net radiative forcings from forest fires in the ABoVE domain. Fire is the dominant disturbance in boreal North America and strongly regulates ecosystem composition and land-atmosphere exchanges of carbon, water, and energy. Multiple lines of evidence point to an intensification of the fire regime due to climate change; these disturbances, in turn, influence climate through multiple and often counteracting pathways. For example, fires that combust large amounts of organic matter and deposit black carbon on ice and snow will warm the climate, whereas fires that dramatically increase spring albedo by exposing more underlying snow will lead to cooling. The vulnerability and resilience of other boreal and arctic systems, including permafrost and sea ice, depends in part on how fire regimes interact with climate.

Unlike other large Earth system feedbacks, we have some direct level of control over fire regimes. Federal and state/provincial agencies in Alaska and Canada invest considerable resources into controlling fires for multiple purposes. The warming or cooling potential from fires, however, is currently not taken into account. We believe this represents a significant untapped climate mitigation service from boreal forests. While many of these agencies are keenly interested, the information needed to exploit this ecosystem service is entirely lacking. The value of this information will only increase in time as carbon and climate forcings become monetized and more tightly regulated.

Our primary science goal will be to develop maps of fire forcings across the ABoVE domain during the 2002 - 2011 era. To do so we will employ existing and new remote sensing datasets to quantify carbon consumption by wildfire and long-term changes to spring albedo (which has been shown to be the dominant biophysical forcing from fires in Alaska and Canada). New field measurements of combustion from under-sampled forest and burning types will add critical constraints to our combustion model. We will employ a state-of-the-art land surface and Earth system model to characterize (1) post-fire biomass regrowth as it is affected by spatially-varying drivers, and (2) forcings from carbonaceous aerosols including their subsequent deposition onto snow and ice.

These data layers will allow us to not only improve our understanding of the climate impacts from fires, but to include these impacts into new management frameworks. To facilitate the latter, we will develop a set of predictive models of potential fire forcings that evolve over the fire season and can be integrated into current decision-making tools. Fundamental to this effort will be continued bilateral communication with managers. We will work closely with stakeholders from various agencies in Alaska and Canada to understand their needs and relay the importance and practicality of our research. Results from this first phase will form the foundation for further development in Phase II of ABoVE, including future projections of fire feedbacks and the development and refinement of operational fire management tools.

We have assembled an interdisciplinary team that includes extensive expertise in fire-related field measurements, optical and infrared remote sensing, statistical combustion modeling, Earth system modeling, and fire management. We aim to improve our understanding of climate-disturbance interactions in the ABoVE domain, but perhaps more importantly develop a framework for utilizing the climate mitigation service that fires either create or degrade. A holistic understanding of fire-related ecosystem services is critical for the increasingly complex management of northern forests and the societal benefits they provide.

Robert Striegl/United States Geological Survey
Vulnerability of Inland Waters and the Aquatic Carbon Cycle to Changing Permafrost and Climate Across Boreal Northwestern North America

Water is key to all ecosystem functions, including the carbon (C) cycle. Additionally, rates of C biogeochemical processing are commonly much greater in inland waters than terrestrial landscapes, as they collectively store C in sediments, export C to oceans, and emit carbon dioxide (CO2) and methane (CH4) to the atmosphere. Terrestrial ecosystems are a dominant source of C to inland waters through surface and subsurface drainage networks. These networks are changing across boreal and arctic regions, as permafrost thaw, climate warming, and fire create new conduits for water movement, change vegetative water use and evapotranspiration, and alter the distribution of water on the landscape. It is imperative that we understand the dynamics of these changes in the water cycle if we are to understand and accurately project the effects of climate warming and other environmental drivers on circumboreal and arctic ecosystems.

We propose an integrated interdisciplinary research campaign to evaluate the vulnerability of boreal landscapes to change in the ‘plumbing” that controls water movement and distribution, change in the source and chemical composition of C delivered to inland waters, and change in the rates and processes that control organic and inorganic C processing by inland waters and their emissions of CO2 and CH4 to the atmosphere. Our approach recognizes that permafrost thaw will not only enhance groundwater flow and the development of subsurface connectivity, but that loss of subsurface ice will also change the structure of the land surface, creating thermokarst features in some areas and initiating lake loss or lake creation in others. It also recognizes that terrestrial sources of C to inland waters will change in response to thaw, fire and

other drivers of change. These conditions will be evaluated by geophysical and ecosystem surveys with the goal of extrapolation across the boreal ABoVE domain through remote sensing analysis and mapping.

Geophysical subsurface permafrost characterization via new ground and existing airborne surveys will provide the necessary framework for hydrologic field and modeling efforts to evaluate and project the effects of change in lateral connectivity on surface water flow, groundwater flow, and lake distribution. Permafrost thaw enhances groundwater flow, changes the seasonal distribution of streamflow, and alters lake budgets. However, the dynamics that control these changes are not completely understood, and critical baseline information on subsurface permafrost distribution is typically lacking. Using newly developed capabilities for cold regions, our proposed field and modeling approaches will help to fill these gaps in hydrologic understanding and will also inform on the routing of terrestrial C by flow systems to inland waters and the residence time of C in those systems.

Source, routing, and residence time are imperative to understanding C dynamics in inland waters. We will determine C source and age through analyses of the 14C content of inorganic and organic C species and C-gas emissions. Molecular biomarkers, coupled with measured optical properties of DOC will inform on terrestrial versus autochthonous sources of aquatic C and on its potential for mineralization by biological or photo-degradation. Much of terrestrially-derived aquatic C is degraded before reaching surface waters, so hydrologic modeling of residence times will improve our understanding of where and when inland water C-gas emissions are expected to be greatest. Radiocarbon age of aquatic C will further delineate source and inform on if and where C derived from permafrost or ancient soil sources are delivered to inland waters. Finally, optical properties of water indicative of DOC concentration and composition will be related to remotely sensed lake color and to the potential for C-gas emission, with the goal of extrapolating inland water DOC composition and CO2 and CH4 emissions across the ABoVE domain.

Curtis Woodcock/Boston University
Landscape-Scale Histories and Active Monitoring of Disturbance, Seasonality and Greenness Trends for ABOVE from Landsat

. Boreal and arctic ecosystems are highly dynamic and spatially heterogeneous, and are undergoing rapid change in response to climate forcing. Understanding the nature, magnitude, and drivers behind these changes requires information that captures land cover dynamics at spatial scales that are ecological meaningful, and historical information that provides context for evaluating observed changes relative to historical variability. Landsat, which provides an archive of 30+ years and an ongoing record of well-calibrated multispectral observations at 30 meter spatial resolution is ideally suited for this purpose. To exploit this capability and to address the need of ABOVE for high quality remote sensing data products that characterize spatio-temporal dynamics in land cover and ecological change, we propose to develop wall-to-wall products for the ABOVE domain based on Landsat data that provide historical and ongoing characterization of three key landscape attributes: (1) disturbance, (2) peak season

greening and browning trends, and (3) growing season length. To accomplish this we will use state-of-the-art time series algorithms to generate a multi-dimensional, internally consistent data product that integrates all three of these ecologically critical quantities in a unified fashion at annual time steps. Results from this work will provide a 30+ year historical record and ongoing characterization of disturbance events (fires, pests, logging), lower frequency changes (greening/browning), and both short and long term changes in the phenology of ecosystems located in the ABOVE domain. Analysis of these datasets will lead to an improved understanding of the land cover dynamics in the ABoVE domain as well as trends in ecosystem response and disturbance as they relate to climate trends and variability.