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(NGEE Arctic Phase 3)

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Next-Generation Ecosystem Experiments - Arctic (NGEE Arctic)

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Next-Generation Ecosystems Experiment (NGEE Arctic) – Phase 3 Renewal

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ABBREVIATED TERMS

ABoVE	NASA Arctic-Boreal Vulnerability Experiment
ALD	Active Layer Depth
ATM	Alaska Thermokarst Model
ATS	Advanced Terrestrial Simulator
AVIRIS-NG	Airborne/Visible Infrared Imaging System Next Generation
BEO	Barrow Environmental Observatory
BER	Biological and Environmental Research
CAVM	Circum-Arctic Vegetation Map
CESD	Climate and Environmental Sciences Division
CLM	Community Land Model
CMDV	Climate Model Development and Validation
DEM	Digital Elevation Model
DMT	Data Management Team
DON	Dissolved Organic Nitrogen
DTP	Distributed Temperature Profiling
E3SM	Energy Exascale Earth System Model
ELM	E3SM Land Model
EMSL	Environmental Molecular Science Laboratory
ERT	Electrical Resistivity Tomography
ESM	Earth System Model
ESS-DIVE	Environment Systems Science Data Infrastructure for a Virtual Ecosystem
ET	Evapotranspiration
FCCS	Fuel Characteristic Classification System
FTIR	Fourier-Transform Infrared Spectroscopy
GHG	Greenhouse Gas
GIPL	Geophysical Institute Permafrost Laboratory
GPR	Ground Penetrating Radar
HCP	High-Centered Polygon
IDEAS	Interoperable Design of Extreme-scale Application Software
ILAMB	International Land Model Benchmarking Project
LAI	Leaf Area Index
LiDAR	Light Detection and Ranging
LCP	Low-Centered Polygon
NDVI	Normalized Difference Vegetation Index
NGEE Arctic	Next-Generation Ecosystem Experiments
NMR	Nuclear Magnetic Resonance
NPP	Net Primary Production

OME	Online Metadata Editor
PEcAn	Predictive Ecosystem Analyzer
PFT	Plant Functional Type
PRI	Photochemical Reflectance Index
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SWE	Snow Water Equivalent
TBM	Terrestrial Biosphere Model
TEM	Terrestrial Ecosystem Model
TES SFA	Terrestrial Ecosystem Science (TES) Science Focus Area (SFA)
UAS	Unmanned Aircraft Systems
UQ	Uncertainty Quantification
VD	Variance Decomposition
VSFM	Variably Saturated Flow Model
ZPW	Zero Power Warming

EXECUTIVE SUMMARY

An important challenge for Earth System Models (ESMs) is to represent land surface and subsurface processes and their complex interactions in a warming climate. This is especially important for Arctic ecosystems where permafrost extent, topography, hydrology, vegetation, disturbance, and biogeochemistry are inextricably linked. The implications of such linkages include permafrost thaw and deepening of the active layer, microbial decomposition of vulnerable soil organic matter, altered productivity and migration of tall woody shrubs, and watershed-scale changes in surface and groundwater transport and storage. Although ESMs describe some of these interactions for high-latitude ecosystems, their representation requires extensive confrontation with field and laboratory observations to test and improve models, and to use those models to inspire new observations and experiments.

The Next-Generation Ecosystem Experiments (NGEE Arctic) is a 10-year project (2012 to 2022) to improve our predictive understanding of carbon (C)-rich Arctic system processes and feedbacks to climate. This is achieved through experiments, observations, and synthesis of existing datasets that strategically inform model process representation and parameterization, and that enhance the knowledge base required for model initialization, calibration, and evaluation. In Phase 1 (2012 to 2014), NGEE Arctic tested and applied a multiscale measurement and modeling framework in coastal tundra on the North Slope of Alaska. Field plots, transects, and synoptic surveys near Utqiaġvik (formerly Barrow) were chosen to represent a cold, continuous permafrost region at the northern extent of an ecological and climatic gradient. Much of our research focused on subgrid heterogeneity in thermal-hydrology, biogeochemistry, and vegetation as influenced by topography, landscape position, and drainage networks. These efforts provided datasets, derived products, and knowledge designed to meet project requirements for model initialization, parameterization, process representation, and evaluation.

Building upon research conducted in the first 3 years of the project, in Phase 2 (2015 to 2019) we maintained research at Utqiaġvik and established a set of research sites near Nome in western Alaska (i.e., Seward Peninsula). These field sites are characterized by their proximity to the transition from boreal forest to tundra, as well as by warm, discontinuous permafrost, higher annual precipitation, and well-defined watersheds with strong topographic gradients. We used variation in the structure and organization of the Seward Peninsula landscape to guide a series of process-level investigations (Questions 1 through 3) that were nested at scales ranging from soil core to plot, landscape, and watershed levels. Knowledge from those studies identified mechanisms controlling C, water, nutrient, and energy fluxes, which was used to address two integrated questions regarding the future of the Arctic in a changing climate (Questions 4 and 5):

- Q1. How does the structure and organization of the landscape control permafrost evolution and associated C and nutrient fluxes in a changing climate?
- Q2. What will control rates of CO_2 and CH_4 fluxes across a range of permafrost conditions?
- Q3. How do above- and belowground plant functional traits change across environmental gradients, and what are the consequences for Arctic ecosystem C, water, and nutrient fluxes?
- Q4. What controls the current distribution of Arctic shrubs, and how will shrub distributions and associated climate feedbacks shift with warming in the 21st century?
- Q5. Where, when, and why will the Arctic become wetter or drier, and what are the implications for climate forcing?

In Phase 3 (2020 to 2022), we propose to maintain a core focus on these five key science questions, while also adding a cross-cutting question on disturbance.

- Q6. What controls the vulnerability and resilience of Arctic ecosystems to disturbance, and how do disturbances alter the physical and ecological structure and function of these ecosystems?

Disturbances, both natural and anthropogenic, have the potential to effect profound changes on Arctic ecosystem processes. Question 6 builds on research from Q1 through Q5 and will use field campaigns, modeling, and data synthesis to target improvements in disturbance-related processes (e.g., wildfire, thermokarst, and thermal erosion) that are missing from or poorly represented in ESMs. Sites on the Seward Peninsula encompass a range of thermokarst features and a patchwork of historic tundra wildfires that will allow us to examine changes in ecological and physical structure of the landscape. We will sample across this landscape heterogeneity to measure the controls on storage, processing, and release of C, nutrients, water, and sediments, and how those controls change in response to disturbance severity and time since disturbance.

A major Phase 3 milestone is to have a multiscale and high-resolution representation of Arctic tundra structure and function operating within the DOE's Energy Exascale Earth System Model (E3SM), and to demonstrate the fidelity of that representation against a full suite of observational and experimental benchmarks as established by the Q1–Q6 activities and as synthesized from broader community efforts. Our progress in earlier phases of the project produced the fine-scale, intermediate-scale, and climate-scale modeling capabilities necessary to reach this Phase 3 milestone. However, recognizing that the land system component of E3SM (i.e., the E3SM Land Model, or ELM) must operate seamlessly across biomes and ecosystems at global scales, we are not proposing to replace ELM with a new model specific for use in Arctic tundra. Instead we have identified, based on previous research, six areas in need of model improvement and thus propose, to deliver **six modules of improved Arctic tundra predictive modeling capability**, each of which will demonstrate improved performance as evaluated against previous and new NGEE Arctic measurements and other synthesis-based products. These six modules include (1) improved simulation of inundation dynamics; (2) explicit representation of hillslope hydrologic processes; (3) improved interaction of snow dynamics with vegetation and terrain; (4) unique contributions of the N-fixing shrub alder to Arctic shrub tundra ecosystems; (5) improved simulation of pan-Arctic vegetation dynamics; and (6) improved representation of oxidation-reduction state and acidity in tundra soils. The six modules emerged through multiple iterations of synthesis, modeling, measurement, evaluation, and hypothesis development and represent predictive capabilities that tie together research carried out by the question-based teams.

Our model-inspired vision implemented in Phases 1 and 2, and now extended into Phase 3, strengthens the connection between process studies in Arctic ecosystems and high-resolution scaling strategies that form the foundation of DOE's land surface modeling for Earth system prediction. ***The NGEE Arctic project supports the BER mission to advance a robust predictive understanding of Earth's climate and environmental systems by delivering a process-rich ecosystem model, extending from bedrock to the top of the vegetative canopy and atmospheric interface, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the scale of a high-resolution, next-generation ESM grid cell.*** Implicit in our expanded scope of research in Phase 3 is the ability to build upon the scaling and modeling framework established in prior phases of the project. This will facilitate upscaling our field and landscape-scale observations to regional scales and encourage continued interactions with national partners such as the NASA Arctic-Boreal Vulnerability Experiment (ABoVE). Our research tasks on plant traits, vegetation demography, and trait-enabled modeling are well aligned with that of the NGEE Tropics and E3SM projects (e.g., through the continued development and use of ELM-FATES) and represent areas where close collaboration among our projects will be encouraged. We will continue to collaborate with the Terrestrial Ecosystem Science (TES) Science Focus Area (SFA) at Argonne National Laboratory to share knowledge and samples that together we can use to develop regional maps of soil C stocks and their intrinsic decomposability for model benchmarking. Integration and a truly interdisciplinary perspective, forged by our team in Phases 1 and 2, will be foundational to these Phase 3 activities as we use model sensitivity and uncertainty analysis and new process knowledge to guide computational, experimental, and observational efforts toward improved climate predictions in high-latitude ecosystems. Safety, collaboration, communication and outreach, and a strong commitment to data management, sharing, and archiving are key underpinnings of our model-inspired research in the Arctic.

1. ABSTRACT

An important challenge for Earth System Models (ESMs) is to represent land surface and subsurface processes and their complex interactions in a changing climate. This is true for all regions of the world, but it is especially important for Arctic ecosystems which are projected to warm at a rate twice that of the global average by the end of the 21st century. The Next-Generation Ecosystem Experiments (NGEE Arctic) project seeks to improve the representation of tundra ecosystems in ESMs through a coordinated series of model-inspired investigations conducted in landscapes near Utqiaġvik (formerly Barrow) and Nome, Alaska. ***Our goal is to support the DOE's Biological and Environmental Research (BER) mission to advance a robust predictive understanding of Earth's climate and environmental systems by delivering a process-rich ecosystem model, extending from bedrock to the top of the vegetative canopy and atmospheric interface, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the scale of a high-resolution ESM grid cell.*** This goal is aligned with the High-Latitude Scientific Grand Challenge in the Climate and Environmental Sciences Division (CESD) Strategic Plan. In Phase 1 (2012 to 2014), we tested and applied a multiscale measurement and modeling framework in a coastal tundra ecosystem on the North Slope of Alaska. This region was chosen to represent a site underlain by cold, continuous permafrost at the northern extent of an ecological and climatic gradient in Alaska. In Phase 2 (2015 to 2019), three additional field sites were established on the Seward Peninsula in western Alaska, which, compared to our research site on the North Slope, are characterized by their proximity to the boreal-tundra transition zone; warmer, discontinuous permafrost; and well-defined watersheds. Integrated field, laboratory, and modeling tasks allowed our team to focus on understanding (1) the effect of landscape structure and organization on the storage and flux of C, water, and nutrients, (2) edaphic and geochemical mechanisms responsible for variable CO_2 and CH_4 fluxes across a range of permafrost conditions, (3) variation in plant functional traits across space and time, and in response to changing environmental conditions and resulting consequences for ecosystem processes, (4) controls on shrub distribution and associated biogeochemical and biophysical climate feedbacks, and (5) changes in snow processes and surface and groundwater hydrology expected with warming in the 21st century. A major outcome of our Phase 1 and 2 research was an integrated set of in situ and remotely sensed observations that quantify the covariation of hydro-thermal, ecosystem, vegetation dynamics, and biogeochemical function. These efforts provided unique datasets for model parameterization and benchmarking. Knowledge on topics ranging from watershed hydrology to plant physiology is now being incorporated into DOE's Energy Exascale Earth System Model (E3SM). In Phase 3 (2020 to 2022), we propose to continue our research at sites on the North Slope and in western Alaska, while also adding a cross-cutting component on disturbance. We will use field campaigns, modeling, and data synthesis to target improvements in simulating disturbance-related processes (e.g., wildfire and abrupt permafrost thaw) and connections to dynamic vegetation (e.g., shrubs) that are missing from or poorly represented in ESMs. Our vision in Phase 3 strengthens the connection between process studies in Arctic ecosystems and high-resolution landscape modeling and scaling strategies developed in Phases 1 and 2. Deliverables will consist of six new source-code modules within the E3SM Github code repository, each evaluated against multiscale measurements and process-based models. We also outline a close-out plan for critical components of the project. This plan includes closure of field sites, removal of instruments and infrastructure, shipment of resources back to home institutions, environmental stewardship as lands are returned to native communities from which we obtained permits, and timely transfer of datasets to the Environmental System Science Data Infrastructure for a Virtual Ecosystem (ESS-DIVE). Safety, national and international collaboration, and a commitment to project management continue to be key underpinnings of our model-inspired research in the Arctic.

2. BACKGROUND AND JUSTIFICATION

RESEARCH AND MODELING NEEDS IN ARCTIC TUNDRA ECOSYSTEMS

The Arctic may be the most climatically sensitive region on Earth. High latitudes in the northern hemisphere have experienced the greatest regional warming in recent decades and are projected to warm at a rate twice that of the global average in the coming century (Bieniek et al., 2014). The implications of such warming include permafrost thaw and thickening of the active layer, microbial decomposition of vulnerable soil organic matter, altered productivity and migration of vegetation, and changes in surface and groundwater storage (Hinzman et al., 2013; Loranty et al., 2018). Recent literature, including that from the NGEE Arctic project, emphasizes that the following topics are central priorities for experimental, observational, and model development research:

- Improved representation of subgrid heterogeneity related to permafrost distribution, soil C stocks, surface inundation, distribution of vegetation, and atmospheric forcing (Rowland et al., 2010; Aleina et al., 2013; Treat et al., 2018);
- Better descriptions of permafrost thaw and deepening of the active layer, and the consequences for microbial dynamics and C feedbacks to climate (Cahoon et al., 2012; Hodgkins et al., 2014; McCalley et al., 2014; Schuur et al., 2015; McGuire et al., 2016; Schadel et al., 2016, 2018);
- Increased understanding of the fundamental controls on vegetation dynamics and their representation in models, including the relationships and trade-offs among plant functional traits, above- and belowground, that enable future innovations in modeling (Epstein et al., 2004a; Wookey et al., 2009; Freschet et al., 2010; van Bodegom et al., 2014; Koven et al., 2015a; Lopez-Blanco et al., 2018; Myers-Smith et al., 2018);
- Enhanced understanding of shrub expansion (e.g., dynamic vegetation) including how climatic and disturbance regimes (e.g., wildfire and permafrost thaw) may influence shrub abundance in large-scale models (Myers-Smith et al., 2011; Jiang et al., 2012; Zhang et al., 2013; Frost et al., 2014; Wullschleger et al., 2014; Duchesne et al., 2018; Zhang et al., 2018); and
- Improved characterization of snow processes and hydrology at watershed to regional scales and integration of surface and subsurface processes that drive water distribution across Arctic ecosystems, especially as a function of disturbance and landscape transitions in a changing climate (Lara et al., 2015; Natali et al., 2015; Fisher et al., 2018; Zhang et al., 2018).

ESMs lack many of the key processes that govern interactions between Arctic ecosystems and climate (Koven et al., 2013a; Hayes et al., 2014; Schaefer et al., 2014). Multiple C, water, nutrient, and energy feedbacks that occur in response to rising temperatures must be resolved if we are to improve model prediction of climate. Observations suggest that permafrost warming, and associated thawing is now occurring throughout the Arctic (Jorgenson et al., 2006; Liljedahl et al., 2016; Romanovsky et al., 2017). Biogeochemical feedbacks are dominated by the potential to release a large amount of currently stored C into the atmosphere as CO_2 and CH_4 (Schuur et al., 2015; Schadel et al., 2016). Biophysical feedbacks include changes in terrestrial radiation and sensible and latent heat flux budgets that can lead to large-scale warming (Swann et al., 2010) caused by changes in vegetation distributions, among other factors (Chapin et al., 2005; Euskirchen et al., 2009; Zhang et al., 2018). These processes will take place not only in response to warmer temperatures but also because of changing disturbance regimes that may promote dynamic changes in vegetation patterns, geomorphic change, and landscape reorganization (Rowland et al., 2010; Grosse et al., 2011).

Although ESMs include some of the important relationships among vegetation, biogeochemistry, and climate, these representations are highly uncertain and require extensive confrontation with observations to test and improve models (Bouskill et al., 2014; Fisher et al., 2014; McGuire et al., 2016). Furthermore, many of the coupled properties and processes characteristic of the Arctic tundra, including interactions among permafrost thaw and surface and subsurface soil moisture distribution (Vogel et al., 2009; Natali et al., 2015) are poorly represented. The presence of ground ice and cryostructures, for example, and their influence on surface topography appear to be critical drivers of landscape-scale processes (Belshe et al., 2013) but cannot be resolved at even the highest grid-cell resolutions presently conceived for global-scale climate models (Aleina et al., 2013; Lee et al., 2014). Current ESM intercomparison protocols define grid resolutions <50 km as high-resolution (Haarsma et al., 2016), while the high-resolution version of E3SM v1 has a 25 km horizontal resolution for land and atmospheric grids. Next generation ESMs are expected to have grid resolution over land of 10 km or finer, but even at this resolution the processes controlling Arctic landscape evolution much be represented through subgrid parameterization. This underscores the importance of conducting holistic, multiscale, multidisciplinary investigations of the Arctic and the representation of tundra ecosystems in models as dynamic, evolving, highly coupled systems (Slater and Lawrence, 2013).

NGEE Arctic Field Sites

A critical component of our Phase 1 and 2 activities included the selection and establishment of field study sites. In Phase 1 NGEE Arctic focused its research on the Barrow Environmental Observatory (BEO) situated on the coastal plain of the North Slope of Alaska near Utqiaġvik, Alaska. At the largest scale, the hydrological basins of the North Slope comprise thaw lakes, drained thaw-lake basins, interstitial polygonal regions and drainage features (Lara et al., 2015). Nested within these land units are ice-wedge polygons of different types. This study area was chosen to represent a cold, lowland, C-rich, continuous permafrost site with low vegetation biomass density and diversity located at the northern extent of an Arctic Alaska landscape and climatic gradient. Lowland landscapes such as the BEO comprise ca. 30% of the Arctic and sub-Arctic. These Alaska coastal plain, river valley, and delta regions have low relief, thin active layer soils (<1 meter) and deep, ice-rich permafrost. This often leads to saturated and flooded conditions across large portions of the landscape throughout the thaw season (Kane et al., 2008).

Figure 1. Location of field sites along the Teller, Kougarok, and Council Roads outside Nome, Alaska. Sites were chosen to allow NGEE Arctic scientists easy access to thermokarst features, fire chronosequences, shrub tundra, and landscapes underlain by permafrost and near-surface bedrock.

In Phase 2, we built upon the success demonstrated in Phase 1 by establishing a network of sites on the Seward Peninsula (Figure 1). In contrast to Utqiaġvik, this warmer region occupies a highly dynamic transition between Arctic and boreal ecosystems (Epstein et al., 2004). Warm, discontinuous permafrost, well-defined watersheds, extensive shallow bedrock, and greater diversity in vegetation composition and plant functional types characterize the Seward Peninsula. Approximately 40% of the Arctic can be classified as hilly, vegetated, soil-mantled landscapes like these, with significant C stored in active layer soils and permafrost (Grosse et al., 2011; Schuur et al., 2015) and this region is experiencing an increased frequency of disturbance (Swanson, 2010; Jones et al., 2012; Rocha et al., 2012). Three sites were established on the Seward Peninsula. These include (1) a lowland wet, warm, and discontinuous permafrost region with extensive thermal erosion and drained thermokarst lakes near Council; (2) hillslopes and watersheds near Kougarok where vegetation varies with hillslope position and aspect, including a site previously affected by wildfire and subsequent ground surface subsidence; and (3) landscapes underlain by near-surface bedrock along the Teller road where numerous linkages exist among vegetation patterns, subsurface characteristics, and hillslope and watershed position (i.e., geomorphology). A focus on the Seward Peninsula allows the opportunity to compare new insights with knowledge gained on the North Slope, as well as to continue to refine our scaling and modeling approaches to predict ecosystem-climate feedbacks across the full climatic gradient between our sites.

SCIENCE QUESTIONS AND MODEL DEVELOPMENT OBJECTIVES

Given recent progress in ESM development and advances in computational resources, there is an opportunity to target high-resolution land surface and subsurface simulation capabilities that allow explicit representation of properties and processes at the spatial and temporal scales at which they occur, and methods to incorporate the effects of these fine-scale processes into larger-scale model representations. Such high-resolution modeling can only be achieved through synthesis of new knowledge and understanding of processes emerging from mechanistic studies carried out in the field and in the laboratory. Thus, to cover this broad set of processes and model requirements, we identify six overarching science questions that will continue to guide our research in Phase 3:

- Q1. How does the structure and organization of the landscape control permafrost evolution and associated C and nutrients fluxes in a changing climate?
- Q2. What will control rates of CO_2 and CH_4 fluxes across a range of permafrost conditions?
- Q3. How do above- and belowground plant functional traits change across environmental gradients, and what are the consequences for Arctic ecosystem C, water, and nutrient fluxes?
- Q4. What controls the current distribution of Arctic shrubs, and how will shrub distributions and associated climate feedbacks shift with expected warming in the 21st century?
- Q5. Where, when, and why will the Arctic become wetter or drier, and what are the implications for climate forcing?
- Q6. What controls the vulnerability and resilience of Arctic ecosystems to disturbance, and how do disturbances alter the physical and ecological structure and function of these ecosystems?

We will use variation in the structure and organization of the landscape, at field sites near Utqiaġvik and Nome, to guide a series of process-level investigations (Questions 1 through 3) that are nested at scales ranging from soil core to plot, landscape, and watershed levels. Knowledge derived in these studies will identify mechanisms controlling C, water, nutrient, and energy fluxes, which will then be brought to bear on two integrative and timely questions concerning the future of the Arctic in a changing climate (Questions 4 and 5). Questions 1–5 helped focus our research in Phase 2, and our research plan describes how those questions will continue to guide our research. Question 6 is added in Phase 3 given the strong need to understand how shrub distribution and disturbance processes in tundra ecosystems may drive future biophysical feedbacks to climate.

We focus our modeling efforts in Phase 3 on a series of process-based improvements within the E3SM Land Model (ELM, including its dynamic biogeography component ELM-FATES). These improvements to ELM use NGEE Arctic findings and syntheses from the broader Arctic science community to anchor new model development in current system understanding, and to evaluate new ELM processes and parameterizations against independent observations at spatial and temporal scales appropriate to the use of ELM and E3SM for future climate prediction.

Our multiscale measurement and modeling approach is motivated by three major deficiencies in E3SM, which are also common to other ESMs. These are (1) inadequate high-resolution representation of land surface heterogeneity, including the temporal transition of landscapes (i.e., evolution of the land surface) with projected warming, (2) distribution and fate of permafrost and associated loss of stored C the atmosphere, and (3) biophysical feedbacks to climate brought about by changes in vegetation dynamics and especially tall shrub migration and infilling from the low to high Arctic. Within the first deficiency, we identified three specific improvements to ELM that we expect will enhance the fidelity of the coupled system for prediction of future water and energy states and fluxes over the Arctic tundra region. These are improved representation of the subgrid fraction of inundated land area, improved representation of snow accumulation as influenced by winds, terrain, and vegetation, and improved subgrid parameterization of hillslope transport of water and energy. Within the second deficiency, we identified the inclusion of more complete reduction-oxidation chemistry within the soil biogeochemistry module as a critical capability for improved prediction of greenhouse gas fluxes. For the third deficiency, we will focus on representing plant types with unique functionality, such as N-fixing shrubs, and on simulation of dynamic biogeography at the pan-Arctic scale. With these model deficiencies as our guide, in the following sections we lay out our 10-year vision for the NGEE Arctic project. In the final phase of this project, we aim to deliver model improvements that are the culmination of a decade of observations, experiments, and synthesis activities that inform the way Arctic processes are conceptualized, parameterized, and evaluated in models.

3. VISION

The NGEE Arctic project is an integrated effort to increase our understanding of how tundra ecosystems will respond to changing environmental conditions. Increasing our confidence in model projections for high-latitude northern hemisphere regions of the world requires a coordinated set of model-inspired investigations that target improved process understanding and model representation of important ecosystem-climate feedbacks. Our approach to achieving that vision is ambitious and requires a focused effort from our large and interdisciplinary team. Continued research in Phase 3 on the North Slope and Seward Peninsula will allow novel questions to be asked and answered in ways that broaden our spatial and temporal perspective of the Arctic. ***Our goal is to support the BER mission to advance a robust predictive understanding of Earth's climate and environmental systems by delivering a process-rich ecosystem model, extending from bedrock to the top of the vegetative canopy and atmospheric interface, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the scale of a high-resolution ESM grid cell.*** Major milestones identified for Phase 3 of the NGEE Arctic project allow us to evaluate progress towards this goal (see sidebar).

The integrated and interdisciplinary approach forged by our team throughout the previous phases of this project will be critical to Phase 3 success as we seek to deliver six process-rich modules of tundra ecosystems that can be applied at pan-Arctic scales using the E3SM model. Our model-inspired vision implemented in Phases 1 and 2, and now extended into Phase 3, strengthens the connection between process investigations in Arctic ecosystems and high-resolution scaling strategies that form the foundation of DOE's land surface modeling for Earth system prediction. Our Phase 3 vision is focused on key questions of importance to Arctic ecosystems in a changing climate. A combination of field campaigns, laboratory analyses, multiscale modeling, and data synthesis will be used to target improvements in how hydrology, biogeochemistry, vegetation dynamics, and disturbance are represented in models. Disturbances, both natural and anthropogenic, have the potential to induce profound changes in ecosystem structure and function; thus, the scientific community strongly supports incorporation of abrupt change in predictive models. We are excited to add this research component to our suite of empirical and modeling activities that collectively put us in a strong position to conduct pan-Arctic simulations using a model that is parameterized and evaluated against a multiscale, nested hierarchy of measurements and synthesis products. This is consistent with our long-term objective to establish a process-rich land and ecosystem science capability within future generation ESMs, thus making effective use of the burgeoning compute power anticipated on the path toward exascale computation. We envision the data collected in Phases 1–3 of the NGEE Arctic project will serve as input to, and evaluation of, modeling frameworks now and for many years to come. These data will be made available to the broader public through the DOE-funded Environmental System Science Data Infrastructure for a Virtual Ecosystem (ESS-DIVE).

PHASE 3 MILESTONES

1. Process-rich model modules of tundra ecosystems that can be applied at ecosystem scales.
2. Modules parametrized and evaluated against multiscale measurements and synthesis products.
3. Spatial and temporal characterization of Arctic plant functional types and simulation of dynamic vegetation due to changing climate and disturbance regimes.
4. Linkages among surface and subsurface properties and hydrobiogeochemistry.
5. Robust and dynamic simulations of landscape changes in response to changing environmental conditions.
6. Transfer of all NGEE Arctic data and metadata to ESS-DIVE.

4. PROGRESS AND ACCOMPLISHMENTS

Our progress to date includes results from data synthesis, field observations, laboratory experiments, model development and simulations, publications, presentations, and outreach. Our team has published 165 journal articles, including publications in *Nature*, *Nature Climate Change*, *Nature Geoscience*, and PNAS, and given presentations to local native communities and at major scientific conferences around the world (see sidebar). NGEE Arctic scientists convened workshops and chaired sessions at major conferences, mentored students, postdoctoral candidates, and early career staff, and participated in educational activities at our home institutions and also in Utqiaġvik and Nome. These efforts ensure that our research is visible and supports the mission of the BER Climate and Environmental Sciences Division (CESD).

In this section we highlight the depth, breadth, and impact of our Phase 2 research. Significant accomplishments illustrate that we have successfully (1) maintained our field research site on the Barrow Environmental Observatory (BEO), while also expanding to field sites on the Seward Peninsula; (2) undertaken multiscale characterization of tundra landscapes that guide our modeling and scaling strategies; (3) used this land surface understanding to organize our field and laboratory studies; (4) integrated an iterative philosophy into our observational, experimental, and modeling activities; and (5) created a public resource that makes data and metadata available in a searchable format to the larger community.

INTEGRATED MODELING

A primary focus of model development in NGEE Arctic has been on multiscale modeling strategies that allow improved process understanding from field site and laboratory investigations. We focused integrated modeling efforts during Phase 2 on building this strategy from very fine scales that allow direct connection with observations to landscape scales that are the proximal connections to high-resolution climate modeling grid cells.

Fine and intermediate-scale thermal hydrology modeling

In Phase 2, we developed and tested a state-of-the-art, process-based, highly parallel modeling capability, the Advanced Terrestrial Simulator (ATS). ATS filled a key gap in the permafrost modeling community (Painter et al., 2013) and required novel advances in physics-based representations of permafrost processes (Painter et al., 2016; Atchley et al., 2015), computer science for multiphysics models (Coon et al., 2016), and numerical methods (Svyatskiy and Lipnikov, 2017). The resulting model has been rigorously benchmarked in model intercomparison studies (Kollet et al., 2017; Grenier et al., 2018) and evaluated with field data (Atchley et al., 2015; Sjoberg et al., 2016). This capability was used to better understand how fine-scale thermal hydrology processes manifest at larger scales, a capability that allowed us to develop

NGEE ARCTIC BY THE NUMBERS

People

- More than 140 members
- Four national labs and the University of Alaska Fairbanks
- More than 100 have traveled to Alaska, including 27 modelers

Publications

- More than 165 publications since the project's inception in 2012
- Published in 37 journals, including *Nature*, *Nature Climate Change*, *Nature Geoscience*, and PNAS
- Cited > 3600 times

Data and Metadata Metrics

- 130 datasets in the NGEE Arctic Data Portal
- 60 datasets released to the public
- 360 unique users of our datasets

new model structures that scale to watershed-based grid cells in ELM. Through a series of modeling studies (Painter et al., 2016), we found that lateral heat flow was sufficient to equilibrate seasonal patterns in active layer thickness within ice-wedge polygons. Using that insight, we collaborated with the DOE's Interoperable Design of Extreme-scale Application Software (IDEAS) project to develop a novel intermediate-scale representation of permafrost polygonal ground (Jan et al., 2018a). This advancement uses polygon-aligned columns to represent vertical processes and then links them through lateral surface flow. To capture the temporal effect of polygon evolution, we developed and evaluated a model that represents the effects of subgrid topography (i.e., high- vs low-centered polygonal topography) (Jan et al., 2018b). The ATS intermediate-scale model is unique in its capability for physics-based representation of surface and subsurface thermal hydrology and thaw-induced subsidence at scales approaching a global model grid cell, thus enabling representations used in global models to be rigorously evaluated and refined.

Coupled thermal-hydrology and tracer transport

Transport and biogeochemistry are rarely considered in model simulations of the surface water system. To address this deficiency, we developed a new capability within the ATS model, leveraging the transport capabilities of the Amanzi framework, to fully couple integrated hydrology with nonreactive transport. To build confidence in this capability, we performed simulations of plausible tracer experiments on synthetic high- and low-centered polygons and demonstrated the important impact of the freeze-thaw cycle on both the tracer distribution within the polygon and the tracer fluxes to the trough. In collaboration with the IDEAS project, we then used Alquimia, a generic interface library for biogeochemistry engines, to develop a fully coupled capability with integrated hydrology and reactive transport in the surface and subsurface water. Through Alquimia we can access either the PFLOTRAN or CrunchFlow reaction engines.

Subsurface biogeochemistry connections to ELM

With these fine-scale modeling studies as a process-resolving foundation, a major science objective for NGEE Arctic was to migrate new knowledge concerning the connections of Arctic tundra ecosystems to the broader Earth system into DOE's flagship Energy Exascale Earth System Model (E3SM). NGEE Arctic modeling team members have played a central role in the development, evaluation, and public release of version 1 of E3SM (DOI: 10.11578/E3SM/dc.20180418.36), including the E3SM Land Model (ELM v1). An area of emphasis has been the development and testing of new representations of soil biogeochemistry processes and development and integration of improved reactive transport submodels into the ELM v1 code base. Building on the work of Xu et al. (2015), who demonstrated an improved ability to simulate CH_4 production and consumption in permafrost by adding a microbial functional group to the default ELM decomposition cascade, Tang et al. (2016a) introduced into ELM improved treatments of organic substrate turnover, fermentation, iron reduction, and methanogenesis to predict redox state and pH in tundra soils. Because the native numerical representation of organic matter decomposition in ELM is poorly suited to the complex reaction networks required to track redox state and pH, further work was done (Tang et al., 2016b) to migrate the ELM reactions into a community-supported reactive transport code (PFLOTRAN). In this development pathway for improved treatment of processes relevant to CH_4 cycling, we are following a roadmap of model improvement laid out by Xu et al. (2016). We have further generalized the modeled treatment of moisture and temperature responses to improve prediction skill across a wider range of soil types and oxic vs. anoxic conditions (Zheng et al., in press). Additional work by the NGEE Arctic modeling team has prepared ELM v1 for high-resolution implementation over field site domains near Utqiaġvik and Nome.

Hydrology and vegetation dynamics connections to ELM

In Phase 2, progress was made on several topics that provide a foundation for Phase 3 modeling work and integration with ELM. We successfully developed a mechanistic three-dimensional (3D) capability in ELM (ELM-3D), tested the model against hydrological and thermal observations at the NGEE Arctic BEO site, and analyzed the effect of spatial heterogeneity on soil moisture and temperature across the polygonal tundra (Bisht et al., 2018). We also applied an independent ecosystem model "*ecosys*" at field sites near

Utqiaġvik, to inform needed improvements in ELM and ELM-3D, improve understanding of the role of 3D surface and surface hydrology, vegetation competition, and nutrient dynamics on the polygonal tundra (Grant et al. 2017a, b), and predict changes in shrub abundance over the 21st century (Grant et al. 2018a, b). We also made progress on Q2 modeling tasks, including developing new model representations for general redox reaction networks and soil moisture constraints on decomposition (Tang and Riley, 2017) and explicit thermodynamic representations for microbial decomposition, nitrification, and denitrification (Maggi and Riley, 2017); we are currently integrating these representations into ELM. For Q3 modeling tasks, we integrated into ELM improved representations of root traits and compared to NGEE Arctic field observations of nutrient uptake (Zhu et al., 2016) and plant nutrient allocation (Ghimire et al., 2017). We also improved the model's wetland representation and examined results against site-, regional-, and global-scale methane emissions (Xu et al., 2016) and are using the improved ELM to participate in the Global Carbon Project methane budget analysis and Powell Center methane synthesis activities. Finally, we used *ecosys* to inform ELM-FATES development of plant functional types (PFTs) and nutrient cycling, and to examine expected changes in North American tundra vegetation and C cycling over the 21st century (Mekonnen et al., 2018a, b).

SCIENCE QUESTIONS

QUESTION 1. HOW DOES THE STRUCTURE AND ORGANIZATION OF THE LANDSCAPE CONTROL PERMAFROST EVOLUTION AND ASSOCIATED C AND NUTRIENT FLUXES IN A CHANGING CLIMATE?

Research associated with this question in Phase 2 focused on three distinct yet complementary themes, including improving our understanding of how (1) surface and subsurface properties co-vary and how the properties can be used to define representative ecosystem types; (2) biogeochemical fluxes vary within and across ecosystem types; and (3) permafrost degradation and other geomorphic processes influence C fluxes.

Correlations between surface and subsurface properties provide useful construct for scaling and informing models

In Phase 2, we successfully identified relationships between subsurface properties, topographic characteristics, and vegetation. In turn, the developed relationships have enabled us to estimate the spatial boundaries and associated properties of diverse ecosystem types, which are defined as parcels in the landscape that have a unique distribution of surface and subsurface properties important for C and nutrient cycling relative to neighboring units (Wainwright et al., 2015). We focused on the estimation of ecosystem types because the scale of the unit can be tractably represented in regional climate models while still honoring local heterogeneity and field-scale measurements of important ecosystem processes and properties.

Advanced quantification of surface-subsurface interactions has been enabled by the development of several innovative acquisition and numerical techniques and their application in the Utqiaġvik region. An example is provided by Dafflon et al. (2017), who developed an autonomous networked sensing system using pole-mounted optical cameras, point-scale and surface geophysical data. This system was used to monitor the significant spatiotemporal relationship between plant vigor and subsurface properties, such as thaw depth and soil moisture. We have similarly highlighted significant relationships between above- and belowground characteristics in other studies including (1) the influence of geomorphological features on ground ice distribution in the top ~2 m while recognizing the geological influence of soil salinity on decreasing ice-content at greater depths in coastal regions (Dou et al., 2016; Dafflon et al., 2016); (2) the influence of geomorphology on ice-wedge and permafrost structures (Leger et al., 2017), soil physicochemical properties (Wu et al., 2017), CO_2 and CH_4 fluxes (Arora et al., 2017; Grant et al., 2017b), snow distribution (Wainwright et al., 2017) and microbial community composition (Tas et al., 2018); and (3) the importance of topography and shallow soil properties for improved modeling of the soil thermal behavior (Harp et al., 2016; Jan et al., 2018b; Abolt et al., 2018; Tran et al., 2017; Bisht et al., 2018; Kumar et al., 2016; Grant et al., 2017a).

To complement our advances in understanding permafrost distribution and controls in continuous permafrost regions, we also focused on investigating surface and subsurface interactions within discontinuous permafrost at field sites on the Seward Peninsula. A variety of point-scale measurements, networks of distributed sensors, geophysical imaging techniques, as well as remotely sensed ground and surface elevation and plant properties using UAS platforms have proven valuable. An example of this co-location of measurement capabilities includes the development and application of a new sensing array called a Distributed Temperature Profiling (DTP) system. As described by Leger et al. (submitted), the DTP system provides unprecedented spatiotemporal information about the vertical and horizontal distribution of soil temperature at a low-cost (Figure 2). Use of the DTP system at sites on the Seward Peninsula demonstrated significant spatial variability in soil temperature measurements over length scales of decimeters. Because soil temperature is influenced by plant type/height/density, microtopography, snow thickness, soil physical properties and depth to permafrost, the dense DTP information is extremely helpful for investigating associated interactions.

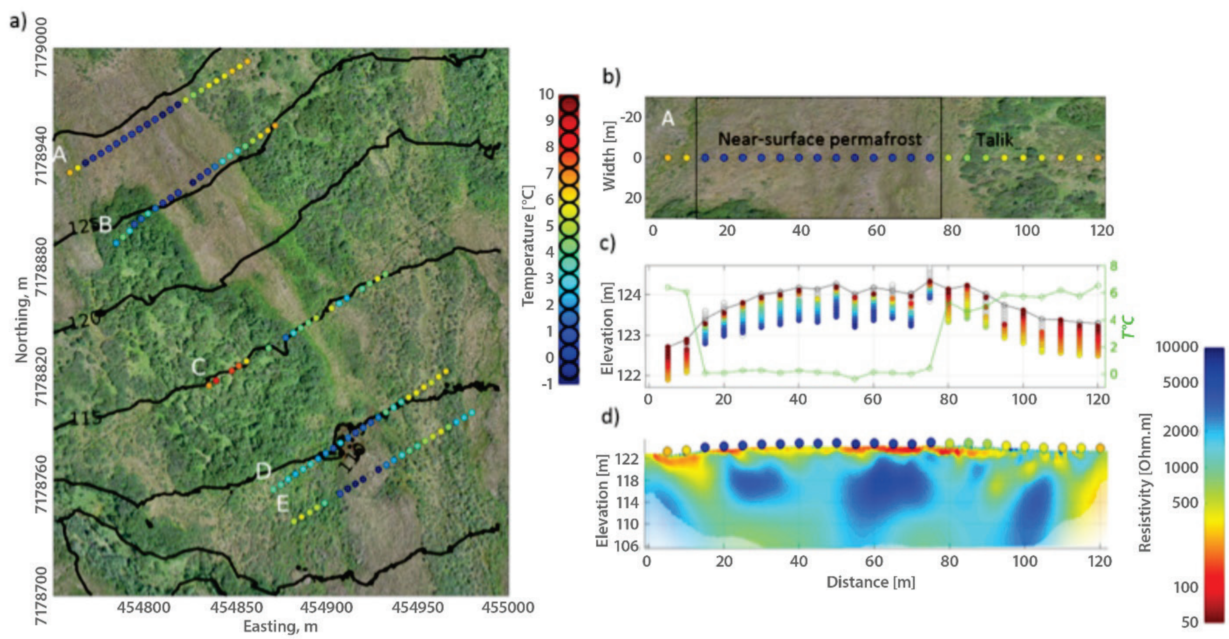


Figure 2. (a) Plan view map of soil temperature at 0.8 m depth measured on July 17, 2017 at Teller using a DTP system; (b) closer look along Transect A, where (c) the vertically resolved profiles of soil temperature and (d) soil electrical resistivity both suggest the presence of near-surface permafrost and talik areas along the transect. Transitions from near-surface permafrost to talik areas along the transect are collocated with changes in vegetation type and micro-topography (Leger et al., submitted).

Another key advance in Phase 2 was the statistical identification of ecosystem types that have distinct suites of geomorphic, hydrologic, pedologic, vegetative and/or permafrost characteristics relative to neighboring units, and the use of ecosystem types to guide upscaling and to inform models. By clustering observations of in situ temperature from individual monitoring stations within identified ecosystem types, Cable et al. (2016) were able to upscale mean annual ground temperature distributions to a regional scale. The ecosystem-type concept was also advanced by Nicolsky et al. (2017), who integrated in situ observations with a 30-m resolution ecological map (Jorgenson et al., 2014) and then parameterized the Geophysical Institute Permafrost Model (GIPL-2) to simulate future ground temperatures. This approach is currently being applied to model permafrost dynamics in the Seward Peninsula using in situ ground temperature measurements. The multiscale (plot-watershed-regional) information about surface-subsurface interactions and ecosystem types will be useful for enhancing the parameterization of ELM.

Ecosystem types have distinct CO_2 flux signatures

Another significant contribution during Phase 2 was the observation that ecosystem types have distinct C flux signatures. Wainwright et al. (submitted) documented how net ecosystem exchange (NEE, from ground-based chamber measurements) and normalized difference vegetation index (NDVI, from an automated mobile sensor system), both collected along an intensive "tram" transect, can be used with spatially extensive LiDAR and NDVI datasets to estimate C fluxes at local (~meters) scales as a function of ecosystem types based on polygon microtopography. This study demonstrated that when upscaled based on ecosystem types, the local-scale C flux estimates agreed favorably with measurements collected using the flux tower. Grant et al. (2018a, b) performed biogeochemical modeling and documented that polygon microtopography affects temporal and spatial variations in CO_2 and CH_4 emissions due to its effects on water and snow movement. These modeling and data-driven studies demonstrate that the ecosystem type construct provides a tractable approach for scaling and simulating terrestrial C fluxes (Arora et al., 2019).

Geomorphological processes contribute to C fluxes

Following the NGEE Arctic Phase 1 research by Lara et al. (2015) that documented how the evolution of thermokarst and polygon tundra is expected to influence the distribution of CO_2 uptake and CH_4 production, several Phase 2 efforts have concentrated on improving the predictive understanding of the rate of change in geomorphology and the associated C fluxes. Liljedahl et al. (2016) synthesized research observations to document ice wedge degradation, revealing that melting at the tops of ice wedges over recent decades and subsequent decimeter-scale ground subsidence is a widespread Arctic phenomenon. Several collaborative studies have focused on evaluating the spatial distribution of permafrost (Obu et al., submitted; Karjalainen et al., submitted) or thermokarst terrain (Farquharson et al., 2016) across the Alaska Arctic and even larger scales. One effort involved investigating the abundance and distribution of key permafrost region disturbances along four continental-scale transects in North America and Eurasia using dense time series analysis of 30-m resolution Landsat satellite imagery from 1999 to 2014. This analysis documented the spatial patterns and global-scale vulnerability of permafrost terrain to disturbances and potentially rapid future thaw across very large regions (Nitze et al., in press).

The role of geomorphological processes related to hillslope transport and erosion was investigated in Phase 2 at several sites on the Seward Peninsula. A combined modeling and field effort examined the role of downslope soil transport and storage of soil organic carbon (SOC) on the distribution and accumulation of SOC in toeslope deposits across the Arctic. This work indicated that uncertainty related to under sampling and poorly constrained permafrost hillslope processes resulted in uncertainties of SOC storage of greater than 200% compared to current estimates (Shelef et al., 2017). Ongoing research on hillslope and watershed processes and the storage and loss of SOC includes coring, repeat GPS surveys, and UAS-based LiDAR and photogrammetry to quantify rates of soil transport and document ongoing erosion associated with hillslope processes and interaction with disturbance regimes (e.g., thermokarst).

QUESTION 2: WHAT WILL CONTROL RATES OF CO_2 AND CH_4 FLUXES ACROSS A RANGE OF PERMAFROST CONDITIONS?

Field and laboratory measurements of biogeochemical processes from molecular to landscape scales fostered mechanistic understanding of critical controls on greenhouse gas (GHG) fluxes from Arctic tundra landscapes during Phase 2. We used new datasets to structure and parameterize models of soil organic matter (SOM) decomposition and GHG production and emissions.

Molecular analyses identified controls on SOM degradation and GHG emissions

Spectroscopic analyses of organic matter dissolved in soil pore water demonstrated preferential decomposition of labile classes of C molecules and constraints of SOM structure and enzyme-mineral sorption on decomposition. High-resolution mass spectrometry experiments performed in collaboration with colleagues at the Environmental Molecular Sciences Laboratory (EMSL) characterized temperature-driven decomposition of dissolved carbohydrates, peptides and amino sugars (Chen et al., 2018). Studies at the Teller Road field site demonstrated that soil microorganisms readily degraded and assimilated organic N, such as glutamate, which stimulated iron reduction and methanogenesis under anoxic conditions in the field and laboratory (see sidebar; Philben et al., 2018).

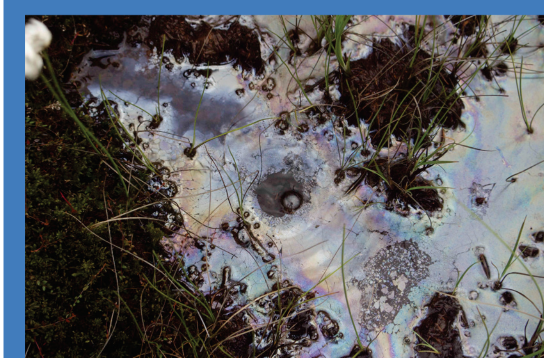
The radioisotopic composition of respired CO_2 also indicated that old, frozen SOM can be readily degraded after soil thaws in the Arctic (Vaughn and Torn, 2018). We measured flux rates and radiocarbon contents of ecosystem respiration, as well as radiocarbon in the soil profile CO_2 in Utqiaġvik during the summers of 2012–2014. The highly depleted $\Delta^{14}C$-CO_2 values in soil pore-space and in autumn ecosystem respiration indicate that unfrozen, very old soil C was being decomposed. Furthermore, a novel analytical approach using radiocarbon identified temperature-enhanced decomposition of C that cycles on millennial timescales (Vaughn and Torn, submitted). It was shown that decomposition of this slow-cycling C had the same temperature sensitivity as faster-cycling soil C.

Microbial activities respond differentially to their local environment

Microbial community and functional gene compositions differ across microtopographic features and soil depths, and they change during soil incubations to reflect key biochemical processes. The distribution of microbial taxa varied across different polygon types on the BEO (Taş et al., 2018), and microbial gene abundance was generally higher in organic than mineral soil horizons (Yang et al., 2017). Methanogen indicator genes were more abundant in saturated low-centered polygon soils than in drained high-centered polygon soils, consistent with observed CH_4 concentrations and fluxes.

IRON BIOGEOCHEMISTRY

In the iron-rich soils of the BEO, organic-mineral interactions modulate SOM decomposition. Iron may stabilize two-thirds of the organic C that is associated with high-density fractions in soil (Herndon et al., 2017). Additionally, measurements of β-glucosidase enzyme sorption to soil minerals quantified the temperature sensitivity of adsorbed enzyme activity under Arctic conditions (Yang et al., submitted). While iron reduction is key to anaerobic respiration in these systems, reduced iron is re-oxidized to form nanoparticle films at the air-water interface, which can sink into sediments and again accept electrons, driving anaerobic respiration (Jubb et al., 2018). These data will be useful to parameterize and validate a new model structure integrating microbial processes with organic-mineral interactions and plant litter inputs, which improve predictions of SOM stocks with depth (Dwivedi et al., 2017).



Iridescent films of iron oxide nanoparticles float on the surface of a thermokarst in Council, Alaska, interspersed with methane bubbles.

The low soil pH buffering capacity that we measured for organic-rich soil and permafrost explains substantial pH differences with depth in the soil profile and illustrates the soils' high sensitivity to pH changes caused by fermentation or anaerobic respiration. Soil pH manipulation experiments demonstrated distinct pH response functions for methanogenesis and anaerobic respiration coupled to iron reduction, which forecasts significant differences in GHG emissions among sites independent of soil water content. A new soil aqueous-phase model was developed to simulate pH buffering for dynamic predictions of pH in ecosystem models (Zheng et al., in press). These results show how soil microorganisms drive SOM decomposition in collaboration with respiratory organisms that use oxygen or Fe(III) to oxidize C to CO_2 and acetoclastic methanogens that release both CO_2 and CH_4.

Reaction rates usually accelerate at higher temperatures; however, our work identified significant differences in the temperature sensitivities among microbial processes under arctic conditions. A meta-analysis of incubation results determined that temperature response parameters depend critically on environmental conditions (such as hydrology) as well as the microbial process (Schädel et al., 2016). Methanogens and CH_4 oxidizers can co-occur in flat-centered polygon soil horizons but have markedly different temperature sensitivities (Zheng et al., 2018a). When soils from high-centered polygon troughs were warmed in microcosm incubations, functional gene composition changed substantially at 8 °C but generally remained constant at -2 °C (Yang et al., 2017). Therefore, gene expression changes were more sensitive to temperature change than the cells' metabolic processes (Yang et al., 2016). A theoretical evaluation showed greater temperature sensitivity of the Michaelis constant (related to equilibrium complexation) compared to turnover rates, providing a new thermodynamic perspective on temperature response functions (Maggi and Riley, 2017).

Field measurements of GHG fluxes combined with enhanced model structures improved estimates of annual GHG emissions

Fine-scale modeling accurately simulated GHG production and its temperature sensitivity from anoxic incubation experiments using data on labile C pools and fermentation rates to constrain a new model (Tang et al., 2016; Zheng et al., 2018b). This process-rich model introduced a unique anaerobic C decomposition framework coupled to a mechanistic description of aqueous-phase microbial redox processes. Another model structure simulated aerobic soil respiration rates well at low-to-moderate soil saturation, bridging microbial activities with soluble substrates and mineral surface associations (Tang and Riley, 2017).

Surface gas flux and eddy covariance measurements identified wide variation in GHG emissions across the microtopography of the BEO and throughout the thaw season. Degraded ice-wedge polygon tundra had lower CH_4 emissions and greater CH_4 oxidation than did intact low-centered polygons, attributable to differences in water chemistry and flow as well as soil moisture and temperature (Vaughn et al., 2016). Thaw depth and saturation were key predictors for CH_4 flux Soil temperature and vegetation changes were also predictors of multi-year variability in CO_2 flux, while seasonal thaw and vegetation explained early-season respiration (Arora et al., 2019). Continuous field measurements revealed substantial pulses of GHG emissions outside of the growing season. Cold season CO_2 and CH_4 emissions are a significant source of uncertainty due to limited field and remote sensing measurements (Parazoo et al., 2016; Xu et al., 2016a). A large pulse of CO_2 and CH_4 was emitted during a 2-week period in 2014 when surface ice thawed prior to snowmelt, representing a large portion of the annual GHG emissions (Raz-Yaseef et al., 2017). Winter freeze-up delayed the release of biogenic gas produced during the thaw season and zero-curtain window. Current models underestimate these cold season CH_4 emissions. To evaluate GHG fluxes in a region with later freeze-up than Utqiaġvik and to extend chamber-ecosystem scaling approaches, we set up a new AmeriFlux eddy covariance site (US-NGC) in the Council watershed in 2017; preliminary results suggest that growing season CO_2 uptake is higher and CH_4 emissions are lower relative to the northern AmeriFlux site set up and maintained by NGEE Arctic on the North Slope (US-NGB).

Increasing the complexity of processes simulated by terrestrial ecosystem models can significantly improve estimates of CH_4 production and emissions (Xu et al., 2016b). We improved the methane module in ELM, compared predictions with tower and aircraft observations and atmospheric inversions, and highlighted new observations and model requirements to improve Arctic and global CH_4 predictions (Xu et al., 2016a). A parameterized ecosystem scale model (*ecosys*) accurately simulated CO_2 and CH_4 emissions from polygonal tundra and reproduced diurnal CO_2 flux profiles (Grant et al., 2017a, b). We found excellent model-observation agreement using our spatial scaling approach from sub-meter to landscape scales, both for hydrology and energy and C exchanges with the atmosphere. When used to simulate future responses of polygonal tundra to 21st century warming, the model estimated that net CH_4 emissions are much more sensitive to changes in temperature than were CO_2 emissions, indicating potentially large feedbacks with climate warming.

QUESTION 3: HOW DO ABOVE- AND BELOWGROUND PLANT FUNCTIONAL TRAITS CHANGE ACROSS ENVIRONMENTAL GRADIENTS, AND WHAT ARE THE CONSEQUENCES FOR ARCTIC ECOSYSTEM C, WATER, AND NUTRIENT FLUXES?

Arctic plant traits, and their variation in response to changing environmental conditions, will play a key role in the response of tundra ecosystems to warming, permafrost thaw, and the wetter or drier conditions expected in the future. The appropriate representation of these functional traits in models is necessary to accurately represent ecosystem C, water, and nutrient cycling in tundra ecosystems, now and in the future. In Phase 2, we characterized the variation in above- and belowground plant traits in response to varying edaphic and environmental conditions in Utqiaġvik, and on the Seward Peninsula near Nome. These new data, combined with remote sensing and synthesis activities across the Arctic and the globe, have been used to inform model structure and parameterization of key processes such as photosynthesis, nutrient dynamics, and trait variation across the landscape.

New data improve representation of Arctic photosynthesis and inform model development

Model representation of photosynthesis, and particularly plant traits used to parameterize the Farquhar et al. (1980) model of photosynthesis, has repeatedly been demonstrated to drive a large fraction of model uncertainty (e.g., Ricciuto et al., 2018). Previously, model representation of Arctic photosynthesis relied on data and understanding from temperate ecosystems (Rogers, 2014). In Phase 2, we highlighted the steps necessary to improve model representation of tundra plant photosynthesis in Terrestrial Biosphere Models (TBM) (Figure 3a; Rogers et al., 2017a), deepened our understanding of Arctic photosynthetic physiology, and provided new characterization of tundra plant photosynthetic traits and their temperature response functions (Rogers et al., 2017b; Rogers et al., submitted; Lin et al., 2015). These data filled a critical knowledge gap (i.e., measurements from low-temperature ecosystems) and have enabled new evaluations of the representation of photosynthetic physiology in models, including enabling the development of trait-environment relationships and updated algorithms that can be used to account for thermal acclimation of photosynthetic traits (Ali et al., 2015, 2016; Lin et al., 2015; Rogers et al., 2017b; Ghimire et al., 2017; Smith et al., submitted; Kumarathunge et al., submitted). To better address acclimation of photosynthesis to rising temperature, we designed, and field-tested a zero-power warming (ZPW) chamber capable of elevating air temperature by ~4°C (Lewin et al., 2017). The successful field test of this approach led to the deployment of a warming experiment that will continue in Phase 3.

Remote sensing enables scaling of Arctic plant traits through space and time

Our understanding and modeling of the broad spatial and temporal patterns of leaf and plant functional traits across the Arctic has been limited due to the logistical challenges of direct field measurements. To address this issue, we focused in Phase 2 on linking measurements of leaf traits that describe Arctic plant physiological (e.g., foliar pigments, leaf mass per area, N, leaf photosynthetic traits (V_{cmax})) and structural (e.g., plant height) characteristics to optical and thermal remote sensing signatures to enable mapping traits across space and time. We developed novel "spectra-trait" algorithms to enable the connection between spectral signatures and Arctic leaf traits (Serbin et al., submitted). These new algorithms include the capacity to estimate V_{cmax} at the leaf and canopy scales using only spectral measurements, allowing for rapid characterization of this key trait across space and time. At the larger landscape scales, the automated NGEE Arctic tram (Utqiaġvik) captured important changes in Arctic plant optical and thermal properties during key phenological stages, including snowmelt, green up, and brown down, allowing us to resolve the temporal dynamics of plant functional traits. A series of UAS campaigns in the Seward Peninsula has begun to characterize species and drivers of functional trait variation across Arctic plant communities (Shiklomanov et al., 2019). We have also coordinated closely with the NASA ABoVE airborne campaign team to collect high-resolution spatial and spectral AVIRIS-NG imagery over the NGEE Arctic sites across the Seward Peninsula. We are using these airborne spectral observations to develop watershed-scale functional trait maps based on our new Arctic algorithms.

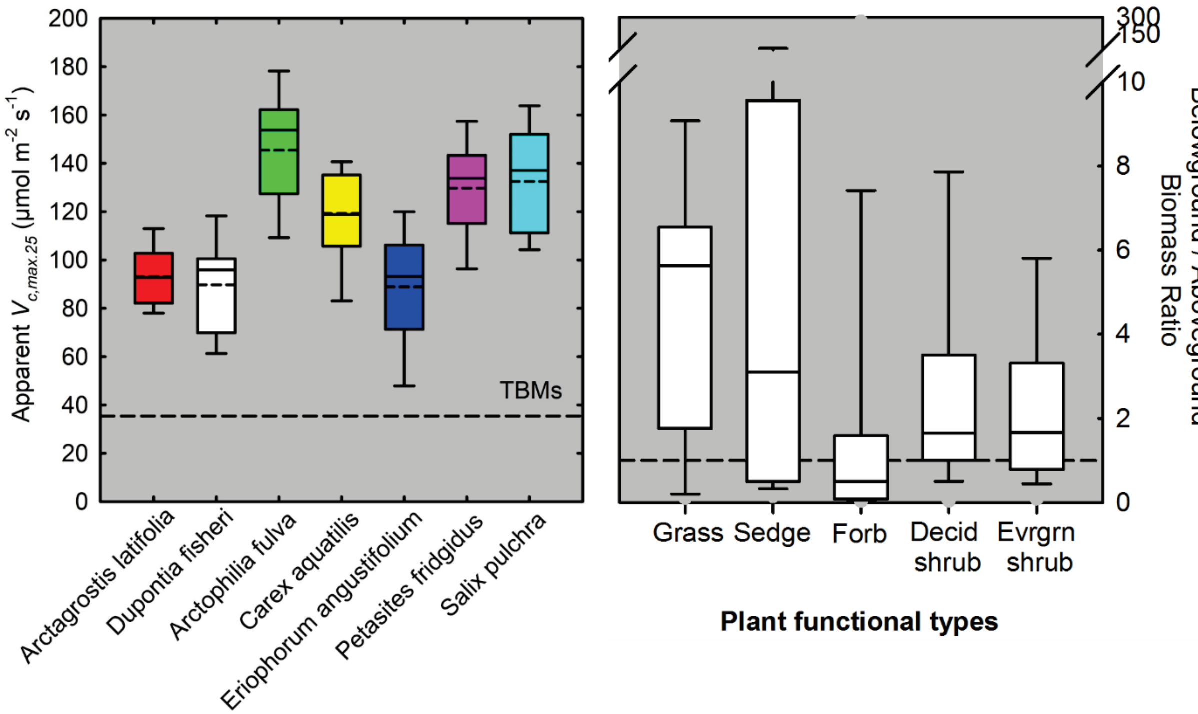


Figure 3. Observations and synthesis activities inform the improved representation of above- and belowground plant traits in terrestrial biosphere models. (a) Apparent maximum carboxylation rate normalized to 25°C (apparent $V_{c,max.25}$) measured in seven species located on the Barrow Environmental Observatory, Utqiaġvik, AK (Rogers et al., 2017b). (b) Below- to aboveground biomass ratio of plant functional types across tundra ecosystems (Iversen et al., 2015). Dashed lines in a, b represent current terrestrial biosphere model representation of these plant traits.

Belowground tundra plant traits influence ecosystem processes

We synthesized the available literature on tundra plant roots across the Arctic and found that there can be up to five times as much plant biomass belowground compared to aboveground, with clear implications for ecosystem C storage and nutrient cycling (Figure 3b; Iversen et al., 2015). However, there are limited data on belowground plant structure and function across the vast array of tundra ecosystems. In Phase 2, we improved our understanding of belowground processes in Arctic tundra in Utqiaġvik, as well as across a range of more southerly sites near Nome. In Utqiaġvik, we found that tundra plant fine roots were relatively shallowly distributed in the soil profile, while N available in deeper soil increased throughout the growing season as the active layer thickened. This potentially results in a mismatch between vertical distribution of plant roots and available soil N (Norby et al., 2018). We followed up on this work by using an ^{15}N tracer to determine where in the soil profile tundra plants obtain the most N—shallow organic soil, deeper mineral soil, or at the cold permafrost boundary. We found that the vertical distribution of root biomass did not necessarily predict the depth at which tundra plants acquired N. Instead, a modeling analysis indicated that plant nutrient acquisition was better predicted by a model that included rooting depth distribution, microbial competition, and root uptake kinetics (Zhu et al., 2016). On the Seward Peninsula we found that the N-fixing shrub *Alnus viridis* subspp. *fruticosa* (alder) was a keystone species that increased the availability of N in the soil beyond the footprint of an individual stand and elevated the foliar N content of adjacent plant communities. The effects of alder on surrounding communities was directly linked to the amount of nodulation of its rooting system. This new understanding strongly supports our effort in Phase 3 to include a PFT that has an N-fixing capacity in ELM.

Tundra plant traits vary across changing environmental conditions

An improved understanding of the variation of tundra plant traits across changing environmental conditions is needed to inform our understanding and modeling of tundra plant communities now and in the future (Bjorkman et al., 2018). In Phase 2, we improved our understanding of plant trait variation across polygonal tundra in Utqiaġvik. We observed that plant N pools were primarily impacted by interactions between temperature and moisture across polygonal gradients in microtopography (Norby et al., 2018). Furthermore, the *ecosys* model, informed by NGEE Arctic observations, showed that elevation across polygons was a primary driver of variation in ecosystem C fluxes and that increased productivity in high polygonal features was associated with warmer temperatures and increased precipitation (Grant et al., 2017a, b). In Phase 2, we established new research sites along hillslope gradients in watersheds at Kougarok, Teller, and Council near Nome. At Kougarok, we quantified the variation in plant community composition as well as leaf, wood, and fine-root traits across gradients of soil moisture, temperature, and nutrient availability. At all sites, plant community composition was surveyed according to the Alaska Vegetation Archive standardized protocols and contributed to a broader understanding of pan-Arctic plant community composition across different environments (Walker et al., 2016). These datasets also provide important ground-truth datasets for UAS campaigns and broader remote sensing applications across the project, including our efforts to build new detailed maps of the distribution of tundra plant species and plant functional types to inform pan-Arctic models (Langford et al., 2019). Furthermore, these data have also contributed to a pan-Arctic plant trait database (Bjorkman et al., 2018a) and syntheses of changes in tundra plant traits along environmental gradients (Bjorkman et al., 2018b; Thomas et al., 2018).

QUESTION 4: WHAT CONTROLS THE CURRENT DISTRIBUTION OF ARCTIC SHRUBS, AND HOW WILL SHRUB DISTRIBUTIONS AND ASSOCIATED CLIMATE FEEDBACKS SHIFT WITH EXPECTED WARMING IN THE 21ST CENTURY?

In Phase 2, NGEE Arctic researchers advanced our capability to quantify existing and predict future shrub distributions and their impacts on climate through an integrated program of multiscale observations, experiments, modeling, and model benchmarking. Scientists made good progress in developing dynamic vegetation models for the Arctic as well as establishing observational benchmarks and manipulative experiments to inform and evaluate those models. We explored controls on Arctic vegetation distributions at site and regional scales. We also developed and applied novel approaches to integrating and scaling remote sensing and field observations. This link to airborne and satellite imagery builds off a close collaboration with the NASA ABoVE project that will be expanded in Phase 3.

Fine-resolution, scalable maps of vegetation distribution for benchmarking land models

Accurate and high-resolution vegetation maps are important to inform, parameterize, and evaluate vegetation models that contain dynamic vegetation representations. We developed a remote sensing-based approach, using multiple orbital remote sensing platforms, to generate high-resolution maps of vegetation communities at NGEE Arctic sites on the Seward Peninsula. We faced challenges because cloud cover and polar darkness limit the quality of Arctic images, and cross-platform variation in sensor characteristics, spatial resolution, and temporal frequency make data fusion challenging. To overcome this, we developed a deep learning–based approach to exploit the information in all available imagery (see sidebar pg. 20).

Landscape disturbance promotes shrub establishment

To determine the processes controlling shrub recruitment and generate demographic trait data for predicting future distributions of shrub tundra, we initiated a novel study on the effects of wildfire and landscape disturbance on shrub-seedling germination and survival. We surveyed seedling presence and microclimate in sites of four tundra-burn histories near Quartz Creek (along the Kougarok road). We found a large impact of wildfire on seedling success; only the recent, severe burn (2015 Mingvk Lake fire) had a cohort of shrub germinants (Figure 4). In addition to directly showing the importance of wildfire, these results helped prompt the addition of a new integrated research area for NGEE Arctic in Phase 3 on wildfire and thermokarst (Q6). To experimentally test the mechanisms by which disturbance affects germination and establishment, we set up controlled experiments within shrub zones and north of shrubline. On the Seward Peninsula, we sowed seeds of five species of tall shrubs into sites of different burn and thermokarst histories, with and without manipulation of the seedbed (moss or litter layer). To examine the potential for warming to promote shrub establishment, we sowed seeds in Utqiaġvik with and without passive warming. This experiment took advantage of the ZPW and ITEX chambers. We will continue measuring the effect of these treatments on seed success in Phase 3.

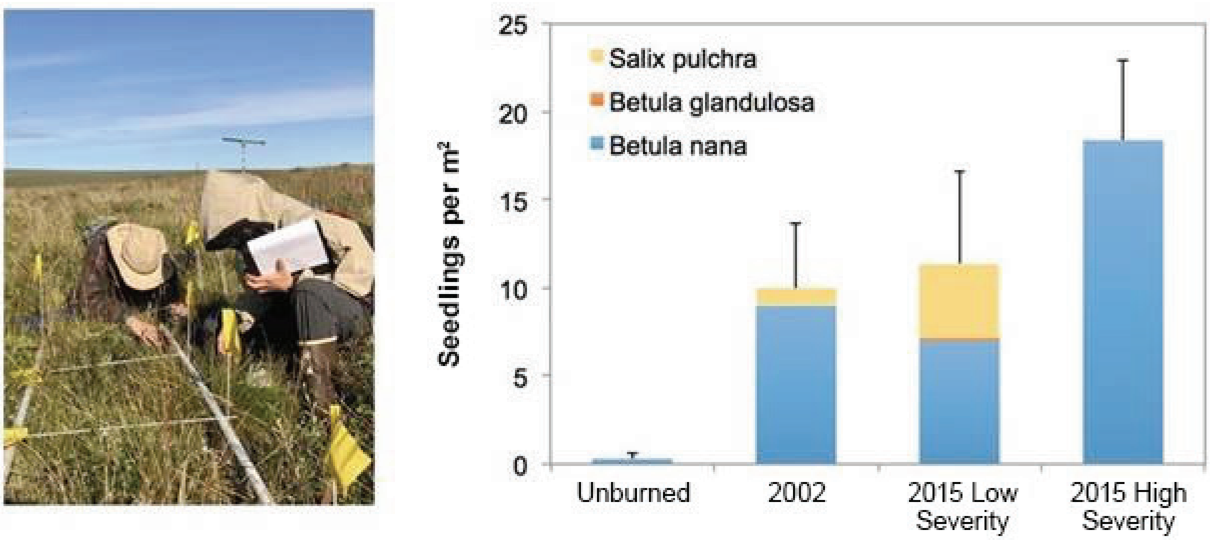


Figure 4. NGEE Arctic researchers survey a low-severity burn site on the Seward Peninsula. Seedling success depends on burn history, shown here for seedlings surveyed in 2017 at a fire chronosequence along the Kougarok Road.

A multiscale remote sensing system for studying vegetation, landform, disturbance, and the surface energy budget

In Phase 2, NGEE Arctic developed a multi-platform, multi-sensor UAS system and carried out campaigns on the Seward Peninsula. Passive optical, thermal, and LiDAR produced fine-scale spatial datasets for vegetation structure and surface temperature, reflectance, and albedo across a mix of vegetation and landscape features. We found that nonvascular vegetation like moss tend to be warmer and uncoupled from air temperature, with low visible albedo, while sedges and shrubs tend to be cooler with higher near-infrared albedo, and tussock tundra is generally coupled with air temperature. Working closely with NASA ABoVE we were able to acquire AVIRIS-NG images for Teller, Kougarok, and Council in 2017 and 2018. Analysis showed that that optical properties change from UAS to AVIRIS-NG to Landsat scales, resulting in apparent shifts in vegetation reflectance with pixel size. This will be explored in Phase 3. Leveraging the DOE AmeriFlux Management Project, NGEE Arctic developed UAS capabilities to study the links between subsurface and surface properties at the watershed scale. These systems will be used in Phase 3 to study snow-vegetation interactions, scale plant types and traits, and to collaborate with NASA ABoVE.

Changes in geomorphology and vegetation-soil interactions mediate the effect of climate change on Arctic greenhouse balance.

A high-resolution 3D model with dynamic landscape and vegetation evolution (*ecosys*) was parameterized and tested against NGEE Arctic observations (e.g., Raz Yaseef et al., 2017 for ET and Raz Yaseef et al. 2016 and Vaughn et al. 2016 for CO_2 and CH_4 fluxes) for Utqiaġvik. In simulations over the 21st century, the topographic response to warming had effects on vegetation type, surface water, and snow movement that drove significant changes in active layer depths, soil moisture, and soil temperature (Grant et al., 2017b). These interactions altered CO_2 and CH_4 fluxes to the atmosphere (Grant et al., 2017a). A key result was the important role of hydrological energy transport (energy in water moving into and through the subsurface), which had a stronger influence on inter-annual variability of active layer depth than did air temperature. By 2100, climate-driven changes to vegetation structure and composition led to less warming of the soil than predicted by air temperature alone (Grant et al., 2018a), and thus less decomposition than would otherwise be predicted, and resulted in polygonal tundra in the Utqiaġvik region remaining a net CO_2 sink through the century (Grant et al., 2018b). Expanding our analysis to the whole North American Arctic, we found that accelerated nutrient cycling and increased plant competition will lead to 21st century expansion of shrub distributions and the C sink in North American tundra. We projected the impact of climate change on vegetation shifts in the Arctic using *ecosys*. The RCP8.5 climate scenario substantially increased shrub expansion (Mekonnen et al., 2018a), leading to widespread shrubification and net tundra C uptake through the 21st century (Mekonnen et al., 2018b). The system responses were explained by competition between deciduous and evergreen plants for nutrients and light.

Snow cover duration may be more important than shrub albedo in positive feedback to warming

Using the Terrestrial Ecosystem Model (TEM) coupled to a transient biogeographic model (ALFRESCO), we quantified the biogeophysical feedbacks due to changes in vegetation and snow cover between 2010–2099 in Alaska and northwest Canada (Euskirchen et al., 2016). Changes in snow cover duration, both snowmelt and snow return, generated the largest positive feedback to climate. Increased fire frequency due to shrub expansion in western Alaska resulted in higher albedo and generated the largest negative feedback to climate from changes in vegetation. The positive feedbacks from snow cover duration, which was up to 66 days shorter by 2099, were three to six times larger than negative feedbacks from changes in vegetation. Nevertheless, in uncertainty analysis with TEM, we found that

MACHINE LEARNING (AI) USED TO MAP ARCTIC VEGETATION

Land cover datasets are essential for modeling and analysis of Arctic ecosystem structure and function and for understanding land–atmosphere interactions at high spatial resolutions. Hyperspectral, multispectral, L-band synthetic aperture radar remote sensing and topography data were used to develop a multi-sensor data fusion scheme for spatial mapping of Arctic vegetation at 5-m resolution (Langford et al., 2017). Maps were used in support of our fine-scale modeling activities. Furthermore, we developed and applied deep neural network models using field observations at Kougarok; field-based vegetation surveys demonstrate the accuracy of these new vegetation maps (Langford et al., 2018b). Developed maps provide high-resolution vegetation distribution commensurate with field studies, essential to adequately resolve the heterogeneity with high accuracy. These machine learning techniques will enable vegetation mapping in Phase 3 at all field sites by incorporating field surveys, satellite remote sensing, and airborne remote sensing data from NASA ABOVE and will provide a benchmark for NGEE Arctic fine-scale and global models.

improving aboveground plant parameters related to photosynthesis and growth will be key to reducing model uncertainty in shrub feedbacks to climate change. We integrated TEM into the Predictive Ecosystem Analyzer (PEcAn) to conduct uncertainty quantification and variance decomposition (UQ/VD). We performed TEM-PEcAn simulations in three locations, including wet sedge near Utqiaġvik, tussock tundra near Toolik Field Station, and shrub tundra at Kougarok. These simulations indicate that aboveground plant parameters, such as those that influence photosynthesis and light competition, are key to understanding model uncertainty in plant productivity. These parameters include specific leaf area, extinction coefficient, and parameters related to optimal photosynthesis temperatures. We are currently developing model drivers and initialization to run simulations for Council and Teller locations under historic and future conditions and are incorporating NGEE Arctic plant trait observations (from Q3) in the PEcAn database and using them to parameterize alder in TEM.

QUESTION 5: WHERE, WHEN, AND WHY WILL THE ARCTIC GET WETTER OR DRIER?

The spatial distribution and temporal dynamics of soil saturation, inundation and snow in Arctic landscapes impact permafrost stability and drive subsurface and surface ecosystem responses and their feedback to the climate system. Observational and modeling research activities undertaken in Q5 aimed to identify and develop critical missing data and process parameterizations required to improve representation of permafrost hydrology in ELM. In Phase 2 we assessed gaps in global land models, added new process representations to our fine- and intermediate-scale permafrost hydrology models, and explored our understanding of the controls on, and evolution of, permafrost hydrology by applying our models in the context of new in situ, UAS, airborne, and satellite data.

NGEE models and data help explain high uncertainty of hydrologic response in permafrost-enabled global land models

NGEE Arctic scientists investigated the performance of the CMIP5 generation of permafrost-enabled land models. Large divergence in spatial and temporal wetting and drying trends between the models was due to differences in the representations of surface and subsurface thermal and hydrologic properties and processes. Despite projected increases in precipitation over the high Arctic in the coming century, many of the models suggest drying of the near-surface soil layers. The projected decrease in near-surface soil moisture could enhance CO_2 emissions and suppress CH_4 flux from soils. However, none of the models include representation of key landscape processes known to control soil moisture (e.g., subsidence, inundation, and lateral flow); thus, these results suggest significant uncertainty on the future hydrological state of Arctic tundra and the associated permafrost C-climate feedback (Andresen et al., submitted).

We explored the role of missing and divergent process representations in the land models by applying enhanced permafrost hydrology models with data collected at NGEE Arctic field sites on the North Slope and Seward Peninsula. Applications of the ATS, ELMv1-3D, *ecosys*, and GIPL models showed that micro-topography, soil properties, surface inundation dynamics, snow depth variation, lateral flux of heat and water, and physically realistic representation of the saturation of unfrozen and frozen soil water all have significant impacts on predicted active layer depth, seasonal soil moisture and long-term permafrost stability (Jafarov et al., 2018; Nicolsky and Romanovsky, 2018; Bisht et al., 2018; Abolt et al., 2018; Atchley et al., 2016; Harp et al., 2016). A new version of ATS (Painter et al., 2016; Jan et al., 2018) now enables simulations of dynamic inundation and ground subsidence, and their coupled impact on landscape-scale Arctic wetting and drying through topographic reorganization (Rowland and Coon, 2017). Our modeling demonstrated best-in-class process representations, data requirements, and new scaling approaches (Grant et al., 2017a, b) for ELM and other permafrost-enabled land models.

Our models depend on scarce, yet critical, thermal and hydrologic data products. Scientists developed forcing, initialization and evaluation data to inform our modeling exercises. Forcing data include multiple continuously recording meteorology stations at each of the Utqiaġvik and Seward Peninsula field sites. Initialization data include airborne and UAS LiDAR high-resolution Digital Elevation Models (DEMs) and subsurface stratigraphy and soil properties from cores, pits and geophysical surveys. Model evaluation datasets include continuous subsurface and surface soil temperature, heat flux and soil moisture across the dominant ecosystem types found at the NGEE Arctic field sites, as well as soil water table levels, end of winter snow depth, snow ablation and stream flow data. We are supporting NASA ABoVE airborne campaigns with in situ ground measurements during overflights and are in the early stages of developing high-resolution regional to pan-Arctic soil moisture, ground deformation, inundation and other products from our ABoVE and other collaborations (Muster et al., 2017, 2019) to inform ELM and other land models.

Subsurface lateral water fluxes drive hydrologic responses and states across diverse topographic settings

Low-gradient, cold/continuous, wet tundra landscapes: In Phase 2, we continued to build better conceptual and quantitative models of the linkage between micro-topography, hydrology and geochemical conditions in polygonal ground and drained thaw lake landscapes. The tight linkages between polygon types and features with hydrological and biogeochemical conditions in the Arctic coastal plain are well established (Heikoop et al., 2015; Newman et al., 2015; Throckmorton et al., 2015, 2016; Raz-Yaseef et al., 2017; Wainwright et al., 2015; Wu et al., 2018; Young-Robertson et al., 2018), and our field studies are providing important data for model testing. This new understanding of the drivers of thermal-hydrologic conditions and the spatial correlations between hydrology and ecosystem function is enabling meaningful categorization of the landscape for sub-grid representations in ESM scale models (Lara et al., 2015).

We also learned that the lateral redistribution of surface and subsurface heat and water plays a critical role in active layer thickness and hydrologic conditions. Data from our multi-year conservative tracer experiment in Utqiaġvik showed that preferential flow paths were important for tracer transport from polygon centers to rims and troughs (Wales et al., submitted). Tracer applied in a low-centered polygon had more frequent and more rapid transport into rims and troughs compared to the high-centered polygon. This is likely related to the unsaturated conditions that occur in the near surface of the high-centered polygon. Significant changes in tracer concentrations were observed between freeze up and thaw, indicating continued flow and transport during the winter months. Key aspects of our field results were also observed in tracer-enabled simulations with ATS model. Tracer transport in our modeled polygons showed faster lateral redistribution of tracer in the low center polygon model than in the high center model, confirming the importance of microtopography on saturation and its enabling effect on lateral transport. We also found that active layer freeze-thaw dynamics drive significantly faster subsurface lateral transport of water and tracer compared to simulations with no soil freeze-thaw cycle. This analysis demonstrated that it is inappropriate to apply isothermal approximations to evaluate contaminant or water transport processes in permafrost environments by assuming transport only takes place through thawed layers or zones (Svyatsky et al., submitted).

Hilly, warm/discontinuous permafrost, shrub tundra landscapes: Based on integration of ground temperature and moisture measurement sites with a larger Seward Peninsula dataset, we learned that there is considerable variation in the distribution of permafrost among our field sites. It is sporadic at Teller, discontinuous at Council, and continuous at Kougarok. We also established that near-surface permafrost at the Teller and Council sites was absent within clusters of dense tall shrubs. Permafrost conditions in the Seward Peninsula is also characterized by rapid temporal changes. At many locations, complete freeze-up of the active layer never occurred in the winter of 2017–2018, which was characterized by mild temperatures and an exceptionally thick snow layer. The formation of widespread talik indicates an important threshold in permafrost degradation, which impacts subsurface hydrology and the biogeochemical processes in the permafrost region (Parazoo et al., 2018). Electrical Resistivity Tomography (ERT) has been acquired continuously along transects at the NGEE Arctic Teller site that traverse regions having both near-surface and deep or no permafrost. Initial results show that near-surface permafrost locations are surrounded by locations showing the presence of talik, which implies hydrological connectivity between shallow and deep groundwater flow within the watershed (Figure 5). Both in situ and ERT data show perennially unfrozen ground under tall shrub patches. Soil, springs and stream water geochemistry at Teller also indicate patterns of shallow and deep groundwater sources at the watershed scale. These data are being combined to inform 2- and 3-D watershed hydrology models (Jafarov et al., 2018).

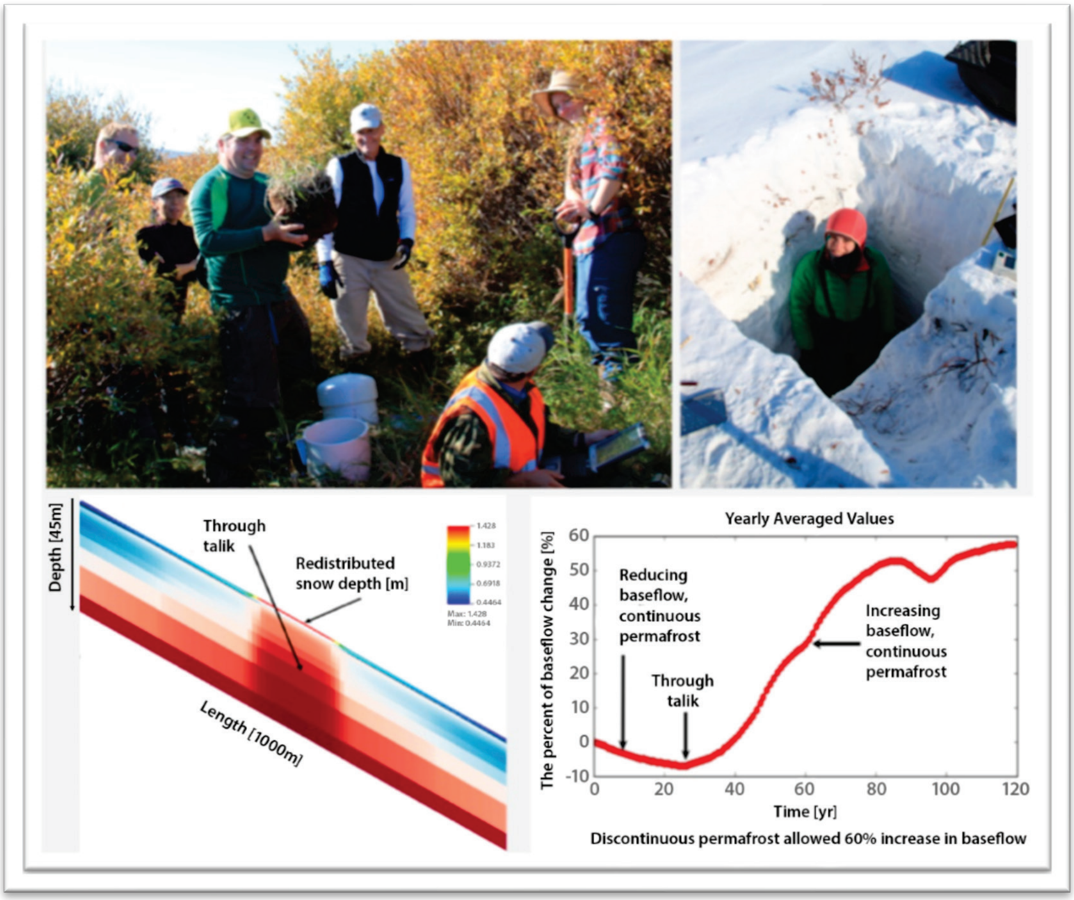


Figure 5. Tall shrub patches (top left) preferentially trap deep snow (top right), which our models show can drive through talik formation (bottom left) and changes in deep groundwater flow (bottom right). Jafarov et al. (2018).

Strong interactions between topography, snow, and vegetation control thermal-hydrologic states and processes

The spatial distribution of snow thickness strongly influences ground temperatures and is poorly represented in global land models. We developed a relationship between snow depth and topography across the low-gradient, wet tundra landscape of the BEO using a combination of ground-penetrating radar (GPR) and UAS-based PhoDAR measurements and LiDAR data (Wainwright et al., 2017). UAS and intensive ground-based snow thickness measurements have also been carried out at the NGEE Arctic Teller and Kougarok watersheds and are being integrated with UAS-LiDAR DEMs and ground temperature data to develop a snow redistribution parameterization for hilly shrub-tundra landscapes. At the Teller watershed, we learned that snow depth is strongly positively correlated with snow pack density and snow water equivalent (SWE), and the spatial distribution of SWE was consistent across 3 years of end-of-winter surveys (2016–2018). As expected, ground surface and subsurface temperatures were warmer under deeper snow. Snow depth and SWE are significantly controlled by the distribution of tall shrubs (deepest snow), elevation, macro-topography and micro-topography.

We further explored the role of shrub-snow-permafrost interactions using the ATS model to ask whether tall shrub patches can drive permafrost thaw and through-talik formation and whether through-talik will drive changes in hydrologic flow pathways? Our simulations showed that even under detrended climate conditions (historic regional warming trend was removed from the forcing data), deeper snow caused through-talik, which allowed water from the seasonally thawed layer into sub-permafrost waters, increasing sub-permafrost groundwater flow (Figure 4). These numerical experiments suggest that Arctic shrub abundance may intensify the transition from continuous to discontinuous permafrost and may drive significant changes in permafrost hydrology (Jafarov et al., 2018).

DATA MANAGEMENT AND OUTREACH

The NGEE Arctic Data Management Team (DMT) is charged with compiling, curating, documenting, archiving, and sharing data with project members, the larger scientific community, and the public to meet NGEE Arctic's mission and DOE Data Policy. The identification of Data Representatives in Phase 2 greatly improved the coordination of data submission across the project by giving a "face" to NGEE Arctic data management at each institution. The DMT holds regular monthly meetings and are involved in monthly calls with each Science Question Team. We found that this consistent level of engagement with the science team has benefited the data management effort across the entire project. The DMT recently updated the policies and guidelines on sharing and citing data to align with the DOE Data Policy and the expectations of the ESS-DIVE data center. Lessons learned from interactions with other data centers include creating project guidelines for spatial reference systems and ideas on how best to manage data from UAS platforms.

Data publication and impact: As of January 2019, 131 metadata records in the NGEE Arctic Data Catalog (Figure 6). In Phase 2, we added over 100 records to the portal. The NGEE Arctic public data have been downloaded over 1600 times by over 380 unique users.

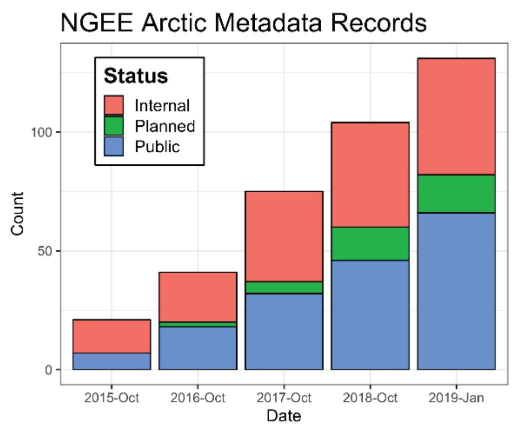


Figure 6. NGEE Arctic metadata records available each year from 2015–2019.

In Phase 2, we encouraged project scientists to "share data early and often" with project team members. Through conversations with the team, we learned that "planned" datasets would help the team to communicate about future data to be collected at specific locations. We also solidified the concept of "internal" datasets, which are shared with the project team members only. These options provide team members with more visibility into data collection efforts and availability across the project. To encourage data submission and highlight researchers that exhibit the spirit of the NGEE Arctic data-sharing goals, data awards were presented in 2017 and 2018 based on portal use metrics.

Website and data access: The DMT has primary responsibility to maintain the NGEE Arctic public (https://ngee-arctic.ornl.gov/) and internal websites. This is the main entry point to the NGEE Arctic Data Portal (https://ngee-arctic.ornl.gov/data/) and summarizes scientific accomplishments of the program. We have updated the website to a new version of Drupal and made numerous improvements to the content. We also implemented Google Analytics to capture usage metrics. In Phase 2, new filters or facets were added to the data search tool to facilitate better search results and data discovery. Both the online metadata editor (OME) and data portal were updated in Phase 2 to display the dataset citation. To facilitate search and discovery, the Keywords field was also reviewed and edited for consistency.

Data management system: Efforts in Phase 2 enhanced the tools used to capture metadata and publish data produced by NGEE Arctic science. In 2017, the OME received a user interface upgrade with new features to create templates, view submitted records, and admin dashboard. We now assign each record a unique ID, which facilitates tracking. Standard data and metadata archive formats are supported to ensure interoperability with other data sources and repositories. In May 2017, the NGEE Arctic project purchased two new Intel Xeon E5-2620v4, 2.1GHz systems to address growing data needs of the project. One system is used to host the data, website and tools and the other primarily for data backup. NGEE Arctic data are currently being archived on the esddrupal-prod.ornl.gov server and are being backed up constantly using the enterprise version of Bacula.org software. The old servers were out of warranty and have been decommissioned.

Community outreach: We hosted a Town Hall at the 2015 American Geophysical Union (AGU) Fall meeting to update the research community with a brief overview of the project covering both Phase 1 and Phase 2 work including data management tools and services. Presentations and posters about NGEE Arctic data and tools were presented at AGU, IEEE International Conference, and the TES PI Meeting. We actively participate in annual DOE BER Cyberinfrastructure Working Group meetings. We continue to interact and share lessons learned with OSTI, ESS-DIVE, ORNL's NASA DAAC, and other groups.

5. RESEARCH PLAN

INTEGRATED MODELING

Our modeling objective for the end of Phase 3 is to have a multiscale and high-resolution representation of Arctic tundra structure and function operating within E3SM and to have demonstrated the fidelity of that representation against a full suite of observational and experimental benchmarks, as established by the Q1-Q6 activities and as synthesized from broader community efforts. Our progress in earlier phases of the project has produced the fine-scale, intermediate-scale, and climate-scale modeling capabilities necessary to reach this Phase 3 objective (Figure 7). By developing process-rich models at multiple scales and using those models and multi-faceted observations to challenge our understanding of the connections among Arctic tundra geophysics, hydrology, geomorphology, vegetation communities, and biogeochemistry, we have identified several aspects of these complex ecosystems where advanced modeling capabilities would likely lead to improved prediction of current and future ecosystem-climate system interactions.

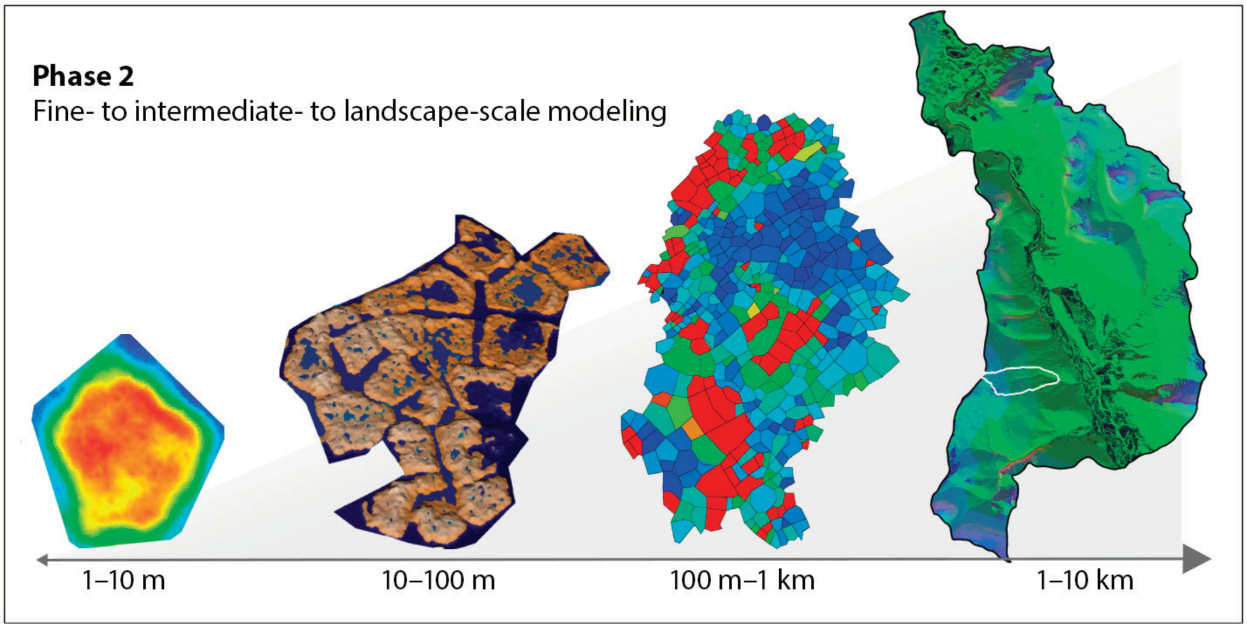


Figure 7. The NGEE Arctic Phase 2 multiscale modeling strategy produced fine-scale models representing microtopographic variations and their impacts on water and energy fluxes and produced intermediate-scale models, which use knowledge derived from fine-scale simulations to parameterize sub-grid process variation. These multiscale models span the full range of spatial detail as measured at the NGEE Arctic field sites up to the scale of a very high-resolution climate modeling grid cell (10 km). The figure shows representative fine-scale modeling domains (left) and intermediate-scale modeling domains (right). The annotation indicates the typical domain size for our model implementations at each scale. Two-way arrows indicate that knowledge from finer scales is being used to parameterize sub-grid processes at larger scales, while larger-scale results are used to define boundary conditions for fine-scale domains. Starting from the left, the first three figures show a single ice-wedge polygon, a group of polygons simulated at high resolution, and a larger group of polygons based on sub-grid parameterizations. The white outline within the far-right domain shows the Teller watershed, an intensive study site on the Seward Peninsula, in the context of its local larger watershed, which itself is an area characteristic of a single land/atmosphere grid cell in a high-resolution Earth system model.

Recognizing that the land system component of E3SM (the E3SM Land Model, or ELM) must operate seamlessly across the global span of biomes and ecosystems, we are not proposing to replace ELM with a new model specific for operation in Arctic tundra. Instead we have identified six aspects of the integrated model for targeted improvement and propose to deliver **six modules of improved Arctic tundra predictive modeling capability**, each of which will demonstrate improved performance as evaluated against previous and new NGEE Arctic measurements and other synthesis-based metrics. These six modules of improved model capability are (1) improved simulation of inundation dynamics; (2) improved representation of hillslope hydrologic processes; (3) improved interaction of snow dynamics with vegetation and terrain; (4) unique contributions of the nitrogen-fixing shrub alder to Arctic tundra ecosystems; (5) improved simulation of pan-Arctic vegetation dynamics; and (6) improved representation of chemical, mineral, and microbial interactions in tundra soils.

The focus for these six modules of improved capability has emerged through multiple iterations of synthesis, modeling, measurement, evaluation, and hypothesis development. They represent integrative predictive capabilities that tie together research carried out by the question-based NGEE Arctic teams. The following sections describe the rationale, development, and research plans for each module of Arctic tundra modeling capability. Additional details relating these new capabilities to ongoing measurements and experimentation in the field and laboratory are given in the Q1–Q6 research plans.

Improved simulation of inundation dynamics

Microtopography, surface-subsurface coupling of heat and water transport, snowpack accumulation, and large-scale drainage patterns determine the fraction of inundated land surface in polygonal and low-relief tundra landscapes (Grosse et al., 2007). Timing, duration, and depth of inundation control surface water and energy fluxes (Cohen et al., 2015), vegetation activity (Walther et al., 2018), and soil biogeochemical states and fluxes (Kittler et al., 2017; Kim, 2015). Thaw-induced changes in surface elevation and sub-surface properties drive predictable variation in inundation dynamics over time (Liljedahl et al., 2016). During Phase 2 we developed new fine-scale and intermediate-scale models and demonstrated their ability to represent realistic surface and subsurface thermal and hydrologic behavior of variably inundated low-relief Arctic tundra landscapes (Painter et al., 2016; Jan et al., 2018a, b). NGEE Arctic targets new climate-scale capability development within ELM. Our starting point for Phase 3 climate-scale development is ELM v1 (Ricciuto et al., 2018), an independent development branch of the Community Land Model (CLM 4.5, Oleson et al., 2013). ELM inherits from CLM a detailed representation of soil thermal and hydrologic processes, including developments specifically targeting permafrost soils (Swenson et al., 2012; Koven et al., 2013).

Although ELM includes a dynamic estimate of sub-grid fraction of inundated area, it does not include influence of local topographic or microtopographic variance in this calculation. Observations and process-resolving models have shown that microtopography in low-relief Arctic tundra landscapes and changes in microtopography resulting from progressive thaw and loss of ground ice are important determinants of fractional inundated area. We will use our fine- and intermediate-scale modeling results, high-resolution digital elevation data, and high-resolution remote sensing products to define regionally varying relationships between water table depth and fractional inundated area for the climate-scale regions that include NGEE Arctic study sites. We will explore the use of soil properties, ecosystem types, and improved understanding of through-talik formation as developed in Q1 to inform these regional relationships. We will extend these regional analyses to the scale of pan-Arctic low-relief tundra based on high-resolution Arctic-wide digital elevation data, pan-Arctic simulation, and parameter optimization based on observationally derived large-scale patterns in spatial and temporal dynamics of water bodies developed in Phase 2 (Muster et al., 2017).

Improved representation of hillslope hydrologic processes

Central to the modeling strategy of ELM and other global models is the “sub-grid paradigm,” which replaces explicit representations of 3D fine-scale processes with one-dimensional phenomenological parameterizations. In the Arctic, runoff generation and other fine-scale hillslope-driven processes can change dramatically as soils freeze and thaw. Because of that sensitivity to thermal conditions, there are large uncertainties in the subgrid parametrizations of Arctic hillslope processes in a changing climate. We will test and refine new parameterizations of hillslope-driven lateral flow and runoff generation in permafrost-affected regions and implement those new parameterizations in ELM. Specifically, we will use ATS (Painter, 2018; Painter et al., 2016) to simulate hillslopes with representative morphologies in a range of current and future climates and then use the results of those simulations to test and refine parameterizations. Present-day results from ATS will be evaluated against soil temperature observations and compared with additional modeling results from Q1. Based on our initial hillslope simulations (Jafarov et al., 2018), we hypothesize that existing runoff generation parameterizations related to topographic-soil index (Beven and Freer, 2001) can be extended to include permafrost state. Operationally, we envision using the existing column-based thermal model in ELM, including recently improved ELM hydrology capability (VSFM, Bisht et al., 2018a), to dynamically update parameters in the runoff model as active layer thickness increases in warming climates. We will use the ATS hillslope simulations to test that hypothesis, refine the approach as needed, and develop functional relationships between the model parameters and active layer thickness. These hillslope hydrology parameter relationships will be implemented and evaluated within ELM with both prescribed vegetation distributions, and with dynamic biogeography of vegetation as predicted by ELM-FATES using new knowledge gained under Q4. Field studies of hillslope hydrology under changing conditions of permafrost thaw from Q5 will be used to evaluate new model performance.

Improved interaction of snow dynamics with vegetation and terrain

Snowfall amounts, and snowpack redistribution are driven by interactions of mean topography, mesoscale terrain-influenced winds, vegetation structure, hillslope position, and microtopography (Dvornikov et al., 2015; Ménard et al., 2014). Snowpack also drives variation in soil temperature (Ge and Gong, 2010), and the timing and amount of soil water availability in macro- and micro-topographic settings, and these variations in soil temperature and moisture in turn control the distribution, structure, and function of vegetation and microbial communities (Ackerman, 2018). In Phase 2, we developed fine-scale modeling approaches to represent snow distribution and its influence on ground heat flux and groundwater flow in low-relief (Bisht et al., 2018b) and hilly tundra landscapes (Jafarov et al., 2018). The current treatment of snowpack accumulation and snow melt in ELM is relatively sophisticated in its representation of vertical layering, variation in snow layer properties, and the insulating influence of snowpack on soil temperature. ELM does not, however, include wind-driven snow redistribution or the influence of vegetation height, terrain, or microtopography on snow accumulation.

We will improve the treatment of co-variation in terrain, vegetation, and snow in ELM by including sub-grid topographic variation in elevation, slope, and aspect (currently in development for ELM v2), indices of microtopography based on sub-grid elevation variance, and improved prediction of vegetation height in tundra shrublands. Shrub height improvements will be developed in conjunction with the Q3 team. Improvements in modeled distribution and duration of snowpack will be evaluated through high-resolution remote-sensing estimates of observed regional snowpack and intensive field collection of ground-based observed snowpack. For fully coupled E3SM simulations, surface wind speed and direction from the atmospheric model component will be used to drive snow redistribution among sub-grid topographic units within grid cells. We will evaluate the influence of modeled snow distribution on talik formation against observations from Q1. We will evaluate the influence of dynamic shrub distributions with improved snow dynamics using observations and remote-sensing based mapping developed under Q4. Field-based studies of snow-vegetation interactions and measurements of snow depth from Q5 will be used to parameterize and evaluate new model formulations.

Unique contributions of alder to Arctic shrub tundra ecosystems

Siberian alder (*Alnus viridis* subsp. *fruticosa*) is an important species in tundra shrub communities in Alaska's Seward Peninsula and across the Arctic (Caudullo et al., 2017). It is an interesting species from the perspective of global climate prediction because its distribution appears to be increasing compared to other Arctic shrubs in response to climate warming (Myers-Smith et al., 2015), and it tends to allocate more photosynthesis to biomass growth than other shrubs such as birch (Street et al., 2018). Because of their ability to form symbiotic associations with N-fixing bacteria in soil, alder shrubs can maintain a high tissue N concentration (Bühlmann et al., 2016). The decomposition of alder shrub litter can produce rates of net N mineralization which are several to many times faster than rates in other tundra vegetation communities

(Hart and Gunther, 1989). All these factors can contribute to downslope export of dissolved inorganic N from alder communities (Callahan et al., 2017). Because of their tall stature, alder communities also have the potential to trap wind-blown snow, adding another dimension of variance to their behavior in the shrub tundra landscape.

ELM currently includes Arctic shrub vegetation types, but they are parameterized very generically. There is no specific association of N fixation with any plant type in ELM, although the model does represent a broad global pattern of variation in ecosystem-level N fixation rates. The current model is, therefore, not able to capture the unique and important aspects of alder shrub community distribution and function in the Arctic tundra. Based on extensive new data collection within NGEE Arctic, and on synthesis of plant trait information from the broader community, we propose to introduce a new plant functional type in ELM to capture the alder tundra community. We will use that new parameterization to explore hypotheses for alder ecosystem feedbacks across multiple spatial scales, from single site interactions with soil hydrology and mineralogy, to hillslope relationships between alder and other tundra vegetation communities, to regional and pan-Arctic explorations of alder expansion in conjunction with increased shrub distributions generally under a warming climate. This final extension to pan-Arctic scale will require new work to acquire, synthesize, or develop a more detailed map of shrub distributions. All model development efforts will be conducted in close coordination with measurements and syntheses being undertaken by the Q3 team.

Improved simulation of pan-Arctic vegetation dynamics

Northern ecosystem plant species composition and abundance are already responding to recent warming (Hudson and Henry, 2009; Pieper et al., 2011). Several observational studies have shown increasing shrub abundance, including from repeat photography (Tape et al., 2006; Tremblay et al., 2012), tundra warming experiments (Cornelissen et al., 2001), and satellite observations (Forbes et al., 2010). Dynamic vegetation models have also predicted shrubification (Zhang et al., 2013; Mekonnen et al., 2018). Overall, these studies found recent increases in shrub productivity in response to warming across many of the study sites, although the extent of these changes varied with site conditions. Several interacting processes control the relative abundance of high-latitude shrubs under changing climate, for example, disturbance (Bond-Lamberty et al., 2007), seed viability (Lantz et al., 2010), nutrient availability (Lantz et al., 2009), and thickening of the active layer (Schuur et al., 2015). Decadal trends in vegetation may not be apparent from results of relatively short-term warming experiments, highlighting the importance of using these types of measurements to develop mechanistic ecosystem models (Bouskill et al., 2018).

We will integrate what we have learned from these recent analyses and the broader literature with the new ELM-FATES ecosystem demography model and apply the model at site (e.g., Kougarok), regional (e.g., Alaska tundra), and pan-Arctic scales. This modeling task will integrate NGEE Arctic work occurring in Q3 (e.g., development of shrub PFT parameters), Q4 (e.g., seedling recruitment and establishment, nutrient dynamics, plant hydraulics, large-scale benchmarking), and Q6 (e.g., the effects of wildfire on shrub processes). This work will also take advantage of ongoing E3SM and CMDV efforts (1) integrating nutrient (Riley et al., 2018) and plant hydraulic (Bisht et al., 2018) controls in ELM-FATES and (2) conducting analyses with the model at Alaskan sites. Vegetation assemblages predicted by ELM-FATES will be compared to the synthesis of ecosystem types produced by Q1.

Improved representation of chemical, mineral, and microbial interactions in tundra soils

Greenhouse gas emissions and the fate of organic matter in thawing permafrost depend on a combination of chemical, biological, and mineral interactions (Schuur et al., 2008; Natali et al., 2015; Evgrafova et al., 2018; Tas et al., 2018; Gentsch et al., 2018). Permafrost organic matter decomposition depends on microbial enzymatic capabilities and organic matter properties, both of which vary with depth and across tundra landforms (Tas et al., 2018; Zheng et al., 2018). In addition, the gradient of oxic to anoxic processes in tundra soils depends on interactions of organic and mineral phases in connection with redox and pH conditions. Representing these processes and their variability within terrestrial biogeochemical models is a prerequisite to scaling up from the ecosystem scale to the scale of an earth system model grid cell. Global models including permafrost representations have suggested the potential for significant feedbacks to climatic warming from permafrost thaw (e.g., Koven et al., 2011; MacDougall et al., 2012) but generally do not represent landscape heterogeneity or microbial-chemical interactions (e.g., Ekici et al., 2014) and are subject to substantial uncertainties related to data availability, process representation, and spatial scaling (Mishra et al., 2013; McGuire et al., 2016). We will leverage ongoing research to refine and constrain models of permafrost biogeochemical dynamics across permafrost landscapes.

Expanded representation of these reaction networks in the existing ELM-PFLOTRAN module will improve predictability of seasonal variation in CO_2 and CH_4 fluxes. Connections to soil moisture and temperature state can be informed by laboratory incubations and new theoretical developments (Tang et al., 2017; Tang and Riley 2017; Zheng et al., 2018b). We will integrate microbial-explicit SOM decomposition and mineral stabilization functionality based on the CORPSE (Sulman et al., 2014) and MEND (Wang et al., 2014) models within the reaction network capabilities in ELM-PFLOTRAN to better represent differences in decomposition and greenhouse gas emission potential between active layer and thawed permafrost layers, including the ability to simulate the roles of microbial priming effects and interactions with fire history. Many aspects of the research work carried out under Q2 will be relevant to constraining and evaluating these ELM developments, including improved understanding of oxic-anoxic reactions in the transition layer, field measurements of CO_2 and CH_4 fluxes in contrasting environments, improved understanding of the decomposability of newly-thawed permafrost and influence of changes in the length of the growing season on C fluxes. We will also leverage our recent work with the wetland methane module (Xu et al., 2016) to further improve plant and soil process representations in ELM to dynamically predict biogeochemical and vegetation interactions with temperature and moisture at the hillslope scale, focusing first on the Kougarok site.

Deliverables: Deliverables from the Phase 3 Integrated Modeling team will consist of new, tested source code modules within the E3SM Github code repository, as well as modeling results from these new modules with comparisons to baseline model versions and evaluations against observations at appropriate scales. Specific deliverable from the six modules of improved Arctic tundra modeling capability include:

- IM1: Pan-Arctic, regionally variable parameterization of sub-grid fractional inundated area as a function of water table depth in ELM, and a paper evaluating performance of this parameterization at pan-Arctic scale against observed fractional area of standing water from remote sensing products.
- IM2: A new column-level algorithm for dynamically varying runoff-generation parameters as a function of evolving permafrost thickness and active layer depth in ELM, and a paper evaluating performance of this parameterization against runoff observations in multiple Arctic tundra watersheds.
- IM3: A new sub-grid algorithm for distributing precipitation received as snow from the atmosphere component of E3SM onto multiple ELM topographic units, landunits, and soil columns in response to varying terrain, winds, and vegetation height and abundance. This deliverable includes a paper evaluating the performance of this snow-redistribution module against field and remotely-sensed observations of snow cover and snow depth.
- IM4: A new ELM trait-based PFT description for the N-fixing shrub alder, a pan-Arctic map including best observation-based estimates of the occurrence and fractional cover of alder, and new algorithms in the ELM vegetation code to represent observed relationships between environment and nitrogen-fixation rates in alder. This deliverable includes a paper evaluating the predicted growth and nutrient dynamics of alder against a synthesis of field observations and estimating the influence of alder communities on down-slope soil and vegetation nitrogen cycling.
- IM5: A pan-Arctic implementation of the ELM-FATES vegetation module using improved representation of Arctic plant traits (including those delivered for alder under IM4), improved plant demography, improved plant hydraulics, and improved fire processes. This deliverable includes a paper evaluating the distributions of Arctic vegetation communities and their productivity as predicted by ELM-FATES, against a synthesis of site-level and remotely-sensed observations.

- IM6: A new predictive model for redox conditions and pH in Arctic tundra soils that includes explicit microbial dynamics and is implemented within the ELM-PFLOTRAN module, combined with new sub-grid representations of tundra soil properties such as organic and mineral distributions with depth. This deliverable includes a paper evaluating the new soil biogeochemistry capability against multi-scale measurements of greenhouse gas fluxes in the field, and under laboratory incubations.

SCIENCE QUESTIONS

QUESTION 1. HOW DOES THE STRUCTURE AND ORGANIZATION OF THE LANDSCAPE CONTROL PERMAFROST EVOLUTION AND ASSOCIATED C AND NUTRIENT FLUXES IN A CHANGING CLIMATE?

Permafrost characteristics and associated hydrobiogeochemical behavior widely vary across the Arctic as a function of climate, geomorphology, vegetation and soil characteristics (e.g., Jorgenson et al., 2010). Question 1 is aimed at improving our understanding of how the heterogeneity of these environmental factors interact with permafrost distribution and evolution (Figure 8). Such information is needed to quantify the integrated response of the system to warming as well as the parameterization of models used to predict terrestrial feedbacks to climate.

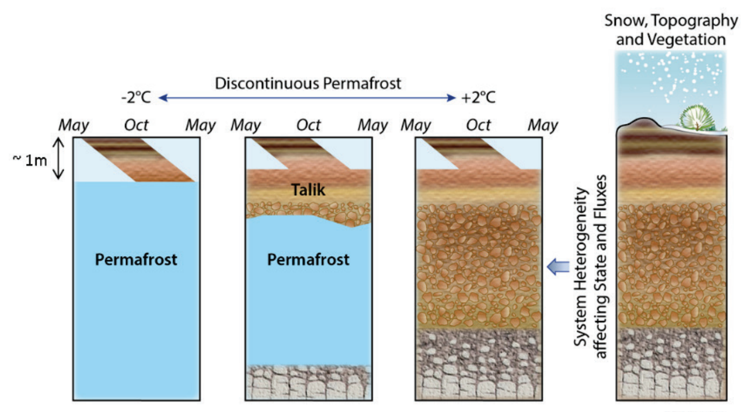


Figure 8. Schematic indicating a range of permafrost conditions, as well as seasonal freeze and thaw of active layer with depth. Spatiotemporal variability in both the active layer and permafrost influence thermal hydrology and biogeochemical processes that govern C fluxes.

Building on insights developed through previous NGEE Arctic results, research in Phase 3 will concentrate on improving the quantification of critical subsurface properties (including ground-ice, organic matter content and bedrock structure) and their linkages to vegetation and geomorphological characteristics, as well as on scaling the information to larger scales. Our previous work highlighted that the ecosystem-type construct, which is related to functional zone (Wainwright et al., 2015), ecosystem type (Zhang et al., 2013; Nicolsky et al., 2017), ecotype (Jorgenson et al., 2004) and ecosystem functioning type (Paruelo et al., 2001) concepts, was useful for delineating regions having distinct physical, hydrological and/or biogeochemical properties (Wainwright et al., 2015; Cable at al., 2016; Nicolsky et al., 2017) that influence hydro-biogeochemical behavior of that parcel. We also documented the value of the ecosystem-type construct to upscale key above- and belowground characteristics that influence C cycling from intensive site to regional scales, as needed to inform models. In Phase 3, we will further advance our understanding of subsurface properties that are notoriously difficult to characterize with resolution and over scales important for regional models. We will refine the linkages between subsurface and aboveground properties, the latter inferred from high-resolution imagery available at the NGEE Arctic sites on the Seward Peninsula. We will then scale the refined ecosystem types up to the entire Seward Peninsula. Finally, research associated with Q1 will also provide improved estimates of current and future distribution of ground temperature and improved understanding of how taliks develop in warm permafrost environments and the associated implications for C fluxes.

Task 1.1: How do soil and bedrock properties relate to soil thermal behavior at local to watershed scale?

The following three tasks focus on improving our understanding of subsurface properties, the relationship between soil/bedrock and permafrost characteristics, and the thermal behavior of the system. This information will be used in subsequent tasks to improve our understanding of below- and aboveground interactions and to refine the existing ecosystem-type construct, and its incorporation into models to simulate permafrost degradation with warming.

Task 1.1A: Hydrogeophysical estimation of the distribution of key soil, bedrock and permafrost properties

Soil, bedrock and permafrost properties exert a significant influence on soil thermal characteristics. These characteristics modulate heat fluxes and, in many cases, influence water, C and nutrient fluxes. In Phase 3, we will continue to improve our ability to quantify subsurface properties at field sites on the Seward Peninsula using core soil samples and geophysical measurements. Building upon NGEE Arctic research that involved laboratory experiments and theory (e.g., Dou et al., 2017), we will develop petrophysical relationships based on site core samples to link geophysical observables to subsurface properties. We will also advance petrophysically constrained inversion approaches to estimate the distribution of suites of subsurface soil components (such as fraction of mineral content, organic matter, water, ice and air) using multiple field geophysical datasets (seismic, electrical, magnetic, thermal). This will include improvement in estimating permafrost thickness, ice-content, and depth to permafrost table. Our inversion work will build upon several recent NGEE Arctic hydrogeophysical inversion advances, including the use of ERT and thermal data to estimate soil organic content (Tran et al., 2017) and the use of ERT and seismic data to estimate ice content and soil moisture. The core soil sampling and advanced hydrogeophysical inversion work will be performed along key transects at the Teller, Kougarok and Council sites, which as an ensemble include a range of subsurface properties, states of permafrost degradation and PFTs. This task will benefit from information obtained from temperature time-series in Task 1.1B and from "deep" drilling in Task 1.1C.

Task 1.1B: Advanced monitoring of spatiotemporal variation in soil temperature and associated variables

A major limitation in observing the spatial and temporal variability in active layer, soil thaw layer dynamics, and thermal behavior in the landscape is the difficulty in measuring ecosystem properties and processes continuously over time with sufficient spatial resolution and coverage. In this task, we propose to complement the existing soil temperature monitoring stations on the Seward Peninsula by deploying the DTP system developed during Phase 2 (Leger et al., submitted) to monitor near-surface air temperature and soil temperature (top 1 m) with high vertical and lateral resolution. The system will be deployed at a statistically significant number of locations (>200 per field site) as needed to evaluate soil temperature dynamics and below/aboveground (air, snow, vegetation, soil) coupling over a variety of PFTs and positions in the landscape. This information will be integrated with time-lapse geophysical data and remote-sensing products, including UAS-inferred terrain and vegetation datasets, and snow surface digital models (in collaboration with Q5). The time-series of soil temperature will also be used in the hydrogeophysical inversion approach in the Task 1.1A for the estimation of fraction of soil components (following Tran et al., 2017). A few of the DTP locations will be equipped with autonomous CO_2 flux chambers and soil moisture sensors and will be sampled to measure fraction of soil components and C and nutrient storage. Additional episodic measurements of surface gas fluxes and vegetation properties will be performed in collaboration with Q2 and Q3. Various metrics will be extracted from the time-series datasets to quantify the duration of specific processes (such as duration of snow melt, thawing/freezing front dynamics, and soil thaw period). The developed methodology will improve our ability to quantify various patterns and trajectories in thermal behaviors and their link to diverse ecosystem types (as described in subsequent tasks).

Task 1.1C: Quantify how bedrock characteristics influence thermal behavior and permafrost degradation

Near-surface bedrock is common in many permafrost regions, including the Seward Peninsula. In warming environments, bedrock physical and thermal parameters may significantly impact the subsurface thermal diffusion and convection, the permafrost thickness and the formation of preferential hydrological pathways below the active layer, or taliks. While the influence of thermal gradients in "deep" regions below the active layer (>2m) may play a significant role on permafrost degradation and associated water and C cycling in the coming decades, the control of bedrock characteristics on permafrost degradation is understudied.

To acquire data needed to evaluate thermally induced permafrost phenomena in bedrock environments, we will drill up to fifteen 20 m deep boreholes at various locations at the Teller site (during winter time to avoid any disturbance on the tundra). If possible, a few more wells will be drilled along the road at Council and Kougarok sites. Wellbore data, hydrological tests, core analysis and field geophysical datasets will be used to quantify the influence of bedrock depth, fracture characteristics, hydraulic and thermal properties, conductive and convective heat fluxes and thermal gradients on permafrost characteristics. Boreholes will be repeatedly logged, including using a temperature string and a nuclear magnetic resonance (NMR) tool, to estimate intra-annual temporal variability of geophysical, hydraulic and thermal characteristics. Using the hydrogeophysical inversion approaches described above, the obtained wellbore log, and core information will be integrated with geophysical field datasets to estimate the distribution of bedrock and permafrost characteristics. The influence of bedrock thermal parameters, thermal gradient and heat diffusion and convection processes on the present-day permafrost distribution will be assessed at local scales using field data and the physically based permafrost model GIPL and ecosystem model *ecosys* (Grant et al., 2017). The models will be challenged with the field data and used to predict the extent of permafrost degradation and associated C distribution by the end of this century. This sub-task will be closely coordinated with Q5.

Deliverables: Improved quantification of soil, bedrock and permafrost characteristics and their relationships and new approaches to estimate key subsurface properties using geophysical information.

Task 1.2: How can covariation of above- and belowground factors be used to refine ecosystem types, and how are ecosystem types distributed from intensive sites to regional scales?

With the improved understanding of the distribution of ground-ice, organic layer and bedrock structures, we propose to refine the ecosystem-type definitions by exploring the linkage between subsurface, vegetation, snow and geomorphologic characteristics at the NGEE Arctic sites.

Task 1.2A: Quantify linkage between key subsurface, vegetation and geomorphological characteristics from local to watershed scales

With the improved subsurface soil, permafrost and bedrock information and building upon previous NGEE Arctic ecosystem zonation contributions (Wainwright et al., 2015; Nicolsky et al., 2017), we will develop relationships between above- and belowground properties and develop refined ecosystem-type maps at the various NGEE Arctic sites. Ecosystem types will be statistically identified and delineated using datasets associated with geomorphology (in collaboration with Q5), vegetation type and structure (in collaboration with Q3 and Q4) and subsurface properties at local scales. Examples of datasets include existing classification of Arctic vegetation type and soil texture (Jorgenson et al., 2004, 2014), high-resolution maps of Arctic PFT distributions (from Q3), existing and newly acquired UAS-inferred multi-spectral imagery, digital surface and terrain models, and derived snow thickness and vegetation type, height and density. Informed by the covariance between key properties, we will also seek novel approaches to upscale information. For example, if we identify a strong covariance between vegetation type, height, density and/or reflectance (obtained from UAS-based surveys) and the fraction of soil components (including ice content, SOM content), we will explore the use of vegetation metrics obtained from satellite spectral imagery to estimate the spatial distribution of soil characteristics over regional scales. If we identify a strong covariance between estimated subsurface ice content and surface seasonal or annual ground surface displacement at the local scale, we will explore the use of InSAR observations to estimate ice content over larger scales. Ecosystem types will be defined to have distinct distribution of properties while being identified by using only remotely sensed information such as geomorphological, substrate and vegetation attributes. This task will be closely aligned with Tasks 1.2B–C. Data acquisition and analysis will be closely aligned with vegetation mapping efforts (see Q4) and hydrological investigations (see Q5).

Task 1.2B: Generate ecosystem-type map and estimate current and future subsurface temperatures at 30 m resolution over Seward Peninsula and beyond

Using the ecosystem-type construct developed for NGEE Arctic sites (Task 1.2A) and through synthesis of available core, ground temperature, ecological and climatological data from the large scientific community, the ecosystem type approach will be applied to the entire Seward Peninsula and then to selected regions within Alaska. As available, high-resolution Seward Peninsula maps of Arctic PFT distributions will replace the Alaska Existing Vegetation Type (AKEVT; Fleming, 2015) and complement ecotype (Jorgenson et al., 2004) and topographic (including ArcticDEM (Porter et al., 2018)) maps for ecosystem-type delineation across the Seward Peninsula. Exploratory investigations will be performed to assess the applicability and value of other remote-sensing products at the Seward Peninsula scale (e.g., snow thickness, shrub characteristics) as available.

The resulting maps will provide both the boundaries of unique ecosystem-type parcels in the landscape as well as their associated distributions of subsurface and surface characteristics—both will be used to inform ecosystem modeling. For example, as part of this task, the ecosystem-type estimates will be used to parameterize the GIPL model to estimate the current distribution of ground temperature, permafrost and ALT across the Seward Peninsula and selected regions. Distributed networks of measurement sites outside of the three study areas will also be used to validate the obtained spatially explicit GIPL modeling results (e.g., from LTER, ABoVE, AON and NEON sites). Finally, GIPL will be used to generate probabilistic maps of landscape permafrost degradation vulnerability by the end of this century and to assess uncertainty in the prediction of such future states. The vulnerability assessment will consider various future climate scenarios as well as uncertainties in ecosystem-type soil and bedrock characteristics.

Task 1.2C: Evaluate the value of the ecosystem-type concept for improving land model predictions

Evaluating the value of including ecosystem-type constructs in the regional-scale model ELM will be performed through a sensitivity analysis and a field test case at watershed scale. Ecosystem-type parameterized simulation runs, where ecosystem types with various level of heterogeneity will replace the current land unit and soil column in the ELM architecture, will be compared to conventional ELM simulations. In addition, simulations with the different configuration will be performed at each of the NGEE Arctic intensive sites and the model predictions will be compared to the existing data, including temperature and CO_2 fluxes. Results will guide the transfer of knowledge and data to ELM.

Deliverables: Understanding of how subsurface characteristics co-vary with vegetation and geomorphology at the watershed scale. Refinement of ecosystem-type definitions for discontinuous permafrost domains and development of ecosystem-type map of the Seward Peninsula and beyond. Use of ecosystem-type information to improve parameterization and decrease uncertainty in NGEE Arctic models. Process-informed prediction of current and future permafrost states over Seward Peninsula and selected regions.

Task 1.3: How do environmental factors influence the presence of taliks, and what are the consequences for associated C fluxes?

Thaw of permafrost and associated changes in landscape structure can take many forms and occur at highly variable rates (Jorgenson and Osterkamp, 2005). Besides being influenced by episodic events (e.g., thermokarst, lake drainage, gullying or wildfire—see Q6), permafrost thaw is influenced by a gradually warming climate and modulated by spatial variability in geomorphological, vegetation and soil characteristics. Spatial variability in permafrost thaw rate increases heterogeneity in the system, and in warm permafrost regions, such as Teller and Council sites and in the Alaskan interior. At these locations, a small increase in soil temperature can lead to a shift from frozen to unfrozen conditions and thus the juxtaposition of taliks and near-surface permafrost (Leger et al., submitted). Development of deep active layers and/or taliks can lead to a variety of consequences, including settlement, change in soil moisture, reorganization of preferential flowpaths (Q5), shifts in vegetation (Q3 and Q4), changes in storage and flux of C and nutrient, and modifications in GHG production (Q2) (Olefeldt et al., 2013; Koven et al., 2015; Parazoo et al., 2018). Knowledge derived from this task will help us understand controls on key talik-related processes occurring in transitional permafrost landscapes and how they reshape landscape structure and connectivity. Results will provide knowledge to improve ecosystem modeling in transitional landscapes.

Task 1.3A: Understanding dynamics occurring in talik environments over winter and shoulder seasons

Significant spatial heterogeneity in near-surface/talik distribution can drive a large fraction of the spatial and temporal changes in hydro-biogeochemical fluxes. Investigating this heterogeneity, and how it relates to specific C fluxes, will help to understand how future shifts in landscape structure and organization may lead to different surface-subsurface CO_2 exchanges (assuming spatial heterogeneity can be used as a proxy for temporal changes). With year-round, autonomous above- and belowground monitoring capabilities developed through NGEE Arctic research (including Task 1.1B), we will evaluate the influence of vegetation and geomorphology and related spatial variability in snowpack thickness, thaw season timing and length, and inter-annual shift in timing on the thermal-hydro-biogeochemical processes and fluxes, across various ecosystem types. Field-based understanding will be complemented by modeling various scenarios using the *ecosys* and ATS models along 2D transects crossing various talik behaviors to decouple the effect of the various environmental factors on subsurface heat, water and C fluxes (aligned with Q4–Q5). Improving our understanding of processes occurring during the winter and its shoulder seasons will also serve investigations on understanding the implications of the temporal offset between early season peak in radiation and late season peak in unfrozen soil thickness on root-soil interaction and nutrient budget (Q3–Q4).

Task 1.3B: Evaluate similarities between rate of changes in vegetation type and indices, surface temperature and simulated thermal behaviors at NGEE sites and across the Seward Peninsula

Warm permafrost present at the Teller and Council sites (and likely at many other locations across the Seward Peninsula and in the Alaskan interior) and the availability of historical data provide a unique opportunity to evaluate if landscape changes due to gradually warming climate have been correlated with an increased presence of taliks over the last 20 years. We will use MODIS time-series of surface temperature together with meteorological data to evaluate potential difference in trajectories and changes in air and soil temperature in the last 20 years across Seward Peninsula, and in zones that are expected to have permafrost close to 0^{o}C. In addition, we will use historical satellite imagery analysis performed in Q4 and Q6 and other studies (e.g., Ju and Masek, 2016) that evaluate rates of change in landscape characteristics. The above dataset will be compared to field observations, the newly developed ecosystem-type map, and GIPL current soil temperature predictions to evaluate the extent to which different thermal trajectories and possible transition to a talik-dominated landscape over the last 20 years across Seward Peninsula were correlated with specific shifts in vegetation and surface temperatures.

Deliverables: Quantify influence of taliks on hydrological and biogeochemical processes to improve ecosystem modeling in transitional landscapes. Document the distribution of talik areas, their thermal trajectories, and their influence on landscape organization and rate of change in landscape characteristics.

QUESTION 2: WHAT WILL CONTROL RATES OF CO_2 AND CH_4 FLUXES ACROSS A RANGE OF PERMAFROST CONDITIONS?

Organic matter frozen in Arctic active layer soils and permafrost will decompose to simpler compounds after thawing, but the timing and processes of complete decomposition to CO_2 and CH_4 remain uncertain due to the complex interplay among SOM structure and accessibility, microbial activity, temperature, degradation of permafrost, hydrology, and geochemistry. In Phase 2 we examined the effects of temperature and geochemistry on microbial decomposition and GHG production to improve process representations and parameterization of fine-scale ecosystem models. During Phase 3, we propose coordinated measurements, experiments, and model development activities in three areas critical to the NGEE Arctic multiscale and high-resolution simulation strategy.

Task 2.1: Oxic-anoxic transition layer measurements and modeling

Most soil biogeochemistry models do not explicitly simulate oxygen (O_2) transport in the soil column, which directly affects microbial activity and SOM degradation. Rather, they modulate aerobic and anaerobic processes based on water table depth and soil saturation, which frequently correlate with dissolved O_2 and redox gradients in wetlands. Enhancements in ATS and ELMv1 hydrology are improving simulations of Arctic soil water content, yet varying water tables and thaw depths, soil aggregate heterogeneity and anoxic microsites, plant O_2 transport via aerenchyma, and lateral water flow require more explicit, dynamic simulations of dissolved O_2 concentrations to improve predictions of SOM decomposition and GHG production (Elberling et al., 2011; Smyth et al., 2019).

In Phase 3, we will focus on coupled biogeochemistry and hydrology at the oxic-suboxic-anoxic transition in wet Arctic soils. Together with the Integrated Modeling team, we will form a working group to develop a new model structure and parameterization that predicts explicit O_2 concentrations, redox and pH properties. This work will begin with a survey of current soil oxygen transport models (Fan et al., 2014) and diffusivity measurements (Deepagoda and Elberling, 2015). We will identify the most promising model structures for Arctic soils. For example, mechanistic modeling of two-phase oxygen diffusion coupled with consumption reactions will be used to provide simplified parameterizations of aerobic/anaerobic zonation. Based on both measurements and theory development, we will develop a continuous response function on explicit aerobic and anaerobic microbial activities to improve representation of oxic and anoxic processes in ELM and fine- to intermediate-scale models coupled through the Alquimia interface to geochemistry codes (see IM6).

This survey will also identify knowledge gaps or uncertainties in parameterization (such as tortuosity) that must be prioritized for measurement. Experiments and field observations are planned to characterize similarities (e.g., dissolved oxygen and nitrate and moisture content relations) and differences (e.g. litter input, SOM, iron biofilms, precipitation and temperature) between Utqiaġvik and Seward Peninsula sites. Gaseous and dissolved oxygen measurements will be performed using optical and electrochemical sensors (Wang and Wolfbeis, 2014). Microsensors will be used in the laboratory to provide high-resolution data from soils at different temperatures and soil moistures, while more rugged sensors will be deployed in the field to measure O_2 concentrations in minimally disturbed soil. Concurrent measurements of oxyanion and Fe(II) concentrations as well as dissolved CO_2 and CH_4 will be used to characterize the redox potential. In collaboration with the Q5 team, we will utilize the full chemistry of the BEO polygon bromide tracer test samples to examine the effects of transport of ions with higher reduction potentials than CO_2 or acetate on anaerobic processes. These results from field and laboratory experiments will be synthesized to produce datasets for model parameterization and validation.

The lateral transport of nitrate and oxygen species significantly changes the redox potential of soils at our Seward Peninsula watershed sites. Integrating tracer tests from our Teller field site and laboratory column transport and transformation experiments (e.g., controlled DON tracer/nutrients additions) with hydrologic simulations will inform lateral transport models that are key to predicting GHG emission patterns. As these experimental studies are conducted, it will be critical that we understand and predict the geochemical environment for thawing permafrost and to quantify microbial growth and transport in this medium to assess frozen organic matter decomposition potential. We will continue to develop mechanistic model structures of microbial and mineral surface interactions, coupled with hydrological, biogeochemical measurements in the field and temperature effects.

Deliverables: New model frameworks for oxygen transport in Arctic soil and continuous moisture response functions for explicit microbial activities. Datasets on redox potential gradients from the oxic to anoxic layers of tundra soil.

Task 2.2: Field measurements of soil and ecosystem CO_2 and CH_4 fluxes

In Phase 2, flux sites were established and registered with AmeriFlux at Utqiaġvik (US-NGB) and Council (US-NGC). In Phase 3, we will continue measurement at Council while the system in Utqiaġvik will be refurbished for portable use and deployed in support of Q2, Q4, and Q6. Data from the NGEE Arctic tram located on the BEO will be synthesized to generate benchmark time-series on vegetation, soil moisture, and a suite of surface energy and optical properties. At Council, flux data from the tower will be analyzed to infer fluxes according to inundation and vegetation composition in different positions of the flux footprint and to contrast the shoulder season dynamics with those at Utqiaġvik (Raz Yaseef et al., 2017a, b).

Soil and ecosystem fluxes of CO_2 and CH_4 will be measured in the field using chambers connected to LGR or Picarro gas analyzers. Fluxes in the footprint of the Council eddy flux tower will be analyzed to understand topographic and vegetation controls. In addition, we will complete our multi-year study of GHG fluxes from channels, thermokarst slopes, and intact permafrost areas in Council (Wainwright et al., 2015). These fluxes will be correlated with adjacent soil measurements of dissolved CO_2 and CH_4 and geochemical parameters to develop a model validation dataset. Fluxes will also be measured on the Teller geophysics transects (see Q1) and to support interpretation of the subsurface chemistry in Task 2.1.

Deliverables: GHG flux datasets from eddy covariance measurements and integrated tram dataset. Surface gas flux measurements from Council correlated with soil biogeochemistry

Task 2.3: Permafrost decomposition to GHG

One of the biggest uncertainties in Arctic feedbacks to warming is predicting the decomposition rate of organic matter currently stabilized in permafrost (Ping et al., 2015). When permafrost thaws, the organic matter frozen in permafrost can be mineralized by microorganisms with roughly the same temperature sensitivity for new and older SOM (Vaughn et al., submitted). However, freshly thawed permafrost organic matter decomposes more slowly than active layer SOM in incubation experiments. The hydrology, geochemistry, and microbiome will change when permafrost thaws in the field, due to subsidence, transport processes, and priming. Moreover, models currently impose a universal parameterization for the limitation of decomposition rates with depth (Koven et al., 2013), or they lack representation of depth altogether. Therefore, we need to understand the decomposition potential for permafrost organic matter for process-enabled ecosystem models. Coordinated simulations, in situ microwarming manipulations, and laboratory experiments will address the fate of thawing permafrost organic matter. Using thermokarst formation as an example of thermal disturbance, we will integrate measurements of GHG emissions, change in microbial community functions, and SOM decomposition to understand the impact of rapid permafrost degradation on GHG production.

We will compare decomposition dynamics of near-surface and deep cores that contain permafrost paired with cores of active layer soils or talik. Current and emergent thermokarsts at the Council site provide excellent opportunities to sample organic-rich permafrost under tundra only meters from saturated soils in thermokarsts with thaw depths > 1 m. Council cores will be compared with other deep permafrost cores from the BEO and interior Alaska. Decomposition dynamics and GHG production will be evaluated as a function of oxic and anoxic conditions, temperature, and soil organic matter composition (measured by molecular analysis and by density fractionation). Methods developed for these analyses can also be applied to characterize changes in subsurface SOM changes caused by disturbance, such as the wildfire chronosequence near Quartz Creek (Kougarok). Coordinated, monthly measurements of surface GHG flux along the chronosequence during the growing season would be used to constrain decomposition models.

Models that simulate soil organic matter turnover require better estimates of dissolved and solid-phase C content and their rates of exchange to accurately predict decomposition rates and GHG production. Although many spectroscopic and chemical methods have been applied to measure functional groups and bulk properties of soil C, the amount of solid-phase organic C available for enzymatic hydrolysis and microbial decomposition is hard to quantify. We have pioneered an analytical method using secreted fungal enzymes to hydrolyze polysaccharides from soil and permafrost samples. Using this method, we estimated that 5–12% of solid-phase organic C in a BEO core sample could be hydrolyzed to sugars (Figure 9), which can be readily decomposed to GHG gases under both oxic and anoxic conditions. This approach promises distinct advantages over chemical characterization or traditional incubations alone.

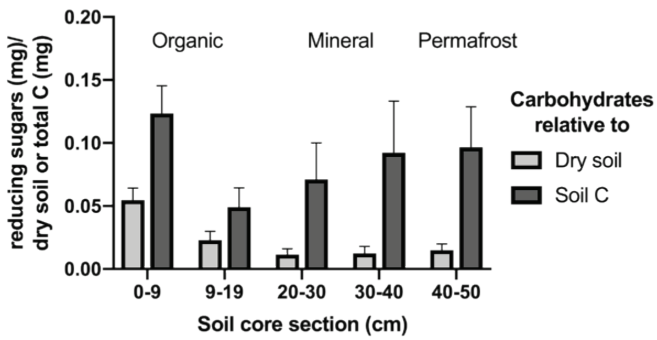


Figure 9. The enzymatic hydrolysis assay released significant quantities of sugars from sections of a BEO low-centered polygon core.

We will optimize this assay for soil carbohydrates and apply it to soil and permafrost samples from Seward Peninsula sites. In parallel, we will test soil C decomposition potential using native or introduced fungal cultures in standardized aerobic incubations, measuring CO_2 production using respirometry. The resulting measurements will be compared with spectroscopic measurements (e.g., FTIR and NMR) to develop a dataset for parameterization of Arctic soil C decomposition models and evaluation of model predictions. Radiocarbon measurements of filtered hydrolysates or CO_2 from these bioassays will be used to estimate carbohydrate turnover and mineralization rates relative to total soil C (Vaughn et al., 2018).

Deliverables: New analytical methods for bioavailable carbohydrates in organic soils and permafrost. Decomposition potential measurements and turnover rates of permafrost solid-phase organic C, for model parameterization

Task 2.4: Synthesis of warming effects on thaw season length and GHG production

Increased warming in the Arctic and changes in precipitation patterns are expected to prolong the annual thaw season, and some soils may not freeze during the winter. Prolonged warming and insulation may cause the formation of taliks—perennially unfrozen ground in permafrost areas. Simulations predict that taliks will become widespread in northern high-latitude regions, leading to increased C decomposition and GHG production (Parazoo et al., 2018). In cooperation with Q1 and Q5, we will prepare a synthesis of multiscale data and simulations on thaw season length and talik formation. By integrating our process knowledge on SOM degradation, enhanced models of thermal hydrology, and extensive datasets, we will address uncertainties in shoulder season GHG dynamics and controls on talik formation.

Deliverable: Synthesis of datasets and process knowledge on thaw season dynamics and talik formation

QUESTION 3: HOW DO ABOVE- AND BELOWGROUND PLANT FUNCTIONAL TRAITS CHANGE ACROSS ENVIRONMENTAL GRADIENTS, AND WHAT ARE THE CONSEQUENCES FOR ARCTIC ECOSYSTEM C, WATER, AND NUTRIENT FLUXES?

Arctic plant traits affect key processes in tundra ecosystems, including C capture and storage, nutrient and water cycling, and feedbacks among snowpack, soil temperature, and permafrost extent (Chapin et al., 1996; Sturm et al., 2005; Rogers et al., 2017b; Bjorkman et al., 2018a). Observations that capture the variation in tundra plant traits across environmental gradients, above- and belowground, are needed to understand and predict the responses of tundra plant communities to environmental change (Myers-Smith et al., 2018) and to inform the development of models. In Phase 3, we will complete our quantification of the variation in key tundra plant functional traits on the North Slope and the Seward Peninsula, synthesize NGEE Arctic and pan-Arctic plant trait data in collaboration with national and international partners, inform the representation of plant traits and parameterization of a new N-fixing PFT in ELM, and evaluate new model developments by comparing point model simulations with data from our NGEE Arctic field sites.

Task 3.1: How will photosynthesis and respiration acclimate to elevated air temperature?

A critical component of accurately representing the response of the uncertain Arctic C cycle to global change is accounting for thermal acclimation of key functional plant traits, particularly photosynthesis, respiration and phenology (Smith and Dukes, 2013; Way et al., 2014; Yamori et al., 2014; Smith et al., 2016; Rogers et al., 2017a; Stinziano et al., 2018; Richardson et al., 2018). This is highly relevant in the Arctic where warming has been, and is projected to be, markedly greater than the global mean (IPCC, 2013). A challenge of advancing knowledge of acclimation to rising temperature in Arctic ecosystems has been that viable approaches for elevating temperature rely on passive warming that can achieve a maximum of ~1.5°C of warming. In Phase 2 we designed and evaluated a novel Zero-Powered Warming (ZPW) chamber that is capable of elevating and modulating air temperature by ~4°C (Lewin et al., 2017, Figure 10) and began a multiyear warming experiment. In Phase 3 we will complete this experiment and continue to deepen our understanding of low-temperature plant physiology—a critical uncertainty in models (e.g., Rogers et al., 2017b; Rogers et al., submitted).

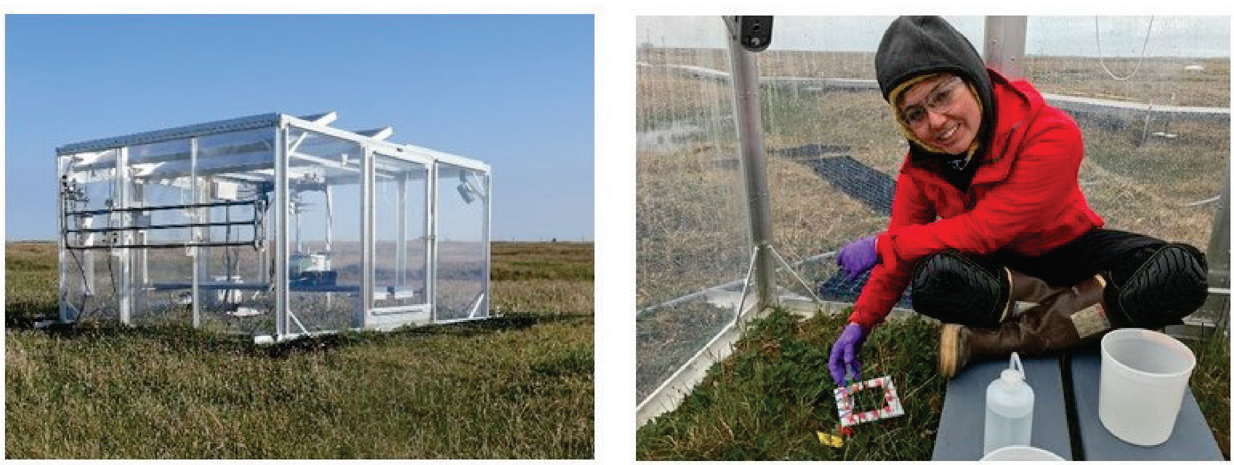


Figure 10. A Zero-Power Warming (ZPW) chamber. The chamber is warmed passively by solar radiation. The combination of an internal and an external heat exchanger modulates venting of the chamber, which enables the air temperature to be elevated by about 4°C.

Task 3.1A: Understanding acclimation to elevated temperature

In 2017 we initiated a replicated warming experiment (n=5) on the BEO. To avoid ponding associated with multiyear warming and enable us to capture our species of interest in sufficient numbers, we move the chambers to new microsites each thaw season. We have completed measurement of leaf respiration and photosynthetic CO_2 response curves at 5, 10, 15, 20 and 25°C in ambient plots and inside our ZPW chambers. This enables us to develop temperature response curves for key functional plant traits and to understand how those traits and their temperature response functions acclimate to warming. Our first 2 years focused on the plant species *Petasites frigidus* and *Arctagrostis latifolia*, and we plan to continue this experiment in Phase 3 with two additional species, starting with *Eriophorum angustifolium* in 2019 and followed by *Salix pulchra* in 2020. The focus of the ZPW experiment is leaf-level physiology, but our Phase 3 plans also include measurements of root respiration to improve our understanding and modeling of linkages between above- and belowground physiology. In addition, the experiment includes passive monitoring of leaf phenology (visual imagery), greenness (NDVI), and health (PRI) throughout the thaw season.

Task 3.1B: Understanding low-temperature physiology

In Phases 1 and 2 we examined model representation of Arctic photosynthesis and worked through the model formulations, providing new understanding of low-temperature photosynthesis and Arctic PFTs, including new parameterization that can be implemented in current models. In Phase 3 we will build upon the foundation laid in Phase 2 to expand basic understanding of the photosynthetic response to irradiance at low temperature through examination of the mechanism and dynamics associated with low-temperature reductions in quantum yield. We will also further parameterize and evaluate stomatal models through gas exchange measurements designed to measure the stomatal slope parameter associated with model formulations used to represent stomatal conductance (e.g., Ball et al., 1987; Medlyn et al., 2011).

Deliverables: Measurements of the response and thermal acclimation of key photosynthetic and respiratory parameters, their temperature response functions, and the leaf health and phenology associated with growth at elevated temperature coupled with an improved understanding of low-temperature physiology.

Task 3.2: How does alder, a keystone species, shape N cycling across tundra landscapes?

Alder, a deciduous shrub which hosts an N-fixing bacterium in root nodules, is a keystone species that plays an essential role in mediating vegetation dynamics within rapidly warming Arctic ecosystems. The introduction of biologically available N into nutrient-poor high-latitude ecosystems has a direct impact on the productivity, composition, successional trajectory, and soil C cycling of surrounding plant communities (Uliassi and Ruess, 2002; Mitchell and Ruess, 2009; Vogel and Gower, 1998). Parameterization of a novel, N-fixing PFT will be crucial for capturing the structure and function of Arctic ecosystem dynamics.

Task 3.2A: Characterizing alder plant traits for the development of an N-fixing PFT

Building upon the morphological and chemical observations of above- and belowground alder plant traits collected across the Kougarok hillslope in Phase 2, we will expand our observations of aboveground alder trait data to the Council site and Sinuk River bed near Teller. This will allow us to better quantify the intraspecific variation in alder plant traits across environmental gradients and enable multiple test beds for evaluation of an N-fixing PFT. We will also quantify leaf-level alder photosynthetic parameters as well as alder root and nodule respiration to develop a comprehensive assessment of the C gains and costs associated with N-fixation in Arctic shrubs (e.g., Ruess et al., 2013). These data, along with observations of alder from across the globe, will be used to quantify the pan-Arctic trait space occupied by high-latitude alder in a synthesis workshop attended by national and international collaborators. We will quantify the consequences of alder N-fixation in conjunction with Q2 by quantifying nitrate availability directly downslope of alder shrublands and in surrounding stream waters at the Council and Kougarok sites. These observations will build upon preliminary results from Phase 2 that indicated substantial spatial and temporal variability of porewater nitrate downslope of alder shrublands.

Task 3.2B: Fine-scale mapping of alder across the landscape

Implementation of a N-fixing PFT within ESMs requires knowledge of where alders currently grow on the landscape and identification of areas where they may expand in the future. Alder expansion likely correlates with spring and summer warming, landscape and topographic characteristics, soil characteristics, and nutrient availability (Tape et al., 2012). We will leverage remote-sensing data to develop high-resolution (5-m or finer), detailed maps of the current distribution of alders across Alaska and ultimately the pan-Arctic region. Our approach, which was developed in Phase 2 (Langford et al., 2016, 2017), will leverage observations of plant community composition collected in Phase 2 from across the three Seward Peninsula sites, existing pan-Alaskan vegetation maps, and environmental databases to develop probabilistic niche models for alder growth and expansion. Given the late senescence of alder leaves, the algorithm will be further informed by phenology data from Landsat temporal composites. Uncertain areas of the resulting alder map will be prioritized for ground-truthing campaigns across the Seward Peninsula. When combined with global to regional model projections of climate and ecohydrology, these models will allow projection of potential alder distributions across pan-Arctic landscapes.

Deliverables: We will provide comprehensive plant trait data required to develop a novel Arctic N-fixing PFT, as well as maps of the current and potential future extent of alder across the Seward Peninsula that will in turn be used to explore the linkages between vegetation dynamics and the transport of N across arctic landscapes.

Task 3.3: How do tundra plant traits vary across the landscape?

Understanding of Arctic above- and belowground plant trait variation within and across species as well as along environmental and edaphic gradients is needed to predict the future of tundra ecosystems (Myers-Smith et al., 2018). However, a pan-Arctic understanding has traditionally been limited by the logistical challenges of direct field measurements in remote locations. Along with targeted field campaigns, we will use remote-sensing observations to provide the data necessary for capturing and integrating the broad spatial and temporal patterns of Arctic plant traits needed to inform model process representations (e.g., Figure 11).

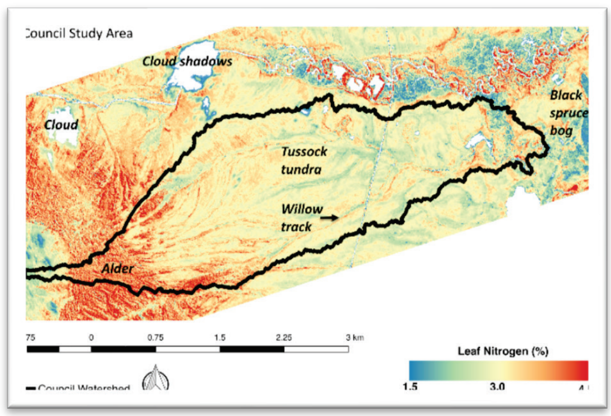


Figure 11. Map of foliar nitrogen across the Council watershed derived from our canopy-scale trait algorithms and NAS ABoVE imagery (Serbin et al., in preparation).

Task 3.3A: Characterizing above- and belowground tundra plant trait variation over space and time

Shrubs that have the capacity to grow tall are expected to have a disproportionate effect on ecosystem C and nutrient cycling and to be particularly sensitive to changes in climate (Sturm et al., 2005; Tape et al., 2006; Myers-Smith et al., 2015). We will quantify the seasonality of how tall shrubs interact with their surrounding environment to facilitate scaling across the landscape and throughout the year. Automated pheno-cameras and greenness sensors (NDVI) will be installed in stands of tall alder and willow on the Kougarok and Teller hillslopes to capture shrub vegetation phenology and enable tracking of snowpack in collaboration with Q5. Furthermore, we will select areas of the Teller hillslope dominated by the common willow species *Salix pulchra* and use a ^{15}N tracer to determine the amount and seasonality of plant N acquisition and allocation of a representative tall shrub (until recently, nutrient acquisition experiments have focused mainly on tundra communities dominated by short-statured vegetation, e.g., McKane et al., 2002; Hewitt et al., 2018).

As a final synthesis, we will use NGEE Arctic observations of above- and belowground plant traits collected from across the tundra since the onset of the project to determine whether leaf and root traits co-vary along a predicted whole-plant economics spectrum (Reich, 2014). These functions will be applied to maps of aboveground functional traits (Serbin et al., submitted) to enable the prediction of belowground traits using multiscale remote sensing. If successful, this approach could then be applied to pan-Arctic trait databases (i.e., the Tundra Trait Team database, Bjorkman et al., 2018b; see Appendix for Letter of Collaboration) to facilitate the development of novel, pan-Arctic maps of belowground plant traits (see sidebar next page).

Task 3.3B: Scaling and mapping of Arctic plant trait variation across space and time

We will continue to develop and apply novel leaf- and canopy-scale algorithms to link a host of Arctic plant traits to remote-sensing signatures (Serbin et al., submitted). We will also leverage direct trait-trait, trait covariance, or above-belowground trait links to provide the capacity to upscale these relationships across space and time through the combined use of continuous and discrete remote-sensing data products. Our existing "spectra-trait" models will be applied to locations across the Seward Peninsula to provide rich descriptions of leaf trait variation. We will also focus on capturing temporal variation in key leaf traits (e.g., leaf N and $V_{c,max}$) through the application of our spectra-trait model over the growing season. We will continue development of canopy-scale spectra-trait models and apply these to remotely sensed measurements from our UAS platforms and existing NASA ABoVE AVIRIS-NG hyperspectral imagery to provide landscape- (e.g., Shiklomanov et al., 2019) to watershed- (and larger) scale descriptions of Arctic plant trait variation (e.g., Figure 11) through space and time. In addition, a machine learning-based multiscale, multi-platform remote-sensing approach developed during Phase 2 (Langford et al., 2017) will be expanded to all NGEE Arctic field sites to develop site-specific maps of Arctic PFT distributions. Multi-platform remote-sensing data will also be used in conjunction with environmental data to detect the impacts of changing environmental conditions on vegetation growth (e.g., phenology, greening and browning).

Deliverables: We will provide empirical linkages between above- and belowground plant traits to inform belowground trait mapping, as well as improved understanding of the seasonality of tall shrub growth, nutrient acquisition, and interaction with the snowpack. We will also improve understanding of aboveground plant trait variation from near-surface to regional scales, develop multiscale, multi-platform remote-sensing data products of Arctic PFT distributions, and direct and remote-sensing-based characterization of the biotic and abiotic drivers of Arctic plant trait variation.

SYNTHESIS: A PAN-ARCTIC PERSPECTIVE

NGEE Arctic has participated in several international synthesis efforts through the Permafrost Carbon Network, the Tundra Trait Team, and the sROOT working group within the German Centre for Integrative Biodiversity Research (iDiv). These international collaborations have leveraged NGEE Arctic observations to better understand the balance of CO_2 and CH_4 efflux from warming tundra soils (Treat et al. 2015; Schadel et al. 2016); to understand the genomic variation of tundra plants and the representation of tundra plant traits within plant functional types (Wullschleger et al. 2014; Wullschleger et al. 2015); to develop a pan-Arctic plant trait database (the Tundra Trait Team database, Bjorkman et al., 2018a); and to better understand pan-Arctic variation in aboveground- (Bjorkman et al., 2018b; Thomas et al., 2018) and belowground tundra plant traits (Iversen et al. 2015; Iversen et al. 2017).

In Phase 3, we propose to extend these international collaborations and synthesis activities. We will leverage NGEE Arctic observations, along with observations from our international partners across the globe, to answer timely questions related to plant trait variation across the pan-Arctic. For example, what is the pan-Arctic trait space occupied by high-latitude alder, and how should N fixation be represented in models? Do leaf and root traits co-vary along a whole-plant economics spectrum, and can novel, pan-Arctic maps of belowground plant traits be developed using multi-scale remote sensing?

Task 3.4: How does the synthesis of existing observations into model frameworks reduce predictive uncertainty and guide ongoing modeling needs?

Process models encapsulate our best understanding of the connections between vegetation structure and function (i.e., plant traits) and ecosystem-scale cycling of C, water, and energy (Fisher et al., 2014). Demographically enabled ecosystem process models (e.g., Moorcroft et al., 2001; Fisher et al., 2015; Fisher et al., 2018) facilitate incorporation of process understanding and trait observations into predictive frameworks capable of projecting how climate, disturbance, and other global changes will affect plant competition, succession, distribution and growth as well as related biogeochemical cycles through time and space. However, numerous challenges exist in parameterizing models for high-latitude Arctic ecosystems that have historically been severely data limited (Schimel et al., 2015). Improving the predictive capacity of our model projections is a critical motivation of NGEE Arctic; therefore, we will undertake a formal iterative approach to facilitate critical feedbacks between data synthesis activities, ongoing plant trait observations, and model structural and process improvements.

Task 3.4A: Guiding model parameterization and development needs

Model-data synthesis via uncertainty quantification (UQ) and variance decomposition (VD) tools (e.g., Dietze et al 2014; Raczka et al., in press) will be used to inform model parameterization needs and identify key remaining sources of model predictive uncertainty. This work will prioritize model development and research efforts as well as reduce uncertainties related to the representation of plant traits to maximize model fidelity. In addition, these tools will be used to test and efficiently parameterize new Arctic PFT descriptions using ongoing plant trait measurements and enable examination of model outputs in relation to proposed PFT descriptions. These tools will also enable us to compare different model representations and predictive capacity to identify trade-offs in complexity versus parsimony.

Task 3.4B: Integrating Arctic plant traits into improved land surface model simulations

Model simulations will integrate measurements of plant traits and their variations using a spatial hierarchical approach, starting with single-point simulations and then expanding to larger scales. Single-point simulations will leverage the unique characteristics of the NGEE Arctic field sites to drive targeted model improvements. Point simulations of Utqiaġvik will use plant trait measurements including photosynthetic physiology, leaf phenology, and root allocation to improve Arctic PFT parameterization across the polygonal landscape. Point simulations of the Kougarok hillslope will focus on the role of N-fixing alder shrubs in biogeochemical cycling and will include development of a new N-fixation module within ELM. Single-point simulations for each site using contemporary conditions will be evaluated using both *in situ* measurements and remotely sensed observations. Simulations using projected changes in climate at each site will then be conducted to project changes in plant function and biogeochemical cycling. Spatially-explicit simulations at the landscape scale to evaluate model performance across environmental gradients will be conducted using spatial data products from previous (e.g. Langford et al., 2016) and ongoing work. Concurrently, the new model developments will be integrated into ELM simulations covering the pan-Arctic region, where the Tundra Trait Team database of more than 92,000 tundra plant observations will be used to inform parameterization of plant functional types (Bjorkman et al., 2018b; see Section 10 for Letter of Collaboration).

Deliverables: We will quantify key parameter and structural sources of model uncertainty and identify the key measurements needed to constrain model uncertainties. We will improve parameterization of Arctic PFTs and N fixation processes and conduct site-scale, landscape-scale, and pan-Arctic ELM simulations of vegetation and biogeochemistry under contemporary and future conditions.

QUESTION 4. HOW WILL SHRUB DISTRIBUTIONS CHANGE AND GENERATE CLIMATE FEEDBACKS WITH EXPECTED CLIMATE WARMING IN THE 21ST CENTURY?

Feedbacks generated by changing distribution of Arctic vegetation contribute large uncertainty to climate predictions. This is because most ESMs inadequately represent dynamic vegetation processes or Arctic-specific PFT representations. Observations show increased shrub growth and colonization with regional warming (Sturm et al., 2001a; Tape et al., 2006; Myers-Smith et al., 2011; Frost et al., 2014); as climate warms, shrubs may become more widespread (Euskirchen et al., 2014; Buntgen et al., 2015). Shrubs affect climate, via albedo, C storage, energy and water fluxes, N cycling, interactions with snow and moss, and fuel for fires (Chapin et al., 2005; Swann et al., 2010; Cahoon et al., 2012; DeMarco et al., 2014; Sturm et al., 2001b; Berner et al., 2013; Blok et al., 2015; Chae et al., 2015; Weintraub and Schimel, 2005; Hiltbrunner et al., 2014; Bonfils et al., 2012; Zhang et al., 2018).

Future climate feedbacks will depend on how quickly vegetation patterns change in response to warming. Predicting such changes is difficult, however, because they are affected by more than climate per se. For example, shrub expansion is influenced by soil and hydrologic conditions, biogeochemical cycling, and disturbance (Myers-Smith et al., 2011, Naito and Cairns 2014). In tackling this challenge, NGEE Arctic brings to bear new understanding of landscape evolution, plant traits, and disturbance within an advanced modeling framework. Question 4 is addressed in four sub-tasks that progress from (1) benchmarking models against current and historical observations; (2) understanding and representing shrub growth in models; (3) quantifying and scaling how shrubs influence climate; and (4) integration of robust predictions of future climate effects on Arctic shrub ranges and vice versa.

Task 4.1: How well do land models represent present day and trending distributions in Arctic vegetation types?

To advance dynamic global vegetation model predictability, we must evaluate model performance against observations. Building on fine-scale characterization data and maps (Langford et al., 2017) in Phase 2 and new NASA collections, we will develop additional products to enable improved mapping of vegetation communities, as well as geomorphic and climatic influences on those communities over time. We will leverage ILAMB (International Land Model Benchmarking Project) and develop metrics to assess how new model representations affect the ability of models to capture contemporary vegetation distributions.

Task 4.1A: Produce observation-based maps of vegetation and vegetation traits

We will continue to develop maps of vegetation distributions, traits, and ecoregions (Hoffman et al., 2013; Langford et al., 2017). For the Seward Peninsula, we will employ remote sensing (e.g., WorldView2/3, MODIS, Landsat) with historical photos and data, ground-based spectral data, LiDAR, and additional field data. Recent AVIRIS-NG flights by NASA ABoVE have produced data that will be analyzed and incorporated. We will create data products representing trends in land cover, vegetation status, and phenology for Alaska and the pan-Arctic domain and evaluate model results in the context of multiple project hypotheses (e.g., Q3, Q4, and Q6).

Task 4.1B: Develop representations of dynamic Arctic vegetation for ELM-FATES

To predict future shrub distributions and climate feedbacks, a dynamic vegetation framework in an ESM is required. E3SM is developing a demographic, trait-enabled vegetation model (ELM-FATES) embedded in the land surface scheme (Fisher et al., 2015; Holm et al., submitted). For the proposed work, we will integrate arctic vegetation traits necessary to represent arctic tundra systems. We will leverage the ongoing E3SM/CMDV-supported effort to integrate nutrient dynamics, plant hydraulics, and boreal forest PFT representations in ELM-FATES. We will build on this framework to develop five Arctic shrub types, including N-fixing alder. Data for parameterization will be drawn from literature and NGEE Arctic observations for (1) demographic traits from Task 4.2A; (2) functional traits, allometry, and alder in ELM from Q3; and (3) subcanopy optical properties and size-structure from Task 4.3A. Testing will utilize NGEE Arctic vegetation maps, albedo, LAI, height distributions, and other data from Q1, Q3, and Q4. By leveraging E3SM and multiple NGEE Arctic products, we will produce new Arctic vegetation types, simulate current and future distributions, and evaluate model performance. Further, leveraging the large group working on ELM-FATES (e.g., through NGEE Tropics and other DOE- and NSF-funded efforts) and the two well-tested and different dynamic vegetation models being applied in this project will ensure a broad range of concepts and capability integration.

Task 4.1C: Simulate current and historical vegetation distributions

We will predict current vegetation distributions with ELM-FATES, *ecosys*, and TEM at the Alaska scale and recent historical trends in regions with an observational record. In addition, vegetation will be modeled and evaluated at finer scales for sites with rich observational datasets, such as the Seward Peninsula sites. For TEM we will continue analyses at the site level, with the addition of alder and other shrub communities (e.g., tall vs. shorter shrubs). We will apply ELM-3D (Bisht et al., 2018) and *ecosys* to predict hillslope vegetation cover and compare with observations.

Task 4.1D: Establish benchmarking protocols and compare observed and simulated vegetation

We will synthesize current vegetation distribution products (Task 4.1) and incorporate them, along with plant trait data, and other measurements (Myers-Smith et al., 2011), into ILAMB to quantitatively assess model predictions (Task 4.1C, see sidebar). We will compare predictions of current and recent vegetation distributions to several data products including the Circum-Arctic Vegetation Map (CAVM; new version slated for delivery in 2019) and LANDFIRE-Fuel Characteristic Classification System (FCCS) Maps in collaboration with NASA ABoVE. We will evaluate simulated shrubification with observationally inferred changes in cold-temperature limitation (Keenan and Riley, 2018) and with observed greening (Zhu et al., 2016; Mao et al., 2016). Since we hypothesize that landscape hydrology is a dominant control on shrub growth and distribution, new fine resolution (e.g., hillslope, watershed) benchmark data from Q1, Q3, and Q5 for Seward Peninsula sites, including field observations (e.g., biomass, NPP, LAI) described in Task 4.1A and high-resolution products from NASA ABoVE to test ELMv1-3D and *ecosys* predictions. New benchmarks will be used to evaluate ELM-FATES, *ecosys*, and TEM at regional to pan-Arctic scales and to evaluate relative contribution of different PFTs to LAI, biomass, and NPP.

A SYSTEMATIC APPROACH FOR MODEL BENCHMARKING (ILAMB)

NGEE Arctic develops and tests model parameterizations of ecosystem function and responses to environmental change that must be rigorously evaluated through comparison with observations and synthesis data. To systematically benchmark model performance, the International Land Model Benchmarking (ILAMB) framework was adopted. Developed within DOE-CESD with international community engagement (Hoffman et al., 2017), the open source ILAMB package performs comprehensive model assessment across a wide range of land variables and generates a hierarchical set of web pages containing statistical analyses and diagnostic figures designed to provide insights into the fidelity of models (Collier et al., 2018). It scores performance across multiple models or model versions for rapid discrimination of differences or changes in model predictions.

In Phase 3, we will increase use of ILAMB for constraining model predictions and extend its capabilities for pan-Arctic model assessment through incorporation of new observational and synthesis data sets. For example, remote sensing and in situ measurements of vegetation distributions, biomass, and phenology for the Seward Peninsula, ABoVE domain, and pan-Arctic will be integrated into ILAMB to benchmark simulations of evolving vegetation properties from the ELM-FATES, *ecosys*, and TEM models. Functional relationships across multiple variables will provide insights into mechanisms and constraints on ecosystem processes. New evaluation metrics, along with data, will be contributed to the community for use in ILAMB, making NGEE Arctic data immediately useful to modelers.

Deliverables: (1) Data products synthesized from remote sensing and in situ measurements for vegetation distributions, biomass, and phenology for the Seward Peninsula, ABoVE domain, and pan-Arctic; (2) New evaluation metrics and data products incorporated into ILAMB and used to benchmark model simulations of vegetation distribution, biomass, and structure; and (3) Dynamic arctic plant functional types implemented and tested in a demography-enabled model (ELM-FATES).

Task 4.2: What controls rates of shrubification and current and future distributions of shrubs?

Shrubs occur throughout most of the Arctic biome, with highest densities in the warmest subzone. While temperature is a dominant control, shrub cover is also influenced by many other factors. To focus our study of shrub dynamics, we are identifying processes and conditions that exert dominant control over changes in shrub cover and *rates* of shrubification. We are advancing prediction of shrub distributions by conducting literature synthesis and strategic field surveys and experiments—continued from Phase 2—and applying these to develop dynamic Arctic shrubs types in ELM-FATES for Earth system modeling.

Task 4.2A: Seedling recruitment: Experiments and surveys on thermokarst, fire, and warming

We are investigating the controls on seedling establishment because recruitment is considered a likely bottleneck for shrub expansion (Myers-Smith et al., 2011; Gough et al., 2015; Angers-Blondin et al., 2018). We are conducting surveys and experimental manipulation of seedling density and litter/moss cover across wildfire and thermokarst gradients on the Seward Peninsula and passive warming in Utqiaġvik. Plots established in 2017 and seeds sown in Phase 2 (See Progress Section). We will census rates of establishment across disturbance regimes and north of current shrubline. Alongside Q3 study of growth traits, we will study demographic traits for three tall shrub species (*A. viridis*, *B. glandulosa*, and *S. pulchra*). This work will produce knowledge about the controls of shrub recruitment and establishment, including species-specific responses to warmer temperatures and seed-bed disturbance from fire. It will also produce demographic trait data for incorporation into dynamic vegetation models like ELM-FATES.

Task 4.2B: Evaluate representations of Arctic vegetation dynamics and sensitivity to climate

We will explore the influence of climate on shrub growth and properties in three main ways. First, we will synthesize knowledge and literature (e.g., Myers-Smith et al., 2011; 2015) about the processes controlling change in shrub cover and type (e.g., deciduous versus evergreen), like recruitment, competition, and mortality, and compare this process understanding with how a broad range of land models represent shrub dynamics. This analysis will identify priorities for new studies and model development and will provide concrete approaches for the ELM-FATES shrub development.

Second, to develop observationally constrained estimates of near-term shrub expansion potential and benchmarks for model evaluation, we will generate statistical relationships for environmental influences on tundra shrub expansion. We will quantify how environmental conditions (e.g., topography, soil properties, deep bedrock, air temperature, precipitation, snow) explain variation in shrub expansion under present conditions, in collaboration with ABoVE. Finally, we will explore the sensitivity of predicted shrub growth, recruitment, and expansion in ELM-FATES, *ecosys*, and TEM to climate, ecosystem properties, plant properties and disturbance characteristics such as fire intensity. We will also analyze how competition for light, water, and nitrogen across community types affects vegetation distributions.

Deliverables: Synthesis of literature and NGEE Arctic results on the dominant controls of changing shrub distributions and how models represent these processes. Assessment of the climatic and ecological factors influencing vegetation distribution in a subset of dynamic vegetation models (e.g., FATES).

Task 4.3: How do shrubs influence C, water, and energy fluxes in Arctic Landscapes?

A critical step in understanding vegetation-atmosphere interactions is quantifying the surface properties and fluxes associated with vegetation, including albedo, ET, CO_2 flux, and canopy interactions. We will address plant influences on hydrology (e.g., ET, snow distribution; Pearson et al., 2013); energy budget and thermal regime (e.g., snow thickness and seasonal albedo; Sturm et al., 2001); and biogeochemistry (e.g., Weintraub and Schimel 2005, DeMarco et al., 2014). Moreover, analyzing the climate impacts of shrub dynamics requires scaling observations over individual, community, watershed, and regional scales.

Task 4.3.A: Near-surface characterization of shrub structure and energy exchanges

To characterize fine-scale surface properties of shrubs we will utilize near-surface (i.e., canopy, tower, and UAS) field measurement systems developed in Phase 2, with campaigns conducted along vegetation and environmental gradients. UAS sensing of vegetation albedo, plant optical properties, vegetation structure and thermal properties will be used to quantify patch- to watershed-scale relationships with vegetation communities, structure, and functioning. Ground- and remote-sensing data will be used to derive shrub density, height, and patch size. At Council we will link vegetation spatial patterns with fluxes by eddy covariance C and energy flux measurements (e.g., DuBois et al., 2018).

Arctic plant phenology and snow-vegetation interactions help regulate arctic energy budgets and snowmelt. Along with continuous tower-based phenology measurements, we will conduct ground-based and UAS campaigns on surface optical and thermal properties in the spring and fall shoulder seasons, coordinated with Q5. We will start at Kougarok and extend to Council and Teller (snow surveys in 2017 and 2018). Landscape-scale albedo will be estimated from Landsat temporal composites (He et al., 2018) and ground measurements. These relationships will inform ELM-FATES albedo simulations tested at Teller and Kougarok hillslopes. Results will be combined with information on plant traits (Q3), landscape patterns, and terrain features to generate a dataset for improving surface energy balance and radiative transfer modeling (Alton et al., 2007; Pearson et al., 2013; Juszak et al., 2014).

Task 4.3B: The NGEE-ABoVE collaboration on watershed to regional scaling

The NASA ABoVE project and its airborne campaign data provide important research opportunities for NGEE Arctic focused on functional trait scaling (Q3), vegetation mapping (Q4), soil moisture (Q5), and analysis of fire and vegetation cover (Q6). We will integrate ABoVE AVIRIS-NG overflights in 2017 and 2018 with multiscale NGEE Arctic observations to quantify the role of shrubs on surface reflectivity, albedo, and energy balance (see sidebar). We will scale Arctic vegetation reflectance and albedo from plant to watershed scales. The impacts of spatial and temporal scales and vegetation composition, structure, and topography (using the 2 m Arctic DEM product) on the retrievals will be explored. We will leverage remote-sensing datasets including NGEE Arctic UAS flights, ABoVE AVIRIS-NG, Landsat, and MODIS. These maps will be combined with products from Task 4.1A and Task 4.3A to assess differences in retrievals across PFTs and topographic features. We will derive products to characterize seasonality of vegetation surface reflectance, albedo, and phenology on watershed and larger scales and evaluate these using mid-season ABoVE data and our detailed surface measurements at key phenological stages. We will utilize AVIRIS-NG images to build watershed-scale trait and other

NGEE Arctic and NASA ABoVE Collaboration in Phase 3

Working together, NASA ABoVE and NGEE Arctic are linking ground and UAS measurements with coordinated remote sensing by SAR and AVIRIS-NG to answer key questions about drivers of change in arctic carbon, energy, and water flows. This includes deconvolving how surface albedo relates to landscape features such as vegetation type, structure, moisture status, and topography. We will map vegetation biophysical properties and functional traits (DuBois et al., 2018) to test whether models accurately produce patterns across important below- and aboveground and disturbance gradients (Dafflon et al., 2017). New synthetic decadal time series observations will be used to test the ability of models to recreate greening and browning trends, hotspots of change, and their drivers. Thus, this collaboration will extend process-understanding from NGEE Arctic intensive sites to the larger pan-Arctic domain of interest and enable model-data interactions not possible for either project alone.

biophysical maps and work with ABoVE investigators and additional image collections to generate regional-scale maps, expanding on the results of Task 4.1 and Q3.

Task 4.3C: Observations and modeling of the impact of current Arctic vegetation on C, nutrient, water, and energy fluxes

Latent heat, sensible heat, CO_2, and CH_4 fluxes will be measured by eddy covariance at Council (description in Q2) along with chamber-based measurements in the tower footprint. Chamber measurements in different vegetation communities and thermokarst conditions, collected 2016–2018, will be analyzed to produce new model constraints. Land-atmosphere exchanges for extant vegetation distributions will be modeled, and we will benchmark predictions of latent heat, sensible heat, albedo, and CO_2 and CH_4 exchanges and evaluate the effects of plant traits, relative abundance of PFTs, and shrub-moss interactions. For the latter, we will quantify the impact of moss on thaw depth, soil temperature, moisture, and decomposition. This analysis will be aided by the well-tested moss PFT in *ecosys*, which will be leveraged along with development of moss in ELM (Q3) to develop moss in ELM-FATES. We will use multiscale observations of vegetation structure and ecosystem properties to benchmark model outputs over observation periods.

Deliverables: Detailed characterization of vegetation impacts on surface energy balances from fine to regional scales in collaboration with NASA ABoVE. Quantitative relationships between individual plant traits and community-to-watershed scale land-atmosphere exchanges. Multiscale model benchmarks for surface energy balance, thermal properties, albedo, and community-level GHG fluxes.

Task 4.4: How will Arctic shrub distributions and resulting C, water, and energy fluxes change over the 21st century, and what are the major uncertainties?

The impacts of 21st century shrubification on Arctic C, water, and energy budgets are very uncertain. Therefore, the goals of Task 4.4 are to (4.4A) use high-latitude ecosystem models to predict 21st century changes in Arctic shrub and associated vegetation (e.g., shrubs, moss, sedge, lichen) productivity and distributions; (4.4B) predict surface energy and C budgets and quantify controls on those budgets; and (4.4C) quantify uncertainties in these predictions.

Task 4.4A: Predict how vegetation distributions will change under future climate

We will use three structurally different ecosystem models (ELM-FATES, *ecosys*, and TEM) to project vegetation distributions over the 21st century. ELM-FATES will be developed for application in tundra in Task 4.1B, which is important to achieve the NGEE Arctic goal of developing an ESM-scale representation of terrestrial processes for the high-latitudes. *ecosys* has mechanistic representations of the dominant processes for vegetation competition which we will leverage for ELM-FATES tundra development and for further analysis. TEM has been specifically developed for the Arctic and boreal ecosystems of Alaska and Northwestern Canada. As with ELM-FATES and *ecosys*, the most recent version of TEM includes dynamic organic soil layers in permafrost soils and detailed dynamic vegetation representations, with competition among PFTs for water, light, and nitrogen. The models will be run from the historical period through 2100, and predictions of changes in vegetation distributions will be compared and analyzed. In conjunction with Q6, we will evaluate the effects of wildfire on vegetation distributions through 2100.

Task 4.4B: Analyze C, water, and energy impacts from 21st century vegetation changes

For the predicted vegetation changes in 4.4A, we will analyze the impacts on C, water, and energy exchanges. We will apply RCP4.5 and RCP8.5 climate scenarios (e.g., temperature, precipitation, CO_2; e.g., Mekonnen et al., 2018a, b; Tang and Riley, 2018) to individually and jointly characterize system responses and how those responses vary from the fully forced simulations (e.g., Koven et al., 2015). We will analyze the underlying process responses (e.g., warmer air temperature increasing thaw depth and therefore water and nutrient availability) at site-, Alaska-, and pan-Arctic scales; compare results across the three models; and assess needed process representations and parameterizations for ELM-FATES. Finally, since long-term effects of vegetation change on soil C fluxes are difficult to quantify with short-term experiments or gradients (Bouskill et al., submitted), we will also test the hypothesis that short-term warming experiments estimate much higher emergent soil C temperature sensitivities than would be predicted when including longer-term effects of temperature on soils mediated by vegetation.

Task 4.4C: Determine and analyze uncertainty in 21st century predictions

A key challenge in ecosystem modeling is determining how parameter and structural uncertainty influence model results. We propose to use the Predictive Ecosystem Analyzer (PEcAn), a tool developed to perform model parameterization, error propagation, and error analysis (LeBauer et al., 2013; Dietze et al., 2014; Raczka et al., in press). With PEcAn, the models can be run with the same climate forcing, domain, and when possible, input parameters and evaluated against a common set of observations. We will explore uncertainties and differences in model projections based on their assumptions, complexity, and scale. ELM-FATES and TEM have been integrated with PEcAN; *ecosys* will be integrated for this task. This effort will address whether (1) the models are sensitive to similar parameters; (2) how model parameter sensitivity varies by ecosystem type and location; (3) the impacts of model structure in depicting vegetation and soil dynamics on prediction outcomes and uncertainty; and (4) what future data collection would be most beneficial for overall predictability.

Deliverables: Predictions of Arctic vegetation changes across the 21st century and of the resulting C, energy, and water exchanges with the atmosphere. Quantification of structural and parametric uncertainty associated with each model's predictions.

QUESTION 5: WHERE, WHEN, AND WHY WILL THE ARCTIC BECOME WETTER OR DRIER, AND WHAT ARE THE IMPLICATIONS FOR FEEDBACK TO THE CLIMATE SYSTEM?

The spatial distribution and temporal dynamics of soil saturation, inundation and snow in Arctic landscapes drive subsurface and surface ecosystem responses, the C and water cycles and the local- to regional- scale energy balance. Even relatively small climate driven changes in thermal-hydrology may drive significant shifts in ecosystem response and vice versa (Andresen and Lougheed, 2015; Andresen et al., 2017). Permafrost enabled ESMs predict an overall drying of shallow Arctic soils by the end of the century due to increased summer ET and active layer depth (Lawrence et al., 2015). However, these predictions are highly uncertain due to variation and limitation in the representation of thermal-hydrology processes, including snow cover, across permafrost models (Andresen et al. submitted; McGuire et al., 2016, 2018). In Phase 3 we will complete observations of surface and subsurface thermal-hydrology across NGEE Arctic sites in the Seward Peninsula, and synthesize NGEE Arctic and other pan-Arctic data with national and international collaborators to develop permafrost-hydrology parameterizations for ELM. We will use our data in column, watershed and regional models to explore and unravel the complex interactions between landscape structure, vegetation, snow, permafrost and hydrology that determine the evolution of where, when and why the Arctic will get wetter or drier under changing climate. Finally, we will quantify the impact of improved representation of permafrost hydrology on feedback to the climate system in coupled ELM-E3SM simulations.

Task 5.1: What are the spatial and temporal interactions between snow, vegetation, and permafrost, and how do these interactions influence hydrology under current and future climate conditions?

We do not yet have a quantitative understanding of how projected Arctic greening through shrub expansion will interact with changing snow conditions to impact ground temperatures and permafrost hydrology. In Phases 1 and 2, we explored the relationships between snow and micro- and macro- topography, vegetation, and permafrost using diverse techniques (Figure 12) including automatic data collection (meteorological stations); in situ gridded and transect based surveys; ground-based geophysics; UAS mapping techniques and numerical modeling at sites in the BEO and Seward Peninsula (Wainwright et al., 2017; Jafarov et al., 2018; Chen et al., submitted). In Phase 3, we will finalize field- and modeling- based activities to develop snow redistribution parameterizations to examine interactions between snow climatology, permafrost hydrology and terrestrial ecosystem processes at watershed to pan-Arctic scales.

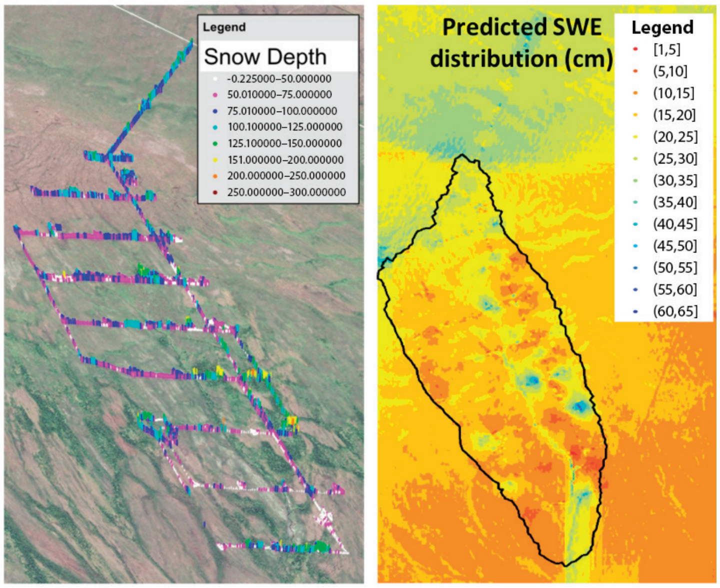


Figure 12. End of Winter snow depth and density surveys (left panel) are being used to develop physics-informed empirical watershed and regional snow redistribution models. A statistical model of SWE (right panel) derived from our 2017 snow survey at the Teller site, showed vegetation height was the biggest contributing factor to predicted snow depth.

Task 5.1A: Interactions between snow, vegetation, permafrost and hydrology across a range of ecosystem types and landscape scales

In collaboration with Q1 we will continue the end-of-winter (EOW) snow campaigns and ablation surveys that focus on collecting the primary variables required to inform our modeling activities. The EOW surveys will sample the dominant ecosystem and topographic types found at our research sites, as well impacts of predominant wind direction. We will scale our point measurements to produce watershed coverage using UAS and/or airborne LiDAR, photogrammetry and geophysical (GPR and EM) surveys. To expand our site-specific observational knowledge beyond the BEO and Seward Peninsula sites, we will collaborate with NOAA's new Alaska-wide snow-hydrology remote sensing and modeling project. Using these data, we will investigate robust, persistent signatures of ecosystem-based snow property and snow hydrology patterns and dynamics across a wide range of landscapes with which to build new snow distribution parameterizations for ELM.

Task 5.1B: The impact of vegetation patch- height, size, and density on snow properties and ground temperatures

Our Phase 1 and 2 field observations and models align with other studies (e.g. Myers-Smith et al., 2011) showing that snow distribution is altered in part by the presence or absence of shrubs and that snow timing, depth and duration of cover has a strong role on ground temperature. In collaboration with Q1, we will further refine the relationships that exist between snow, shrubs, ground temperature and hydrology by executing detailed gridded snow surveys within shrub patches of varying sizes and density at the EOW snow campaign sites. The sites will be instrumented with arrays of sensors to measure sub-surface temperature and soil moisture, and snow pack depth and temperature within shrub patches. These data will inform new models relating vegetation patch structure (e.g., plant type/size, plant arrangement/density, patch size) to snow accumulation/ablation, ground temperature and hydrology.

Task 5.1C: Snow-vegetation-permafrost interactions impacts on hydrologic processes

In Phase 2, data-informed modeling demonstrated that snow trapping in tall shrub patches can lead to through talik formation that activates abrupt changes in runoff sources and lateral groundwater flow in hillslopes (Jafarov et al., 2018) In Phase 3 we will use our hillslope and watershed scale models to develop quantitative relationships between snow climatology, ecosystem type distributions, permafrost continuity and watershed scale hydrologic responses. The simulations will be guided by Q5 hydrogeochemical datasets that characterize water sources, sinks, residence time, and pathways (surface, near surface and deep sub-surface) across the diverse eco-climatic regions represented by NGEE Arctic field sites. This task will integrate data and modeling across the NGEE Arctic Q3-Q4 science questions to investigate groundwater flow parameterizations for ELM that account for evolving talik driven by the interaction between Arctic greening and changing snow climatology.

Deliverables: Outcomes include: (1) watershed- to regional-scale snow benchmark datasets, (2) a dynamic snow redistribution model for watershed and regional scale land models, and (3) with Q1, watershed- to regional- scale assessment of coupled snow-vegetation-permafrost impacts on hydrologic pathways and processes.

Task 5.2: What are the primary controls on the spatial and temporal distribution of water pathways, fluxes and residence times in Arctic landscapes, and how will these change in the future?

The current generation of permafrost-enabled ESMs lack critical thermal-hydrology processes that control the evolution of the distribution of water in Arctic landscapes. In Phase 3 we will continue to focus on three missing components that significantly impact hydrologic states and dynamics in permafrost landscapes. These are: degradation of ice-rich permafrost in wet-tundra systems; interactions between surface and subsurface vertical and horizontal/lateral water pathways; and pond and wetland inundation dynamics. Phase 2 results show that improved models of these missing components require the development of comprehensive topographic, vegetation, and ground (soil, permafrost and bedrock) property datasets at watershed to regional scales (Atchley et al., 2016; Jan et al., 2018b; Painter et al., 2016; Jafarov et al., 2018). With Q1 we will build on previous multi-scale remote and in-situ observations to create benchmark datasets for the NGEE Arctic Seward and Barrow Peninsula watersheds and use these data with fine- and intermediate-scale models to develop parameterizations of these three missing components for ELM.

Task 5.2A: Evolution of hydrology in ice rich permafrost landscapes

In Phases 1 and 2 we developed and tested fine scale 1-, 2- and 3-D models of thermal-hydrology and deformation using a wide range of meteorological, geophysical and geochemical datasets developed across a gradient of high-center to low-center ice wedge polygons at the BEO. While most permafrost models are formulated as 1-D vertical columns, we learned through tracer experiments and 2-D modeling that lateral heat and water flux in the subsurface drives spatially and temporally diverse frost table and water level elevations toward uniformity across polygon features (centers, rims and troughs). In Phase 3 we will perform a "post mortem" of our tracer application experiment to better understand the role of subsurface soil structure and preferential pathways in the observed lateral redistribution of tracer. The sites will be trenched, mapped and sampled in collaboration with ANL's Julie Jastrow (see Section 10 for Letter of Collaboration), to develop soil and permafrost structure parameterizations that will be combined with ERT-derived ground properties to inform our tracer-enabled permafrost hydrology model. The model will be used to determine the relative importance of lateral versus vertical (1-D infiltration/evapotranspiration) water fluxes in watershed-scale soil moisture and inundation dynamics under current and future climate conditions. Wet tundra landscapes are projected to continue to experience active layer deepening, subsidence and thermokarst (e.g., Liljedahl et al., 2016). In collaboration with AWI (see Section 10), we will apply the Cryogrid model alongside the UAF Alaska Thermokarst Model (ATM) to explore how land deformation impacts hydrologic processes in ice-wedge polygon landscapes.

Task 5.2B: Evolution of hydrology in hilly, warm permafrost landscapes

In Phase 2, Q1 and Q5 researchers developed, tested and deployed emerging and conventional geophysical and geochemical observational techniques to characterize the structure of spatial and temporal variation in meteorology, permafrost, snow, soil moisture, runoff, and soil and vegetation properties at 3 hilly watersheds with conditions ranging from continuous to sporadic permafrost on the Seward Peninsula. In Phase 3 we will build on these data to develop contrasting benchmark datasets used to inform hillslope and watershed model simulations to examine the independent and interacting roles of climatology, meteorology, landscape structure, vegetation, and ground properties on permafrost hydrology. Through continuing collaboration with the NASA ABoVE project we will use in-situ and near surface watershed-scale datasets to produced regional scale benchmark products for ELM. We will also finalize observations on talik-driven fluxes of water, heat and solutes between shallow perched (above permafrost) and deep bedrock/diluvium hydrologic domains. We will collaborate with Q1 to characterize local to regional properties that control permafrost hydrology with a focus on identifying interactions between surface and shallow-to-deep subsurface flow paths. This will include soil and bedrock borehole thermal and hydrologic tests, time-lapse geophysical imaging, UAS-based imaging, distributed sensor networks, borehole monitoring, rainfall simulator responses, and environmental tracer dynamics (including stable isotopes). Since snow-vegetation interactions play a key role in ground temperature and through talik formation, we will integrate findings from Q1, Q5.1, Q5.2 and Q3 and Q4 snow tasks to inform watershed scale simulations using the ATS and *ecosys* models. The simulations will inform functional relationships between hydrologic response and the key watershed characteristics (topography, geology, soils, ecosystem types and permafrost) required to create new hydrologic parameterizations for ELM that include the influence of subsurface lateral fluxes.

Task 5.2C: Role of disturbance and extreme events on permafrost hydrology

Projected increases in Arctic tundra fire frequency and intensity, winter snow accumulation, and multi-year high temperature excursions, will drive significant changes in ground heat fluxes and the depth and persistence of the seasonal thaw layer. Resulting talik, thermokarst and thermal erosion may drive gullying of drainage networks, soil loss, and changes in ecosystem types and hydrology that result in temporal and spatial shifts in landscape wetting and drying at local to regional scales. In Phase 3 we will work with Q6, to determine the dominant interactions and between landscape disturbance, permafrost degradation, and hydrologic processes. We will carry out hydrologic experiments (e.g., small scale rainfall simulator) across chronosequences of fire and/or thermal erosion to explore impacts of disturbance on infiltration and runoff processes for mean and extreme precipitation events under current and future climate.

Deliverables: Outcomes include (1) watershed- to regional- scale soil moisture and inundation benchmark datasets, (2) assessment of role of warming and subsidence on soil moisture and inundation, and (3) characterization of factors controlling shallow and deep hydrologic pathways and processes for 5.3 ELM hydrologic parameterizations.

Task 5.3: At what spatial and temporal scales do changes in hydrology impact the regional climate system?

In Phase 2 we demonstrated that the diversity of representation of thermal-hydrology processes in the IPCC5 generation of permafrost-enabled land models caused widely divergent wetting and drying patterns in space and time across the pan-Arctic. Our model inter-comparison analyzed offline simulations forced with CMIP5 climate projections, and as such could not evaluate the impact of different hydrologic trajectories on feedback to the climate system at a range of scales. In Phase 3 we will use Phase 2 advances in snow and permafrost hydrology data and models to develop and implement parameterizations of currently ignored thermal hydrology processes in regional and global models and assess the impact of improved representations on the pan-Arctic C cycle, water cycle and energy balance.

Task 5.3A: Sensitivity analysis to evaluate the relative importance thermal hydrology processes

Using our fine- and intermediate-scale models developed in Phase 2 and enhanced in Phase 3, we will perform sensitivity analyses to explore the spatial and temporal scales at which improved representations of thermal hydrologic processes described above drive significant shifts at the watershed to basin scale for both: soil moisture and inundation patterns and dynamics; and, runoff generation mechanisms resulting in basin scale stream and river peak- and base- flow amounts and timing. We will focus on the following processes: (1) topography-snow-vegetation-permafrost interactions and deep flow path evolution, (2) lateral surface and shallow-to-deep subsurface runoff pathways, (3) topographic evolution (e.g., thermal erosion, subsidence, thermokarst) and its influence on soil moisture and inundation, (4) seasonal inundation dynamics, and (5) extreme events and disturbance processes (rain-on-snow, warm winter, extreme snow, wildfire intensification, thermal erosion, thermokarst).

Task 5.3B: Develop, implement and test new thermal-hydrology parameterizations for ELM

Processes and interactions that are deemed significant in influencing terrestrial system interactions, changes and thresholds at the basin scale will be further developed for implementation in ELM. In collaboration with ELM developers, the simulations for Task 5.3A will be designed in a manner that can be used to produce reduced order parameterizations of thermal hydrology processes that are readily adopted into the ELM snow and permafrost hydrology modules.

Task 5.3C Evaluate impact of improved hydrologic parameterizations on terrestrial feedbacks to the climate system

As a cross-cutting exercise with Q1, Q2, Q3, and Q4, we will use the new parameterizations developed in 5.3B, to investigate how new representations of basin scale thermal hydrology processes and responses interact with the other components of the terrestrial system. We will assess how snow, inundation, and lateral flow parameterizations in ELM interact with: (1) biogeochemical processes that control the timing, rates and quantities of CH_4 and CO_2 production and emissions, (2) the water and soil temperature constrained behavior of NPP and ecosystem demography, and, (3) albedo and ET, and their impact on sensible and latent heat fluxes.

Deliverables: Outcomes include: (1) quantification of relative importance of currently missing thermal hydrology processes in land models, (2) implementation of new parameterizations of thermal hydrology in ELM, and (3) quantification of the impact of improved representation of snow and permafrost hydrology on terrestrial feedback to the climate system using coupled ELM-E3SM simulations.

QUESTION 6: WHAT CONTROLS THE VULNERABILITY AND RESILIENCE OF ARCTIC ECOSYSTEMS TO DISTURBANCE, AND HOW DO DISTURBANCES ALTER THE PHYSICAL AND ECOLOGICAL STRUCTURE AND FUNCTION OF THESE ECOSYSTEMS?

Disturbances have the potential to effect profound changes on ecosystems. Biotic and abiotic processes, both natural and anthropogenic, can destabilize ecosystems from their ambient structure and function (Walker and Walker, 1991; Turner, 2010). Question 6 is a new question added in Phase 3 to better understand disturbance-driven changes to vegetation and ecosystem dynamics, shrub migration, and their biophysical feedback to climate to inform modeling efforts (US DOE 2018). This new question cross-cuts and integrates ongoing research from Q1 through Q5. In Phase 3, we will evaluate the response of Arctic ecosystems to pulse, or discrete, physical disturbances. We focus on wildfire, thermokarst and thermal erosion (i.e., ground surface subsidence and erosion resulting from permafrost thaw), and the interaction between the two as abrupt thaw is often triggered by wildfire which appears to be intensifying in the tundra region (Schuur and Mack, 2018).

Task 6.1: What are the dominant controls on the spatial and temporal patterns of historic disturbances in the Arctic, and what do these patterns reveal about the vulnerability of tundra ecosystems to disturbance?

We will use the historical record, field surveys, and remote sensing to identify the dominant controls on disturbance patterns across the climate gradient in Arctic Alaska from the Seward Peninsula north to the Arctic Coastal Plain. Through identification of these controls, we can assess vulnerability, or degree to which a system is likely to change in structure and function following a specific disturbance.

Task 6.1A: Identify the landscape attributes and antecedent climatic conditions associated with past occurrence of wildfire and thermokarst in the tundra region

We will analyze the historical record of wildfires in Arctic Alaska to understand trends in parameters such as frequency, return period, and area burned. To identify antecedent conditions and precursors to wildfire, we will examine concurrent environmental and biophysical data from the historical record for wildfire affected regions. Wildfire exhibits large spatio-temporal variability, so we will summarize results across the bioclimate gradient and for specific vegetation types that vary in flammability. Using available remote sensing datasets from satellite-based platforms and from NASA ABoVE (e.g., Loboda and Hall, 2017; Loboda et al., 2018; Pu et al., 2018) we will characterize patterns of post-fire vegetation recovery and succession. Remote sensing has the added benefit that it can detect small and short-lived wildfires that often go unreported in public fire databases (Langford et. al., 2018).

To identify controls on hillslope thermokarst, we will examine environmental and biophysical historical data for anomalous conditions of precipitation and temperature that may set the stage for thermokarst in select areas of Arctic Alaska where thermokarst is well mapped such as the Noatak Basin in northwest Alaska (Balser et al., 2014; Lara et al., 2019) and the northern Alaska (Jorgensen et al., 2006). For example, we will examine areas of anomalous early winter precipitation (snow insulation preventing summer ground heat from escaping) which are then followed by anomalously warm summer temperatures. We will then determine if these areas and timing correspond to the timing of thermokarst in the few well studied regions.

To identify the links between wildfire and thermokarst development, we will also conduct an investigation to determine subsidence rates due to thermokarst, combining remote sensing techniques and field surveys. Target areas will correspond to our Seward Peninsula field sites and a chronosequence network of wildfire- and thermokarst-affected landscapes (see Task 6.2), depending on availability of repeat Synthetic Aperture Radar (SAR) imagery and accessibility to the field. DInSAR (Differential Interferometry Synthetic Aperture Radar) will be performed using data from L-band SAR (ALOS-PALSAR, ALOS2) and C-band SAR (Sentinel-1). Field data collected for Task 6.2 will be used for evaluation and validation of the remote sensing analyses. Optical space-borne sensors capable of capturing ground objects in sub-meter spatial resolution will be used to capture thermokarst development through land surface texture changes.

Task 6.1B: Identify where on the landscape is most vulnerable to future wildfire and thermokarst disturbance

Understanding of wildfire and thermokarst precursors in Arctic Alaska (from Task 6.1A) will be used to assess the vulnerability of larger landscapes to future disturbance. For wildfire, lightning is the primary natural ignition source in the tundra, although its occurrence is difficult to predict. Under projected future climate conditions, vegetation distributions, and soil moisture we will evaluate where the landscape is vulnerable to wildfire and develop probabilistic fire risk maps if an ignition occurs. These maps will identify regions and vegetation types likely to burn, potential burn area and severity, and thus potential impacts on the C cycle. For thermokarst, ground ice is the primary predictor of vulnerability to thaw. Under projected future climate conditions, we will use surface properties, such as vegetation type, slope and microtopography, to identify regions and vegetation types likely to experience thermokarst to develop probabilistic thermokarst risk maps. These analyses will be conducted at various scales and resolutions for the Seward Peninsula and in the larger Alaskan Arctic domain in general, depending on availability of climate, environmental, and remote sensing datasets.

Task 6.1C: Determine attributes of tundra ecosystems to incorporate into the ELM fire model and ATM thermokarst model to apply or improve their application to tundra ecosystems

We will identify process representations, based on the results from Tasks 6.1A and 6.1B, that need to be incorporated into the ELM fire model to apply to tundra ecosystems and to improve the ATM thermokarst model. For example, parameterizations that capture how landscape change and transitions impact how water is redistributed on the landscape are inadequately described and require further development and testing. A sensitivity analysis of ELM and ATM will be conducted to determine which parameters are required for a broader range of Arctic ecosystems.

Deliverables: We will provide current and potential future probabilistic wildfire and thermokarst risk maps and conduct sensitivity analyses for ELM and ATM.

Task 6.2: How resilient are Arctic ecosystems to wildfire and thermokarst disturbance?

A critical component to understanding changing disturbance regimes in the Arctic is to determine the level of resilience, or the capacity of the physical and ecological system to maintain or recover its structure and function after perturbation. The resilience of polar ecosystems is not well characterized (Bolter and Müller, 2016), although that is changing particularly in the Arctic with the recognition of the potential for significant anthropogenic disturbance resulting from new infrastructure, tourism, and changing land use. Ecological disturbances such as wildfire and soil subsidence and erosion resulting from thaw of ice-rich permafrost are often part of the ongoing successional cycle in tundra ecosystems. However, these climate-sensitive pulse disturbances appear to be increasing across the tundra region (Hinzman et al., 2015) and have the potential to alter the landscape distribution of successional ecosystem states and potentially lead to novel trajectories of change (Rowland et al., 2010; Schuur and Mack, 2018).

Task 6.2A: Measure and characterize the physical and ecological structure and function of disturbance affected landscapes across a chronosequence of sites that vary in time since disturbance and severity

Disturbance provokes change in the state of an ecosystem, including both quantifiable and qualitative changes to physical and ecological conditions in a defined area and is thus responsible for the resulting impacts and the systems-based implications of the impacts. We will establish a chronosequence network of wildfire- and thermokarst-affected landscapes on the Seward Peninsula where measurements of ecological, physical, and biogeochemical attributes will be used to characterize recovery patterns and compared to putatively undisturbed tundra. Our sampling design will allow us to quantify resilience and the timing associated with ecosystem recovery. Our suite of measurements will include (1) physical - microtopography, thaw depth, surface and soil moisture, seasonal surface displacement, ground ice content, active layer, and permafrost temperature; and (2) ecological - vegetation cover, soils, whole ecosystem flux, plant regeneration traits, demography, dispersal, and establishment. These data and our improved understanding of post-disturbance recovery will be used for model validation and improvement.

Task 6.2B: Measure fluxes of sediment, water, and geochemical constituents of disturbance affected landscapes across a chronosequence of sites that vary in time since disturbance and severity

At present, little data exists to relate the magnitude of sediment, water, and geochemical constituent fluxes to hydrological forcing. In addition to the ambient conditions of our chronosequence, we will perform experimental manipulations at paired locations to directly contrast the hydrological, erosional, and geochemical responses of landscapes with a range of disturbance severity and times since recovery. We will use small-scale (~4m × 6m) rainfall simulators to apply a controlled quantity of water to landscapes and measure both surface and subsurface fluxes generated. Water and sediment fluxes will be used to develop parameterizations for hydrological and landscape evolution models as functions of vegetation, burn severity, erosion and depth of thaw layer. Geochemical fluxes, both surface and subsurface, will inform how vegetation, burn severity, time since burn, depth of active layer detachments, and thaw depth change the seasonality and long-term fluxes on C and N from tundra ecosystems. Tracer studies will be used to quantify flow paths and site-scale hydrological properties.

Task 6.2C: Use ATS to quantify how disturbance related vegetation and soil properties change or alter the thermo-hydrological properties of the landscape

Building on Phase 2 simulations exploring interactions between permafrost, hydrology, thermal conditions, and shrub/snow interactions (Jafarov et al., 2018), we will use ATS to examine how, and for how long, changes in surface properties due to fire and loss of vegetation associated with thermal erosion will alter the thermal and hydrological state of permafrost. Specifically, we will explore the potential effects of wildfire-induced changes in surface albedo and the impacts that a loss surface insulation due to vegetation cover might have on the thermal regime of active layer soils and permafrost. A focus will be placed on identifying conditions that lead to loss of shallow permafrost, formation of near-surface taliks, or thermokarst formation.

Task 6.2D: Incorporate representation of permafrost into landscape evolution models to explore erosional feedbacks of disturbance-caused hydro-thermal and land cover changes on watershed structure and fluxes

No models that simulate landscape evolution currently incorporate the influence of frozen ground on hydrology or erodibility of the landscape. Many of these models, such as the ERODE model or LandLab suite of models, use simplified representation of physical processes to explore coupled interactions of hydrology, sediment transport, and in some instances vegetation. This modeling represents a first step toward simulating land surface dynamics in permafrost landscapes, in order to quantify the physical properties and climatic drivers that control system feedbacks that may propagate or dampen erosional disturbances across watersheds. Information gathered will ultimately inform ESM parameterizations. This modeling effort will incorporate parameterizations for water infiltration and erosion informed by results from 6.2B. We will also work with ATM and the coupling of ATM with ELM to explore these relationships between landscape evolution and hydrology (in collaboration with Q5).

Deliverables: We will provide the first comprehensive model validation datasets on impacts of fire and thermokarst on ecosystem function in Arctic tundra. We will also provide model capabilities and analyses (ATM, ATM + ELM, and landscape evolution models) for these dynamics.

Task 6.3: What are the cumulative impacts of disturbance and climate change on Arctic tundra ecosystems across various spatial scales, including thresholds?

Disturbances in vulnerable systems may cross thresholds that tip or direct them into new states because of transformations, where novel dynamics may emerge. We will investigate cumulative impacts and thresholds through field and modeling studies. The knowledge gained from Tasks 6.1 and 6.2 will be used for model improvement and development, and to produce local- to circumpolar model projections for future rates, distributions and impacts of disturbance on vegetation and ecosystem dynamics.

Task 6.3A: Model decadal- to centennial-scale ecosystem dynamics to identify threshold crossing responses

Observation and modeling efforts undertaken in Task 6.2 aim to identify and quantity system dynamics and process responses to disturbance. Depending on the ecosystem or process domain under investigation, it may take decades to centuries to understand whether a system will return to its pre-disturbance state, particularly under changing climatic conditions. We will use permafrost (GIPL), thermokarst (ATM), and full ecosystem (ELM-FATES, *ecosys*, and TEM) models to investigate long-term system responses to disturbance induced changes in ecosystem properties. For example, GIPL may be used to quantify how wildfire-driven changes in vegetation cover and hydro-thermal properties will impact active layer temperature and potential talik development under projected 21st century climate. Ecosystem models that include (*ecosys*) or are under development to include as a cross-cut with Q3 and Q4 (ELM-FATES), representation of vegetation dynamics will be used to evaluate how wildfire-driven successional dynamics alter ecosystem C, water, and energy exchanges with the atmosphere and affect soil thermal and hydrological dynamics. The fire model development in ELM is being accomplished via the E3SM Next Generation Development (NGD) project, in collaboration with UC Irvine.

Task 6.3B: Project likely temporal and spatial distributions of future disturbances and model their effects on ecosystem dynamics

Under the RCP8.5 climate scenario, projections using the *ecosys* model show increases in woody plants, N mineralization, and net C accumulation over the 21st century (Mekonnen et al., 2018). Lessons learned from these *ecosys* simulations in the Arctic will be used to inform experiments in the dynamic vegetation and demographic model ELM-FATES. Specifically, we will quantify how wildfire affects vegetation dynamics and thereby thermal, hydrological, and interactions with the atmosphere and ecosystem resiliency. In addition to ELM-FATES and *ecosys*, the ALFRESCO-TEM model will be used to investigate future vegetation distributions in response to disturbances including PFT recovery with a focus on recovery of lichens and mosses. In conjunction with wildfire modeling, a literature synthesis on expected 21st century fire regimes will be developed that considers projections of fire and lightning scenarios as a collaboration with NASA's ABoVE program.

Deliverables: We will provide new development and testing of several components of ELM-FATES. For example, working closely with the fire model development in ELM, we will focus here on representations in tundra systems for ELM-FATES. We will also leverage ongoing work with GIPL, TEM, *ecosys*, and ATM to improve biogeochemical, thermal, hydrological, and plant process representations in ELM-FATES.

6. MANAGEMENT PLAN AND TEAM INTEGRATION

BACKGROUND

The Next-Generation Ecosystem Experiments (NGEE Arctic) is a 10-year project (2012 to 2022) to reduce uncertainty in ESMs through developing a predictive understanding of C-rich Arctic system processes and feedbacks to climate. This is achieved through experiments, observations, and synthesis of existing datasets that strategically inform and enhance the knowledge base required for model initialization, calibration, and evaluation.

The NGEE Arctic project supports the BER mission to advance a robust predictive understanding of Earth's climate and environmental systems by delivering a process-rich ecosystem model, extending from bedrock to the top of the vegetative canopy/atmospheric interface, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the scale of a high-resolution, next-generation ESM grid cell.

In Phase 1 (2012 to 2014), NGEE Arctic tested and applied a multiscale measurement and modeling framework in coastal tundra on the North Slope of Alaska. Building upon research conducted in the first 3 years of the project, in Phase 2 (2015 to 2019) research was maintained at Utqiaġvik but also established a series of research sites near Nome in western Alaska (i.e., Seward Peninsula). These field sites are characterized by transitional ecosystems, warm, discontinuous permafrost, higher annual precipitation, and well-defined watersheds with strong topographic gradients.

In Phase 3 (FY2020 to FY2022), we expect to be in a strong position to conduct pan-Arctic simulations using a model that is parameterized and evaluated against a multiscale, nested hierarchy of measurements and synthesis products. Integration and a truly interdisciplinary perspective, forged by our team in Phases 1 and 2, will be foundational to Phase 3 activities and beyond as we use model sensitivity and uncertainty analysis and new process knowledge to guide computational, experimental, and observational efforts toward improved climate predictions in high-latitude ecosystems. Safety, collaboration, communication and outreach, and a strong commitment to data management, sharing, and archiving are key underpinnings of our model-inspired research in the Arctic.

PROJECT MANAGEMENT APPROACH

This Management Plan details the approach to Phase 3 activities for the period October 1, 2019 to September 30, 2022. The NGEE Arctic project involves multidisciplinary scientists, collaborating across several national laboratories and universities in the United States, growing and improving since 2012. The project resides within the Energy and Environmental Sciences Directorate (EESD) of Oak Ridge National Laboratory (ORNL) and is composed of a laboratory research director (LRD), a chief scientist (CS), technical project manager (TPM), and science teams, each of which has a science team leader (STL) and contributing research staff and collaborators. Institutional leads (ILs) have been designated to assist the LRD in planning and tracking budgets and deliverables across the science topic areas.

The project reports to and receives direction from D. Stover, Terrestrial Ecosystem Science Program Manager under the DOE Biological and Environmental Research Program.

PROJECT ROLES, RESPONSIBILITIES, AND AUTHORITIES

LEADERSHIP TEAM

The NGEE Arctic project is led by S. D. Wullschleger, who reports to M. Khaleel (Director of the Energy and Environmental Sciences Directorate, at ORNL). S.D. Wullschleger has established a Leadership Team to collaboratively provide the skills, insight, and integration necessary to successfully (1) execute this large multi-institution project, (2) develop proposals to further the objectives established by DOE BER, (3) address and evaluate new science questions, (4) act as the change control board during the life of the project, and (5) provide direct feedback to the project sponsor at DOE BER both at defined intervals and upon request. The NGEE Arctic Leadership Team is composed of the LRD, CS, TPM, STLs, ILs, and Data Manager (DM). Figure 13 shows the organizational chart and staffing for the NGEE Arctic project.

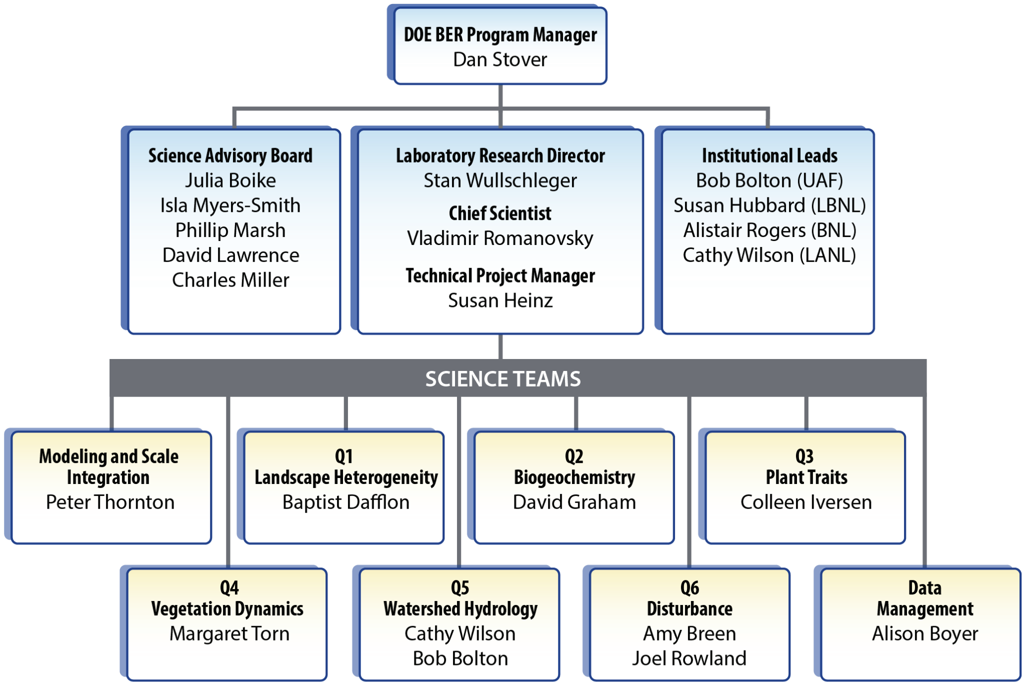


Figure 13. NGEE Arctic Organization Chart.

S. D. Wullschleger, as LRD, has overall responsibility for the NGEE Arctic project and serves as the single point of contact (POC) for direct communications with program managers at DOE BER. He has full authority to manage all aspects of the NGEE Arctic project with DOE approval and works closely with the TPM, CS and the STLs for updates of milestones/deliverables and financial reports. He creates the project performance vision and communicates expectations for compliance by all participants of the NGEE Arctic project members as they fulfill their assigned missions. He oversees capability and facilities development, including leadership and succession planning, national and international collaboration, and outreach. Responsibilities and authorities for all roles on the project team are listed in Table 1 in the following Teams and Integration section.

A Science Advisory Board (SAB) has been established, by the LRD, to provide input to the NGEE Arctic project LRD through review of plans, progress, and participation in periodic team conference calls and meetings. Members have been selected from the national and international community across a wide range of disciplines, including researchers in the carbon cycle and subsurface sciences, ecosystem and climate modelers, representatives from other state and federal agencies, data management specialists, and members who possess traditional knowledge of local native communities. We will rotate off any members who because of their association with the project become collaborators on the NGEE Arctic project. There are currently five members on the SAB: J. Boike (AWI, Germany), I. Myers-Smith (University of Edinburgh), P. Marsh (Wilfrid Laurier University), D. Lawrence (NCAR), and C. Miller (JPL). Membership will be modified in Phase 3 based on proposed scope of research and associated milestones.

The NGEE Arctic Chief Scientist is V. Romanovsky, from the University of Alaska, Fairbanks. The CS serves at the project advisor for the scientific direction and liaises with the national and international scientific community. The CS seeks, influences and nurtures existing and future collaborations.

The Technical Project Manager, S. Heinz, will monitor cost, scope and schedule for the project. The TPM will maintain awareness and plan for field campaign operations and logistics, generate regular reports, monitor deliverables, manage procurements and is responsible for ESH&Q.

Institutional Leads include B. Bolton (UAF), S. Hubbard (LBNL), A. Rogers (BNL), and C. Wilson (LANL). IL's regularly advise the LRD, track institutional budgets and deliverables, actively participates with planning and reviews and is responsible for resolution of staffing issues and performance concerns.

The STLs, including A. Boyer, D. Graham, C. Iversen, J. Rowland, P. Thornton, C. Wilson, and M. Torn, B. Bolton, B. Dafflon, and A. Breen are responsible for integrating activities within and across the science teams, gathering project data, generating regular reports, meeting safety and monitoring requirements, and managing deliverables and scientific performance.

Teams and Integration

Participants are responsible for conducting the planned studies and for meeting science team deliverables; assessing, presenting, and publishing results, including uploading data to the ORNL portal for the project, and mentoring postdoctoral associates, students, and guests.

The Data Management Team (DMT) is tasked to assist with all steps of the data life cycle. The DMT resides at ORNL and leads the project data management activities in coordination with Data Representatives at each of the partner institutions. Along with the upload of data, participants request a DOI to be assigned to their data as it matures for publication. Including the DOI in all publications related to the dataset helps to fulfill a sponsor requirement for data availability and tracking.

In addition to the leadership team, participants are assigned to science teams. Key participants are named and included in the following teams, with time allocations defined in Sections 12 and 13, "Budget" and "Budget Justification." Each team is committed to meet the deliverables listed within the Research Plan section of the proposal. Named researchers will be assisted by post-doctoral researchers at all institutions.

Table 1. NGEE Arctic project personnel's roles, responsibilities, and authorities

Role	Responsibilities	Authorities
Laboratory Research Director (LRD)	• Provide overall leadership for the NGEE Arctic project • Single contact point for DOE • Ensure project integration • Seek inputs from the core team; data, operations and finance managers • Capability development • Monitor deliverables	• Exercise full authority to manage all aspects of the project with DOE approval; approve yearly program plan and release budget; make requests to STL's, project manager for regular milestone/deliverable and finance manager for financial report documentation; data manager for input/ reports
Science Advisory Board (SAB)	• Advise on the scientific thrusts of the project • Review project plans • Review progress toward project goals	• Assess performance of the project R&D team • Assess scientific quality and discuss progress with project director and chief scientist
Chief Scientist (CS)	• Contribute to scientific direction of the project • Establish connections to national and international scientific community	• Represent NGEE Arctic project goals and objectives to larger Arctic science community • Seek out collaborations on behalf of the project

Table 1. NGEE Arctic project personnel's roles, responsibilities, and authorities (continued)

Role	Responsibilities	Authorities
Technical Project Manager (TPM)	• Field Campaign Operations management • Generate regular reports • Monitor deliverables • Subcontractor management • Provide financial management and reporting to project director, • Responsible for ESH&Q	• Manage planning documents including project time lines and work breakdown structure (WBS) • Request project information from the Core Team and report to project director • Request input from subcontractors for Project Director and STL • Assess research safety and quality plans
Institutional Lead (IL)	• Advise LRD • Track institutional budgets against deliverables • Assist with planning and reviews • Anticipate staffing issues and resolution of performance concerns	• Coordinate development of institutional task plan and budgets • Monitor institutional deliverables across science areas • Plan adjustments to project plan and budget allocations as appropriate
Science Team Leader (STL)	• Develop work plans to integrate activities within and across the project elements • Monitor deliverables and progress planned. • Conduct periodic reviews of their plan and adjust via the change control plan. • Track budgets against tasks and deliverables • Provide inputs for periodic reports • Mentor staff and facilitate collaboration	• Set objectives and deliverables for their focus area • Develop multi-year plans and annual scope of research to attain deliverables • Build and review budgets • Monitor progress and meet financial performance targets • Assess subcontractor performance
Key Task Leader	• Plan tasks to complete assigned Key Tasks as assigned by STL • Execute Key Tasks	• Develop work plans especially for Field Work • Consult with institutional safety support when planning work with new hazards.
Participants	• Execute scope of research consistent with proposal plan. • Investigators are responsible for data collection, documentation, upload and release. • Modelers are responsible for planning and modifying code, documenting, and uploading and releasing • All are responsible for record keeping, analysis, interpretation, and submission of required reports and publications	• Modify scope of work as appropriate in consultation with TL and/or STL • Alert appropriate STL or Project Director when problems arise
Data Manager	• Develop a data management strategy based on the resources allocated by LRD • Execute the data management practices • Seek input from QA manager for initial QA/quality control for data collected • Direct Data Representatives	• Request data status reports from STLs and data inputs from science teams with approved data reporting and archival procedures • Raise issues to metadata contact, STL, TL, or Data Representative if a data quality problem arises
Data Representative	• Serve as local data submission guidance support • Monitor Project Module and Metadata Database for potential data products and upcoming submission dates	• Liaison between local project staff and central DMT • Raises questions with appropriate project staff when metadata records have problems, submission dates are missed, and data issues arise • Consult data manager when problems arise

Table 1. NGEE Arctic project personnel's roles, responsibilities, and authorities (continued)

Role	Responsibilities	Authorities
Officer of the Day (Field Operations)	• Ensure that daily meeting occurs, everyone has a buddy, and return times are known • Gather weather information and bear reports. • Serve as point of contact to ORNL and other institutions in the event of an accident.	• Halt field work when weather or other hazards that could jeopardize participants arise. • Ensure that information is gathered from witnesses to any accident involving an NGEE participant in field locations

PROJECT SCOPE MANAGEMENT PLAN

The NGEE Arctic Phase 3 project scope baseline is described in Sections 5 and 7, Research Plans and Data Management Plan. This scope is a matrixed result of contribution from five institutions. The scope is in adequate detail to be foundational in building a solid science research plan and correlate cost and schedule for this period. A major Phase 3 milestone is to have a multiscale and high-resolution representation of Arctic tundra structure and function operating within the DOE's Energy Exascale Earth System Model (E3SM), and to have demonstrated the fidelity of that representation against a full suite of observational and experimental benchmarks as established by the Q1–Q6 activities and as synthesized from broader community efforts. Tasks, Milestones and Deliverables are addressed around these science questions in addition to the Integrated Modeling and Data Management activities.

Scope is developed, established and communicated through the integrated teams. This approach minimized delays, unnecessary work, failure to achieve deliverables, cost overruns and other unintended consequences.

- The LRD has authority and responsibility for the scope management and is supported by the TPM. STL's plan the baseline and decompose into detailed work, in coordination with the integrated teams. The IL's assume responsibility to ensure the matrixed resources are available and meet cost and schedule requirements.
- The initial Phase 3 scope baseline is documented in this proposal and will be detailed at the beginning of each fiscal year as a Statement of Work (SOW), considering progress or adjustments to research. The approved SOW and deliverables are added to the institution's procurement document.
- The scope is further decomposed into a work breakdown structure (WBS) and tasks are documented in the online collaboration project management tool Teamwork Projects.
- Quarterly and annually, the scope and deliverables are verified, and progress/changes reported. Change control process may be initiated.
- The LRD and Project Sponsor is responsible for accepting the final project deliverable and approves acceptance of project scope.

TASK/DELIVERABLE LIST

Section 5, Research Plan, and Section 7, Data Management Plan, outline the 3-year project baseline of tasks and deliverables for this Phase 3 period. The high-level WBS is listed below.

- IM.0: Integrated Modeling
- 1.0: Q1. How does the structure and organization of the landscape control permafrost evolution and associated C and nutrient fluxes in a changing climate?
- 2.0: Q2. What will control rates of CO_2 and CH_4 fluxes across a range of permafrost conditions?

- 3.0: Q3. How do above- and belowground plant functional traits change across environmental gradients, and what are the consequences for Arctic ecosystem C, water, and nutrient fluxes?
- 4.0: Q4. What controls the current distribution of Arctic shrubs, and how will shrub distributions and associated climate feedbacks shift with expected warming in the 21st century?
- 5.0: Q5. Where, when, and why will the Arctic become wetter or drier, and what are the implications for climate forcing?
- 6.0: Q6.What controls the vulnerability and resilience of Arctic ecosystems to disturbance, and how do disturbances alter the physical and ecological structure and function of these ecosystems?
- DM.0: Data Management and Community Outreach

SCHEDULE BASELINE AND WORK BREAKDOWN STRUCTURE

The collaborative Project Management tool, Teamwork Projects, will be used to develop the WBS for Tasks and Deliverables in this proposal. The WBS is a key project deliverable that organizes the team's work into manageable sections. Each task will be documented and detailed with milestones and due dates and accessible to the entire team. As progress is accomplished, it is documented and reviewed quarterly and annually and reported to the LRD, project sponsor and team.

CHANGE MANAGEMENT PLAN

During the remaining lifecycle of the NGEE Arctic project, we anticipate change against this project baseline to facilitate research progression. Science discovery and results will lead to optimal focus of final objectives. As described in the roles and responsibilities, the LRD serves as the change control board for the project and may delegate review of activities but will have overall responsibility for awareness and implementation. Change observations and requests may be evaluated at any time during the project but review of each task and deliverable will occur on a quarterly and annual basis. Assessment will include the use of triple constraint (cost, scope, schedule) impact assessment. Subsequent management and control of change will be documented and executed in concert with the team. Teamwork Projects software will serve as the log and library to document changes.

COMMUNICATIONS MANAGEMENT PLAN

Communication Type	Description	Frequency	Format	Participants/ Distribution	Deliverable	Owner
Final Project Report	Final project report of results, science highlights and suggested next research steps	Once, end of project	PDF	Sponsor, Team, Stakeholders	9/30/2022	LRD
Annual Reports	Annual report of progress with science highlights	Annual	PDF	Sponsor, Team, Stakeholders	7/30/2020 7/30/2021 7/30/2022	LRD
Quarterly Reports	Quarterly report of progress with science highlights	Q1, Q2, Q4	PDF	Sponsor, Team, Stakeholders	Q1, Q2, Q4: 2020 2021 2022	LRD
Website Updates	Update images, science highlights, media mentions and publications	Quarterly	Web	Global	Q1-4: 2020 2021 2022	TPM
Safety Field and Lab Manual	Annual updates to safety manuals	Annual	PDF	Project Team	6/30/2020 6/30/2021 6/30/2022	TPM

Communication Type	Description	Frequency	Format	Participants/ Distribution	Deliverable	Owner
Safety Training Module	Annual updates to the Safety Training Module	Annual	Web	Project Team	6/30/2020 6/30/2021 6/30/2022	TPM
Science & Technical Highlights	S&T Results	As they occur	Web / PDF	Sponsor, Team, Stakeholders	Real time submission	PI/LRD
Leadership Telecon	Regular 60-minute telecons for project leadership	Every 2 weeks	Telecon	Leadership Team	Telecon Agenda and Notes	LRD
Science Question Telecons	Science question team meetings	Every 2 weeks	Telecon	Science Team members	Telecon Agenda and Notes	STL's
Science Talks	Science presentation from a team member or collaborator	Monthly	Telecon	Project Team and Collaborators	Presentation Archived	LRD
BER Sponsor Call	Monthly call between LRD and Sponsor	Monthly/Ad hoc	Telecon	LRD, Sponsor, Science Guests		LRD
Project Management Review	Monthly meeting for project status	Monthly	Meeting	LRD, TPM		TPM
Project All Hands Meeting	All hands annual meeting for team, collaborators and stakeholders	Annual	Meeting	All stakeholders		LRD

COST MANAGEMENT PLAN

The LRD is responsible for the overall management of project budget and cost. The TPM executes budget plans, monitors funding, and facilitates incremental funding. The ORNL Division Finance Officer provides monthly and ad hoc financial reports and supports the TPM and LRD with internal cost management. The LRD has authority to approve changes to the project and its budget. The TPM provides LRD a monthly cost performance report on planned/actual budgets along with ancillary information.

PROCUREMENT MANAGEMENT PLAN

Significant project procurements are defined by the LRD and executed by the TPM and the ORNL Procurement Services group. The TPM serves as the Technical Project Officer (TPO) on all procurements and ensures proper contracting procedures and quality of services are met. The LRD and TPM are the approvers and verifiers for all procurements.

SCHEDULE MANAGEMENT PLAN

The project schedule for Phase 3 will begin October 1, 2019 and end September 30, 2022.

The master schedule will be detailed in Teamwork Projects tool along with the constraints of tasks and cost. The TPM will maintain schedule and communicate details to the leadership and team.

QUALITY MANAGEMENT PLAN

The NGEE Arctic project has been planned to include methods for ensuring quality in research and for implementing standard procedures for regulatory requirements. Leadership of the project has been established that provides communication among the teams via the project core team. The leadership team of this project is committed to the delivery to our sponsor of a process-rich ecosystem model based on the studies and observations of the evolution of Arctic ecosystems in a changing climate.

The project will leverage numerous existing systems and will be executed with the collaborative efforts of highly qualified researchers. The provision of adequate infrastructure and work environment has been planned in the field and at the participating institutions

RISK MANAGEMENT PLAN

A framework for identifying, monitoring, and managing the risk associated with uncertainties will be established to provide tools to science leaders and the project director to ensure that risk that threatens the success of the project are mitigated in a timely and efficient manner. A Risk Register will be maintained in a collaborative workspace and reviewed at the Leadership Telecons.

PROJECT CLOSE-OUT

GENERAL PROJECT INFORMATION

NGEE Arctic is a 10-year project (2012-2022) to improve our predictive understanding of Arctic tundra processes and feedbacks to climate. In achieving this goal, multiple field research sites were established near Utqiaġvik on the North Slope and near Nome in western Alaska on the Seward Peninsula. Land use and land access permits were arranged for these field sites each year in collaboration with one of four native corporations. Contractual agreements were based on an annual scope of research described as part of the land application process. Each field site contains a suite of instruments that at the project's completion will need to be removed. There are also leased facilities (e.g., sea-land containers and storage buildings) in Utqiaġvik and Nome that will need to be vacated and materials and supplies either transferred to other individuals, properly salvaged, or shipped back to home institutions (see Deposition Options). Here we briefly describe our plans for handling all aspects of the project completion or close-out process. This plan includes closure of field sites, removal of instruments and infrastructure, shipment of resources back to home institutions, environmental stewardship as lands are returned to native communities, data and metadata management, and timely transfer of datasets to the ESS-DIVE (Figure 14).

FIELD SITE CLOSURE AND EQUIPMENT REMOVAL

Four field sites are maintained by the NGEE Arctic project. One is located just outside Utqiaġvik on the Barrow Environmental Observatory and three others on native corporation lands near Nome. Since the project's inception in 2012 each field site has been instrumented for a variety of scientific purposes including monitoring of local weather, recording active layer and permafrost temperature and soil moisture, and quantifying energy balance of the land surface either at static locations associated with eddy covariance towers or mobile platforms along the 70-m NGEE Arctic tram. All these instruments and associated infrastructure, and more, will need to be removed according to land use agreements. So too will wooden boardwalks and trail mat that is installed at field sites. While we are constantly taking instruments to and from the field in support of specific research endeavors, the 2022 field season will be targeted for decommissioning of field sites. We will begin the process of site closure in Utqiaġvik with a series of discussions in Spring 2021 involving representatives from the North Slope Borough (NSB) and our logistics provider UIC Science who manages lands on behalf of the NSB. We will outline steps to remove equipment and boardwalk which will require some actions during the summer field seasons but also actions during snow-covered periods of the year. These decisions will be agreed upon based on best practices for recovery and transport of equipment to and from the field. Snow machines will be used as appropriate, as will helicopters to quickly and efficiently removed heavy equipment from the field. Similar discussions will be held in Fall 2021 with representatives from the native corporations who manage lands on which our field sites are located outside Nome (e.g., Council Native Corporation, Mary's Igloo Native Corporation, and Sitnasuak Native Corporation).

Disposition Options

There are several options to dispose of project purchased property that is in the field. Beginning in Year 3, an equipment and material inventory will be developed, and preferred disposition will be noted. Cost benefits will be a main consideration for final disposition.

Dispose in Place

- The ORNL Property Division will identify equipment and property eligible for disposition in place. DOE has services in place through their National Laboratories to identify entities eligible to receive disposed property.
- Priority will be placed on re-using and recycling equipment and property to be used to further arctic research. Property transfer to partners currently at the field sites will reduce cost to dispose or return to the institution. All DOE and project placards and labels will be removed at transfer.

Return to Institution

- Project level purchases deemed necessary or useful to return to ORNL will be shipped via container barge to ORNL in the summer of 2022. Barge schedules are seasonal and will be scheduled early to avoid the risk of having to leave the container in place over the winter.
- Collaborating partners that have purchased equipment and material need to be transferred back to their institution will bear the cost to do so. Similar guidelines for disposition decisions will be followed.

Project Close-Out Schedule

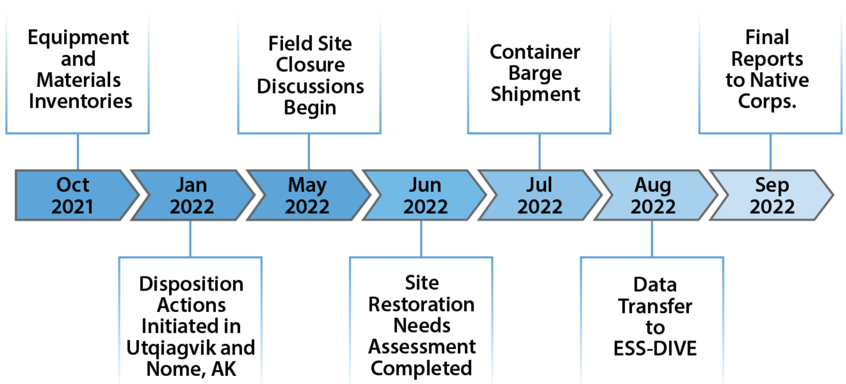


Figure 14. Timeline for general project close-out items beginning in October 2021. Timeline is meant to be illustrative and will be developed further in Phase 3 as part of our overall project management scheme.

Environmental Stewardship and Return of Lands to Native Communities

Closure of field sites near Utqiaġvik and Nome will be done in manner that is mutually agreeable to all parties involved. Since all field sites are located on native lands we will work diligently to limit all visual evidence of our presence. Environmental Impact Assessments were conducted at each site prior to our establishment of field sites so the NGEE Arctic project already has stewardship practices in place for returning lands to native communities. These will be documented, shared with representatives of the various native corporations, and sites closed with full agreement with land owners. Annual reports are prepared for each native corporation and we will also work to provide final reports summarizing our findings.

LAND USE PERMITS AND SUBCONTRACT CLOSURE

Land permits and applications are submitted on an annual basis. We will work with each native corporation to ensure that they are aware of our intent to close field sites at the end of the 2022 field season. Subcontracts are also in place with parties in Utqiaġvik and Nome, including but not limited to UIC Science, University of Alaska Northwest Campus (e.g., laboratory space), Gnome Courier (e.g., shipment services), and Centurion LLC (e.g., duplex housing). We will notify all parties and ensure that subcontracts are closed in a timely and orderly fashion.

INFORMATION DISTRIBUTION AND DATA ARCHIVE

We have already developed plans to transition all project data and metadata to the ESS-DIVE. This will be initiated in 2022 and completed by the project's close-out in September 2022. Because we also have a strong web presence, steps will be archive important information, including project reports, field and laboratory safety manuals, quality assurance documents, etc. Websites will be left on-line for a 12-month period after the projects termination but will be identified as closed using wording agreed upon by ORNL and DOE sponsors.

7. DATA MANAGEMENT AND COMMUNITY OUTREACH

DATA RESEARCH PLANS

The NGEE Arctic project supports the sharing of data 'early and often' to promote vital scientific collaboration within and beyond the project. During Phase 3, the Data Management Team (DMT) will continue to support the archival and sharing of data generated by NGEE Arctic. A primary focus will be on improving the visibility and scientific impact of project data both within and beyond the NGEE Arctic team by pushing public data to the ESS-DIVE. Secondary focus will be on improving data management workflows and systems to enable the timely and open sharing of data and on supporting synthesis activities. The DMT will continue work to provide data guidance, identify and track data from its collection into the archive, develop tools to capture metadata and facilitate data submission, assign DOIs, maintain the NGEE Arctic website, track data usage, and plan for post-project data stewardship at ESS-DIVE. We will continue to hold monthly calls with Data Representatives from each focus area. We will participate in bi-weekly leadership team calls, monthly Science Task calls, and the annual All-Hands meeting. We have found that communication between the DMT and the science team is critical to the success and efficiency of the data management activities. For details on the types and content of data the project will generate, data formats, metadata, data discovery, and preservation, please refer to the Data Management Plan document in the Appendix. We also provide a detailed Policy for Data Publication and Sharing (Appendix) which provides information on citation and reuse of NGEE Arctic data. High-level roles and responsibilities for data management are defined and described in the Management Section of the proposal.

Data Submission and Publication Activities: Early in Phase 3, we will complete an inventory of all data produced in Phases 1 and 2 and work to bring them into the archive. We will work with Data Representatives to archive data supporting published papers. Metadata describing the NGEE Arctic data products is captured in the Online Metadata Editor (OME). Incremental improvements to the OME are planned for Phase 3 to reduce the effort associated with entering and maintaining metadata records. These improvements will include: improved look and feel, metadata management dashboard, integrated registration of DOIs, user help, author lookup and autocomplete, and integrating ORCID for authors. We will enable submission of large-volume datasets using Globus (https://www.globus.org/), as opposed to the anonymous FTP system that we had used in Phase 1 and 2. We will continue to ensure that robust data and metadata backups are in place and maintain hardware and software infrastructure in compliance with ORNL cybersecurity guidance.

Data Support for Phase 3 Synthesis Activities: In Phase 3, we will add several tasks in support of proposed synthesis activities and collaboration with NASA ABoVE. We will set up an internally-accessible location for sharing working versions of commonly-requested data layers. This may include (1) standardized model inputs, (2) custom subsets and projections of geospatial data, (3) data from partners including NASA ABoVE, and (4) model validation data. We will work closely with the NGEE Arctic Leadership and Modeling Teams to expand our ability to archive code, large-scale spatial data, NetCDF format model outputs, and synthesis products to support Phase 3 science objectives. We will also work to standardize formats, spatial characteristics, variable names, and metadata with the NASA ABoVE project to enable harmonization and synthesis across the two projects.

Collaboration with ESS-DIVE and other BER Projects: In Phase 3, we will work closely with ESS-DIVE to ensure a seamless flow of data and metadata via the ESS-DIVE bulk submission API (see sidebar). We will begin metadata submissions for public datasets in April 2019 and will develop a fully-automated transfer process. We plan to meet with ESS-DIVE at least quarterly throughout Phase 3 and will provide constructive feedback throughout. We will work with ESS-DIVE to adapt our metadata to work smoothly with their EML metadata model, and will add any necessary fields, such as ORCID for authors, to fully comply with ESS-DIVE metadata standards. One specific area of collaboration with ESS-DIVE is the joint development of a standard metadata model for data from UAS. We will also share lessons-learned regarding search engine optimization for dataset search engines. The NGEE Arctic search interface currently includes Arctic-relevant data holdings from the ARM Archive and NASA's ORNL DAAC. Additional data resources from Spruce and Peatland Responses Under Changing Environments (SPRUCE), and NGEE Tropics will be added to the search interface in Phase 3.

Website and Data Access: In Phase 3, we will enhance the visibility of project data both within and beyond the NGEE Arctic team. We will continue to maintain and improve the structure, features, and content of the project website (https://ngee-arctic.ornl.gov/) as a resource for communicating the progress and impacts of NGEE Arctic science both within and outside the project team. Data are discoverable through the NGEE Arctic Data Portal (https://ngee-arctic.ornl.gov/data/) which leverages an open-source tool developed at ORNL that is used by numerous data centers and projects. The data portal provides a distributed metadata harvesting, indexing, and search system. To improve the discoverability and impact of NGEE Arctic data, we have identified the following tasks for Phase 3. We will immediately share all public data and metadata through ESS-DIVE. We will provide standards-compliant DOI landing pages for all datasets. Landing pages will include access to the data, metadata, download metrics, and a user guide. We will enhance search engine optimization of the NGEE website and the dataset landing pages. We will capture rich data usage metrics, including page views, downloads, and citations to data, and expose these metrics to project management and program managers through our quarterly reports and an internal dashboard. We will facilitate search and data discovery by populating Global Change Master Directory (GCMD) standard keywords for all datasets. We will announce the release of new data on the NGEE Arctic website and by email subscription list.

CLOSEOUT AND TRANSFER OF DATA TO ESS-DIVE

At the end of Phase 3, the data management team will be responsible for a smooth transition of all metadata and data from NGEE Arctic to the ESS-DIVE for long-term stewardship. We plan to be early testers and adopters of ESS-DIVE's API for bulk data submission. We will begin metadata submissions for all public datasets in April 2019 and will develop a fully-automated transfer process by the end of FY21. During the final six months of the project, the Data Management Team and Data Representatives at each institution will help NGEE scientists to organize, finalize, document, and release all NGEE Arctic data products. By the end of the project, any data products remaining "internal" in the system will be made public and will be sent to ESS-DIVE for release under the CC-BY 4.0 license (see Policy for Data Publication and Sharing).

Communication and Scientific Integration: The NGEE Arctic website is a primary mechanism for communicating our science, with easy access to news, project updates, and data. To enhance the visibility and impact of NGEE Arctic data, we propose to work with ESS-DIVE and the environmental sciences data community to provide guidance on data management, code management, data citation, and data publication. This effort will involve holding a data management training webinar for NGEE Arctic team members, and providing simple tutorials on using the OME, working with NetCDF files, and structuring csv files. Working with ESS-DIVE, we will ensure that NGEE metadata are shared widely, including with data.gov, GCMD, NASA, NSF Arctic Data Center, NEON, and other groups. In addition, we will be active in the Arctic science and data community by actively participating in DOE BER Cyberinfrastructure Working Group meetings, data integration workshops, interacting with NASA's ABoVE science team, and in the Interagency Arctic Research Policy Committee (IARPC) data working group.

8. KEY PERSONNEL

Key personnel for NGEE Arctic Phase 3 have been selected to provide a unique combination of skills and experiences deemed necessary to achieve the project vision. Additional information about these personnel are available in Section 14, "Curriculum Vitae."

Stan Wullschleger (ORNL) is the Project Director. He is a Corporate Fellow and Director of the Environmental Sciences Division. He will provide overall leadership to the project and contribute to experimental and modeling tasks in the biogeochemistry, vegetation dynamics, and hydrology.

Vladimir Romanovsky (UAF) is the Chief Scientist for the entire NGEE project. His research efforts will focus primarily on developing high resolution models of permafrost thermal dynamics and permafrost degradation

Peter Thornton (ORNL) will lead the modeling team. He is a Senior Research Scientist in the Environmental Sciences Division. He will serve as co-PI and science lead for the NGEE modeling activities across landscape organization and structure, biogeochemistry, plant traits, shrub dynamics, and hydrology.

Alison Boyer (ORNL) is the Data Manager. She is a Research Scientist in the Environmental Sciences Division and Chief Scientist for the NASA-sponsored Distributed Active Archive Center (DAAC). Her research interests include global change biology, biodiversity, and biogeography. Alison will lead the data management and publication activities to preserve, share, and measure the impact of data generated by the NGEE Arctic project.

Susan Heinz (ORNL) is the Project Manager. Susan has over 20 years of experience managing projects and measuring performance. While managing scope, schedule, and cost, she will develop improved methods for planning and measuring work, improving risk management, and a dashboard reporting methodology for the project.

Science Question Leaders

Baptiste Dafflon (LBNL) will lead the Question 1 Team. He is a Research Scientist in the Earth and Environmental Sciences Area. He will contribute his expertise in hydrogeophysical and thermal processes to improve the quantification of soil, bedrock and permafrost characteristics and their linkages with aboveground properties and dynamics.

David Graham (ORNL) will lead the Question 2 Team. He is a Senior Research Scientist and Group Leader in the Biosciences Division. He will contribute his expertise in microbial biogeochemistry to specific tasks in the shrub dynamics tasks as well.

Colleen Iversen (ORNL) will lead the Question 3 Team to harness the variation in key Arctic plant functional traits for use in trait-enabled models. She is a Senior Scientist in the Environmental Sciences Division. She is an expert in ecosystem ecology, with a specific focus on root-soil interactions.

Margaret Torn (LBNL) will lead the Question 4 Team for Shrub-Climate feedbacks. During Phase 1, she led the "Independent Observations for Integrated Model Evaluation." She provides expertise in terrestrial C and nutrient cycling and ecosystem-atmosphere trace-gas fluxes.

Cathy Wilson (LANL) will lead the Question 5 Team to explore Watershed Hydrology and work closely with the other question leaders to optimize and integrate infrastructure and observations. Wilson will work closely with the NGEE modeling team to ensure that fine scale modeling efforts support process parameterization of ELM. Cathy is also the Institutional Lead for LANL.

Joel Rowland (LANL) will co-lead the Question 6 Team. He will work closely with LBNL geophysics team and the ORNL landscape modeling team to characterize and understand surface and subsurface landscape properties, organization and controls at Seward field sites.

Amy Breen (UAF) will co-lead the Question 6 team. She will work closely with the ORNL shrub team and the dynamics vegetation group to ensure that aspects of disturbance ecology are represented in these two core science questions.

Institutional Representatives

W. Robert Bolton (UAF) will serve as the UAF Institutional Representative. He will also be responsible for leading hydrologic measurements and in developing a model of surface deformation in response to melting of buried massive ice and thawing of ice-rich permafrost.

Susan Hubbard (LBNL) will serve as the LBNL Institutional Representative. She will also contribute her expertise in advancing the use of geophysical and integration methods for terrestrial system characterization and monitoring, with a primary focus on tasks in Question 1.

Alistair Rogers (BNL) will serve as the BNL Institutional Representative. He is responsible for plant physiological measurements, including leaf gas exchange and biochemistry, and the ZPW warming experiment in Utqiaġvik.

Cathy Wilson (LANL) will serve as the LANL Institutional Representative. Cathy will also lead the Question 5 Science Team and work closely with the other question leaders to optimize and integrate infrastructure and observations. Wilson will work closely with the NGEE modeling team to ensure that fine scale modeling efforts support process parameterization of ELM.

Stan Wullschleger (ORNL) will serve as the ORNL Institutional Representative. Stan is also Project Director and is responsible for all aspects of the NGEE Arctic project.

9. FACILITIES AND RESOURCES

Investigators working on the NGEE Arctic project made good use of DOE facilities and capabilities in executing our Phase 1 and 2 scope of research. We anticipate similar interactions with staff at these facilities in Phase 3. A summary of past, current, and future use of these resources includes the following:

Atmospheric Radiation Measurement (ARM)

The DOE ARM Program's North Slope of Alaska (NSA) site maintains highly instrumented capabilities for the study of cloud, radiative, and land-atmosphere processes at high latitudes. The principal NSA facility in Utqiagvik (established 1997) is a valuable resource for NGEE Arctic, whose researchers use ARM data streams, such as Eddy Correlation Flux Measurements (ECOR) of CO_2, CH_4, energy and water fluxes; soil moisture, temperature, and net radiation (AMC); and Surface Meteorological Instrumentation (MET). We used the AMR eddy covariance tower and the NGEE Arctic eddy covariance tower on the BEO to address the flux of greenhouse gases from polygonal landscapes (Raz-Yaseef et al, 2017). Analysis of several years of data suggest that the Arctic CO_2 and CH_4 spring pulse is a delayed release of biogenic gas production from the previous fall and that the pulse can be large enough to offset a significant fraction of the moderate Arctic tundra C sink.

DOE High-Performance Computing (HPC) Capability

In Phase 2, the project team's NGEE Arctic modeling activities made significant use of DOE leadership computing facilities (Titan, ORNL; NERSC, LBNL) and mid-range HPC resources (Wolf and Mustang at LANL; ORNL's Compute and Data Environment for Science (CADES); LBNL Lawrencium cluster; Jasper cluster at the University of Alberta; and BNL institutional cluster). The team plans to continue using these resources in support of Phase 3 activities, as well as the Cory capability at LBNL. The CADES facility originated from a desire to build upon ORNL's key strengths in data system infrastructure and delivery of new capabilities through data intensive science to meet the mission needs of R&D projects at ORNL and beyond, while addressing big data analytics and science needs. The technical objective of the CADES facility is to provide a data intensive infrastructure that supports the mission needs of key internal and external projects at ORNL. The hardware infrastructure is comprised of a multi-petabyte data storage environment coupled with a multi-teraop data intensive HPC compute environment and a multi-node cloud compute infrastructure. This environment includes the necessary software to apply the system to important data intensive problems at ORNL. The NGEE Arctic modeling team at ORNL has priority access to approximately 1000 processing cores on the CADES system, with a total system memory (DDR4 RAM) of 64 TB. The team also has dedicated access to an NVIDIA DGX Station consisting of four NVIDIA Tesla VT100 GPUs, with a total of 20,480 GPU cores. This NVIDIA system is used for machine-learning workflows that help, for example, with classification of Arctic tundra landforms and vegetation distributions from remote sensing imagery. As part of the ExaSheds project funded by BER in FY19, NGEE Arctic team members and collaborators will be refactoring ATS for use on OLCF's Summit, currently the fastest computer in the world. As this capability becomes available in the coming years, it will be leveraged for Phase 3 integrated modeling simulations.

Environmental Molecular Science Laboratory (EMSL)

The NGEE Arctic team collaborated with Nancy Hess, Errol Robinson, Stephen Callister, and Nikola Tolic to undertake ultra-high resolution mass spectrometry analysis of permafrost soil organic C composition and interactions from field sites in northern Alaska. EMSL facilities including electron spray ionization Fourier transform ion cyclotron resonance mass spectrometry (ESI-FTICR MS), Nano-secondary ion mass spectrometry (NanoSIMS), and ^{1}H-^{13}C cross-polarization magic angle spinning nuclear magnetic resonance (CP-MAS NMR) spectroscopy were used to probe the molecular signatures of soil organic matter (SOM) transformation in arctic soils. In Phase 2, we applied ESI-FTICR MS to determine SOM degradation during a simulated warming experiment. Two collaborative manuscripts describing results from these studies were published (Mann et al., 2015; Chen et al., 2018). For Phase 3, we expect to expand ESI-FTICR MS and other advanced spectroscopic analyses through new user proposals to assess the ecological significance of changing SOM composition due to fractionation by sorption and microbial decomposition.

Joint Genome Institute (JGI), Walnut Creek, California

A JGI community sequencing proposal (CSP 1044) was granted during NGEE Arctic Phase 1 to study the role of microbial communities in cycling of C and regulation of greenhouse gas fluxes at intensive study sites on the BEO. In collaboration with Susannah Tringe and Tanya Woyke, over 120 samples were processed to determine the microbial community composition in active layer and permafrost samples (up to 2.65 m in depth) using a high-throughput molecular phylotyping technology. In an article just published (Tas et al., 2018) we used comparative metagenomics, genome binning of novel microbes, and gas flux measurements to show that microbial greenhouse gas (GHG) production is strongly correlated to landscape topography. Active layer and permafrost harbor contrasting microbiomes, with increasing amounts of Actinobacteria correlating with decreasing soil C in permafrost. While microbial functions such as fermentation and methanogenesis were dominant in wetter polygons, in drier polygons genes for C mineralization and CH_4 oxidation were abundant. The active layer microbiome was poised to assimilate N and not to release N_2O, reflecting low N_2O flux measurements. These results provide mechanistic links of microbial metabolism to GHG fluxes that are needed for the refinement of model predictions. We continue to analyze this massive amount of data and exploring the relationship of community composition and microbial function. By reconstructing hundreds of active layer and permafrost genomes, we are identifying key microbes involved in GHG production under projected climate scenarios.

Capital Equipment Requests

Terrestrial Laser Scanning (TLS) system: TLS is a portable, ground-based imaging tool (LiDAR) to capture high-resolution structural information across a wide range of NGEE applications. In combination with a DGPS system we will use the TLS to quantify shrub and tundra canopy structure, thermokarst, thermal erosion and deformation features and rates, over domains for model development. Leica P20 TLS ($165k) with Trimble R8-4 system ($60k) system: $225k.

LiCor greenhouse gas eddy flux tower package is requested for expanded eddy covariance measurements of CO_2, CH_4, H_2O, and energy fluxes. This would be deployed at our Teller field site, like in Utqiaġvik, but with solar power. This system is necessary to make ecosystem-scale carbon, water, and energy flux estimates on the Seward Peninsula. Cost: $85k.

Columbus Instruments Micro-Oxymax 20 chamber CH_4/CO_2/H_2 respirometer uses a closed loop measurement system to automatically measure the production or consumption of greenhouse gasses in sealed samples (microcosms). This will allow high-throughput measurements of soil organic matter decomposition and methanogenesis for the Biogeochemistry tasks that will parameterize models of SOM turnover and GHG flux. Cost: $72k.

Tower-mounted full-spectrum (i.e., 350–2500 nm) spectroradiometer would allow for measurement of surface optical properties and reflectance over a fixed or variable (with a system to move the field of view) region. This information can be used to capture vegetation seasonality and to link with measurements of eddy covariance to develop scaling techniques to the larger landscape. The system would consist of a Spectral Evolution UDS-3500. Cost: $102k.

DART (Vista Clara) is a relatively novel NMR logging (in wells as small as 2 inches diameters) tool that has proven to be extremely valuable for precise determination of porosity and water content, and to evaluate permeability, mobile/bound water fraction, pore-size distributions. This approach will enable reliable depth profiles (for occasional survey as well as for monitoring purpose) of unfrozen water content in active layer, frozen ground and saline layer. Cost: $85k. (DART $50k, Control unit $35k).

WalkTEM is a transient electromagnetic sounding system used to infer the distribution of subsurface electrical conductivity in the top 100 m (or more). This tool is very useful to perform 1D soundings at multiple locations in a limited amount of time (compared to electrical resistivity tomography), this in summer as well as in winter/spring because it does not require a galvanic contact with the ground. This tool will help the quantification of subsurface characteristics at multiple sites over large areas only accessible with snowmobile. Cost: $70k.

Portable Photosynthesis System LI-COR 6800 would enable us to maximize the signal to noise ratio and make more challenging measurements, e.g. respiration, confidentially and quickly and increases the precision of response curves measured at low CO_2 fluxes. These features enable improved understanding of the response of photosynthesis to VPD and temperature – key model uncertainties. We are requesting two 6800s to enable effective use of manpower while in the field. Cost: $65k each, $130k total.

Field-Portable Spectrometer SVC HR-1024i will allow us to link all our data collection to leaf and canopy spectra, and therefore capture valuable opportunities to pair spectral measurements with traditional data collection. This instrument purchase includes real-time monitoring of sky conditions during spectral collection to ensure quality spectra. Cost: $85k.

Parrot Sequoia MultiSpectral Camera will allow us to collect spectral imagery in combination with our thermal and point spectrometer data, thereby allowing us to develop enhanced multi-sensor scaling approaches to capture a range of plant traits over space and time. This system contains a 4-channel camera system as well as an ambient sensor to monitor sky conditions to produce imagery that should match the spectral information provided by our point (i.e. non-imaging) spectrometer system. Cost: $4k.

HySpex integrated UAS VNIR-SWIR system, and a FLIR Vue Pro thermal camera for unmanned aerial (UAV) collection of spatially continuous, high resolution chemical, physical and biological spectral data in the shortwave-infrared (SWIR) range from 950-2500 nanometers and the visible-near-infrared (VNIR) range from 400-1000 nanometers. Hyperspectral and thermal data of this will be used to jointly detect, identify, characterize, and quantify (abundance) diverse signatures and properties of terrestrial ecosystems. Cost: $250k.

Gryphon X8 heavy-lift UAS carbon fiber coaxial quadcopter, with power delivery system providing up to 157 lbs. of thrust with a maximum take-off weight of 79 lbs., giving the system a usable payload up to 43 lbs. The airframe will be used to co-mount and fly multiple NGEE Arctic UAS instruments at the same time (cross-lab resource). The new airframe would be configured to allow 2 to 4 instruments (Lidar, photogrammetry, spectrometers, thermal imagers, etc.) to be deployed simultaneously in single flights to enable exact co-registration of diverse signatures of ecosystem conditions and properties. Cost: $75k.

SUNA real time, field deployable nitrate probes to quantify highly dynamic nitrogen cycling on hourly to sub-seasonal scales. Current water sampling technology (ISCO deployments or manual sampling daily) are insufficient to adequately resolve the dynamics recently discovered by NGEE researchers. The SUNA nitrate analyzers can provide minute resolution and continuous high precision time series to capture the effects of rapid N cycling and exports in runoff from Alder and Willow dominated watersheds. It will also be possible to use these to map nitrate distributions at Seward and Barrow at large scales. They are well tested, low maintenance, and unique enough that the resulting data sets should lead to high profile papers. We are requesting funds for two SUNA probes and data loggers. Cost: $60k.

Portable rainfall simulator system to deploy in remote environments to characterize thermal-hydrologic properties of diverse ecosystem types, and subsurface (soil, bedrock and permafrost) conditions. It will primarily be deployed across disturbance chrono-sequences to characterize thermal-hydrologic, geomorphologic and biogeochemical impacts of disturbance (fire, thermal erosion, subsidence) and recovery. Cost: $50k

10. PROPOSED COLLABORATORS

Elsewhere we have outlined our use of DOE facilities and capabilities in support of the NGEE Arctic project (see Section 9). Interactions with staff at those facilities have allowed us to conduct the required field and laboratory measurements and model simulations required for the project. In addition, we will continue and, in some cases, establish new Phase 3 collaborations with several national and international collaborators as we conduct our investigations on the North Slope and Seward Peninsula, and as we undertake a series of synthesis activities in support of answering our science questions. These interactions are categorized as national or international partnerships, the extend of that partnership described, and supported by including contributed Letters of Collaboration.

National Collaborations

Alaska Climate Adaptation Science Center (AK CASC): The AK CASC has agreed to collaborate with NGEE Arctic in the continued development of the Integrated Ecosystem Model (IEM) and the Alaska Thermokarst Model (ATM). In Phase 3, AK CASC science team will collaborate specifically with Bob Bolton to integrate the concepts behind the ATM landscape evolution processes into DOE's Energy Exascale Earth System Model (E3SM). In addition, a co-production pilot project focused on landscape change on the North Slope and Western Alaska offers continued opportunity to interact and collaborate with natural resource managers and decision makers in Alaska. See Letter of Collaboration from Steve Gray and Scott Rupp.

Arctic and Boreal Vulnerability Experiment (ABoVE): NASA's Terrestrial Ecology Program has launched a major field and airborne campaign in Alaska and western Canada. ABoVE seeks to better understand the vulnerability and resilience of ecosystems and society to a changing environment. We have and will continue to explore opportunities to interact with ABoVE by providing modeling expertise while at the same time receiving input and guidance on remote-sensing products that will facilitate Phase 3 milestones of NGEE Arctic. See Letter of Collaboration from Scott Goetz.

Argonne National Laboratory (ANL): The ANL Terrestrial Ecosystem Sciences (TES) Science Focus Area (SFA) on soil C responses to environmental change focuses on soils of the northern circumpolar permafrost region. Members from NGEE Arctic and ANL have and will continue to work together on investigations at the Barrow Environmental Observatory (BEO). We are especially interested in working with ANL on a conservative tracer study to study lateral flow of water and nutrients in ice-rich polygon landscapes. See Letter of Collaboration from Julie Jastrow.

Atmospheric Radiation Measurement (ARM): The DOE ARM Program's North Slope of Alaska (NSA) site maintains highly-instrumented capabilities for the study of cloud, radiative, and land-atmosphere processes at high latitudes. We will continue to benefit from the wealth of insights gained by ARM investigators over the past 20 years or more. In addition, with the deployment of the NGEE Arctic tram and multi-spectral drones, we will capitalize on shared data for multiscale interpretation of energy balance for permafrost-dominated land surfaces. See Letter of Collaboration from Mark Ivey.

Energy Exascale Earth System Model (E3SM): In Phase 3, we will work with members of the E3SM land modeling team as they adopt the watershed-based representation of land surface heterogeneity. We will focus on ELM-FATES and ELM-PFLOTRAN for coupled thermal-hydrology and biogeochemistry being developed for global-scale implementation under E3SM. This interaction will leverage DOE investments in CMDV liaisons at ORNL and partner national laboratories to deliver improved Arctic vegetation, hydrology, and biogeochemistry parameterizations, as well as expanded benchmarking datasets for model evaluations over Arctic regions. See Letter of Collaboration from Dave Bader.

International Land Model Benchmarking Project (ILAMB): The ILAMB project is designed to improve the performance of land models and, in parallel, to improve the design of new measurement campaigns to reduce uncertainties associated with key land surface processes. In Phase 3, we will continue our collaboration with ILAMB investigators to (1) develop new model benchmarks centered on measurements proposed for collection and distribution, and (2) use ILAMB diagnostic toolsets to benchmark and evaluate model processes. See Letter of Collaboration from Forrest Hoffman.

National Center for Atmospheric Research (NCAR): Scientists at NCAR have a long history of incorporating knowledge about Arctic ecosystems into climate models. Because of this experience, there are ample, near-term opportunities to pursue model-inspired research between NGEE Arctic and NCAR staff. Cathy Wilson (LANL) is collaborating with David Lawrence to explore critical uncertainties related to permafrost thaw and surface and groundwater hydrology in the Arctic (e.g., inundation). This relates directly to deliverables outlined in Q5. See Letter of Collaboration from David Lawrence.

Next-Generation Ecosystem Experiments (NGEE Tropics): NGEE Tropics, led by the Lawrence Berkeley National Laboratory is sponsored by the Department of Energy's Biological and Environmental Research (BER) program. Its goal to develop a hierarchical, modular modeling platform that integrates crucial processes needed to represent tropical forest ecosystem responses to global changes, including belowground biogeochemistry, plant demography and ecophysiology, plant functional traits, and aquifer-to-canopy hydrology. Launched in 2015, NGEE Tropics shares many objectives and approaches with the NGEE Arctic project. In Phase 3, we will leverage these similarities to jointly pursue topics of interest to the larger goal of improving ESMs. We anticipate close collaboration and formation of working groups across topics of plant traits, vegetation dynamics, and shrub demography (e.g., FATES). See Letter of Collaboration from Jeffrey Chambers.

Permafrost Carbon Network (PCN): The goal of the PCN is to synthesize and link existing research about permafrost C and climate in a format that can be assimilated by biospheric and climate models, and that will contribute to future assessments of the Intergovernmental Panel on Climate Change (IPCC). Because synthesis is a major component of NGEE Arctic, we will continue to interact with the PCN in activities related to permafrost thaw, C cycle processes, hydrology, and thermokarst. This is an extension of Phase 1 activities that yielded several join publications between the PCN and NGEE Arctic. Cathy Wilson (LANL) and Christian Andresen (University of Wisconsin) will be our point of contact between NGEE Arctic and the PCN. See Letter of Collaboration from Ted Schuur.

U.S. Fish and Wildlife Service (USFW): The USFW is motivated by the importance of arctic wetlands to migratory birds and other wildlife species, and the potential effects of changes in surface hydrology on a food chain that supports water birds and, ultimately, people. Ice-wedge polygon degradation is widespread and has the potential to alter surface hydrology and habitat quality over the next few decades. Because of the intersection of NGEE Arctic and the USFW, we will continue to share information and resources where appropriate. Our work on the North Slope and Seward Peninsula broadly overlaps with FWS interests, although the focus of the USFW is on the regional scale, natural-resource management, and ecosystem services. See Letter of Collaboration from Wendy Loya.

International Collaborations

Alfred-Wegener Institute, Potsdam, Germany: Researchers with the AWI are conducting research on the Lena River delta of Northern Siberia. They have produced a rich source of data from polygonal landscapes. NGEE Arctic will collaborate to with AWI colleagues to develop a more thorough understanding of how polygonal landscapes evolve due to warming and how that landscape evolution can shift the hydrology across large regions of the Arctic. More specifically, we will share data from our sites and compare results from recent ATS simulations with those from the AWI CryoGrid3 Land Surface Model. Both models can simulate the changing micro-topography of polygonal tundra and associated lateral fluxes of heat, water, and snow. See Letter of Collaboration from Julia Boike.

Chinese Academy of Science, Lanzhou, Gansu, China: Scientists with the CAS just recently set up a new field site on the Seward Peninsula near, Teller, AK. A weather and permafrost monitoring station has been deployed. We will work with the CAS to integrate environmental measurements into our larger datasets and collectively use those for modeling purposes. See Letter of Collaboration from Shichang Kang and Tonghua Wu.

Earth Cryosphere Institute, Tyumen, Russia: The Siberian Branch of the Russian Academy of Sciences has a long history of research in the Russian Arctic, including the problems of gas-emission crater formation, ground ice thaw, and activity of slope processes. The Earth Cryosphere Institute shares a common interest with the NGEE Arctic project with regards to long-term observations of primary permafrost parameters, such as ground temperature and active layer thickness, processed time series of satellite imagery, and results of monitoring activation of permafrost-related processes. We anticipate developing this collaboration to support model development and evaluation at another tundra site and for site-specific parameters for pan-arctic simulations. See Letter of Collaboration from Marina Leibman.

Korea Polar Research Institute, Songdomirae-ro, Yeonsu-gu, lncheon, Korea: Researchers from KOPRI are working to analyze changes in permafrost throughout the Arctic. The project includes observations of greenhouse gases across several research locations in Canada, Greenland, Iceland, Norway (Svalbard), Russia and the United States (e.g., Council, AK). NGEE Arctic is closely co-located with the KOPRI field site in Alaska and we will share data, knowledge, and collaborate strategically as appropriate. See Letter of Collaboration from Bang Yong Lee.

Tundra Trait Team, Frankfurt, Germany: The Tundra Trait Team is an international effort to increase the depth and breadth of trait data available for tundra plant species. Version 1 of the Tundra Trait Team database contains nearly 92,000 trait observations on nearly 978 species. Colleen Iversen has worked closely with the Tundra Trait Team to conduct several recent synthesis activities for the Arctic, focusing on plant traits both above- and belowground. The Tundra Trait Team is an inclusive group of tundra ecologists involved in ongoing efforts to understand patterns of functional trait variation across scales and the consequences of these changes for tundra ecosystem function. See Letter of Collaboration from Anne Bjorkman.

Western Sydney University, Australia: Colleagues at Western Sydney University are working to conduct several synthesis and meta-analysis products of plant responses to environmental drivers, with the aim of quantifying the ability of plants to acclimate to changes in environmental conditions. The dataset collected via NGEE Arctic is the only one being collected at the coldest extent of vegetation. It thus fills a very important niche, extending analyses of plant capacity to adapt to cold temperatures. We will continue to interact with this group as it has already produced several high-impact publications. See Letter of Collaboration from Belinda Medlyn.

NORTHERN ARIZONA UNIVERSITY

Ecological and Environmental Informatics

5 November 2018

Stan Wullschleger
Director, Environmental Sciences Division
NGEE Arctic Project Director
Oak Ridge National Laboratory
Oak Ridge, TN 37831

Dear Stan,

It is with pleasure that I write in support of your NGEE Arctic phase 3 renewal and continued partnership with NASA's Arctic Boreal Vulnerability Experiment (ABoVE). As you know, NGEE Arctic and ABoVE have signed a memorandum of understanding the lays out our agreement to collaborate and leverage resources. In the case of ABoVE the latter includes provision of substantial airborne data acquisitions in the form of multi-frequency radar, hyperspectral and lidar data collected by NASA facility instruments, as well as a suite of airborne data collected by principal investigators as part of ABoVE research solicitations (including extensive airborne concentration measurements and additional radar, hyperspectral and lidar data). ABoVE investigators have also collected a large amount and diversity of field data across our domain of interest (Alaska and northwestern Canada) that complements the intensive field measurements NGEE Arctic has collected in northern and western Alaska.

Our MOU provides a foundation for advancing research efforts of mutual interest, but in particular I note key opportunities to extend field measurements to broader spatial scales, linking field, airborne and satellite observations, and informing terrestrial ecosystem models – including the extensive modeling efforts of NGEE Arctic in permafrost landscapes. I also note that as NGEE Arctic moves into Phase 3 and ABoVE into Phase 2 we have tremendous opportunity to significantly advance the cross-cutting science question NGEE Arctic will focus on for phase 3 (i.e. *What controls the vulnerability and resilience of Arctic ecosystems to disturbance, and how do disturbances such as fire and thermokarst alter the physical and ecological structure and function of these systems?*). This question, as well as the other 5 thematic research questions on which you will focus, are closely aligned with ABoVE objectives and emphasizes the maturity of our complementary and mutually beneficial projects. More specifically, an example of where we can jointly advance research going forward is comparison of field measurements of thaw depth and soil moisture, and retrievals of these variables over larger spatial extents using multifrequency and interferometric radar data. We coordinated on this in each of the last two years at NGEE Arctic field sites in Nome and Barrow, and would like to advance this research and co-publish findings. Another example is in collecting multi-scale measurements of albedo dynamics and how this scale spatially as we move from field measurements to airborne and satellite extents. There are many additional avenues of joint research that both NGEE Arctic and ABoVE can advance via our collaboration. I look forward to continuing the relationship.

Sincerely,

Scott Goetz
Science Lead, Arctic Boreal Vulnerability Experiment (ABoVE)
Professor, School of Informatics, Computing, and Cyber Systems
Northern Arizona University
scott.goetz@nau.edu

AK CASC
Alaska Climate Adaptation Science Center
University of Alaska Fairbanks • PO Box 757245 • Fairbanks, AK 99775-7245 • 907-474-7535

November 16, 2018

Dr. Stan D. Wullschleger
Climate Change Science Institute
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN 37931

RE: Letter of Collaboration

Dear Stan,

We are excited to submit a letter of collaboration as the leadership (Gray, USGS Director; Rupp, University Director) of the Alaska Climate Adaptation Science Center (AK CASC). We offer our continued support and collaboration with respect to the AK CASC funded Integrated Ecosystem Model (IEM) and the Alaska Thermokarst Model (ATM) originally developed under the IEM. As in the NGEE-Arctic Phase 2 period, in Phase 3 the IEM team and the broader AK CASC science team will collaborate with Bob Bolton to integrate the concepts behind the ATM landscape evolution processes into DOE's Energy Exascale Earth System Model (E3SM). In addition, the AK CASC co-production pilot project focused on landscape change on the North Slope and Western Alaska offers continued opportunity to interact and collaborate with natural resource managers and decision makers in Alaska.

We, the IEM team, and the AK CASC science team look forward to continued fruitful collaborations and interactions with the NGEE-Arctic team during the coming years.

Sincerely,

Steve Gray, USGS Director
Alaska Climate Adaptation Science Center

Scott Rupp, University Director and Professor
Alaska Climate Adaptation Science Center
International Arctic Research Center
University of Alaska Fairbanks

UAF UNIVERSITY OF ALASKA FAIRBANKS

Julie D. Jastrow
Senior Terrestrial Ecologist/Group Leader
Group Leader

Environmental Science Division
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November 28, 2018

Dr. Stan D. Wullschleger
Climate Change Science Institute
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN 37931

Dear Stan:

As principal investigator for Argonne's Department of Energy sponsored Terrestrial Ecosystem Sciences (TES) Science Focus Area (SFA) on *Soil Carbon Response to Environmental Change* (tessfa.evs.anl.gov), I want to assure you that our SFA team looks forward to continued interactions and collaborations with the NGEE Arctic team. As you know, our SFA aims to develop spatially explicit estimates of soil carbon stocks for the permafrost region coupled with an understanding of the organic matter composition and potential decomposability of these stocks. As such, our data sets and geospatial products can provide valuable information, constraints, and benchmarks for NGEE Arctic model development.

In reading the overview plans for NGEE Arctic's Phase 3 renewal, I see that our ongoing interactions with the thermal-hydrology team are in line with Phase 3 plans to parameterize the Advanced Terrestrial Simulator (ATS) to account for subsidence caused by thawing permafrost and melting ice wedges. We are providing depth-resolved data on variations in ice contents and particle density for different types of ice-wedge polygons to inform ATS model development. In addition, we are talking with other members of the hydrology team about future field collaborations near Utqiaġvik to determine the spatially explicit fate of tracers applied to characterize and compare lateral transport across polygon types with contrasting oxic-anoxic conditions.

Further, our shared interests with NGEE Arctic in land surface heterogeneity and the vulnerability of soil organic carbon to decomposition represent other areas for future interactions. Recent SFA field campaigns targeting toposequences in the Arctic Foothills of the Brooks Range are investigating how hillslope geomorphology in the continuous permafrost zone influences cryostratigraphy, soil carbon distributions, and soil organic matter composition. We expect our results can provide useful comparisons with hillslope studies in the warmer, discontinuous permafrost environment of the NGEE Arctic sites on the Seward Peninsula. With regards to the vulnerability of soil organic carbon, we would welcome contributions of soil subsamples from NGEE Arctic studies for scanning and inclusion in our growing infrared spectroscopy database of permafrost region soils. We are developing calibrations to predict the particle-size composition and potential decomposability of soil organic carbon from the infrared spectra of bulk soils. So, in addition to producing spectra, we would be very interested in exploring the potential for obtaining selected samples from NGEE Arctic sites or experiments for analysis and inclusion in our calibration model development efforts.

As always, the Argonne TES SFA looks forward to exploring opportunities to interact and collaborate further with the NGEE Arctic team.

Sincerely,

Julie D. Jastrow

Julie D. Jastrow, Ph.D.
Senior Terrestrial Ecologist/Group Leader

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6 November 2018

Stan D. Wullschleger, PhD
Director, Environmental Sciences Division
Oak Ridge National Laboratory
Building 4500N, F126
Oak Ridge, TN 37831-6301

RE: Letter of Support for NGEE Arctic Phase 3 Renewal Proposal

Stan,

I was happy to learn that you are moving forward with a full proposal for Phase 3 of the NGEE Project. Our collaboration during Phase 2 has been very positive and beneficial. The North Slope team of the DOE ARM Program looks forward to continuing our excellent working relationship as you move into Phase 3 of NGEE Arctic.

Our collaboration with Alistair Rogers and the NGEE team for the recent Utqiagvik community science outreach event at the Barrow Arctic Research Center is one excellent example of the benefits to ARM, ASR, and NGEE from our collaboration. The "BARC Barbecue" science event was by all accounts a highly-visible and positive outreach success. I doubt we would have had the same results without combing forces and sharing costs.

The UAS measurements that you are proposing for Phase 3 of NGEE Arctic could have particular benefits to ARM and ASR. As you know, understanding how best to make these measurements has been a major challenge in addition to the regulatory and logistical challenges associated with UAS and tethered balloon platforms. We hope to work with you and learn from your team as you move forward in this important and exciting science area.

As we have in the past, we will continue to offer the NGEE Arctic project access to laboratory and also possible office space if needed in the Barrow Arctic Research Center (BARC). This shared space has served both groups well in recent years, and we hope to continue that collaborative use of space into Phase 3. We are also more than willing to exchange information and written materials on safety protocols and best practices for working in Arctic environments, although NGEE has certainly demonstrated an excellent safety record and resolved safety-related issues beyond the scope of our ARM operations on the North Slope.

Both Joe Hardesty and I plan to attend the NGEE All-hands meeting held just before the AGU Fall meeting in early December. That meeting provides an excellent opportunity for sharing information and

Exceptional Service in the National Interest plans. Thank you for inviting us. I hope we get a chance to talk there about your Phase 3 Proposal. In the meantime, we are glad to express our strong support and hope for continued collaboration with NGEE Arctic.

Sincerely

s/Mark D. Ivey

Mark D. Ivey, P.E., Ph. D.
Geophysics and Atmospheric Sciences Department
Sandia National Laboratories

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Stan D. Wullschleger
Director, NGEE Arctic Project
Oak Ridge National laboratory
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PD Dr. Julia Boike
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Phone: +49331-288-2119
Fax: +49331-288-2137
julia.boike@awi.de

November 16, 2018

Letter of collaboration

Dear Stan,

I am pleased to see that NGEE is developing strongly and you are preparing for Phase 3 (renewal proposal). Two areas of collaboration are particularly appropriate as your team enters Phase 3 of its research. As you know, our research on the Lena River delta of Northern Siberia has produced a rich source of data from polygonal landscapes. We would be pleased to work with you and your NGEE Arctic colleagues to develop a more thorough understanding of how polygonal landscapes evolve due to warming and how that landscape evolution can shift the hydrology across large regions of the Arctic. Two areas of interest come to mind. One would be to share data from our sites and compare results from your recent ATS simulations with those from our CryoGrid3 Land Surface Model. Both models can simulate the changing micro-topography of polygonal tundra and associated lateral fluxes of heat, water, and snow. Another area would be for us to compare how knowledge from plot-scale investigations can be represented in large-scale regional to Earth system models (ESMs). Our team has recently developed a coupled two-tile framework suitable for implementation in ESMs and applied that to a polygonal tundra site in Northern Siberia and a peat plateau location in Northern Norway. Like your field sites near Barrow and Nome, AK, our two sites represent cold, continuous permafrost and warm, sporadic permafrost, respectively. Sharing data and model results would be useful as we move towards implementing models for circumpolar simulations of carbon and water balance.

We at AWI strongly support your proposed proposal and we look forward to fully collaborating with you. We believe that stronger of German and

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Polar- und Meeresforschung

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American Arctic research is essential for rapidly improving our knowledge of Arctic ecosystem change and the implications for Resource Development across the Arctic, and contributing to the international development of Arctic science under a rapidly warming globe.

Julia Boike

Julia Boike
Moritz Langer

HELMHOLTZ

SKL 冰冻圈科学国家重点实验室

W. Robert Bolton
International Arctic Research Center
2160 Koyukuk Dr, Fairbanks, AK 99775- 7335

Tel: (907) 474-6421

wrbolton@alaska.edu

Dear Dr. Bolton:

As the Principle Investigator of Arctic Cryosphere Changes and Sustainable Development (ACCSD), a project funded by Chinese Academy Sciences, I am pleased to offer a letter of collaboration for our research in the future.

The ACCSD's goal is to detect the changes of Arctic Cryosphere including permafrost, sea ice, glacial and snow cover under climatic warming, to assess their impacts on local hydrology, ecosystem, and welfare of the local people, and to propose strategies for sustainable development. For the permafrost study, we aimed to establish more than two integrated cryosphere sites in Seward Peninsula of Nome for long-term observations. We will also continuously monitor the soil temperature, soil moisture content and changes of active layer and permafrost in this region. In addition, vegetation phenology will be also monitored using digital camera in our study regions. With these datasets, we will further simulate the ground temperature, active layer thickness, and permafrost temperatures and analyze changes of vegetation concurrently occurring with permafrost dynamics.

Our understanding is that NGEE Arctic project has been already established powerful field observation network in Seward Peninsula in Western Alaska, and the NGEE Phase 3 scope will include several integrated research plans including the vulnerability and resilience of Arctic ecosystems to disturbance. During our previous work, we already conducted site visits for the NGEE field sites in the past 2 summers, and we have already established an AWS at Mile 47 Teller Road in 2018. In addition, we also had the *"Arctic Cryosphere Changes and Their Impacts: Defining a Collaborative Research Agenda"* workshop which has been held in the September of 2018 at University of Alaska, Fairbanks. Based on these understandings, we believe that our collaboration with Bob Bolton's group will make great contribution to the NGEE project. We are also pleased to find that NGEE project already established so many plots to investigate the vegetation dynamics, which we believed the published data in the future will be benefit for the following research on the sustainable development in the Arctic region.

I, and the ACCSD team, look forward to our future collaboration and interaction with the NGEE-Arctic team during coming years.

Sincerely,

Dr. Shichang Kang
Professor of Environmental Chemistry and Geography
Director of State Key Laboratory of Cryospheric Science,
Cold and Arid Regions Environmental and Engineering Research Institute,
Chinese Academy of Sciences

Dr. Tonghua Wu
Professor of Physical Geography
Deputy Director of State Key Laboratory of Cryospheric Science,
Cold and Arid Regions Environmental and Engineering Research Institute,
Chinese Academy of Sciences

Lawrence Livermore National Laboratory
Physical and Life Sciences

December 14, 2018

Stan D. Wullschleger, PhD
Director, Environmental Sciences Division
Oak Ridge National Laboratory
Building 4500N, F126
Oak Ridge, TN 37831-6301

Dear Dr Wullschleger:

As Lead Principal Investigator of the Energy Exascale earth System Modeling (E3SM) Project, I am writing to express my support and commitment to continued collaboration between E3SM and the NGEE-Arctic Project as you pursue NGEE-Arctic's renewal. The E3SM leadership considers there to be a strong mutual benefit for both projects to continue a two-way exchange of ideas, data, and code.

As you know, E3SM has a clearly articulated Collaboration Policy. There are specifics about co-authorship of papers and sharing of model simulation data that we ask that NGEE participants follow.

The strong connection between E3SM and NGEE-Arctic has already provided mutual benefit to the two projects, and we look forward to further productive collaboration.

Sincerely,

David C Bader

David C. Bader, Ph.D.
Climate Program Leader
Physical and Life Sciences Directorate
Lawrence Livermore National Laboratory

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CC: E3SM Leadership Council

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Vladimir E. Romanovsky
Professor of Geophysics
Geophysical Institute UAF
Fairbanks, AK 99775-7320

22 November 2018

Dear Vladimir,

I am pleased to write the letter of support of your NGEE Arctic phase 3 renewal as a Principle Investigator and scientific advisor of a number of Projects devoted to studying permafrost dynamics and resulting land cover and landform changes in the Russian Arctic, including the problems of Gas-emission crater formation, ground ice thaw, and activity of slope processes.

Our results may be of mutual interest on the basis of long-term observations organized into GIS databases, which cover records of main permafrost parameters, such as ground temperature and active layer thickness, processed time series of satellite imagery, results of monitoring activation of permafrost-related processes or, on the contrary, recovery of natural and human impact disturbances. Our research is mainly linked to Research stations in the North of West Siberia, but our team also has experience in other regions of the Russian Arctic.

Several other permafrost-related aspects may also be of mutual interest. We can also extend our collaboration to the topics that are temporarily inactive, such as study of geochemical properties of soil and vegetation cover, distribution and expansion or reduction of shrublands in Central Yamal.

Our cooperation in study of the thermal state of permafrost will only benefit from adding other research activities in mutual effort.

I look forward to continuing the relationship.

Sincerely,

Marina Leibman
Dr. of Science,
Chief Scientist
Laboratory of the complex studies of cryogenic geosystems
Earth Cryosphere Institute TSC SB RAS

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October 20, 2018

Stan Wullschleger, Principal Investigator
Next-Generation Ecosystem Experiments (NGEE Arctic)
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831

Dear Stan,

This letter is to express collaborative interest on behalf of the International Land Model Benchmarking (ILAMB) activity for the research proposed for Phase 3 of the Next-Generation Ecosystem Experiments (NGEE Arctic) project. The objectives of ILAMB are to confront Earth system models (ESMs) with best-available *in situ* measurements and remote sensing data, to develop a set of open source tools for model evaluation and diagnostics, and to deliver those tools to the larger scientific community for their own use and extension. Recognizing the significance of the potentially vulnerable carbon stores at high latitudes and the inability of most models to capture the physical and biogeochemical processes required to make credible predictions about responses of Arctic ecosystems to a warming climate and elevated atmospheric CO_2, the ILAMB community would enjoy the opportunity to collaborate with NGEE Arctic in developing model benchmarks focused on measurements proposed for collection and distribution as a part of the third phase of the project.

As the ILAMB diagnostics toolset has evovled over the last few years, the international modeling community has progressively adopted it for systematic assessment of models within modeling centers and for evaluation of model results in collaborative activities like the Global Carbon Budget. Continued collaboration with NGEE Arctic in Phase 3 is important as new functional relationships and permafrost metrics are being developed for ILAMB. Changing plant functional traits and vegetation distributions, particularly as they are influenced by disturbance at high latitudes, are challenging for models to simulate. NGEE Arctic data will be important for evaluating high latitude greening, shrub expansion, permafrost degradation, and wildfire disturbance and recovery process representations in the Energy Exascale Earth System Model (E3SM).

I look forward to continued collaboration as NGEE Arctic Phase 3 extends data collection in Alaska and expands its research to address disturbance processes. Please contact me if I can provide any additional information or answer any questions.

Sincerely,

Forrest M. Hoffman, Laboratory Research Manager
Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computation (RUBISCO) Scientific Focus Area (SFA)

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Republic of Korea
Tel: +82-(0)32-770-8400/Website: www.kopri.re.kr

Dr. Robert Bolton
International Arctic Research Center (IARC)
University of Alaska Fairbanks
PO BOX 757340, Fairbanks, AK 99775-7340

November 19, 2018

Dear Dr. Bolton,

I am pleased to offer a letter of support as the Principal Investigator of the research project "Circum Arctic Permafrost Environment Change Monitoring, Future Prediction and development Techniques of useful Biomaterials (CAPEC)", funded by the Ministry of Science and ICT and the National Research Foundation of the Republic of Korea.

With an aim to analyze circum-Arctic permafrost environmental change and its correlation with the Earth's atmosphere-permafrost-ecosystem, the project includes observing greenhouse gases and climate cooling factors from the circum-Arctic research nodes in Canada, Greenland, Iceland, Norway (Svalbard), Russia and the United States.

It is my understanding that in Phase 3 of the Next Generation Ecosystems Experiments (NGEE Arctic) program, the coordination of a model-inspired investigation is planned to advance our understanding of the Earth's climate and environmental systems through an extensive ecosystem model.

As the NGEE Arctic program's research area overlaps with our interests, we would like to convey our support to collaborate and ensure the effective and improved research coordination. We look forward to the fruitful cooperation with the NGEE Arctic team to advance our knowledge of critical Earth system processes.

Yours sincerely,

Bang Yong Lee

Bang Yong Lee
Principal Research Scientist,
Division of Polar Climate Sciences,
Korea Polar Research Institute (KOPRI)

National Center for Atmospheric Research
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NCAR

November 29, 2018

Cathy Wilson
Atmosphere, Climate & Ecosystem Sciences Team Leader
Earth and Environmental Sciences Division
Los Alamos National Laboratory
MS J495, Los Alamos, NM 87545

Dear Cathy,

I am writing to express support for the Next Generation Ecosystem Experiments (NGEE-Arctic) Phase 3 proposal. Having enjoyed our successful collaboration on uncertainty in Arctic hydrologic projections across the Permafrost Carbon Network models, I look forward to the opportunity to continue to collaborate with you and your team on Arctic permafrost modeling and synthesis projects. The Community Land Model (CLM) has benefitted from several recent advances of key thermal, hydrologic, and biogeochemical processes that are thought to be relevant for permafrost and its response to climate change and therefore provides an excellent framework for testing field driven hypotheses. I will be happy to participate in modeling experiments utilizing CLM and the Community Earth System Model. Understanding gained through NGEE-Arctic has and will continue to be invaluable for CLM improvements and consequently more reliable projections of the role of hydrology, for example, in the permafrost-carbon feedback.

Sincerely,

David Lawrence
Senior Scientist
CESM Land Model Working Group co-chair
Climate and Global Dynamics Laboratory
National Center for Atmospheric Research
Phone: 303 497-1384

BERKELEY LAB Lawrence Berkeley National Laboratory

Earth & Environmental Sciences Area

EARTH & ENVIRONMENTAL SCIENCES

November 30, 2018

Dear Stan,

Thank you for sharing the NGEE Arctic Phase 3 Renewal White Paper. Speaking on behalf of the NGEE-Tropics team, which is currently developing our Phase-2 proposal, we recognize a number of intersecting research objectives in common with NGEE Arctic. Those objectives include vegetation-soil biogeochemistry interactions, trait-based approaches to modeling plant variation in functional strategies, remote sensing (including remotely-piloted aerial systems – RPAS) techniques for mapping and upscaling vegetation structural and functional attributes, and biome boundary transitions under a changing climate. Other areas for additional collaboration include those related to data and project management. We look forward to continued collaboration and engagement with your team as datasets, knowledge, and modeling frameworks further develop for both NGEE projects.

Sincerely,

Jeffrey Q. Chambers
Faculty Scientist and
Director, Next Generation Ecosystem Experiment (NGEE) Tropics
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College of the Environment, Forestry, and Natural Sciences

Dr. Stan Wullschleger
Director, Environmental Sciences Division
Oak Ridge National Lab

Dear Stan: November 15, 2018

I am writing this letter in reference to the submission of your phase three proposal for the Next Generation Ecosystem Experiment – Arctic. I have served on the steering committee for phase one of this project as your group has established new observations at Utquiagvik (Barrow) Alaska in order to understand and project changes in Arctic permafrost ecosystems as the climate warms. During phase two the project, I rotated off the steering committee but have remained in close touch with your activities as you expanded your observations and research questions to the Seward Peninsula Alaska, in addition to continued work at Utquiagvik (Barrow). As the lead scientist for the Permafrost Carbon Network (PCN) I encourage and support interactions between NGEE-Arctic scientists and the broader science community through active participation in PCN synthesis activities.

Your proposed investigation to observe, understand, and project the dynamics of permafrost ecosystems aligns with the ongoing synthesis work of the PCN. Indeed, the continued interactions between NGEE Arctic and the PCN have been very fruitful. In particular, Dr. Cathy Wilson's participation in our PCN/SEARCH steering committee and regular interactions at our pre-AGU workshop has been extremely helpful for keeping our projects well integrated. Junior scientists from the NGEE Arctic program have helped to push our modeling intercomparison work forward (see Andresen et al. submitted Hydrology MIP). This effort (among others) was exactly the kind of project that arose from the interaction of our projects. Continued interactions will help to ensure that new data collected by your program becomes integrated with the larger scientific literature on this topic.

The Permafrost Carbon Network, established with funding through the National Science Foundation and now currently supported by the NSF Study for Environmental Arctic Change (SEARCH) program, has been engaged in synthesis science through a series of workshops and other activities. Since you have been an active participant of the network and intend to contribute and lead new synthesis products, I believe that these activities will provide a strong link between current and future NGEE Arctic activities and the larger goals of the Permafrost Carbon

Network. Your project should be able to use our network to ensure success of your proposed activities: as a place where your new research can get leveraged through our science synthesis activities, and also by drawing on our built network of scientists that have come together around this critically important topic to global society. I look forward to our continued interactions on this important topic, and wish you luck with your proposal development and submission.

Sincerely,

Edward (Ted) Schuur
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BiK F | Biodiversität und Klima Forschungszentrum

Dr Stan Wullschleger
Climate Change Science Institute
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN 37931

29 November 2018

Dear Stan,

RE: Letter of support – NGEE Arctic

I am writing to express my interest in collaboration with the NGEE Arctic experiment.

I am co-founder of The Tundra Trait Team, along with Isla Myers-Smith and members of the sTundra working group (German Centre for Integrative Biodiversity Research; iDiv). The Tundra Trait Team is an effort to increase the depth and breadth of trait data available for tundra plant species. Version 1 of the Tundra Trait Team database contains nearly 92,000 trait observations on nearly 978 species. The Tundra Trait Team is an inclusive group of tundra ecologists involved in ongoing efforts to understand patterns of functional trait variation across scales, identify changes in functional traits in response to climate warming, and better understand the consequences of these changes for tundra ecosystem functioning.

I am happy to collaborate with the NGEE Arctic project on the use of the Tundra Trait Team database to inform the parameterization of plant functional types in pan-Arctic modeling simulations using the E3SM land model. Further, I am interested in helping to use the Tundra Trait Team database, in combination with site-specific NGEE Arctic data, to investigate whether tundra plant leaves and roots fall along a whole-plant economic spectrum, and to think about whether we can predict root traits from remote sensing of leaf traits.

Best,

Anne Bjorkman

Dr Anne Bjorkman
Senckenberg Gesellschaft für Naturforschung
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Office of Science Applications - Arctic Program
US Fish and Wildlife Service
1011 E Tudor Road
Anchorage, AK 99503

November 13, 2018

Dr. Robert Bolton
International Arctic Research Center
University of Alaska Fairbanks
PO Box 757340
Fairbanks, AK 99775-7340

Dear Dr. Bolton:

The Office of Science Applications – Arctic Program (formerly the Arctic Landscape Conservation Cooperative (Arctic LCC)) is an applied-science partnership convened by the US Fish and Wildlife Service (FWS). The mission of the Office of Science Applications – Arctic Program is to identify and provide information needed to conserve natural and cultural resources in the face of landscape-scale stressors, including industrial development and climate change, through a multidisciplinary program that supports coordinated actions among management agencies, communities, industry and other stakeholders. One of the overarching goals is to better understand and predict effects of climate change and other stressors on landscape-level physical and ecosystem processes that will affect wildlife habitat.

I am pleased to offer a letter of collaboration for your proposed work under Phase 3 of the Next Generation Ecosystems Experiments (NGEE) program. NGEE aims to improve climate prediction in high-latitude ecosystems through field measurements and modeling of permafrost and snow dynamics and the many cascading impacts of a changing geophysical system on vegetation, subsurface processes, land-atmospheric interactions, and landscape processes. This goal broadly overlaps with FWS interests, although our focus is on the regional scale, natural-resource management, and ecosystem services.

Our interest in these topics is motivated by the importance of arctic wetlands to migratory birds and other wildlife species, and the potential effects of changes in surface hydrology on a food chain that supports water birds and, ultimately, people. Based on recent observational studies, it appears that ice-wedge degradation is widespread and has the potential to alter surface hydrology and habitat quality over the next few decades.

This letter is intended to convey Office of Science Applications – Arctic Program support for the overall goals of your project, but does not constitute peer review or endorsement of any specific methods. We are pleased that work funded by the FWS and USGS will be useful to the NGEE project.

Sincerely,

Dr. Wendy Loya
Coordinator, Office of Science Applications – Arctic Program

WESTERN SYDNEY
UNIVERSITY

Hawkesbury Institute
for the Environment

Dr Stan Wullschleger
Climate Change Science Institute
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN 37931

31 October 2018

Dear Stan,

RE: Letter of support – NGEE Arctic

I am writing to express my support for the continuation of the NGEE Arctic experiment. The data from this unique experiment are proving to be invaluable in advancing our understanding of plant adaptations to climate and I see their continued collection as essential to support the development of globally-applicable models of plant function.

My area of research lies in the synthesis and meta-analysis of plant responses to environmental drivers, with the aim of quantifying the ability of plants to acclimate and adapt to changes in environmental conditions. This research aims to take in datasets obtained in ecosystems spanning the full range of global climates. The dataset collected via NGEE Arctic is the only one being collected at the coldest extent of vegetation. It thus fills a very important niche, allowing us to explore the extent of plant capacity to adapt to cold temperatures. The dataset has thus been pivotal in a number of studies, including the following research co-published with NGEE Arctic Scientist, Alistair Rogers:

Kumarathunge DP, Medlyn BE, Drake JE, Tjoelker MG, Aspinwall MJ, Battaglia M, Carter KR, Cavaleri MA, Cernusak LA, Chambers JQ, Crous KY, De Kauwe MG, Dillaway DN, Dreyer E, Ellsworth DS, Ghannoum O, Han Q, Hikosaka K, Jensen AM, Kelly JWG, Kruger EL, Mercado LM, Onoda Y, Reich PB, Rogers A, Slot M, Smith NG, Tarvainen L, Tissue DT, Togashi HF, Tribuzy ES, Uddling J, Vårhammar A, Wallin G, Warren JM, Way DA (2018) Acclimation and adaptation components of the temperature dependence of plant photosynthesis at the global scale. *New Phytologist* Accepted 20/10/18

De Kauwe MG, Lin Y-S, Wright IJ, Medlyn BE, Crous KY, Ellsworth DS, Maire V, Prentice IC, Atkin OK, Rogers A, Niinemets Ü, Serbin S, Meir P, Uddling J, Togashi HF, Tarvainen L, Weerasinghe LK, Evans BJ, Ishida FY, Domingues TF (2015) A test of the "one-point method" for estimating maximum carboxylation capacity from field-measured, light-saturated photosynthesis. *New Phytologist* 210:1130-1144.

Ali AA, Xu C, Rogers A, McDowell NG, Medlyn BE, Fisher RA, Wullschleger SD, Reich PB, Vrugt JA, Bauerle WL, Santiago LS, Wilson CJ (2015) Global scale environmental control of plant photosynthetic capacity. *Ecological Applications* 25: 2349-2365.

Lin YS, Medlyn BE, Duursma RA, Prentice IC, Wang H, Baig S, Eamus D, Resco de Dios V, Mitchell P, Ellsworth DS, Op de Beeck M, Wallin G, Uddling J, Tarvainen L, Linderson M, Cernusak L, Nippert J, Ocheltree T, Tissue DT, Martin-StPaul N, Rogers A, Warren J, De Angelis P, Hikosaka K, Han Q, Onoda Y, Gimeno T, Barton CVM, Bennie J, Bonal D, Bosc A, Löw M, Macinnis-Ng C, Rey A, Rowland L, Setterfield S, Tausz-Posch S, Zaragoza-Castells J, Broadmeadow M, Drake J, Freeman M, Ghannoum O, Hutley L, Kelly J, Kikuzawa K, Kolari P,

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Koyama K, Limousin J-M, Meir P, Costa A, Mikkelsen T, Salinas N, Sun W, Wingate L (2015) Optimal stomatal behaviour around the world. *Nature Climate Change* 5: 459–464.

Continued work offers more opportunities to advance this global-scale research. For example, we are now collaborating with Dr Rogers on an investigation of the role of triose phosphate limitation to photosynthesis globally. The NGEE Arctic data, being the unique dataset available in an extreme cold climate, is the most important dataset in this investigation.

In summary, this experiment has provided many new and valuable opportunities for scientific synthesis at global scale, and I wholeheartedly support its continuation.

Yours faithfully,

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12. BUDGET

This section contains information on FY20 thru FY22 budgets and budget justifications for ORNL, LANL, LBNL, BNL, and UAF as major participants in the NGEE Arctic project. The budget sheets document the annual and three-year total distribution of funds to each of our partners. The estimated average allocation of funds to ORNL, LANL, LBNL, BNL, and the UAF are shown in Figure 15.

While the allocation of funds to each of our partner institutions is important, as they will be responsible for executing a well-defined and specific scope of work, the fractional allocation of funds to tasks is also important. The NGEE Arctic proposal is organized by major science questions as outlined in our research plan (Section 5) and includes additional areas of Project Management (Section 6) and Data Management (Section 7).

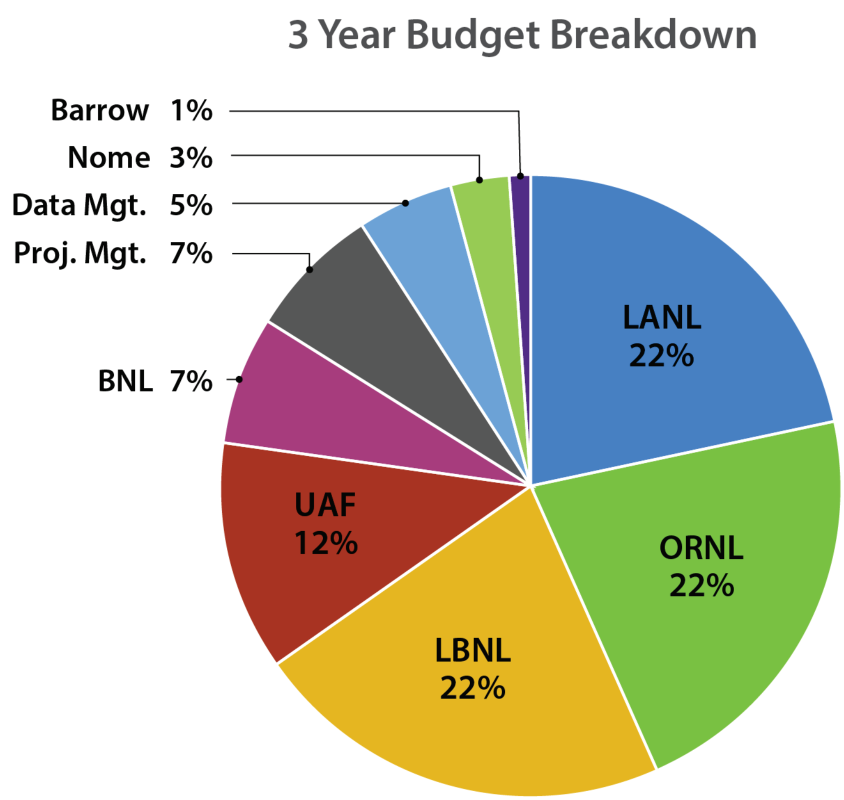

Figure 15. Budget breakdown by institution and infrastructure segment.

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ORGANIZATION OAK RIDGE NATIONAL LABORATORY				**Budget Page No:** YEAR 1	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Stan Wullschelger				Requested Duration: 12 (Months)	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos.			Amounts in Whole Dollars Funds Requested by Applicant	Funds Granted by DOE
	CAL	ACAD	SUMR		
1. Stan Wullscheleger	6.0			141,683	
2. Peter Thornton	1.2			22,470	
3. David Graham	3.6			47,736	
4. Colleen Iversen	4.8			63,648	
5. Sue Heinz	6.0			75,707	
6. (10) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	20.1			272,513	
7. (15) TOTAL SENIOR PERSONNEL (1-6)	41.7			623,757	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (3) POST DOCTORAL ASSOCIATES	24.6			146,395	
2. (8) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.)	20.5			278,329	
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER (CRAFTS)					
TOTAL SALARIES AND WAGES (A+B)				1,048,481	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				388,552	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				1,437,033	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				170,000	
2. FOREIGN					
TOTAL TRAVEL				170,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				222,408	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS				6,463,231	
6. OTHER Division Organization Burden				692,451	
TOTAL OTHER DIRECT COSTS				7,378,090	
H. TOTAL DIRECT COSTS (A THROUGH G)				8,985,123	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				1,014,877	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				10,000,000	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				10,000,000	

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ORGANIZATION: OAK RIDGE NATIONAL LABORATORY				Budget Page No: YEAR 2	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Stan Wullschelger				Requested Duration: 12 (Months)	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR	Amounts in Whole Dollars Funds Requested by Applicant	Funds Granted by DOE
1. Stan Wullscheleger	6.0			147,491	
2. Peter Thornton	1.2			23,391	
3. David Graham	3.6			49,029	
4. Colleen Iversen	4.8			66,255	
5. Sue Heinz	6.0			78,810	
6. (10) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	19.5			276,627	
7. (15) TOTAL SENIOR PERSONNEL (1-6)	41.1			641,603	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (3) POST DOCTORAL ASSOCIATES	22.4			143,560	
2. (8) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.)	32.5			289,743	
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER (CRAFTS)					
TOTAL SALARIES AND WAGES (A+B)				1,074,906	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				399,536	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				1,474,442	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				175,000	
2. FOREIGN					
TOTAL TRAVEL				175,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				199,676	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS				6,433,152	
6. OTHER Division Organization Burden				695,838	
TOTAL OTHER DIRECT COSTS				7,328,666	
H. TOTAL DIRECT COSTS (A THROUGH G)				8,978,108	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				1,021,892	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				10,000,000	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				10,000,000	

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ORGANIZATION OAK RIDGE NATIONAL LABORATORY				**Budget Page No:** YR 3	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Stan Wullschelger				Requested Duration: 12 (Months)	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR	Dollars Funds Requested by Applicant	Funds Granted by DOE
1. Stan Wullscheleger	6.0			153,539	
2. Peter Thornton	1.2			24,350	
3. David Graham	3.6			51,039	
4. Colleen Iversen	4.8			68,972	
5. Sue Heinz	6.0			82,044	
6. (10) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	19.1			278,966	
7. (15) TOTAL SENIOR PERSONNEL (1-6)	40.7			658,910	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (3) POST DOCTORAL ASSOCIATES	21.6			151,083	
2. (8) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.)	32.5			302,605	
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER (CRAFTS)					
TOTAL SALARIES AND WAGES (A+B)				1,112,598	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				413,091	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				1,525,689	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				170,000	
2. FOREIGN					
TOTAL TRAVEL				170,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				148,724	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS				6,416,089	
6. OTHER Division Organization Burden				707,544	
TOTAL OTHER DIRECT COSTS				7,272,357	
H. TOTAL DIRECT COSTS (A THROUGH G)				8,968,046	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				1,031,954	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				10,000,000	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				10,000,000	

ORNL Three Year Budget

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ORGANIZATION OAK RIDGE NATIONAL LABORATORY				**Budget Page No:**	YR 1-3
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Stan Wullschelger				Requested Duration:	36 (Months)
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR	Dollars Funds Requested by Applicant	Funds Granted by DOE
1. Stan Wullscheleger	18.0			442,713	
2. Peter Thornton	3.6			70,211	
3. David Graham	10.8			147,804	
4. Colleen Iversen	14.4			198,875	
5. Sue Heinz	18.0			236,561	
6. (13) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	58.7			828,106	
7. (17) TOTAL SENIOR PERSONNEL (1-6)	123.5			1,924,271	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (2) POST DOCTORAL ASSOCIATES	68.6			441,038	
2. (3) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.)	85.5			870,676	
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER (CRAFTS)					
TOTAL SALARIES AND WAGES (A+B)				3,235,985	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				1,201,179	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				4,437,165	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				515,000	
2. FOREIGN					
TOTAL TRAVEL				515,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				570,808	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER (ADPE) SERVICES				-	
5. SUBCONTRACTS				19,312,472	
6. OTHER Division Organization Burden				2,095,833	
TOTAL OTHER DIRECT COSTS				21,979,113	
H. TOTAL DIRECT COSTS (A THROUGH G)				26,931,278	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				3,068,722	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				30,000,000	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				30,000,000	

Project Partners Budgets

The following budgets, for our partners in the NGEE Arctic project Phase 3, are fully contained within the ORNL budget on the previous pages. A budget is included for each partner; UAF, BNL, LBNL and LANL.

University of Alaska Fairbanks Three Year Budget

	FY 2020		FY 2021		FY 2022	
	Months	Cost	Months	Cost	Months	Cost
Bob Bolton	5.0	$53,507	5.0	$54,577	5.0	$55,669
Vladimir Romanovsky	3.0	$47,056	3.0	$47,996	3.0	$48,956
Amy Breen	3.5	$33,025	3.5	$33,685	3.5	$34,359
tal Salaries, Wages and Benefits Senior Staff Totals	11.5	$133,588	11.5	$136,258	11.5	$138,984
Post Docs		$0		$0		$0
Other Staff	20.5	$170,680	20.5	$174,663	19.5	$175,510
Students	24.0	$67,449	24.0	$67,449	24.0	$67,449
Org/Div Admin. Undergraduate Students		$0		$0		$0
Clerical		$0		$0		$0
Other staff		$0		$0		$0
Total Salaries & Wages		$238,129		$242,112		$242,959
Fringe Benefits		$108,243		$110,857		$112,327
		$479,960		$489,227		$494,270
Equipment		$0		$0		$0
Travel Domestic		$116,070		$120,695		$121,273
Travel Foreign		$7,367		$0		$0
Total Travel		$123,437		$120,695		$121,273
Trainee Costs		$0		$0		$0
Other Direct Costs		$22,740		$22,968		$23,208
Materials and Supplies		$25,000		$16,000		$8,500
Publication Costs		$3,250		$5,500		$7,000
Consultation Fees		$0		$0		$0
Computer Services		$0		$0		$0
Subcontracts		$0		$0		
		$0		$0		$0
Total Direct Costs		$654,387		$654,390		$654,251
Contingency	0.0%	$0	0.0%	$0	0.0%	$0
Indirect Costs		$329,705		$329,707		$329,642
Total Direct and Indirect Costs		$984,092		$984,097		$983,893
Cost Sharing		$0		$0		$0
Project Total Costs		$984,092		$984,097		$983,893

1/3/2019

BROOKHAVEN NATIONAL LABORATORY

Directorate:	***Environment, Biology, Nuclear Energy & Non Proliferation***
Department:	***Environmental and Climate Sciences Department***
Title:	***NGEE ARCTIC PHASE 3***
Principal Investigator:	***ROGERS,ALISTAIR***
Period of Performance:	***10/01/2019 - 09/30/2022***
Sponsor:	***BER/ORNL***

Sum of Amount		Reporting Year			
Cost Type	Cost Element	2020	2021	2022	Grand Total
Direct Costs	BNL Direct Labor	$ 239,945	$ 251,437	$ 263,832	$ 755,214
	Materials and Supplies	$ 30,397	$ 22,641	$ 20,000	$ 73,039
	Travel	$ 45,000	$ 35,000	$ 25,000	$ 105,000
	Contracts	$ 36,279	$ 37,173	$ 25,641	$ 99,093
	Procurement Burden	$ 8,376	$ 7,111	$ 5,298	$ 20,785
	Departmental Charges	$ 100,177	$ 104,975	$ 110,150	$ 315,302
Direct Costs Total		**$ 460,174**	**$ 458,338**	**$ 449,921**	**$ 1,368,433**
Indirect Costs	Indirect Overheads-Project G&A	$ 175,212	$ 177,049	$ 185,465	$ 537,725
	Indirect Overheads - LDRD	$ 14,614	$ 14,614	$ 14,614	$ 43,842
Indirect Costs Total		**$ 189,826**	**$ 191,662**	**$ 200,079**	**$ 581,567**
Grand Total		**$ 650,000**	**$ 650,000**	**$ 650,000**	**$ 1,950,000**

Sum of FTE	Reporting Year			
LaborType	2020	2021	2022	Grand Total
PROFESSIONAL	0.75	0.80	0.36	1.91
SCIENTIFIC	0.66	0.66	0.90	2.22
Grand Total	**1.41**	**1.46**	**1.26**	**4.13**

LANL BUDGET FY20

DOE F 4620.1 (04-93) All Other Editions Are Obsolete	U.S. Department of Energy Budget Page - FY 2020 (See reverse for Instructions)				OMB Control No. 1910-1400 OMB Burden Disclosure Statement on Reverse

ORGANIZATION Los Alamos National Laboratory				Budget Page No: 1	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Cathy Wilson				Requested Duration: 12 (Months) Year 1	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos.			Funds Requested by Applicant	Funds Granted by DOE
	CAL	ACAD	SUMR		
1. Wilson, Cathy	4.80			$115,196	
2. Rowland, Joel	3.60			$65,929	
3. Newman, Brent	3.60			$72,846	
4. Harp, Dylan	3.60			$52,655	
5. Bennett, Katrina	3.60			$59,353	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	13.36			$181,243	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	32.56			$547,222	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES	36.00			$319,313	
2. ( ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS	12.00			$76,891	
4. ( ) UNDERGRADUATE STUDENTS	24.00			$116,948	
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				$1,060,374	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$384,942	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$1,445,316	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				$85,000	
2. FOREIGN					
TOTAL TRAVEL				$85,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				$35,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS				$35,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				$1,565,316	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				$552,434	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				$2,117,750	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				$2,117,750	

LANL BUDGET FY21

DOE F 4620.1 (04-93) All Other Editions Are Obsolete	U.S. Department of Energy Budget Page - FY 2021 (See reverse for Instructions)				OMB Control No. 1910-1400 OMB Burden Disclosure Statement on Reverse
ORGANIZATION: Los Alamos National Laboratory				Budget Page No:	2
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Cathy Wilson				Requested Duration:	12 (Months) Year 2
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR	Funds Requested by Applicant	Funds Granted by DOE
1. Wilson, Cathy	4.68			$115,566	
2. Rowland, Joel	3.49			$65,918	
3. Newman, Brent	3.49			$72,834	
4. Harp, Dylan	3.49			$52,646	
5. Bennett, Katrina	3.49			$59,343	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	12.96			$181,104	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	31.62			$547,411	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES	34.93			$319,128	
2. (					
3. ( ) GRADUATE STUDENTS	11.64			$76,847	
4. ( ) UNDERGRADUATE STUDENTS	23.29			$116,881	
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				$1,060,267	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$384,933	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$1,445,201	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				$85,000	
2. FOREIGN					
TOTAL TRAVEL				$85,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				$35,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS				$35,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				$1,565,201	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				$552,549	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				$2,117,750	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				$2,117,750	

LANL BUDGET FY22

DOE F 4620.1
(04-93)
All Other Editions Are Obsolete

U.S. Department of Energy
Budget Page - FY 2022
(See reverse for Instructions)

OMB Control No.
1910-1400
OMB Burden Disclosure
Statement on Reverse

ORGANIZATION Los Alamos National Laboratory				Budget Page No: 3	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Cathy Wilson				Requested Duration: 12 (Months) Year 3	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos.			Funds Requested	Funds Granted
	CAL	ACAD	SUMR	by Applicant	by DOE
1. Wilson, Cathy	4.53			$115,324	
2. Rowland, Joel	3.39			$65,901	
3. Newman, Brent	3.39			$72,815	
4. Harp, Dylan	3.39			$52,633	
5. Bennett, Katrina	3.39			$59,328	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	12.59			$181,141	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	30.69			$547,142	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES	33.94			$319,390	
2. (					
3. ( ) GRADUATE STUDENTS	11.31			$76,910	
4. ( ) UNDERGRADUATE STUDENTS	22.63			$116,977	
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				$1,060,419	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$384,945	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$1,445,364	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				$85,000	
2. FOREIGN					
TOTAL TRAVEL				$85,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				$35,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS				$35,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				$1,565,364	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				$552,386	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				$2,117,750	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				$2,117,750	

LANL THREE YEAR BUDGET

DOE F 4620.1
(04-93)
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U.S. Department of Energy
Budget Page - Summary
(See reverse for Instructions)

OMB Control No.
1910-1400
OMB Burden Disclosure Statement on Reverse

ORGANIZATION Los Alamos National Laboratory				**Budget Page No:** 4	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Cathy Wilson				Requested Duration: 36 (Months) Summary - All Years	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	DOE Funded Person-mos.			Funds Requested	Funds Granted
	CAL	ACAD	SUMR	by Applicant	by DOE
1. Wilson, Cathy	14.00			$346,086	
2. Rowland, Joel	10.49			$197,747	
3. Newman, Brent	10.49			$218,495	
4. Harp, Dylan	10.49			$157,934	
5. Bennett, Katrina	10.49			$178,025	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	38.92			$543,488	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	94.87			$1,641,775	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES	104.87			$957,831	
2. ( ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS	34.96			$230,648	
4. ( ) UNDERGRADUATE STUDENTS	69.92			$350,806	
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				$3,181,060	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$1,154,820	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$4,335,880	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				$255,000	
2. FOREIGN					
TOTAL TRAVEL				$255,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				$105,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS				$105,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				$4,695,880	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS				$1,657,370	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				$6,353,250	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)				$6,353,250	

LBNL Budget FY20-22

LBNL PROPOSAL BUDGET ESTIMATE
NGEE ARCTIC PHASE III

PIs:	Susan Hubbard		FY20		FY21		FY22		Total Effort	Total Costs
A.	SALARIES AND WAGES		Months	Cost	Months	Cost	Months	Cost	Months	Cost
	A.1 PI:	Hubbard,Susan S	2.00	$67,837	2.00	$70,211	2.00	$72,668	6.0	$210,716
	A.2	Arora,Bhavna	0.60	$6,030	0.60	$6,241	0.60	$6,460	1.8	$18,732
	A.3	Dafflon,Baptiste	3.70	$41,293	3.70	$42,738	3.70	$44,234	11.1	$128,264
	A.4	Peterson,John	1.50	$16,915	0.00	$0	0.00	$0	1.5	$16,915
	A.5	Ulrich,Craig	1.50	$13,123	1.50	$13,582	1.50	$14,058	4.5	$40,763
	A.6	Wainwright,Haruko Murakar	1.20	$13,662	1.00	$11,783	1.00	$12,196	3.2	$37,641
	A.7	Wu,Yuxin	0.75	$8,956	0.75	$9,270	0.60	$7,675	2.1	$25,901
	A.8	Torn,Margaret S	2.35	$50,685	2.35	$52,459	2.35	$54,295	7.1	$157,438
	A.9	Porras,Rachel C	2.50	$15,631	2.50	$16,178	2.00	$13,395	7.0	$45,204
	A.10	Conrad,Mark S	1.00	$17,050	1.00	$17,647	1.00	$18,265	3.0	$52,962
	A.11	Tas Baas,Neslihan	4.00	$42,144	4.00	$43,619	4.00	$45,146	12.0	$130,910
	A.12	Riley,William J	2.35	$42,087	2.35	$43,560	2.35	$45,084	7.1	$130,731
	A.13	Bouskill,Nicholas J	2.50	$30,216	2.50	$31,274	2.50	$32,368	7.5	$93,858
	A.14	Tang,Jinyun	2.50	$28,780	2.50	$29,788	2.50	$30,830	7.5	$89,398
	A.15	Soom,Florian A	1.50	$7,298	1.00	$5,036	1.00	$5,212	3.5	$17,546
	A.16	Dengel,Sigrid	5.00	$36,571	5.00	$37,851	4.00	$31,341	14.0	$105,763
	A.17	Mekonnen,Zelalem Amdie	10.50	$63,356	10.50	$65,574	10.50	$67,869	31.5	$196,799
	A.18	Moyes,Andrew Burton	1.00	$7,762	1.00	$8,034	1.00	$8,315	3.0	$24,112
	A.19	Chin,Sandy	0.75	$7,396	0.50	$5,103	0.50	$5,282	1.8	$17,781
	A.20	*Earth Postdoc Fellow Step	18.00	$104,384	18.00	$108,037	18.00	$111,819	54.0	$324,240
	A.21	Uhlemann,Steffen Sebastiar	5.25	$29,852	5.00	$29,426	5.00	$30,456	15.3	$89,734
	A.22	Vaughn,Lydia Smith	2.50	$11,791	2.00	$9,763	2.00	$10,105	6.5	$31,658
	A.23	Morales,Alejandro	0.75	$4,733	0.75	$4,899	0.75	$5,071	2.3	$14,703
	A.24	*Research Assoc 1	7.00	$33,399	7.00	$34,568	7.00	$35,778	21.0	$103,746
	A.25	*Graduate Student Researcl	5.25	$18,236	5.25	$18,874	5.25	$19,535	15.8	$56,644
	A.26	0	0.00	$0	0.00	$0	0.00	$0	0.0	$0
	TOTAL Labor		**85.95**	**$719,189**	**82.75**	**$715,515**	**81.10**	**$727,455**	**249.8**	**$2,162,160**
B.	PAYROLL BURDEN		Rate	Est Cost	Rate	Est Cost	Rate	Est Cost		
	B.1 Scientific/Career		62.0%	$294,286	62.8%	$303,852	63.6%	$310,160		$908,298
	B.2 Postdoc		34.7%	$68,565	35.2%	$71,469	35.8%	$75,231		$215,265
	B.3 GSRA		2.2%	$401	2.2%	$415	2.2%	$430		$1,246
	B.4 Students/Rehired Retirees		2.2%	$632	2.2%	$215	2.2%	$222		$1,069
	B.5 Summer Faculty		11.7%	$0	11.7%	$0	11.7%	$0		$0
	TOTAL Payroll Burden			**$363,883**		**$375,951**		**$386,043**		**$1,125,878**
C.	TOTAL SALARIES AND PAYROLL BURDEN			$1,083,072		$1,091,467		$1,113,499		$3,288,038
D.	SCIENTIFIC AND SUPPORT BURDEN									
	ALD Burden		various	$200,368	various	$201,921	various	$205,997		$608,287
	TOTAL Scientific/Support Burden			$200,368		$201,921		$205,997		$608,287
F.	PURCHASES									
	F.1 Equipment			$0		$0		$0		$0
	F.2 Other procurements; lab & office supplies, electricity			$37,503		$24,472		$14,844		$76,819
	F.3 Ebuy Procurements			$0		$0		$0		$0
	F.4. Sales Tax			$0		$0		$0		$0
	F.5 Procurement burden/material handling			$3,900		$2,545		$1,544		$7,989
	TOTAL Purchases			**$41,403**		**$27,017**		**$16,387**		**$84,808**
G.	TRAVEL									
	G.1 Domestic			**$80,000**		**$80,000**		**$55,000**		**$215,000**
	G.2 Foreign			**$0**		**$0**		**$0**		**$0**
	G.3 Travel Burden			**$7,280**		**$7,280**		**$5,005**		**$19,565**
H.	OTHER DIRECT COSTS – OVERHEADED									
	H.1 Telephone			$0		$0		$0		$0
	H.2 Central computing facilities			$0		$0		$0		$0
	H.3 Recharges			$0		$0		$0		$0
	H.4 Miscellaneous expenses			$0		$0		$0		$0
	H.5 Stipends			$0		$0		$0		$0
	TOTAL Other Direct Costs, Overheaded			$0		$0		$0		$0
I.	OTHER DIRECT COSTS – NO OVERHEAD									
	I.1 Electricity - see above under Supplies			$0		$0		$0		$0
	TOTAL Other Direct Costs, No Overhead			$0		$0		$0		$0
J.	OTHER									
	J.1 Administrative recharges			$0		$0		$0		$0
	J.2 ER-LTT Tech Transfer Burden (on C thru H)			$0		$0		$0		$0
	J.3 Homeland Security burden		0.0%	$0	0.0%	$0	0.0%	$0		$0
	J.4 Tuition (GSRA)			$9,405		$9,405		$9,405		$28,215
	TOTAL Other			**$9,405**		**$9,405**		**$9,405**		**$28,215**
	Total Direct Costs (C, E,F,G, H, I, J4)			$1,221,160		$1,215,168		$1,199,296		$3,635,625
	Total Burdens (D, J1-J3)			$200,368		$201,921		$205,997		$608,287
K.	**TOTAL DIRECT COSTS and BURDENS**			**$1,421,529**		**$1,417,090**		**$1,405,293**		**$4,243,912**
L.	OVERHEAD									
	L.1 Overhead (on C+D+E5+F5+G3+H+J1-J3)		52.70%	$682,265	52.70%	$686,793	52.70%	$698,826		$2,067,884
	L.2 LDRD Rate (C+D+E+F+G+H+I+J+L1+L3+N+L4)		2.90%	$62,453	2.90%	$62,453	2.90%	$62,453		$187,359
	L.3 IGPP Rate (C+D+E2+E4+E5+F+G+H+J)		2.00%	$28,431	2.00%	$28,342	2.00%	$28,106		$84,878
	L.4 Total Cost Rate (C+D+E+F+G+H+I+J+L1+L3+N)		1.00%	$21,322	1.00%	$21,322	1.00%	$21,322		$63,967
M.	TOTAL LABORATORY COSTS (K+L1-L4)			$2,216,000		$2,216,000		$2,216,000		$6,647,999
N.	Safeguards & Security (C+D+E2+E4+E5+F+G+H+I+J+L1+L3)		0.00%	$0	0.00%	$0	0.00%	$0		$0
O.	DOE Federal Administrative Charge (M+N)		0.00%	$0	0.00%	$0	0.00%	$0		$0
P.	**TOTAL COSTS (M+N+O)**			**$2,216,000**		**$2,216,000**		**$2,216,000**		**$6,647,999**

13. BUDGET JUSTIFICATION

ORNL BUDGET JUSTIFICATION

Cost estimates presented in this science plan have been reclassified in order to be comparable to other research institutions' plans. At Oak Ridge National Laboratory (ORNL), actual costs will be collected and reported in accordance with the Department of Energy (DOE) approved cost accounting system. Total cost presented in this plan and the actual cost totals will be equivalent as will the subtotal of direct and indirect cost.

A.(1-5) Senior Personnel

The ORNL's cost accounting system incorporates wage pool allocations, which are built around job grade classifications. The salary figure listed for Senior Personnel represents the average salary for an Environmental Sciences Division (ESD) staff scientist within a specific wage pool. For budgeting purposes, one calendar month is assumed to be 151.7 hours.

Stan Wullschleger is a Distinguished R&D Scientist and Chief Scientist in the Environmental Sciences Division. He will serve as NGEE Director and contribute to experimental and modeling tasks in the biogeochemistry, vegetation dynamics, and hydrology and geomorphology. Stan will devote 0.5 FTE to these activities.

David Graham is a Senior Research Scientist and Group Leader in the Biosciences Division. He will serve as co-PI and science lead for biogeochemistry (Q2) and will contribute his expertise in microbiology to specific tasks in the shrub dynamics tasks as well. David will devote 0.4 FTE to these activities.

Susan Heinz is a Technical Project Manager in the Environmental Sciences Division. She will serve as Technical Project Manager, reporting to Stan Wullschleger. Susan will be providing project management and support in operations and logistics to the Leadership Team to manage cost schedule and risk across the project. Susan will devote 0.5 FTE to this project.

Colleen Iversen is a Staff Scientist in the Environmental Sciences Division. She is an expert in ecosystem ecology, with a specific focus on root-soil interactions. Colleen will lead the team effort associated with harnessing the variation in key Arctic plant functional traits for use in trait-enabled models (Q3). She will devote 0.4 FTE to these activities.

Peter Thornton is a Senior Research Scientist in the Environmental Sciences Division. He will serve as co-PI and science lead for the NGEE modeling activities across landscape organization and structure, biogeochemistry, plant traits, shrub dynamics, and hydrology. Peter will devote 0.1 FTE to these activities.

A.6 Others

Alison Boyer is a Senior Research Scientist in the Environmental Sciences Division. She will serve as co-PI and science lead for the NGEE data management team. Alison will devote 0.2 FTE to these activities.

Ethan Coon is a Research & Development Staff Member in Environmental Sciences Division. He will work on applications to hydrology and terrestrial ecosystem modeling. Ethan will devote .5 FTE to these activities.

Michael Crow is a computer technical professional in Environmental Sciences Division. He will support software development work on the data management tools at .3 FTE.

Ranjeet Devarakonda is a computer scientist in the Atmospheric Radiation Measurement project with an extensive background in web/software development and data management. He will participate in tasks related to informatics and data systems development, plus oversee management and design of the NGEE web site. Ranjeet will devote 0.1 FTE to these activities.

Baohua Gu is a Distinguished Staff Scientist with experience in soil organic matter and its interaction with minerals, contaminant metals, biogeochemical transformation processes, and spectroscopic studies. He will assist and guide a postdoctoral research associate in biogeochemistry studies, particularly related to rates and mechanisms of soil carbon transformation, carbon-mineral interactions, and preservation. Baohua will devote 0.4 FTE to these activities.

Forest Hoffman is a Senior Computational Earth System Scientist Staff Member in the Computational Sciences & Engineering Division and will devote .1 FTE to modeling efforts.

Les Hook is a scientist in the ORNL Distributed Active Archive Center (DAAC) with a background in environmental data quality management. He will work closely with the director and others on the NGEE team to develop and implement a data management plan for NGEE. A data policy will cover data management, sharing, and archival. Les will devote 0.2 FTE to these activities.

Ahmad Jan is a Technical Professional (PhD) staff member in the Environmental Sciences Division, with expertise in the development and application of integrated surface-subsurface thermal-hydrology and reactive transport models. He will contribute to the fine and intermediate scale modeling efforts, with an emphasis on freeze-thaw processes at hillslope and watershed scales. Ahmad will devote 0.5 FTE to these activities.

Jitendra (Jitu) Kumar is a Research & Development Staff Member in Environmental Sciences Division, Oak Ridge National Laboratory with expertise in ecohydrological modeling, landscape characterization and data analytics. He will contribute to the fine to climate scale ecohydrological modeling and landscape characterization tasks. Jitu will devote 0.4 FTE to these activities.

Scott Painter is a Distinguished R&D Staff Member in the Environmental Sciences Division with more than 20 years of experience in modeling subsurface flow and reactive transport processes. He will contribute to integrated fine-scale modeling activities across landscape organization and structure, biogeochemistry, shrub dynamics, and hydrology. Scott will devote 0.2 FTE to these activities.

Benjamin Sulman is an Associate Research and Development staff member in the Environmental Sciences Division, with expertise in developing and applying models of microbial processes, soil biogeochemistry, and plant-microbe interactions. He will contribute to the biogeochemistry and vegetation modeling components of the project, with a focus on migration of site-level knowledge to Earth system modeling scales. Benjamin will devote 0.25 FTE to these activities.

Fengming Yuan is a Technical Professional (PhD) staff member in the Environmental Sciences Division, with expertise in Arctic vegetation modeling, and in physical and biogeochemical interactions of vegetation with the Arctic environment. He will contribute to the integration of new knowledge from multiple fine and intermediate modeling studies into the E3SM Land Model (ELM). Fengming will devote 1.0 FTE to these activities.

B.1 Postdoctoral Associates

Costs are estimated for a number of postdoctoral associates in each fiscal year. ORNL postdoctoral research associates are now hired as ORNL temporary staff. They are charged out a lower rate with reduced organization burden.

B.2 Other Professional – Technicians

The ORNL's cost accounting system incorporates wage pool allocations, which are built around job grade classifications. The salary figure listed for Other Personnel represents the average salary for an ESD staff technician within a specific wage pool. For budgeting purposes, one calendar month is assumed to be 151.7 hours. Technical professionals include Lowe, Philips, Brice, Yin and Childs.

B.4 Students

There are no undergraduate students planned for this project.

B.6 Other/ORNL Services

Costs are estimated for the service provided by the ORNL Energy and Environmental Sciences Directorate

C. Fringe Benefits

Fringe Benefits for ORNL employees are estimated to be 39.6% for FY20 -22. Fringe Benefits for ORNL Post-Doctoral Associates are estimated to be 21.4% for FY 2020 - FY 2022.

E.1 Travel

Domestic: Costs are estimated based on the destination and length of stay. In each Year, 16 trips to Alaska are planned at an estimated cost of $2800 per week. An additional 30 trips per year are included for the PI and staff to attend a national meeting and for discussions with BER Program Managers in Germantown, MD.

Foreign: Foreign travel is proposed and approved by ORNL management and DOE BER as opportunities arise. Funding is reallocated from other travel funds as needed.

G.1 Materials and Supplies

The NGEE Arctic project anticipates expenditure of funds on miscellaneous materials and supplies, including materials for field research and office and laboratory supplies. These costs are covered as they occur.

G.5 Subcontracts

Subcontract details for each fiscal year are provided below.

ORNL Subcontract #1: University of Alaska Fairbanks

(Year 1 $984,092; Year 2 $984,097; Year 3 $983,893

The University of Alaska Fairbanks is a valued partner in the NGEE Arctic project. Scientists across several departments and institutes will interact with staff from the national laboratories in each of the science teams. Technical capabilities are also strong and UAF staff will play a major role in the design and deployment of instruments for weather and environmental monitoring on the Seward Peninsula. A breakdown of personnel coverage, materials and supplies, equipment, and travel are shown below.

Senior Personnel (Year 1 $133,588; Year 2 $136,259; Year 3 $138,985; Total $408,831)

W. Robert Bolton will serve as lead PI for the UAF team and co-leads Question 5 activities. Bolton is budgeted for 870 hours (at $53.64/hr) per year. He will also be responsible for leading hydrologic measurements and in developing a model of surface deformation in response to melting of buried massive ice and thawing of ice-rich permafrost. Ross Spicer, a Graduate student will work closely with Bolton (academic and summer) to incorporate thermal processes into a landscape-evolution model. Bolton will also assist Busey in data management activities. Bolton will devote 0.41 FTE to these activities.

Vladimir Romanovsky will serve as the Chief Scientist for the entire NGEE project. Romanovsky is budgeted for 522 hours (at $78.63/hr) per year. Efforts will focus primarily on developing high-resolution models of permafrost thermal dynamics and permafrost degradation. Romanovsky will devote 0.25 FTE to these activities.

Amy Breen will co-lead the Question 6 activities. Breen will also characterize arctic plant communities in the shared field plots used to assess plant trait characteristics. Breen will also evaluate mechanisms important for shrub recruitment in the tundra via observations across key environmental gradients such as temperature and wildfire disturbance. Breen is budgeted for 609 hours (at $47.30/hr) per year. Breen will devote 0.29 FTE to these activities.

Other Personnel (Year 1 $238,129; Year 2 $242,112; Year 3 $242,959; Total $723,200)

Eugenie Euskirchen will engage in ecosystem modeling with a goal of linking microscale processes with ecosystem scale models. Eugenie is budgeted for 174 hours ($57.69/hr) per year. Eugenie will primarily contribute to vegetation model/observation integration, and model validation Funding for one PhD student (academic and summer) will be provided to perform the modeling and inter-comparisons with the vegetation models.

Robert (Bob) Busey will assist in field data collection of hydrological and meteorological data and will take a leading role in incorporation of hydrological processes into a landscape evolution model. Busey is budgeted for 1714 hours in Years 1 and 2 and 1914 hours (at $40.80/hr) in Year 3. Busey will also be the UAF data representative for the Data Management Team.

Go Iwahana is budgeted for 348 hours ($44.43/hr) per year and will focus on field data collection and analysis of thermokarst detection through remote sensing products and analysis.

Kirll Dolgikh will lead field efforts to measure land surface and subsurface temperatures in support of permafrost characterization. Kirll is budgeted for 348 hours ($28.23/hr) per year.

Dmitry Nicolsky (at $43.32/hr) is budgeted for 348 hours per year and will participate in the data collection and modeling activities related to permafrost distribution.

Alexander Kholodov will assist in field data collection and analysis of hydrological and thermal properties in Barrow and Council. Alexander is budgeted for 261 hours (at $34.25/hour).

Unnamed technician ($27.41/hr placeholder) will assist in field data collection, data processing and archiving. This technician is budgeted for 348 hours in Years 1 and 2. The unnamed technician will work primarily under the guidance of Busey and will also support Bolton and Breen activities.

Salaries are listed at the current FY19 rate and include a leave reserve of 12.4% for faculty, and 23.0% for professionals. Salaries also include an annual inflation increase of 2.0% for faculty and 2.5% for professionals.

Fringe Benefits: (Year 1 $108,243; Year 2 $110,857; Year 3 $112,327; Total $331,427)

Staff benefits are applied according to UAF's FY19 fixed benefit rates. Rates are 30.4% for faculty salaries, 37.8% for professionals, and 6.5% for students (summers only for students). A copy of the rate agreement is available at http://www.alaska.edu/cost-analysis/negotiation-agreements/. $2,549 per year (academic year 18/19 rate of $896 for fall semester, $889 for spring semester, and $674 for summer semester) is included for graduate student health care, with a 7.0% annual inflation increase.

Travel: (Year 1 $123,437; Year 2 $120,695; Year 3 $121,273; Total $365,405)

Domestic: There are multiple field trips to Barrow and Nome budgeted for this project. Travel to Barrow and Nome is by air. Local on-site vehicles (at $250/per day in Nome) will be provided through a local logistics coordinator. Numerous trips per year are required for instrument installation, monitoring, and data retrieval as well as ground surveys of active layer dynamics, along with several trips set aside in the event of unexpected additional fieldwork needed in Barrow or Nome based on experiences from the previous phases of this proposal.

Airfare to Barrow is estimated at $350/trip/person and meals are $135/day/person. Lodging and ground transportation will be provided. Airfare for Nome is estimated at $565/trip/person; lodging is $185/day/person, and meals are $134/day/person, while ground transportation is estimated at $250/trip/day.

Funds are requested for travel for 6 individuals to attend the annual AGU meeting and two day NGEE meeting (or similar meeting/conference) in San Francisco in Years 1 and 2 and in New Orleans in Year 3. Airfare for San Francisco is estimated at $750/trip/person and $875/trip/person for New Orleans. Per Diem (meals/incidentals/lodging) is San Francisco at $323/day/trip and $221/day/trip for New Orleans. Ground transportation is estimated at $100/per trip/person.

Funds are requested for two individuals per year to travel to Washington D.C. for the DOE ESS PI Meeting. Airfare to Washington D.C. is estimated at $925/trip/person with lodging at $251/day/person and meals at $76/day/person. Ground transportation is estimated at $100/trip/person.

Funds are requested for one individual per year to travel to Los Alamos, NM (placeholder) for various NGEE specific collaboration, workshops, or conferences. Airfare to Los Alamos is estimated at $935/trip/person with lodging at $94/day/person and meals at $55/day/person. Ground transportation is estimated at $100/trip/person.

Foreign: One trip in Year 1 is budgeted for two individuals to travel to Lanzhou, China (estimated at $1,717/ticket/person for airfare) attend the International Permafrost Conference and to meet with collaborators and discuss findings. Lodging for Lanzhou is estimated at $135/day/person and meals at $106/day/person. Ground transportation is estimated at $100/person.

An inflation rate of 10% per year has been included for all transportation costs. All airfare cost data is based on Internet research. All Per Diem is in accordance with GSA/JTR Regulations.

Materials & Supplies: *(Year 1 $25,000; Year 2 $16,000; Year 3 $8,500; Total $49,500)*

Funds are requested for materials and supplies needed in order to conduct the research. The materials and supplies will be used for project support. $14,500 is requested for replacement sensors for field sites. $15,000 is requested for new permafrost, moisture sites, and snow depth sensors. $11,000 is requested for field and safety supplies. An additional $9,000 is requested for unforeseen miscellaneous commodity needs.

Other Direct Costs: *(Year 1 $22,740; Year 2 $22,968; Year 3 $23208; Total $68,916)*

$7,500 per year is requested for freight for shipping equipment and supplies to and from the field sites and an additional $3,000 is requested for shipping field samples. Funds of ($15,750) are budgeted for journal publication charges. Funds ($15,000) are proposed for instrument calibrations/replacements if needed for the 9 HMP155 sensors. Funds ($10,416) are requested for the AGU meeting registration fees (at AY18 rate of $505 per year per PI with a 7.0% inflation increase per year). $1,500 per year is requested for a storage rental unit in Nome. An additional $2,500 per year is requested for unforeseen miscellaneous contractual services needs. Student tuition and fees will be covered for the students on separate projects.

Equipment:

No special purpose equipment is included in this request.

Indirect Costs: *(Year 1 $329,705; Year 2 $329,707; Year 3 $329,642; Total $989,054)*

Facilities and Administrative (F&A) Costs are negotiated with the Office of Naval Research. The predetermined rate for sponsored research at UAF is calculated at 50.5% (FY19 provisional agreement) of Modified Total Direct Costs (MTDC). MTDC includes Total Direct Costs minus tuition and associated fees, scholarships, participant support costs, rental/lease costs, subaward amounts over $25,000, and equipment. A copy of the rate agreement is available at: **http://www.alaska.edu/cost-analysis/negotiation-agreements/**.

ORNL Subcontract #2: UIC Science

(Year 1 $138,250; Year 2 $98,500; Year 3 $73,500; ; Total $310,250)

UIC Science was established in 2006 to provide logistic support for a broad range of industrial and science-related activities being conducted on the North Slope and northern coastal plain of Alaska, including the village of Barrow. UIC Science staff will assist with logistical needs of staff while in the Barrow area and with issues related to the establishment of field research sites on the Barrow Environmental Observatory, Barrow, Alaska. Logistical support requirements for each of four years include: site permits; archaeological and cultural resources survey; provision of lodging, vehicles, and field space; field logistical supports; shipping and receipt of materials; and provision of conditioned and unconditioned storage facilities. Additional funds are requested for logistical support in Nome on the Seward Peninsula. These financial requirements are not well-defined, but will include dry storage, lodging, and temporary technical assistance.

ORNL Subcontract #3: International Information Associates (IIA)

Year 1 $118,981l Year 2 $124,647; Year 3; $130,312

The IIA subcontract supports the full time effort of Terri Velliquette whom is serving as the Scientific Data Curator on the ORNL data management team.

ORNL Subcontract #4: Gnome Courier

Year 1 $15,000 Year 2 $15,000; Year 3; $15,000

The project has established a contract with this woman-owned business to support package and field logistics in and out of Nome, AK.

ORNL Subcontract #4: Bering Air

Year 1 $40,000 Year 2 $40,000; Year 3; $40,000

Bering Air is a Part 135 air transport provider and provides scheduled and charter services on the Seward Peninsula to transport researchers and equipment to various field sites.

ORNL Subcontract #4: Centurion LLC

Year 1 $97,835 Year 2 $97,835; Year 3; $97,835

Centurion LLC dba The Dredge No. 7 provides the project lodging apartments during the field season.

G.6 Other-Division Organization Burden

Division Organization Burden costs include utilities; managerial, technical, and administrative oversight; and support personnel such as plant and equipment, instrumentation and controls, environmental, safety, and health, finance and budget, quality, and health physics provided for the general benefit of a division.

The organization and administrative components have been estimated and are being reported in Item G.6. Inclusion of these costs is necessary to provide a full accounting of the estimated cost for the project period. All costs will be collected and reported in ORNL’s cost accounting system, as approved by DOE.

I. Indirect Costs. ORNL overhead is applied on a cost element basis. The effective ORNL Overhead rates are 35.82% (FY 2020-FY2022) for staff effort, 18.75% for materials, and 13.32% for off-site subcontracts and travel.

NGEE Arctic Phase 3
BUDGET JUSTIFICATION

Total Direct Labor: $755,214

Name	Total Direct Labor Costs	Total FTE	Tasks
Alistair Rogers	$300,142	1.21 Over 3 years	Rogers is a Scientist at BNL and is the institutional lead for BNL. He will work predominantly on Question 3 leading plant physiological measurements in Utquiġvik and the Seward Peninsula and leads the Zero Power Warming Experiment in Utqiġvik.
Shawn Serbin	$196,002	1.01 Over 3 years	Serbin is an Associate Scientist at BNL he will work on Questions 3 & 4 where he leads efforts to scale plant functional traits using spectroscopy and remote sensing and to understand model uncertainty through uncertainty quantification and variance decomposition. He leads the BNL UAS deployments on the Seward Peninsula.
Kim Ely	$138,662	0.96 Over 3 years	Ely is a Science Associate (III) at BNL. She is the institutional data liaison for BNL and assists with fieldwork in Utquiġvik and on the Seward Peninsula.
Andrew McMahon	85,351	0.60 Over 2 years	McMahon is an Associate Staff Engineer. He provides technical support for the Zero Power Warming experiment and is the technical lead for the BNL UAS measurements.
Jeremiah Anderson	$35,057	0.35 Over 3 years	Anderson is a Science Associate (IV). He will provide field assistance and technical support in Utquiġvik and on the Seward Peninsula.

BNL uses standard labor rates which also includes fringe benefits costs and each band includes an escalation for FY2020-2022 from FY2019 standard labor rates. The average escalation is 3% for years FY20 – FY22.

LANL BUDGET JUSTIFICATION

This budget was designed to enable application of unique LANL skills, technology and facilities to the multi-lab NGEE project. LANL will specifically contribute in the areas of 1) science coordination and project management; 2) leadership of the Permafrost Hydrology, and Disturbancescience themes; 3) integration of hydraulic measurements, isotopes, and geochemistry to elucidate and quantify process interactions, fluxes and pathways of water, carbon, and nitrogen at hillslope scales and beyond; 4) integration of field measurements of landscape change, experimental measurements of sediment and water fluxes, remote sensing analysis, and landscape evolution modeling to quantify the impacts and future extents of disturbance. A particular focus of this work will be the identification of coupled vegetation-disturbance feedbacks on both the occurrence of and recovery from disturbance; and 5) extraction of mechanistic-based parameterizations from fine-scale simulations of permafrost hillslope hydrology, oxic/anoxic transition zone, and permafrost reactive and non-reactive transport to enhance the NGEE Earth System Model (ELM).This submission is in collaboration with ORNL, LBNL, BNL and the University of Alaska, Fairbanks; and the outlined budget will provide scientific, technical and engineering expertise to the NGEE project as directed and coordinated by the leaders of the NGEE activities, tasks and challenges.

All salary requests are in months per fiscal year. Salary funding is requested at the level indicated for FY20, FY21 and FY22.

A. Key Personnel

Staff:

Funds are requested for LANL PI ***Wilson*** (starting at 4.8 months/year) to coordinate all LANL personnel performing work within the NGEE project scope, manage LANL resources and ensure delivery of LANL products as outlined under task work plans. Wilson will also lead Science Question 5 (Q5, permafrost hydrology) for the NGEE Arctic project and will work closely with the other Science Question leaders to optimize and integrate observations, experiments and modeling for Q5. Wilson will work closely with the NGEE modeling team to ensure that all LANL activities directly inform critical parameterizations of processes and properties for ELM. ***Rowland*** (starting at 3.6 months/year) will lead the NGEE Disturbance science theme. In these efforts, Rowland and will work closely with UAF co-lead Breen and other UAF researchers to closely integrate physical landscape changes with vegetation change, and use remote sensing change detection and landscape evolution modeling to quantify impacts and evolution of disturbance in permafrost watersheds. ***Newman*** (starting at 3.6 months/year) will be the observational hydrology lead for Q5, and facilitate integration of Q5 activities with Q2 and Q3. He will work closely with UAF staff to coordinate hydrological field monitoring and measurement activities, and with Q2 and Q3 leads to integrate vegetation patch scale to watershed scale nitrogen and redox geochemical data into biogeochemistry and PFT parameterizations for ELM. ***Bennett*** (starting at 3.6 month/year) will lead Q5 snow hydrology tasks and its coordination with snow tasks across Q1 through Q6. ***Harp*** (starting at 3.6 months/year) will lead the LANL NGEE modeling team, be the POC for LANL modeling efforts for Q1-Q6, and be responsible for disseminating the ATS code and training to NGEE modelers. He will focus on applying the ATS in collaboration with NGEE observational scientists in support of ModEx based research. ***Atchley*** and ***Svyatski*** (2 months/year each) will provide oversight to LANL modeling post docs, technologists and students on development and application of the ATS. ***Xu*** (2 months/year) will lead the implementation of FATES in ELM. ***Musa*** (2 months/year) is the LANL POC for data management and will coordinate staff and supervise students performing data tasks for the project. ***Moulton*** (1 month/year) will guide interactions between LANL IDEAS, NGEE Tropics and NGEE Arctic modeling activities.

B. Other Personnel

Funds are also requested for 4 other partially funded staff, 4 partially to fully funded Post Bac and Post Masters students, and 3 fully funded Post Docs in support of the key staff and their tasks described above. In particular we intend to support: 1) 1 Post Doc and 1 Post Master student to carry out field work, data synthesis and modeling to understand and quantify integrated hydrological and geochemical spatial and temporal dynamics in continuous and discontinuous permafrost environments for Q1-Q5, partially funded LANL technologists will also assist in data organization and analysis, as well as laboratory measurements; 2) 1 Post Doc and 1 Post Bac student to support Q6 field, remote sensing and modeling tasks; 3) 1 Post Doc, partial staff and students to support model development and application, including Q5 and Q6 process parameterizations for ELM. 4) 1 Post Masters and partial staff to support snow hydrology field work and modeling, and 5) 1 Post Bac student, and partial staff and students to support GIS, data analysis, formatting and meta-data development for NGEE data portal products.

Travel:

We are requesting annual travel funds of $85K/year to cover travel to the annual American Geophysical Union and NGEE all hands meetings for key staff, students and post docs (~10 people), travel to the annual DOE BER ESS PI meeting for 4-6 people, as well as additional trips for key staff to attend critical science meetings. In addition, our request supports approximately 12 field observation person-trips per year to NGEE field sites in the Seward and Barrow Peninsulas per year. Travel to field sites in the final year will aim to dismantle and clear observational technology to restore sites to pre-project conditions.

Materials and Supplies:

We are requesting $35K/year to purchase field equipment and consumables for hydrologic, geochemical and geomorphic observations and experiments. In addition, we will purchase 3 new desktop computers and 2 new laptop computers to replace outdated hardware during the first 2 years of the funding period. Software licenses will be renewed for specialized remote sensing, GIS, statistical and mathematical analytical software to perform our proposed data analysis, synthesis and modeling tasks.

Fringe Benefits and Indirect Costs:

Total cost over the three-year period of the proposal is $6,353,250 of which total salary including fringe benefits is $4,335,880; total travel and materials is $360,000 and total indirect costs excluding fringe benefits is $1,657,370. Indirect costs are calculated at the standard LANL DOE Office of Science rates for the LANL subcontract with ORNL. This rate is lower than the standard LANL subcontract rate.

LBNL Budget Justification

DIRECT COSTS:

A./B. PERSONNEL:

LBNL Key Personnel	FTE FY20	FTE FY21	FTE FY22	Primary Role/Expertise
Susan S. Hubbard	0.17	0.17	0.17	LBNL NGEE Arctic Institutional representative, responsible for LBNL reporting and budget. Susan also contributes expertise in the use of geophysical methods to investigate Arctic systems
Baptiste Dafflon	0.31	0.31	0.31	NGEE Arctic Science Lead for Q1. Research scientist with expertise in characterizing and monitoring soil hydrological and physical properties and their interactions with landscape properties using geophysical, hydrological, core-based and remote sensing approaches
Margaret Torn	0.20	0.20	0.20	NGEE Arctic Science Lead for Q4. Senior scientist with expertise in terrestrial carbon and nutrient cycling and ecosystem-atmosphere trace-gas fluxes
William Riley	0.20	0.20	0.20	Member of the modeling team and contributor to many Qs. Senior scientist with expertise in development, testing, and application of models for high-latitude carbon and nutrient biogeochemistry and ecosystem dynamics, with a focus on the advance of FATES for Arctic ecosystems.
Neslihan Tas	0.33	0.33	0.33	Contributor to Q2. Research scientist with expertise on soil microbial ecology, biogeochemistry and metagenomics. She will work on determining the impact of climate change on soil and permafrost microbial communities by use of state of the art omics techniques and on integrating microbial responses to data generated by other team members.
Haruko Wainwright	0.1	0.08	0.08	Contributor to Q1 and 5. Research scientist with expertise in spatial statistical analysis, land characterization, parameter estimation and uncertainty quantification, integration of multiscale above and below-ground datasets
Nick Bouskill	0.21	0.21	0.21	Contributor to several Qs. Research scientist with expertise on explicit microbial models, their integration with climate-scale models, and analyses of nutrient impacts on carbon-climate interactions
Jinyun Tang	0.21	0.21	0.21	Contributor to several Qs. Research scientist with expertise in soil biogeochemical modeling and analyzing model simulated land carbon climate feedbacks.
LBNL Other Personnel	**FTE FY20**	**FTE FY21**	**FTE FY22**	**Primary Expertise**
Zelalem Mekonnen	0.88	0.88	0.88	Postdoc with expertise in modeling soil-plant-atmosphere interactions to understand how the changing climate is impacting land-atmosphere carbon exchange and to examine the underlying ecosystem processes that control changes in Arctic plant functional types and associated feedbacks.
Sebastien Uhlemann	0.44	0.42	0.42	Postdoc with expertise in geophysical imaging and monitoring of environmental/ hydrological characteristics and processes.

Sigrid Dengel	0.42	0.42	0.33	Scientific engineering associate with expertise in eddy covariance, Arctic ecosystem dynamics, and greenhouse gases and energy exchange (CO_2, CH_4, H_2O).
John Peterson	0.13	0	0	Senior geophysical research engineer with expertise in acquisition of ground based and unmanned aerial vehicle geophysical datasets as well as advanced inversion approaches.
Craig Ulrich	0.13	0.13	0.13	Geophysical engineering associate with expertise in acquisition of field geophysical and GPS data, including GPR, electromagnetic, and electrical resistance tomography.
Yuxin Wu	0.06	0.06	0.05	Staff scientist with expertise in combing multiple datasets (geophysics, geochemistry, hydrology and microbiology) to understand permafrost processes during freeze – thaw transitions.
Rachel Porras	0.21	0.21	0.17	Research associate with expertise in environmental geochemistry and biogeochemical cycling, soil carbon, stable isotope geochemistry, and radiocarbon analsys
Lydia Vaughn Smith	0.21	0.17	0.17	Postdoc with expertise in soil carbon turnover rates, decomposition processes, and their biogeochemical controls. isotopic methods in field experiments and across natural gradients to ecosystem-climate feedbacks
Mark Conrad	0.08	0.08	0.08	Staff scientist with expertise in isotopic signatures of microbial processes affecting the cycling of greenhouse gases in subsurface environments and the effects of those processes on surface fluxes of those gases.
Florian Soom	0.13	0.08	0.08	Research associate with expertise in geophyscial instrumentation and field measurements, with special focus on permafrost, cryosphere, and high-latitude processes, and near-surface and groundwater characterization.
Bhavna Arora	0.05	0.05	0.05	Research scientist with expertise in characterizing, quantifying and predicting biogeochemical cycling in various types of subsurface environments and at different space-time scales.
Andrew Moyes	0.08	0.08	0.08	Research associate who serves as the LBNL data management liason to the NGEE-Arctic Data Management team.
Alejandro Morales	0.06	0.06	0.06	Mechanical engineering technician for geophyical field instrumentation and fabrication.
Postdoctoral Fellows TBD	1.5	1.5	1.5	Postdoc support of key staff and their tasks described above
Research Associate TBD	0.58	0.58	0.58	Research associate support of key staff and their tasks described above
Graduate Student Researcher	0.44	0.44	0.44	GSR support of key staff and their tasks described above
Sandy Chin	0.06	0.04	0.04	Project management support for LBNL NGEE-Arctic team

FY20	FY21	FY22	TOTAL
$719,189	**$715,515**	**$727,455**	**$2,162,159**

C. Fringe Benefits:
Calculated as Payroll Burden consisting of: fringe benefits + vacation leave + sick leave + holidays. Fringe Benefits rates are: Scientific/Career 62.0% (FY20), 62.8% (FY21), 63.6% (FY22); Postdoctoral Fellows 34.7% (FY20), 35.2% (FY21), 35.8% (FY22); GSRAs/Students/Rehired Retirees 2.2% (FY20, FY21, and FY22).

FY20	FY21	FY22	TOTAL
$363,883	**$375,951**	**$386,043**	**$1,125,877**

D. PERMANENT EQUIPMENT
None

E. TRAVEL
Domestic travel support is requested for the LBNL science team to participate in the NGEE Arctic annual all-hands meetings, AGU Fall Meetings, DOE ESS PI Meetings, and travel to Phase 3 field sites in Alaska.

	FY20	FY21	FY22	TOTAL
Domestic	**$80,000**	**$80,000**	**$55,000**	**$215,000**

F. TRAINEE/PARTICIPANT COSTS
Partial Tuition is requested for one Graduate Student Research Assistant.

FY20	FY21	FY22	TOTAL
$9,405	**$9,405**	**$9,405**	**$28,215**

G. OTHER DIRECT COSTS
Materials and Supplies are requested for lab supplies and consumables, and IT resources (computers, devices, software, archival services, etc.).

FY20	FY21	FY22	TOTAL
$37,503	**$24,472**	**$14,844**	**$76,819**

Other Direct:
a. Scientific Organization support for Earth & Environmental Sciences **Associate Lab Director (ALD) Org** @ 18.5% (FY20, FY21, FY22), based on total Salaries, Wages and Fringe Benefits.

b. **Travel burden** of 9.1% (FY20, FY21, FY22) applied to all domestic and foreign travel costs.

c. **Procurement burden** of 10.4% (FY20, FY2, FY22) applied to equipment, materials and supplies, as well as publication costs.

FY20	FY21	FY22	TOTAL
$211,549	$211,746	$212,546	$635,841

H. TOTAL DIRECT COSTS (A thru G):

FY20	FY21	FY22	TOTAL
$1,421,529	$1,417,090	$1,405,293	$4,243,912

I. INDIRECT COSTS:

* **General and Administrative** (G&A) Overhead on-site rate of 52.7 in FYs 20-22 is collected on on-site projects and applied to salaries, benefits, Org/ALD burden, , procurement burden, and travel burden.

* **Institutional General Plant Projects** (IGPP) rate of 2.0% (FY20, FY21, FY22) is applied to salaries, benefits, Org/ALD burden, procurement, procurement burden, travel, and travel burden, and tuition.

* **Total Cost Rate** (TCR) of 1% (FY20, FY21, FY22) is applied to salaries, benefits, Org/ALD burden, procurement, procurement burden, travel, travel burden, tuition, G&A overhead, and IGPP.

* **Laboratory Directed Research and Development** (LDRD) rate of 2.9% (FY20, FY21, FY22) is applied to salaries, benefits, Org/ALD burden, procurement, procurement burden, travel, travel burden, tuition, G&A overhead, IGPP, and, starting FY20, Total Cost Rate.

FY20	FY21	FY22	TOTAL
$794,471	$798,910	$810,707	$2,404,088

J. TOTAL DIRECT AND INDIRECT COSTS (H + I)

FY20	FY21	FY22	TOTAL
$2,216,000	$2,216,000	$2,216,000	$6,648,000

14. CURRICULUM VITAE

ORNL and its partner national laboratories and universities have identified a comprehensive, experienced team of nationally and internationally recognized experts for the NGEE Arctic project. Biographical information for principal and co-principal investigators and research participants is shown below, grouped by institution and arranged alphabetically within each institution.

Principal and Co-Principal Investigators

Name	Title	Institution
William R. Bolton	Research Assistant Professor	University of Alaska Fairbanks
Alison Boyer	Research Staff Scientist	Oak Ridge National Laboratory
Amy Breen	Research Assistant Scientist	University of Alaska Fairbanks
Baptiste Dafflon	Research Scientist	Lawrence Berkeley National Laboratory
David Graham	Senior Staff Scientist	Oak Ridge National Laboratory
Susan Hubbard	Associate Laboratory Director	Lawrence Berkeley National Laboratory
Colleen Iversen	Senior Staff Scientist	Oak Ridge National Laboratory
Alistair Rogers	Staff Scientist	Brookhaven National Laboratory
Vladimir Romanovsky	Professor	University of Alaska Fairbanks
Joel Rowland	Scientist	Los Alamos National Laboratory
Peter Thornton	Distinguished Scientist	Oak Ridge National Laboratory
Margaret Torn	Senior Scientist	Lawrence Berkeley National Laboratory
Cathy Wilson	Scientist	Los Alamos National Laboratory
Stan Wullschleger	Corporate Fellow	Oak Ridge National Laboratory

Research Participants

ORNL
Alison Boyer
Ethan Coon
Michael Crow
David Graham
Baohua Gu
Susan Heinz
Forrest Hoffman
Les Hook
Colleen Iversen
Ahmad Jan
Jitendra Kumar
Scott Painter
Benjamin Sulman
Peter Thornton
Terri Velliquette
Stan Wullschleger
Fengming Yuan

BNL
Jeremiah Anders
Kim Ely
Keith Lewin
Andrew McMahon
Alistair Rogers
Shawn Serbin

LBNL
Bhavna Arora
Nicholas Bouskill
Baptiste Dafflon
Susan Hubbard
Bill Riley
Jinyun Tang
Neslihan Tas
Margaret Torn
Haruko Wainwright

LANL
Adam Atchley
Katrina Bennett
Min Chen
Dylan Harp
David Moulton
Brent Newman
Joel Rowland
Sanna Sevanto
Daniil Svyatsky
Cathy Wilson
Chonggang Xu

UAF
William R. Bolton
Amy Breen
Bob Busey
Kirill Dolgikh
Eugenie Euskirchen
Go Iwahana
Alexander Kholodov
Dmitry Nicolsky
Vladimir Romanovsky

Stan D. Wullschleger
Corporate Fellow
Environmental Sciences Division, Oak Ridge National Laboratory
Phone: (865) 574-7839
Email: wullschlegsd@ornl.gov

Education and Training

1990	University of Arkansas, Crop Physiology, Ph.D.
1982	Colorado State University, Tree Physiology, M.S.
1979	Colorado State University, Forest Management, B.S.

Research and Professional Experience

2016-Present	Director, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN
2017-Present	Director, Climate Change Science Institute, Oak Ridge National Laboratory, Oak Ridge, TN
2013-Present	Corporate Fellow, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN.
2005-2013	Distinguished R&D Staff Scientist, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN.
2008-2009	Interim Division Director, Environmental Sciences Division, Oak Ridge National Laboratory
2005-2010	Leader, Plant Systems Biology Group, Environmental Sciences Division, Oak Ridge National Laboratory

Selected Publications (5 Years)

Wullschleger, S.D., H.E. Epstein, E.O. Box, E.S. Euskirchen, S. Goswami, C.M. Iversen, J. Kattge, R.J. Norby, P.M. van Bodegom and X. Xu. 2014. Plant functional types in Earth System Models: Past experiences and future directions for application of dynamic vegetation models in high-latitude ecosystems. Annals of Botany 114: 1-16.

Ali, A., C. Xu, A. Rogers, N.G. McDowell, B.E. Medlyn, R. Fisher, S.D. Wullschleger, P.B. Reich, J.A. Vrugt, W.L. Bauerle, L. S. Santiago, and C.J. Wilson. 2015. Global scale environmental control of photosynthetic capacity. Ecological Applications25: 2349-2365.

Herndon, E.M., B.F. Mann, T. Roy Chowdhury, Z. Yang, D.E. Graham, S.D. Wullschleger, L. Liang, and B. Gu. 2015a. Pathways of anaerobic organic matter decomposition in tundra soils from Barrow, Alaska. JGR Biogeosciences 120: 2345-2359.

Herndon, E.M., Z. Yang, J. Bargar, N. Janot, T.Z. Regier, D.E. Graham, S.D. Wullschleger, B. Gu, and L. Liang. 2015b. Geochemical drivers of organic matter decomposition in the active layer of arctic tundra. Biogeochemistry 126: 397-414.

Throckmorton, H.M., J.M. Heikoop, B.D. Newman, G.L. Altmann, M.S. Conrad, J.D. Muss, G.B. Perkins, L.J. Smith, M.S. Torn, S.D. Wullschleger, and C.J. Wilson. 2015. Pathways and transformations of dissolved methane and dissolved inorganic carbon in Arctic tundra watersheds: Evidence from analysis of stable isotopes. Global Biogeochemical Cycles 29: 1893-1910.

Ali, A.A., C. Xu, A. Rogers, R.A. Fisher, S.D. Wullschleger, E.C. Massoud, J.A. Vrugt, J.D. Muss, N.G. McDowell, J.B. Fisher, P.B. Reich and C.J. Wilson. 2016. A global scale mechanistic model of photosynthetic capacity (LUNA V1.0). Geoscientific Model Development 9: 587-606.

Yang, Z., S.D. Wullschleger, L. Liang, D.E. Graham, and B. Gu. 2016a. Effects of warming on the degradation and production of low molecular-weight labile organic carbon in an Arctic tundra soil. Soil Biology and Biochemistry 95: 202-211.

Yang, Z., W. Fang, X. Lu, G-P Sheng, D.E. Graham, L. Liang, S.D. Wullschleger, and B. Gu. 2016b. Warming increases methylmercury production in an Arctic soil. Environmental Pollution 214: 504-509.
Xu, X., S. Goswami, J. Gulledge, S.D. Wullschleger, and P.E. Thornton. 2016. Interdisciplinary research in climate and energy sciences. Wiley Interdisciplinary Reviews: Energy and Environment 5: 49-56.
Xu, X., F. Yuan, P. J. Hanson, S.D. Wullschleger, P.E. Thornton, W.J. Riley, X. Song, D.E. Graham, C. Song, and H. Tian. 2016. Reviews and syntheses: Four decades of modeling methane cycling in terrestrial ecosystems. Biogeosciences 13: 3735-3755.
Throckmorton, H.M., B.D. Newman, J.M. Heikoop, G.B. Perkins, X. Feng, D.E. Graham, D. O'Malley, V.V. Vesselinov, J. Young, S.D. Wullschleger, and C.J. Wilson. 2016. Active layer hydrology in an Arctic tundra ecosystem: quantifying water sources and cycling using stable isotopes. Hydrological Processes 30: 4972–4986.
Langford, Z.L., J. Kumar, F.M. Hoffman, R.J. Norby, S.D. Wullschleger, V.L. Sloan, and C.M. Iversen. 2016. Mapping Arctic plant functional type distributions in the Barrow Environmental Observatory using WorldView-2 and LiDAR datasets. Remote Sensing 8: Article 733.
Raz-Yaseef, N., M.S. Torn, Y. Wu, D.P. Billesbach, A.K. Liljedahl, T.J. Kneafsey, V.E. Romanovsky, D.R. Cook, and S.D. Wullschleger. 2017. Large CO_2 and CH_4 emissions from polygonal tundra during spring thaw in northern Alaska. Geophysical Research Letters 44: 504-513.
Raz-Yaseef, N., J. Young-Robertson, T. Rahn, V. Sloan, B. Newman, C. Wilson, S.D. Wullschleger, and M.S. Torn. 2017. Evapotranspiration across plant types and geomorphological units in polygonal arctic tundra. Journal of Hydrology 553: 816-825.
Rogers, A., S.P. Serbin, K.S. Ely, V.L. Sloan, and S.D. Wullschleger. 2017. Terrestrial biosphere models underestimate photosynthetic capacity and CO_2 assimilation in the Arctic. New Phytologist 216: 1090-1103.
Walker, A.P., L. McCormack, J. Messier, I. Myers-Smith, and S.D. Wullschleger. 2017. Trait covariation: The functional warp of plant diversity? New Phytologist 216: 976-980.
Fisher, J.B., D.J. Hayes, C. Schwalm, D.N. Huntzinger, E. Stofferahn, K. Schaefer, Y. Luo, S.D. Wullschleger, S. Goetz, C.E. Miller, P. Griffith, S. Chadburn, A. Chatterjee, P. Ciais, T. Douglas, H. Genet, A. Ito, B. Poulter, B. Rogers, H. Tian, W. Wang, X. Yongkang, Z-L Yang, and N. Zeng. 2018. Missing pieces to modeling the Arctic-Boreal puzzle. Environmental Research Letters 13: 020202.
Chen, H.M., Z. Yang, R.K. Chu, N. Tolic, L. Liang, D.E. Graham, S.D. Wullschleger, and B. Gu. 2018. Molecular insights into Arctic soil organic matter degradation under warming. Environmental Science and Technology 52: 4555-4564.
Jubb, A.M., J.R. Eskelsen, X. Yin, J. Zheng, M.J. Philben, E.M. Pierce, D.E. Graham, S.D. Wullschleger, and B. Gu. 2018. Characterization of iron oxide nanoparticle biofilms at the air–water interface in Arctic tundra waters. Science of the Total Environment 633: 1460-1468.
Young-Robertson, J.M., N. Raz-Yaseef, L.R. Cohen, B. Newman, T. Rahn, V. Sloan, C.J. Wilson, and S.D. Wullschleger. 2018. Evaporation dominates evapotranspiration on Alaska's Arctic Coastal Plain. Arctic, Antarctic, and Alpine Research 50: e1435931.

Synergistic Activities

Editor – Tree Physiology (2000-2007)
Editorial Review Board – Tree Physiology (1992-present)
Ecological Society of America Student Awards Committee (Buell and Braun Awards)
Reviewer for scientific journals, including Science, Nature, New Phytologist, Global Change Biology, Plant Cell and Environment, Plant Physiology, Plant Cell, GCB Bioenergy, Ecology, Ecology Letters, American Journal of Botany, Journal of Experimental Botany, Tree Physiology, Journal of Environmental Quality, Agricultural and Forest Meteorology, Journal of Geophysical Research, and Functional Ecology.

Fengming Yuan
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Environmental Science Division and Climate Change Science Institute
Oak Ridge National Laboratory
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Education and Training

2003	University of Wisconsin, Madison (Madison, WI, USA), PhD
1993	Chinese Academy of Agricultural Sciences (Beijing, China), M.Ag
1990	Hua-zhong (Central-China) Agricultural University (Wuhan, China), B.Ag

Research and Professional Experience

2015-present	Technical Professional Staff, Oak Ridge National Laboratory, Oak Ridge, TN
2011-2015	Post-doctoral Research Associate, Oak Ridge National Laboratory, Oak Ridge, TN
2008-2011	Post-doctoral Researcher, Institute of Arctic Biology, University of Alaska – Fairbanks, Fairbanks, AK
2007-2008	Research Associate, Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ
2003-2007	Postdoctoral Fellow, Climate Change Research Program (CCRP), School of Geography and Earth Sciences, McMaster University, Canada
1999-2003	Graduate Research Assistant, Agricultural & System Informatics Group (ASIG), Dept. of Soil Science in University of Wisconsin – Madison

Selected Publications

Yao Z., Wang D., Wang Y., and Yuan F., 2018. An Event Detection Framework for Virtual Observation System: Anomaly Identification for an ACME Land Simulation. In: Shi Y. et al. (eds) Computational Science – ICCS 2018. ICCS 2018. Lecture Notes in Computer Science, vol 10861. Springer, Cham.

Bisht, G., Riley, W. J., Wainwright, H. M., Dafflon, B., Yuan, F., and Romanovsky, V. E., 2018. Impacts of microtopographic snow redistribution and lateral subsurface processes on hydrologic and thermal states in an Arctic polygonal ground ecosystem: a case study using ELM-3D v1.0, Geosci. Model Dev., 11, 61-76. DOI: 10.5194/gmd-11-61-2018.

Wang, D. , Luo, X. , Yuan, F. and Podhorszki, N., 2017. A Data Analysis Framework for Earth System Simulation within an In-Situ Infrastructure. Journal of Computer and Communications, 5, 76-85. DOI: 10.4236/jcc.2017.514007.

Yu Pei, Benjamin Hernandez, Brian Smith, Scott Atchley, Fengming Yuan, Chad Steed, and Dali Wang, 2016. In situ Data Visualization of ACME Land Model Simulations. International Environmental Modelling and Software Society (iEMSs), 8th International Congress on Environmental Modelling and Software, Toulouse, France, Sabine Sauvage, JoséMiguel, SánchezPérez, Andrea Rizzoli (Eds.).

Xu, Xiaofeng, Yuan, Fengming, Hanson, Paul J., Wullschleger, Stan D., Thornton, Peter E., Riley, William J., Song, Xia, Graham, David E., Song, Changchun and Tian, Hanqin, 2016. Reviews and syntheses: Four decades of modeling methane cycling in terrestrial ecosystems. Biogeosciences, 13(12): 3735-3755. DOI: 10.5194/bg-13-3735-2016.

Tang, Guoping, Yuan, Fengming, Bisht, Gautam, Hammond, Glenn E., Lichtner, Peter C., Kumar, Jitendra, Mills, Richard T., Xu, Xiaofeng, Andre, Ben, Hoffman, Forrest M., Painter, Scott L. and Thornton, Peter E., 2016. Addressing numerical challenges in introducing a reactive transport code into a land surface model: a biogeochemical modeling proof-of-concept with CLM–PFLOTRAN 1.0. Geoscientific Model Development, 9(3): 927-946. DOI: 10.5194/gmd-9-927-2016

Daniel J Hayes, David W. Kicklighter, A. David McGuire, Min Chen, Qinglai Zhuang, Fengming Yuan, Jerry M. Melillo and Stan D. Wullschleger. 2014. The impacts of recent permafrost thaw on land-atmosphere greenhouse gas exchange. Environmental Research Letters, 9(2014) 045005. DOI:10.1088/1748-9326/9/4/045005.

Kuo-Hsien Chang, Jon S. Warland, Paul A. Bartlett, Altaf M. Arain and Fengming Yuan. 2014. A simple crop phenology algorithm in the land surface model CN-CLASS. Agronomy Journal 106(1): 297-308. DOI: 10.2134/agronj2013.0164.

H. Genet, A. D. McGuire, K. Barrett, A. Breen, E.S. Euskirchen, J. F. Johnstone, E.S. Kasischke, A. M. Melvin, A. Bennett, M. C. Mack, T.S. Rupp, A.E.G. Schuur, M. R. Turetsky and F. Yuan. 2013. Modeling the effects of fire severity and climate warming on active layer thickness and soil carbon storage of black spruce forests across the landscape in interior Alaska. Environmental Research Letters, 8(2013)045016. DOI: 10.1088/1748-9326/8/4/045016.

Kristofer D. Johnson, Jennifer W. Harden, A. David McGuire, Mark Clark, Fengming Yuan and Andrew O. Finley. 2013. Permafrost and organic layer interactions over a climate gradient in a discontinuous permafrost zone. Environmental Research Letters, 8(2013)035028. DOI:10.1088/1748-9326/8/3/035038.

Fengming Yuan, Shuhua Yi, A. David McGuire, Kristofer D. Johnson, Jingjing Liang, Jennifer Harden, Eric S. Kasischke, Werner Kurz. 2012. Assessment of Historical Boreal Forest C Dynamics in Yukon River Basin: Relative Roles of Warming and Fire Regime Change. Ecological Applications 22(8):2091-2109. DOI: 10.1890/11-1957.1

Suo Huang, M. Altaf Arain, Vivek K. Arora, Fengming Yuan, Jason Brodeur, and Matthias Peichl, 2011. Analysis of nitrogen controls on carbon and water exchanges in a conifer forest using the CLASS-CTEM^{N+} model. Ecological Modelling 222:3743-3760.

F.-M. Yuan, T. Meixner, Fenn, M.E., and J. Simunek, 2011. Impact of transit soil water simulation to estimated nitrogen leaching and emission at high- and low-deposition forest sites in Southern California. Journal of Geophysical Research – Biogeosciences 116, G03040, DOI: 10.1029/2011JG001644.

Awards

2006. The American Journal of Potato Research (AJPR) outstanding paper award (2005), Potato Association of America (PAA)

1996. International Agricultural Center (IAC) Fellowship, Ministry of Agriculture, Nature Management and Food Quality, The Netherlands

Synergistic Activities

Reviewer for scientific journals, including Nature Plants, Nature Scientific Reports, Agronomy Journal, Ecosphere, Remote Sensing of Environment, Agricultural and Forest Meteorology, Ecosystem Health and Sustainability, Biogeochemistry, Global and Planetary Change, and Science of the Total Environment.

Alison G. Boyer
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Environmental Sciences Division, Climate Change Science Institute, Oak Ridge National Laboratory
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Education and Training

2008	University of New Mexico, Biology, Ph.D.
2003	Hendrix College, Biology, B.A.

Research and Professional Experience

2016-Present	Chief Scientist. NASA-sponsored Distributed Active Archive Center at Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA.
2014-Present	Staff Scientist. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA.
2011-2014	Research Assistant Professor. University of Tennessee, Knoxville, Ecology and Evolutionary Biology, Knoxville, TN, USA.
2009-2011	Postdoctoral Fellow. Yale University, Ecology and Evolutionary Biology. New Haven, CT, USA.
2008	Postdoctoral Fellow. Smithsonian Institution, National Museum of Natural History, Division of Zoology. Washington, DC, USA.

Selected Publications

Shrestha R and Boyer AG. 2018. Bringing harmony to heterogeneous soil moisture data across North America. In Review at *EOS.*

Cook RB, SKS Vannan, BF McMurry, DM Wright, Y Wei, AG Boyer and JH Kidder. 2016. Implementation of data citations and persistent identifiers at the ORNL DAAC. *Ecological Informatics.* http://doi.org/10.1016/j.ecoinf.2016.03.003

Boyer AG and W Jetz. 2014. Extinctions and the loss of ecological function in island bird communities. *Global Ecology and Biogeography.* 23:679-688. http://dx.doi.org/10.1111/geb.12147

Duncan R, Boyer AG and T Blackburn. 2013. Magnitude and variation of prehistoric bird extinctions in the Pacific. *Proceedings of the National Academy of Sciences USA*. 110: 6436-6441. http://dx.doi.org/10.1073/pnas.1216511110

Davidson AD, Boyer AG, Kim H, Pompa-Mansilla S, Hamilton MJ, Costa DP, Ceballos G, and JH Brown. 2012. Drivers and hotspots of extinction risk in marine mammals. *Proceedings of the National Academy of Sciences USA.* 109: 3395-3400

Smith FA, Boyer AG, *et al.* 2010. The evolution of maximum body size of terrestrial mammals. *Science*. 330: 1216-1219

Boyer AG, James HF, Olson SL and Grant-Mackie JA. 2010. Long-term ecological change in a conservation hotspot: The fossil avifauna of Mé Auré Cave, New Caledonia. *Biodiversity and Conservation.* 19:3207–3224

Boyer AG and W Jetz. 2010. Biogeography of body size in Pacific island birds. *Ecography*. 33: 369–379

Boyer AG 2010. Consistent ecological selectivity through time in Pacific island avian extinctions. *Conservation Biology*. 24: 511-519

Davidson AD, Hamilton MJ, Boyer AG, Brown JH and Ceballos G. 2009. Multiple ecological pathways to extinction in mammals. *Proceedings of the National Academy of Sciences USA*. 106:10702-10705

Synergistic Activities

Editorial Boards: Ecography (2014-2017), PeerJ (2017-present)

Community Leadership

North American Carbon Program (NACP) Science Leadership Group (2017-present)

National Ecological Observatory Network (NEON) data standards working group (2017-present)

Program Committees: NASA 4th ABoVE Science Team meeting (2018), NASA 5th ABoVE Science Team meeting (2019), NASA Terrestrial Ecology Program Investigator's meeting (2019)

Organizer of many symposia and workshops: "Data Workflow for Synthesis, Analysis, and Publication", NASA 4th ABoVE Science Team Meeting, January 2018; "Ecology from Space: How Can NASA Remote-Sensing Data Inform Your Research?" Workshop at Ecological Society of America meeting, August 2017; "Data Management Best Practices Workshop", Joint NACP & Ameriflux meeting, March 2017.

Ad-hoc reviewer for: *The American Naturalist, Biology Letters, Conservation Biology, Diversity and Distributions, eLife, Ecography, Ecological Applications, Ecological Informatics, Ecology, Ecology Letters, Environmental Conservation, Evolutionary Ecology Research, Global Ecology and Biogeography, The Holocene, Ibis, Journal of Animal Ecology, Journal of Biogeography, Nature Communications, Proceedings of the National Academy of Sciences USA, Proceedings of the Royal Society B., The Wilson Journal of Ornithology,* National Science Foundation; Dept. of Defense Strategic Environmental Research and Development Program.

Society memberships: American Geophysical Union, Ecological Society of America, International Biogeography Society.

Graduate and Postdoctoral Advisors

Ph.D. Advisor: James H. Brown (U New Mexico, retired);

Postdoctoral Advisors: Helen F. James (Smithsonian Institution); Walter Jetz (Yale U).

Ethan Coon
Research Scientist
Climate Change Science Institute, Environmental Sciences Division, Oak Ridge National Laboratory
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Education and Training

2010	Columbia University, New York, NY, Applied Mathematics, Ph.D.
2006	Columbia University, New York, NY, Applied Mathematics, M.Phil.
2004	Columbia University, New York, NY, Applied Mathematics, M.S.
2003	University of Rochester, Rochester, NY, Applied Mathematics, B.S.

Research and Professional Experience

4/2017 -	Research Scientist, ORNL, Oak Ridge, TN. Terrestrial Systems Modeling group. Current research efforts include: Computational methods for multi-physics problems, especially ways in which software libraries and frameworks can enable scientists to write code that is easily coupled with other codes. Applications to hydrology and terrestrial ecosystem modeling.
2013 - 3/2017	Research Scientist, Los Alamos National Laboratory, Los Alamos, NM. Led LANL's NGEE-Arctic modeling team and other efforts in fine-scale eco-hydrology simulations.
2010-2013	Post-Doctoral Researcher, Applied Mathematics, Theoretical Division, LANL, Los Alamos, NM. Multiphase flow for carbon sequestration, thermal hydrology for permafrost applications.
2004-2009	DOE Computational Science Graduate Fellow

Selected Publications

Jafarov, E.E., **E.T. Coon**, D. Harp, C.J. Wilson, S.L.Painter, A.L. Atchley, V.Romanovsky. *Modeling the role of preferential snow accumulation in through talik development and hillslope groundwater flow in a transitional permafrost landscape.* Env. Research Letters. 13 (10). 2018.

Jan, A., **E.T. Coon,** J.D. Graham, S.L. Painter. *A Subgrid Approach for Modeling Microtopography Effects on Overland Flow.* Water Resour. Res. 54 (9) 6153-67. 2018.

Grenier, C. et al. *Groundwater flow and heat transport for systems undergoing freeze-thaw: Intercomparison of numerical simulators for 2D test cases.* Adv. Water Resour. 114, 196-218. 2018.

Jan, A. **E.T. Coon**. S.L. Painter, R. Garimella, J.D. Moulton. An intermediate-scale model for thermal hydrology in low-relief permafrost-affected landscapes. Comp. Geosci. 22 (1) 163-77. 2018.

Coon, E.T., J.D. Moulton, and S.L. Painter. *Managing Complexity in Simulations of Land Surface and Near-surface Processes.* Env. Modell. Softw. 78 (134-49). 2016.

Painter, S.L., **E.T. Coon**, A.L. Atchley, M. Berndt, R. Garimella, J.D. Moulton, D. Svyatsky. *Integrated surface/subsurface permafrost thermal hydrology: Model formulation and proof-of-concept simulations.* Water Resour. Res. 52 (8), 6062-77. 2016.

Atchley, A.L., **E.T. Coon**, S.L. Painter, D.R. Harp, C.J. Wilson. *The relative influence of Peat, Surface and Subsurface Water, and Snow on Active Layer Thickness*. 43 (10), 5116-23, Geophys. Res. Letters. May 2016.

Harp, DR, AL Atchley, SL Painter, **ET Coon**, CJ Wilson, VE Romanovsky, JC Rowland. *Effect of soil property uncertainties on permafrost thaw projections: A calibration-constrained analysis.* The Cryosphere Disussions, 9 (3). 2015.

Sjoberg, Y., **E.T. Coon**, A.B.K Sannel, R. Pannetier, D. Harp, A. Frampton, S.L. Painter, S.W. Lyon. *Thermal effects of groundwater flow through subarctic fens – a case study based on field observations and numerical modeling,* in press. Water Resour. Res.

Rowland, J. and **Coon, E.T**. *From documentation to prediction: raising the bar for thermokarst research.* Hydrogeo. J. 1-4. 2015

Project Leadership Roles

Principle Investigator: Co-evolving plant traits and hydrologic environment within watershed models.(ORNL LDRD) $300K / yr, two years. Supports parts of four staff members and one student.

ORNL Laboratory Lead: SciDAC Coupling Approaches for Next Generation Architectures. (DOE SC)$3M / yr, five years ($400K/yr to ORNL). Supports three staff members and one post-masters student.

Task Lead: ExaSheds. (DOE SC) $1.5M/yr, one year seed ($600K/yr to task). New start.

Named Co-Investigator: Next Generation Ecosystem Experiment – Arctic (DOE SC)
$10M/yr, seven years.

Synergistic Activities

Author and primary developer, the *Advanced Terrestrial Simulator*, a code for ecosystem hydrology.Author and primary developer, *Arcos,* the multiphysics framework for ASCEM's Amanzi and ATS.

Member, BER Working Group on Model-Data Integration for Environmental System Science: Modeling Frameworks, Data Management, and Scientific Workflows, Apr 2015-present.

Technical reviewer for Advances in Water Resources, Water Resources Research, Geophysical Research Letters, Computational Geosciences, others.

Collaborators and Co-Authors

A. Atchley, M. Berndt, W. Carey, R. Garimella, P. Jones, Q. Kang, K. Lipnikov, G. Manzini, N. McDowell, J.D. Moulton, M. Porter, J. Rowland, D. Svyatsky, C.J. Wilson, C. Xu (LANL), S. Painter, A. Jan, P. Thornton, S. Wullschleger (ORNL), M. Heroux (SNL), B. Smith (ANL), P. Kelemen, B. Shaw, M. Spiegelman (Columbia Univ), D. Keyes (Kaust), M. Knepley (Rice) R.F. Katz (Cambridge Univ.) S. Kollet (Bonn) Y. Sjoberg, R. Pannetier, A. Frampton, S.Lyon (Stockholm Univ)

Graduate and Postdoctoral Advisees

Adam Atchley, Evgeny Kikinzon, Nick Sutfin, Elchin Jafarov (post-doc) Nathan Wales, Ben Liebersohn (masters)

Michael C. Crow
Associate Technical Professional
Oak Ridge National Laboratory, Environmental Sciences Division
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Email: crowmc@ornl.gov

Education and Training

2015	University of Tennessee at Chattanooga - Computer Science – Software Systems, BS

Research and Professional Experience

07/2018-Present	Software Engineer, Oak Ridge National Laboratory, Environmental Sciences Division, DOE. Supporting Next Generation Ecosystem Experiments (NGEE) - Arctic project, Atmospheric Radiation Measurements (ARM) project, and the Mercury Science Focus Area (MSFA) projects. Developing and maintaining scientific software tools for the management of metadata and Digital Object Identifiers (DOIs). Designing tools to maintain critical infrastructure processes, such as Application Programming Interface (API) development, web service development, and ongoing development for other data management tools.
01/2016-07/2018	Post-Bachelor Research Associate, Oak Ridge Associated Universities for Oak Ridge National Laboratory, DOE. Supporting Next Generation Ecosystem Experiments (NGEE) - Arctic project, Atmospheric Radiation Measurements (ARM) project, Urban Information Systems (UrbIS), and the Mercury Science Focus Area (SFA).
06/2015-01/2016	HERE Intern, Oak Ridge Associated Universities for Oak Ridge National Laboratory, DOE. Supporting development of many data and metadata management software tools.

Skills and Achievements

Languages & Frameworks	Java, Python, Bash, Javascript, HTML5, CSS, Bootstrap, PostgreSQL, Git, SVN, Spring-Boot, Spring MVC, Spring Security, Selenium, Hibernate, Maven, jQuery, MySQL, Vue.js, DataTables, LDAP, Single Sign-on, D3, PHP, Drupal, Perl, C++
Servers & OS	Apache Tomcat, Apache Solr, Apache Server, Unix, Linux (RHEL & Fedora)
Tools	Intellij, PyCharm, Eclipse, MyEclipse, Sublime, iTerm, Vim, DBVisualizer, NetBeans, Postman, ServiceNow, Virtual Box, Visual Studio Code
Metadata Standards	Federal Geographic Data Committee (FGDC), International Organization for Standardization (ISO 19115), Ecological Metadata Language (EML)
Software Tools Managed	NGEE-Arctic Online Metadata Editor (OME), NGEE-Arctic DOI Tool, NGEE-Arctic Mercury Search Tool, NGEE-Arctic Drupal website, ARMLive (REST architecture-based web service to download ARM data), Partial-file Deletion Automation, ARM Online Metadata Editor, Data Reception, ARM DOI Tool, Service Now API (SnApi), ARM Metrics Dashboard Microservices, SBR/MSFA Online Metadata Editor (OME), SBR/MSFA Mercury Search Tool

Selected Presentations and Publications

M. Crow, T. Killeffer, R. Devarakonda, K. Guntapally, K. Dumas, L. Hook, T. Boden, G. Prakash, and S. Wullschleger, “New Tools to Document and Manage Data/Metadata: Example NGEE Arctic and ARM”, American Geophysical Union, New Orleans, LA. 2017

M. Crow, R. Devarakonda, A. Sorokine, A. King and B. Preston, "Mercury: Urban Information Systems Metadata Search", American Association of Geographers, Boston MA, 2017.

M. Crow, T. Killeffer, R. Devarakonda, L. Hook, M. Krassovski, A. King, and S. Wullschleger, “New Tools to Document and Manage Data/Metadata: Example NGEE Arctic and UrbIS”, American Geophysical Union Conference, San Francisco, CA. 2016.

S. Ramireddy, M. Crow., et al., “New CDIAC’s Metadata Management and Data Discovery and Access System”, ORNL 2016 Summer Student Poster Session, Oak Ridge, TN. 2016.

Ranjeet Devarakonda (Senior Member, IEEE)
Research Staff and Data Tools and Services Architect
Atmospheric Radiation Measurement
Environmental Sciences Division, Climate Change Science Institute, Oak Ridge National Laboratory
Phone: (865) 576-1419
Email: devarakondar@ornl.gov

Education and Training

2004 - 2006	Eastern Michigan University, Ypsilanti, MI - Computer Science, MS
2000 - 2004	Jawaharlal Nehru Technological University, India - Electronics, B. Tech.

Research and Professional Experience

04/2016 - Present	Senior Research Staff and Data Tools and Services Architect for Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM), Oak Ridge National Laboratory. Manages a team of Software engineers to develop various tools and services. Provide architecture solutions to automate the metadata flow to 'Archive' databases and provide micro services in support of ARM adaptive architecture. In Addition, Software Architect for Mercury: Distributed data/metadata management, data discovery and access system, which manages data/metadata for more than 15 federally funded projects funded by various federal organizations, including DOE, NASA DAAC's and NSF.
06/2008 - 03/2016	Research Staff, Climate Change Science Institute, NASA-DAAC, Oak Ridge National Laboratory. N-tier scientific data tools development, data management, interface development for Environmental database, and support for current products.
01/2007 - 05/2008	Research Associate, NASA-DAAC, Oak Ridge National Laboratory Sponsored by: Oak Ridge Institute of Science and Engineering. Design and development of Java based toolset (Mercury) for harvesting, indexing and searching structured metadata associated with environmental, ecological and climate science data

Selected Publications

R. Devarakonda, M. Giansiracusa, and J. Kumar, "Machine Learning and Social Media to Mine and Disseminate Big Scientific Data," 2018 IEEE International Conference on Big Data (Big Data), Seattle, WA, December 2018 (Accepted; Awaiting publication)

R. Devarakonda, M. Giansiracusa, J. Kumar and H. Shanafield, "Social media based NLP system to find and retrieve ARM data: Concept paper," 2017 IEEE International Conference on Big Data (Big Data), Boston, MA, 2017, pp. 4736-4737. doi: 10.1109/BigData.2017.8258525

Devarakonda, R., Dumas, K., Beus, S., Rush, E., Krishna, B., Records, R., ... & Prakash, P. (2016, December). Next-Gen Tools for Big-Scientific-Data: ARM Data Center Example. IEEE Big Data (Big Data) Conference.

Devarakonda, R., Palanisamy, G., Green, J. M., & Wilson, B. E. (2011). Data sharing and retrieval using OAI-PMH. Earth Science Informatics, 4(1), 1-5.

Devarakonda, R., Palanisamy, G., Wilson, B. E., & Green, J. M. (2010). Mercury: reusable metadata management, data discovery and access system. Earth Science Informatics, 3(1-2), 87-94.

R. Devarakonda, Y. Wei, M. Thornton, B. Mayer, P. Thornton and B. Cook, "Preparing, Storing, and Distributing Multi-dimensional Scientific Data." Proceedings of the IEEE International Conference on Big Data, DOI: 10.1109/BigData.2015.7364085, pgs. 2811 - 2813 (2015).

Devarakonda, R., Shrestha, B., Palanisamy, G., Hook, L., Killeffer, T., Krassovski, M., ... & Frame, M. (2014, October). OME: Tool for generating and managing metadata to handle BigData. In Big Data (Big Data), 2015 IEEE International Conference on (pp. 8-10). IEEE.

R. Devarakonda, G. Palanisamy and I.S. Gil, "Framework for Building Collaborative Research Environment." International Journal of Recent Contributions from Engineering, Science & IT (iJES), Volume 2, Issue 4 (2014).
L. Pouchard, M. Branstetter, R. Cook, R. Devarakonda, J. Green, G. Palanisamy, P. Alexander and N. Noy, "A Linked Science investigation: enhancing climate change data discovery with semantic technologies." Earth Science Informatics, Volume 6, pgs. 175-185 (2013).
S. Vannan, T. Beaty, R. Cook, D. Wright, R. Devarakonda, Y. Wei, L. Hook and B. McMurry, "A Semi-Automated Workflow Solution for Data Set Publication." International Journal of Geo-Information, Volume 5 (2016).
B. Hadjerioua, S. Kao, M. Sale, Y. Wei, S. Santhana Vannan, H. Shanafield, D. Kaiser, R. Devarakonda, et al., "National Hydropower Asset Assessment Project (NHAAP) Final Annual Report." Technical Manual 2010/260, Oak Ridge National Laboratory (ORNL) (2010).
Devarakonda, R., Hook, L., Killeffer, T., Krassovski, M., Boden, T., & Wullschleger, S. (2015, October). Use of a metadata documentation and search tool for large data volumes: The NGEE arctic example. In Big Data (Big Data), 2015 IEEE International Conference on (pp. 2814-2816). IEEE.
Thornton, P.E., Thornton, M. M., Mayer, B. W., Wei, Y., Devarakonda, R., Vose R.S., and Cook R.B. (2016). Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 3 (DATASET). Oak Ridge National Laboratory (ORNL).
Devarakonda, R., & Shanafield, H. (2011, May). Drupal: Collaborative framework for science research. In Collaboration Technologies and Systems (CTS), 2011 International Conference on (pp. 643-643). IEEE.
Devarakonda, R., Shrestha, B., Palanisamy, G., Hook, L., Killeffer, T., Krassovski, M., ... & Frame, M. (2014, October). OME: Tool for generating and managing metadata to handle BigData. In Big Data (Big Data), 2014 IEEE International Conference on (pp. 8-10). IEEE.
Shrestha, B., Devarakonda, R., & Palanisamy, G. (2014, October). An open source framework to add spatial extent and geospatial visibility to Big Data. In Big Data (Big Data), 2014 IEEE International Conference on (pp. 64-66). IEEE.
Devarakonda, R., Palanisamy, G., Pouchard, L. C., & Shrestha, B. (2014, May). Semantic search integration to climate data. In Collaboration Technologies and Systems (CTS), 2014 International Conference on (pp. 635-636). IEEE.

Synergistic Activities

Sr. R&D Software Architect for Mercury distributed metadata management, data discovery and access system, which manages data/metadata for more than 10 projects funded by various federal organizations, including DOE, NASA DAAC's and NSF.
Principal Investigator for USGS- Core Science Analytics, Synthesis, and Libraries at Oak Ridge National Laboratory. (2017 - present).
CO-Principal Investigator for USGS- Core Science Analytics, Synthesis, and Libraries at Oak Ridge National Laboratory. (2007 - 2017).
CO-Principal Investigator for NASA's Soil moisture Sensing Controller And oPtimal Estimator (SoilSCAPE) project. Principal Investigator: Mahta Moghaddam, University of Southern California, CA. (2012 - 2016).
CO-Principal Investigator for Urban Typologies: Towards an ORNL Urban Information System (UrbIS) at Oak Ridge National Laboratory. (2014 - 2016).
CO-Principle Investigator for National Extreme Events Data Center (NEED) at Oak Ridge National Laboratory. (2015 - 2016).
Data Theme Leader, Climate Change Science Institute, ORNL (2017 - present).
Senior Member, The Institute of Electrical and Electronics Engineers (IEEE) (2009 - present).
Editorial Board member for Springer's Earth Science Informatics Journal.
Invited reviewer for ACM Computing reviews.
Amazon Web Services Certificate of Training on "Developing on AWS"

Member and Recipient of NASA's Peer-recognition Software Reuse Award (2008).
Co-chaired Informatics sessions at the American Geophysical Union Fall Meetings (Invited).
Panel lead and reviewer for the NASA Earth Science Technology Office (ESTO) – Advanced Information Systems Technology (AIST) grants/proposals.

David E. Graham
Senior Staff Scientist
Biosciences Division, Oak Ridge National Laboratory
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Email: grahamde@ornl.gov

Education and Training

2000	University of Illinois at Urbana-Champaign, Microbiology, PhD
1998	University of Illinois at Urbana-Champaign, Microbiology, MS
1995	Cornell University, Biological Sciences and Economics, AB

Research and Professional Experience

2010– present	Group Leader. Microbial Ecology and Physiology Group. Oak Ridge National Laboratory.
2009– present	Biochemistry and Metabolic Engineer. Oak Ridge National Laboratory. Research areas: biofuels, energetics, carbon storage, microbial biochemistry, synthetic biology, metabolism, biosynthesis.
2010– present	Joint Faculty Research Associate Professor. Microbiology Department, University of Tennessee Knoxville.
2003–2009	Assistant Professor. Department of Chemistry and Biochemistry, University of Texas at Austin. Research areas: novel biosynthetic enzymes; archaea; chlamydia
2000–2003	Postdoctoral research in the laboratory of Prof. Robert White. Virginia Tech. Identification and characterization of archaeal cofactor biosynthesis enzymes, including coenzyme M, coenzyme F420, riboflavin, and spermidine.

Selected Publications

Zheng J, Thornton PE, Painter SL, Gu B, Wullschleger SD, Graham DE. 2018. Modeling anaerobic soil organic carbon decomposition in Arctic polygon tundra: insights into soil geochemical influences on carbon mineralization. Biogeosciences Discuss https://www.biogeosciences-discuss.net/bg-2018-63/ (in review).

Zheng J, RoyChowdhury T, Yang Z, Gu B, Wullschleger SD, Graham DE. 2018. Impacts of temperature and soil characteristics on methane production and oxidation in Arctic tundra. Biogeosciences 15:6621-6635.

Moon J-W, Eskelsen JR, Ivanov IN, Jacobs CB, Jang GG, Kidder MK, Joshi PC, Armstrong BL, Pierce EM, Oremland RS, Phelps TJ, Graham DE. 2018. Improved ZnS nanoparticle properties through sequential NanoFermentation. Appl. Microbiol. Biotechnol. 102:8329-8339

Soltanian MR, Amooie MA, Graham D, Pfiffner S, Phelps T and Moortgat J. 2018. Transport of Perfluorocarbon Tracers in the Cranfield Geological Carbon Sequestration Project. Greenhouse Gas Sci. Technol. 8:650-671.

Jubb AM, Eskelsen JR, Yin X, Zheng J, Pierce EM, Graham DE, Wullschleger SD and Gu B. Characterization of Iron Oxide Nanoparticle Films at the Air-Water Interface in Arctic Tundra Waters. Sci. Tot. Environ. 633:1460-1468.

Chen H, Yang Z., Chu RK, Tolic N, Liang L, Graham DE, Wullschleger S.D., and Gu B. 2018. Molecular insights into Arctic soil organic matter degradation under warming. Environ. Sci. Technol. 52:4555-4564.

Soltanian MR, Amooie MA, Cole DR, Darrah TH, Graham DE, Pfiffner SM, Phelps T, Moortgat J. 2018. Impacts of Methane on Carbon Dioxide Storage in Brine Formations. Groundwater 56:176-186.

Grant RF, Mekonnen ZA, Riley WJ, Wainwright HM, Graham D and Torn MS. 2017. I: Microtopography Determines How Active Layer Depths Respond to Changes in Temperature and Precipitation at an Arctic Polygonal Tundra Site: Mathematical Modeling with Ecosys. J. Geophys. Res. Biogeosci. 122:3161-3173.

Yang, Z. *et al*. 2017. Microbial community and functional gene changes in Arctic tundra soils in a microcosm warming experiment. Front. Microbiol.8:1741

Mahan, KM, Zheng, H, Fida, TT, Parry, RJ, Graham, DE, Spain, JC. 2017. A novel, iron-dependent enzyme that catalyzes the initial step in the biodegradation of *N*-nitroglycine by *Variovorax* sp. strain JS1663. Appl. Environ. Microbiol.83:e00457-17

Herndon, E, AlBashaireh, A., Singer, D., Roy Chowdhury, T., Gu, B., Graham, D. 2017. Influence of iron redox cycling on organo-mineral associations in Arctic tundra soil. Geochim. Cosmochim. Acta. 207:210.

Tang, G. *et al.* 2016. Biogeochemical modeling of CO_2 and CH_4 production in anoxic Arctic soil microcosms. Biogeosciences. 13:5021-5041.

Xu, X. *et al.* 2016. Reviews and syntheses: Four decades of modeling methane cycling in terrestrial ecosystems. Biogeosciences. 13:3735-3755.

Throckmorton HM, *et al*. 2016. Active layer hydrology in an Arctic tundra ecosystem: quantifying water sources and cycling using water stable isotopes. Hydrological Processes. 30:4972-4986.

Schädel, C. *et al.* 2016. Potential carbon emissions dominated by carbon dioxide from thawed permafrost soils. Nature Climate Change 6:950-953.

Yang Z, Fang W, Lu X, Sheng G-P, Graham DE, Liang L, Wullschleger SD, Gu B. 2016. Warming increases methylmercury production in an Arctic soil. Environmental Pollution 214:504-509.

Herndon EM, Yang Z, Bargar J, Janot N, Regier TZ, Graham DE, Wullschleger SD, Gu B, Liang L. 2015. Geochemical drivers of organic matter decomposition in arctic tundra soils. Biogeochemistry 126:397-414.

Herndon EM, Mann BF, Roy Chowdhury T, Yang Z, Wullschleger SD, Graham D, Liang L, Gu B. 2015. Pathways of anaerobic organic matter decomposition in tundra soils from Barrow, Alaska. Journal of Geophysical Research: Biogeosciences 120:2345-2359.

Xu, X. *et al.* 2015. A microbial functional group-based module for simulating methane production and consumption: application to an incubated permafrost soil. J. Geophys. Res. Biogeosci. 120:1315-1333.

Mann, B.F., H. Chen, *et al*. 2015. Indexing permafrost soil organic matter degradation using high-resolution mass spectrometry. PLoS ONE. 10(6):e0130557.

Heikoop, J. *et al.* 2015. Isotopic identification of soil and permafrost nitrate sources in an Arctic tundra ecosystem. J. Geophys. Res. 120.1000-1017.

Newman, B.D. *et al.* 2015. Microtopographic and depth controls on active layer chemistry in Arctic polygonal ground. Geophys. Res. Lett. 42:1808-1817.

Roy Chowdhury, T., E. Herndon, T. Phelps, D. Elias, B. Gu, L. Liang, S. Wullschleger and D.E. Graham. 2015. Stoichiometry and temperature sensitivity of methanogenesis and CO_2 production from saturated polygonal tundra in Barrow, Alaska. Global Change Biol. 21:722.

Synergistic Activities

Undergraduate research mentor to nine biochemistry students. Students working on individual projects in the lab applied for and received five undergraduate research fellowships. Supervisor of two high school summer students at UT-Austin: Welch Summer Scholar (2007) and ACS Project Seed student (2008). Supervisor of SULI and ACTS students at ORNL.

Member of 22 doctoral and 2 masters thesis committees.

Editorial board member: *Analytical Biochemistry, Applied and Environmental Microbiology* and *Journal of Bacteriology*

ORNL LDRD Integrated Studies of Complex Biological and Environmental Systems Institutional Review Committee Chair (2016-present)

Grant proposal reviewer: DOE (BES, BER), NSF, NIH, NASA, Auckland Medical Research Foundation, Louisiana NASA EPSCoR, German Academic Exchange Service

ORNL Postdoctoral Program Advisory Committee, Directorate representative (2013-2017)

Baohua Gu, Ph.D.
Corporate Fellow
Environmental Sciences Division, Oak Ridge National laboratory
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Email: gub1@ornl.gov

Education and Training

1991	University of California—Berkeley, Environmental Geochemistry, PhD
1986	University of British Columbia, Vancouver, Canada, Soil Chemistry, MS

Research and Professional Experience

2017–present	Corporate Fellow, Oak Ridge National Laboratory.
1993–2016	Research Staff, Oak Ridge National Laboratory.
2002–present	Joint Professor, Dept. of Biosystems Engineering and Soil Science, Univ. of Tennessee.

Selected Publications (selected from >250, H-Index 66 from Google Scholar)

Chen, H. M.; Yang, Z.; Chu, R. K.; Tolic, N.; Liang, L.; Graham, D. E.; Wullschleger, S. D.; Gu, B., Molecular insights into Arctic soil organic matter degradation under warming. *Environ. Sci. Technol.* **2018**, 52, 4555–4564.

Jubb, A. M.; Eskelsen, J. R.; Yin, X.; Zheng, J.; Philben, M. J.; Pierce, E. M.; Graham, D. E.; Wullschleger, S. D.; Gu, B., Characterization of iron oxide nanoparticle biofilms at the air–water interface in Arctic tundra waters. *Sci. Total Env*. **2018**, 633, 1460-1468.

Qian, C.; Chen, H.; Johs, A.; Lu, X.; An, J.; Pierce, E. M.; Parks, J. L.; Elias, D. A.; Hettich, R. L.; Gu, B., Quantitative proteomic analysis of biological processes and responses of the bacterium *Desulfovibrio desulfuricans* ND132 upon deletion of its mercury methylation genes. *Proteomics.* **2018**, 1700479.

Yang, Z.; Yang, S.; Van Nostrand, J. D.; Zhou, J. Z.; Fang, W.; Qi, Q.; Liang, L.; Wullschleger, S. D.; Graham, D. E.; Yang, Y. F.; Gu, B., Microbial community and functional gene changes in Arctic tundra soils in a microcosm warming experiment. *Frontiers Microbiol*. **2017**, 8, 1741. DOI: 10.3389/fmicb.2017.01741.

Zhao, L.; Chen, H.; Lu, X.; Lin, H.; Christensen, G. A.; Pierce, E. M.; Gu, B., Contrasting effects of dissolved organic matter on mercury methylation by *G. sulfurreducens* PCA and *D. desulfuricans* ND132. *Environ. Sci. Technol.* **2017**, 51 (18), 10468–10475. DOI: 10.1021/acs.est.7b02518.

Lu, X.; Gu, W.; Zhao, L.; Ul Haque, M. F.; DiSpirito, A. A.; Semrau, J. D.; Gu, B., Methylmercury uptake and degradation by methanotrophs. *Science Adv.* **2017**, 3, e1700041. DOI: 10.1126/sciadv.1700041.

Chowdhury, T. R., E. M. Herndon, E. M., T. J. Phelps, D. A. Elias, B. Gu, L. Liang, S. D. Wullschleger, D. Graham. **2015**. Stoichiometry and temperature sensitivity of methanogenesis and CO_2 production from saturated polygonal tundra in Barrow, Alaska. *Global Change Biol*. 21:722-737.

Mann, B. F.; Chen, H.; Herndon, E. M.; Portier, E. F.; Tolic, N.; Callister, S. J.; Chu, R.; Robinson, R.; Graham, D. E.; Wullschleger, S.; Liang, L.; Gu, B. **2015**. Indexing permafrost soil organic matter degradation using high-resolution mass spectrometry. *PlosOne* (in review).

Herndon, E. M., B. F. Mann, T. R. Chowdhury, S. D. Wullschleger, D. Graham, L. Liang, B. Gu. **2015**. Pathways of anaerobic organic matter decomposition in warming tundra soils from Barrow, Alaska. *JGR Biogeosci*. (in review).

H. Lin, J. L. Morrell-Falvey, B. Rao, L. Liang, and B. Gu. **2014**. Coupled mercury-cell sorption, reduction, and oxidation on methylmercury production by *Geobacter sulfurreducens* PCA. *Environ. Sci. Technol.* 48, 11969-11976.

Qian, Y.; Yin, X.; Lin, H., Rao, L., Brooks, S. C.; Liang, L.; Gu, B. **2014**. Why dissolved organic matter enhances photodegradation of methylmercury. *Environ. Sci. Technol. Lett.* 1, 426−431.

Zheng, W.; Liang, L.; Gu, B. **2012**. Mercury reduction and oxidation by reduced natural organic matter in anoxic environments. *Environ. Sci. Technol.* 46, 292-299.
Miller, C.; Liang, L.; Gu, B. **2012.** Competitive ligand exchange reveals mercury reactivity change with dissolved organic matter (DOM). *Environ Chem*. 9, 495-501.
Gu, B., Y. Bian, C.L. Miller, W. Dong, X. Jiang, L. Liang. **2011.** Mercury reduction and complexation by natural organic matter in anoxic environments. *Proc. Natl. Acad. Sci.* 108, 1479–1483.
Gu, B.; Dong, W.; Liang, L.; Wall, N. A. **2011**. Dissolution of technetium(IV) oxide by natural and synthetic organic ligands under both reducing and oxidizing conditions. *Environ. Sci. Technol.* 45, 4771-4777.
Boggs, M. A.; Minton, T.; Lomasney, S.; Islam, M. R.; Dong, W.; Gu, B.; Wall, N. **2011**. Interactions of Tc(IV) with humic substances. *Environ. Sci. Technol.* 45, 2718-2724.
Hatab, N. A., C. H. Hsueh, A. Gaddis, S. T. Retterer, J. H. Li, G. Eres, Z. Zhang, and B. Gu. **2010.** Free-standing optical gold bowtie nanoantenna with variable gap size for enhanced Raman spectroscopy. *Nano Letters* 10, 4952–4955.
Dong, W. M., L. Liang, S. C. Brooks, G. Southworth, and B. Gu. **2009**. Roles of dissolved organic matter in the speciation of mercury and methylmercury in a contaminated ecosystem in Oak Ridge, Tennessee. *Environ. Chem.* 7, 94–102.
Miller, C., G. Southworth, S. C. Brooks, L. Liang, and B. Gu **2009**. Kinetic controls on the complexation between mercury and dissolved organic matter. *Environ. Sci. Technol*. 43, 8548–8553.
Luo, W., and B.Gu. **2009**. Dissolution and mobilization of uranium in a reduced sediment by natural humic substances under anaerobic conditions. *Environ. Sci. Technol*. 43, 152–156.
Gu, B., C. Ruan, and W. Wang. **2009**. Perchlorate detection at nanomolar concentrations by surface-enhanced raman scattering. *Appl. Spectr*. 63, 98–102.
Gu, B., H. Yan, P. Zhou, D. Watson, M. Park, and J. D. Istok. **2005**. Humics impact uranium bioreduction and oxidation. *Environ. Sci. Technol*. 39, 5268–5275.
Delapp, R.C., E.J. LeBoeuf, J. Chen, and B. Gu. **2005**. Advanced thermal characterization of fractionated natural organic matter. *J. Environ. Qual*. 34, 842–853.
Zhou, P., H. Yan, and B. Gu. **2005**. Competitive complexation of metal ions with humic substances. *Chemosphere* 58, 1327–1337.
Gu, B., and J. Chen. **2003**. Enhanced microbial reduction of Cr(VI) and U(VI) by different natural organic matter fractions. *Geochim. Cosmochim. Acta* 67, 3575–3582.
Chen, J., B. Gu, and E .J. LeBoeuf. **2003**. Fluorescence spectroscopic studies of natural organic matter fractions. *Chemosphere* 50, 639–647.
Chen, J., B. Gu, E. J. LeBoeuf, H. Pan, and S. Dai. **2002**. Spectroscopic characterization of the structural and functional properties of natural organic matter fractions. *Chemosphere* 48,59–68.
Gu, B., T. Mehlhorn, L. Liang and J. F. McCarthy. **1996**. Competitive adsorption, displacement, and transport of organic matter on iron oxide. *Geochim. Cosmochim. Acta*. 60, 2977–2992.
Gu, B., J. Schmitt, Z. Chen, L. Liang, and J. F. McCarthy. **1995**. Adsorption and desorption of different organic matter fractions on iron oxide. *Geochim. Cosmochim. Acta*. 59(2), 219–229.
Gu, B., J. Schmitt, Z. Chen, L. Liang, and J. F. McCarthy. **1994**. Adsorption-desorption of natural organic matter on iron-oxide: mechanisms and models. *Environ. Sci. Technol*. 28, 38–46.

Synergistic Activities

Co-Leads the ORNL Mercury Science Focus Area, with focus on fundamental mechanisms and rates of mercury biogeochemical transformation in the environment.

Leads the DoD SERDP-ESTCP projects on the development of surface enhanced Raman sensor and perchlorate environmental forensics.

Member of American Association for the Advancement of Science (AAAS), American Chemical Society (ACS), Geochemical Society (International), and American Geophysical Union (AGU).

Collaborators and Co-Editors

A. Jubb (USGS), W. Burgos (PSU), J. F. Bohlke (USGS); J. D. Coates (UC, Berkeley), C. S. Criddle (Stanford U), D. Graham (ORNL), P. Hatzinger (Shaw), Herndon, E. M. (Kent), J. D. Istok (OSU), W. A. Jackson (TTU), K. Kemner (ANL), J. Semrau (UM), N. C. Sturchio (UIC), N. Tolic (PNNL), J. D. Van Nostrand (OU), Z. Yang (Oakland U.), S. Wullschleger (ORNL), J. Zheng (PNNL), J. Zhou (UO).

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Education and Training

1988	University of California, Santa Barbara, Geography, BA
2001	R6 Sigma Specialist/Raytheon Six Signa Program
2006	Hawaii County Trained Facilitator
2006	English as a Second Language Teaching Certificate
2012	Scrum Alliance, Certified Scrum Master (CSM)
2013	Project Management Institute, Project Manager Professional (PMP)

Research and Professional Experience

2013-Present	Technical Project Manager, Environmental Sciences Division (ESD), Oak Ridge National Laboratory. Project Manager for the Next Generation Ecosystem Experiment Arctic (NGEE Arctic). Program Coordinator for the DOE Biological Environmental Research (BER) Program. Agile Project Manager and Scrum Master.
2011-2013	Technical Project Officer/Manager for the Environmental Data Science Systems Group within the ESD, Oak Ridge National Laboratory. Technical Project Manager for the NASA ORNL Distributed Active Archive Center for Biogeochemical Processes (ORNL DAAC). Scrum Master.
2008-2011	Operations Manager, Situational Maritime Domain Awareness, Fourteenth Coast Guard District, Honolulu, HI. Developed and implemented process to fuse multi source/parameter geo spatial data to a daily situational product.
2005-2008	Operations Manager, GODAE High Resolution Sea Surface Temperature Pilot Project (GHRSST-PP) Applications and User Services.
1998-2005	Operations Manager, NASA Jet Propulsion Laboratory (JPL) Physical Oceanography DAAC (JPL PO.DAAC).
1996-1998	Owner and Operations Manager, The Star Group, Marina del Rey, CA. Geospatial Technical Services.
1995-1996	Manager GIS Applications, ADVANCE, an Economic Development Center, Whittier, CA.
1993-1995	Senior Geographer GIS Applications, Parsons Engineering Science, Inc, Pasadena, CA.
1989-1993	Senior Geographer GIS Applications, Science Applications International Corp., Santa Barbara, CA.
1980-1994	U.S. Air Force, U.S. Air Force Reserve and U.S. Coast Guard Reserve. Morse Systems, Airfield Management, Engineering Draftsmen, Port Security, Federal On-Scene Coordinator, Boarding Officer.

Synergistic Activities

East Tennessee Project Management Institute, Honolulu Project Management Institute and Project Management Institute (2009-present). Scrum Alliance (2013 – present)
Rotary International member and leadership (2005 – present)
Member and Chairperson for the NASA DAAC User Services Working Group (1998 – 2003)
Project Manager for NASA/Oceans.US collaboration on Data Management, Archives and Communications (2007-2008)
Earth Science Information Partners (ESIP) Federation member and leadership (1998-2008)

Forrest M. Hoffman
Senior Computational Earth System Scientist
Computational Sciences & Engineering Division, Oak Ridge National Laboratory Phone: (865) 576-7680
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Education and Training

2015	University of California Irvine, Earth System Science, Ph.D.
2012	University of California Irvine, Earth System Science, M.S.
2004	University of Tennessee Knoxville, Physics, M.S.
1991	University of Tennessee Knoxville, Physics, B.S.

Research and Professional Experience

2017–present	Senior Computational Earth System Scientist, Computational Sciences & Engineering Di- vision, Oak Ridge National Laboratory, Oak Ridge, TN
2016–present	Joint Faculty Professor, Department of Civil & Environmental Engineering, University of Tennessee, Knoxville, TN
2011–present	Earth System Modeling Theme Lead, Climate Change Science Institute, Oak Ridge Na- tional Laboratory, Oak Ridge, TN
2014–2017	Senior Computational Earth System Scientist, Computer Science & Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, TN
2003–2014	Computational Climate Scientist, Computer Science & Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, TN
2002–2006	Contributing Editor and Columnist, Linux Magazine
1993–2003	Staff, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN

Selected Publications (5 Years)

V. Eyring, P. M. Cox, G. M. Flato, P. J. Gleckler, G. Abramowitz, P. Caldwell, W. D. Collins, B. K. Gier, A. D. Hall, F. M. Hoffman, G. C. Hurtt, A. Jahn, C. D. Jones, S. A. Klein, J. Krasting, L. Kwiatkowski, R. Lorenz, E. Maloney, G. A. Meehl, A. Pendergrass, R. Pincus, A. C. Ruane, J. L. Russell, B. M. Sanderson, B. D. Santer, S. C. Sherwood, I. R. Simpson, R. J. Stouffer, and M. S. Williamson. Taking climate model evaluation to the next level. *Nat. Clim. Change*, 2019. doi:10.1038/s41558-018-0355-y.

Z. L. Langford, J. Kumar, F. M. Hoffman, A. L. Breen, and C. M. Iversen. Arctic vegetation mapping using unsupervised training datasets and convolutional neural networks. *Remote Sens.*, 11(1):69, Jan. 2019. doi:10.3390/rs11010069.

Y. Ergüner, J. Kumar, F. M. Hoffman, H. N. Dalfes, and W. W. Hargrove. Mapping ecoregions under climate change: A case study from the biological 'crossroads' of three continents, Turkey. *Landscape Ecol.*, 2018. doi:10.1007/s10980-018-0743-8.

P. A. Levine, J. T. Randerson, Y. Chen, M. S. Pritchard, M. Xu, and F. M. Hoffman. Soil moisture variability intensifies and prolongs eastern Amazon temperature and carbon cycle response to El Niño-Southern Oscillation. *J. Clim.*, 2018. doi:10.1175/JCLI-D-18-0150.1.

G. J. Kooperman, M. D. Fowler, F. M. Hoffman, C. D. Koven, K. Lindsay, M. S. Pritchard, A. L. S. Swann, and J. T. Randerson. Plant physiological responses to rising CO_2 modify simulated daily runoff intensity with implications for global-scale flood risk assessment. *Geophys. Res. Lett.*, 45(22):12,457–12,466, Nov. 2018a. doi:10.1029/2018GL079901.

Z. L. Langford, J. Kumar, and F. M. Hoffman. Wildfire mapping in Interior Alaska using deep neural networks on imbalanced datasets. In *Proceedings of the 2018 IEEE International Conference on Data Mining Workshops (ICDMW 2018)*. Institute of Electrical and Electronics Engineers (IEEE), Conference Publishing Services (CPS), Nov. 2018. doi:10.1109/ICDMW.2018.00116.

N. Collier, F. M. Hoffman, D. M. Lawrence, G. Keppel-Aleks, C. D. Koven, W. J. Riley, M. Mu, and J. T. Randerson. The International Land Model Benchmarking (ILAMB) system: Design, theory, and implementation. *J. Adv. Model. Earth Sy.*, 10(11):2731–2754, Nov. 2018. doi:10.1029/2018MS001354.

C.-E. Yang, J. Mao, F. M. Hoffman, D. M. Ricciuto, J. S. Fu, C. D. Jones, and M. Thurner. Uncertainty quantification of extratropical forest biomass in CMIP5 models over the Northern Hemisphere. *Sci. Rep.*, 8(1):10962, July 2018. doi:10.1038/s41598-018-29227-7.

G. J. Kooperman, Y. Chen, F. M. Hoffman, C. D. Koven, K. Lindsay, M. S. Pritchard, A. L. S. Swann, and J. T. Randerson. Forest response to rising CO_2 drives zonally asymmetric rainfall change over tropical land. *Nat. Clim. Change*, 8(5):434–440, May 2018b. doi:10.1038/s41558-018-0144-7.

G. Keppel-Aleks, S. J. Basile, and F. M. Hoffman. A functional response metric for the temperature sensitivity of tropical ecosystems. *Earth Interact.*, 22(7):1–20, Apr. 2018. doi:10.1175/EI-D-17-0017.1.

J. K. Moore, W. Fu, F. Primeau, G. L. Britten, K. Lindsay, M. Long, S. C. Doney, N. Mahowald, F. M. Hoffman, and J. T. Randerson. Sustained climate warming drives declining marine biological productivity. *Science*, 359(6380):1139–1143, Mar. 2018. doi:10.1126/science.aao6379.

B. Beckage, L. J. Gross, K. Lacasse, E. Carr, S. S. Metcalf, J. M. Winter, P. D. Howe, N. Fefferman,
T. Franck, A. Zia, A. Kinzig, and F. M. Hoffman. Linking models of human behaviour and climate alters projected climate change. *Nat. Clim. Change*, 2018. doi:10.1038/s41558-017-0031-7.

Z. L. Langford, J. Kumar, and F. M. Hoffman. Convolutional neural network approach for mapping Arctic vegetation using multi-sensor remote sensing fusion. In *Proceedings of the 2017 IEEE International Conference on Data Mining Workshops (ICDMW 2017)*. Institute of Electrical and Electronics Engineers (IEEE), Conference Publishing Services (CPS), Nov. 2017. doi:10.1109/ICDMW.2017.48.

X. Song, F. M. Hoffman, C. M. Iversen, Y. Yin, J. Kumar, C. Ma, and X. Xu. Significant inconsistency of vegetation carbon density in CMIP5 Earth system models against observational data. *J. Geophys. Res. Biogeosci.*, 122(9):2282–2297, Sept. 2017. doi:10.1002/2017JG003914.

M. Hoffman, C. D. Koven, G. Keppel-Aleks, D. M. Lawrence, W. J. Riley, J. T. Randerson, A. Ahlström, Abramowitz, D. D. Baldocchi, M. J. Best, B. Bond-Lamberty, M. G. De Kauwe, A. S. Denning, A. R. Desai, V. Eyring, J. B. Fisher, R. A. Fisher, P. J. Gleckler, M. Huang, G. Hugelius, A. K. Jain, N. Y. Kiang,
Kim, R. D. Koster, S. V. Kumar, H. Li, Y. Luo, J. Mao, N. G. McDowell, U. Mishra, P. R. Moorcroft, G. S. H. Pau, D. M. Ricciuto, K. Schaefer, C. R. Schwalm, S. P. Serbin, E. Shevliakova, A. G. Slater,
J. Tang, M. Williams, J. Xia, C. Xu, R. Joseph, and D. Koch. International Land Model Benchmarking (ILAMB) 2016 workshop report. Technical Report DOE/SC-0186, U.S. Department of Energy, Office of Science, Germantown, Maryland, USA, Apr. 2017.

A. L. S. Swann, F. M. Hoffman, C. D. Koven, and J. T. Randerson. Plant responses to increasing CO_2 reduce estimates of climate impacts on drought severity. *Proc. Nat. Acad. Sci.*, 113(36):10019–10024, Sept. 2016. doi:10.1073/pnas.1604581113.

Synergistic Activities

Editorial Board, *Climate* (ISSN 2225-1154; CODEN: CLIMC9), 2018–present.

Lead Author for Chapter 10: Changes in Land Cover and Terrestrial Biogeochemistry, *Climate Science Special Report (CSSR)*, U.S. Global Change Research Program (USGCRP), 2017.

Laboratory Research Manager (Lead PI) for the DOE Scientific Focus Area, *Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computation (RUBISCO)*, 2017–present.

Laboratory Research Manager (Lead PI) for the DOE Scientific Focus Area, *Quantifying Feedbacks and Uncertainties of Biogeochemical Processes in Earth System Models*, 2014–2017.

Member of the Steering Committee for the Coupled Climate–Carbon Cycle Model Intercomparison Project (C^4MIP) for the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6), 2014–present.

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Education and Training

1988	Southern Illinois University-Carbondale, Zoology, PhD
1979	Southern Illinois University-Carbondale, Zoology, MA
1975	Central College, Pella, Iowa, Biology, BA

Research and Professional Experience

1997-Present	Data and Documentation Coordinator, NASA-sponsored Distributed Active Archive Center (DAAC) at Oak Ridge National Laboratory, Environmental Sciences Division. Responsible for archiving DAAC datasets -- interact with investigators to obtain data, QA data and format, assign metadata, and develop documentation.
2009-Present	Data and Documentation Coordinator for DOE TES funded projects. Currently supporting ORNL TES-SFA and SPRUCE, and NGEE Arctic projects. Previously supported the HIPPO project. Responsible for planning and implementing data management workflows for collecting, managing, archiving and sharing data and metadata thru project data systems and in due course the final DOE archive.
1997-2010	Director, NARSTO Quality Systems Science Center. DOE funded. Responsible for providing data and quality management planning and implementation and data archiving support for this multi-national organization dedicated to improving air quality management across North America. Duties included developing data and metadata reporting standards and quality assuring and preparing atmospheric measurement data for archive.
1991-Present	Staff Scientist. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA.

Selected Publications

Cook R.B., Wei Y., Hook L.A., Vannan S.K.S., McNelis J.J. (2018) Preserve: Protecting Data for Long-Term Use. In: Recknagel F., Michener W. (eds) Ecological Informatics. Springer, Cham. https://doi.org/10.1007/978-3-319-59928-1_6

Hanson PJ, Riggs JS, Nettles WR, Phillips JR, Krassovski MB, Hook LA, Gu L, Richardson AD, Aubrecht DM, Ricciuto DM et al. 2017. Attaining whole-ecosystem warming using air and deep-soil heating methods with an elevated CO_2 atmosphere. Biogeosciences. 14:861-883. https://doi.org/10.5194/bg-14-861-2017

Hanson P.J, Gill A.L, Xu X., Phillips J.R, Weston D.J, Kolka R.K, Riggs J.S, Hook L.A. 2016. Intermediate-scale community-level flux of CO_2 and CH_4 in a Minnesota peatland: putting the SPRUCE project in a global context. Biogeochemistry. 129(3):255-272. https://doi.org/10.1007/s10533-016-0230-8

Santhana-Vannan, S.-K & W. Beaty, Tammy & Cook, Bob & Wright, Daine & Devarakonda, Ranjeet & Wei, Yaxing & A. Hook, Les & F. McMurry, Benjamin. (2016). A Semi-Automated Workflow Solution for Data Set Publication. ISPRS International Journal of Geo-Information. 5. 30. https://doi.org/10.3390/ijgi5030030

Krassovski M.B, Riggs J.S, Hook L.A, Nettles W.R, Hanson P.J, Boden T.A. 2015. A comprehensive data acquisition and management system for an ecosystem-scale peatland warming and elevated

CO_2 experiment. Geoscientific Instrumentation, Methods and Data Systems. 4(2):203-213. https://doi.org/10.5194/gi-4-203-2015
Devarakonda, R., Hook, L., Palanisamy, G., and J. Green. 2011. Next-generation search engines for information retrieval. Int. J. Softw. Eng. (IJSE) 2: 1-12.
Pesant, S., L.A. Hook, R. Lowry, G. Moncoiffé, A-M. Nisumaa, and B. Pfeil. 2010. Safeguarding and sharing ocean acidification data. In U. Riebesell, V.J. Fabry, L.Hansson and J-P. Gattuso, editors. Guide to best practices for ocean acidification research and data reporting, 260 p. Luxembourg: Publications Office of the European Union.
Cook, R.B., W.M. Post, L.A. Hook, and R.A. McCord. 2009. A Conceptual Framework for Management of Carbon Sequestration Data and Models. In B.J. McPherson and E.T. Sundquist, editors. Carbon Sequestration and Its Role in the Global Carbon Cycle. AGU Monograph Series 183. pp. 325-334. DOI: 10.1029/2008GM000713.
Hook, L. A., T. W. Beaty, S. Santhana-Vannan, L. Baskaran, and R. B. Cook. 2007. Best Practices for Preparing Environmental Data Sets to Share and Archive. (preparation and electronic publishing by Oak Ridge National Laboratory Distributed Active Archive Center) (https://daac.ornl.gov/PI/bestprac.html). Oak Ridge National Laboratory, Oak Ridge, TN, USA.
Hook, Les A. and Sigurd W. Christensen. 2006. NARSTO Support for Atmospheric Science Research and Data Collection Endeavors. 2006 East Tennessee Ozone Study (ETOS) Science Workshop, Oak Ridge, Tennessee, May 17-18, 2006.
Hook, Les A., Sigurd W. Christensen, Kathleen L. Morris, and Tammy W. Beaty. 2006. Accessing EPA PM Supersites Data in the NARSTO Data Archive. Particulate Matter Supersites Program and Related Studies, An AAAR International Specialty Conference, Atlanta, Georgia, February 7-11, 2005.
Thornton, P.E., R.B. Cook, B.H. Braswell, B.E. Law, W. M. Post, H. H. Shugart, B.T. Rhyne, and L.A. Hook. 2005. Archiving Numerical Models of Biogeochemical Dynamics. Eos, Vol. 86, No. 44, 1 November 2005.
Cushman, R.M., et al. 2004. Carbon Dioxide Information Analysis Center and World Data Center for Atmospheric Trace Gases, Fiscal Year 2003 Annual Report, ORNL/CDIAC-145.
Hook, L.A., S.W. Christensen, and W.B. Sukloff. Data and Metadata Reporting Standards for the U.S. Environmental Protection Agency's PM Supersites Research Program. Quality Assurance -- Good Practice, Regulation, and Law, 9:155-164, 2001/2002.
Cook, Robert B, Richard J. Olson, Paul Kanciruk, and Leslie A. Hook. 2001. Best Practices for Preparing Ecological Data Sets to Share and Archive. Bulletin of the Ecological Society of America, Vol. 82, No. 2, April 2001.
Hook, L.A., P.J. Franco, and J.M. Giddings. 1986. Zooplankton Community Responses to Synthetic Oil Exposure. In Community Toxicity Testing, ASTM STP 920, J. Cairns, Jr., Ed., American Society for Testing and Materials, Philadelphia. Pp. 291-321.69(1):27-42.

Synergistic Activities

SPRUCE Data and Documentation Coordinator. ORNL TES-SFA and Spruce and Peatland Responses Under Changing Environments (SPRUCE). Developed data policy and management plans for SPRUCE experiment.

NGEE Arctic Project Data and Documentation Coordinator. Responsible for working with data providers for collecting, managing, archiving and sharing data and metadata thru project data systems and in due course final DOE archive.

HIPPO (HIAPER Pole-to-Pole Observations (NSF funded)) Data Management and Archive Team, 2009-2017. Responsible for planning and implementing data management work flow for obtaining, quality assuring, formatting, and archiving and distributing data and metadata on project website. Coordination and participation with PI, aircraft instrument team, and independent investigators are keys to success.

Data Management Coordinator, U.S. EPA Particulate Matter Supersites Program, 2000-2004. Worked with EPA PM Supersite Project Managers and Data Coordinators of this national multi-site program to development and implement data, metadata, and format reporting standards for archiving and dissemination of their research data products.

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Education and Training

2008	University of Tennessee, Ecology and Evolutionary Biology, Ph.D.
2004	University of Notre Dame, Biological Sciences, M.S.
1997	Hope College, Biological and Environmental Sciences, B.S.

Research and Professional Experience

2016-Present	Senior Staff Scientist. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA.
2012-2016	Staff Scientist. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA.
2010-2012	Associate Staff Scientist. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA.
2008-2010	Post-doctoral research associate. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA.

Selected Publications

Bjorkman AD, Myers-Smith I, Elmendorf S, Normand S, Rüger N, Beck PSA, Blach-Overgaard A, Blok D, Cornelissen JHC…Iversen CM…et al. 2018. Plant functional trait change across a warming tundra biome. *Nature* 562: 57-62.

Heikoop JM, Throckmorton HM, Newman BD, Perkins GB, Iversen CM, Roy Chowdhury T, Romanovsky V, Graham DE, Norby RJ, Wilson CJ, and Wullschleger SD. 2015. Isotopic identification of soil and permafrost nitrate sources in an Arctic tundra ecosystem. *Journal of Geophysical Research: Biogeosciences* 120: 1000-1017.

Iversen CM, McCormack ML, Powell AS, Blackwood CB, Freschet GT, Kattge J, Roumet C, Stover DB, Soudzilovskaia NA, Valverde-Barrantes OJ, van Bodegom PM, Violle C. 2017. Viewpoints: A global Fine-Root Ecology Database to address belowground challenges in plant ecology. *New Phytologist* 215: 15-26.

Iversen CM, Sloan VL, Sullivan PF, Euskirchen ES, McGuire AD, Norby RJ, Walker AP, Warren JM, Wullschleger SD. 2015. The unseen iceberg: Plant roots in arctic tundra (Tansley Review). *New Phytologist* 205: 34-58.

Kueppers LM, Iversen CM, Koven CD. 2016. Expanding the use of plant trait observations in Earth system models. *Eos* 97 (DOI:10.1029/2016EO049947).

Kumar J, Collier N, Bisht G, Mills RT, Thornton PE, Iversen CM, Romanovsky V. 2016. Modeling the spatio-temporal variability in subsurface thermal regimes across a low-relief polygonal tundra landscape. *The Cryosphere* 10: 2241-2274.

Langford Z, Kumar J, Hoffman FM, Norby RJ, Wullschleger SD, Sloan VL, Iversen CM. 2016. Mapping Arctic plant functional type distributions in the Barrow Environmental Observatory using WorldView-2 and LiDAR datasets. *Remote Sensing* 8: 733.

Norby RJ, Sloan VL, Iversen CM, Childs J. 2018. Controls on fine-scale spatial and temporal variability of plant available inorganic nitrogen in a polygonal tundra landscape. *Ecosystems*, https://doi.org/10.1007/s10021-018-0285-6.

Schädel C, Bader MKF, Schuur EAG, Bracho R, Capek P, De-Baets S, Diakova K, Ernakovich J, Estop-Aragones C, Graham DE, Hartley IP, Iversen CM, Kane E, Knoblauch C, Lupascu M, Natali S, Norby RJ, O'Donnell JA, Roy Chowdhury T, Šantrůčková H, Shaver G, Sloan VL, Treat CC,

Turetsky MR, Waldrop M, Wickland KP. 2016. Potential carbon emissions dominated by carbon dioxide from thawed permafrost soils. *Nature Climate Change* 6: 950-953.
Song X, Hoffman FM, Iversen CM, Yin Y, Kumar J, Ma C, Xu X. 2017. Significant inconsistency of vegetation carbon density in CMIP5 Earth System Models against observational data. *Journal of Geophysical Research - Biogeosciences* 122: 2282-2297.
Treat C, Natali S, Ernakovich J, Iversen CM, Lupascu M, McGuire AD, Norby RJ, Roy Chowdhury T, Richter A, Šantrůčková H, Schädel C, Schuur EAG, Sloan VL, Turetsky M, Waldrop M. A pan-Arctic synthesis of CH_4 and CO_2 production from anoxic soil incubations. *Global Change Biology* DOI: 10.1111/gcb.12875.
Wullschleger SD, Breen A, Iversen CM, Olson M, Nasholm T, Ganeteg U, Wallenstein M, Weston D. 2015. Genomics in a changing Arctic: Critical questions await the molecular ecologist. *Molecular Ecology*, *in press*.
Zhu Q, Iversen CM, Riley WJ, Slette IJ, Vander Stel HM. 2016. Root traits explain observed tundra vegetation nitrogen uptake patterns: Implications for trait-based land models. Journal of Geophysical Research: Biogeosciences 121: 3101-3112. This paper was highlighted here and here.

Synergistic Activities
Editorial Advisory Board, *New Phytologist* (2014 –)
U.S. National Academies 'New Voices in Science, Engineering, and Medicine' Program (2018–2020)
Organizer and co-organizer of numerous meetings and symposia, including: Co-organizer: 'A path forward for improved representation of fine roots in large-scale models: Linking models, data, and experiments', August 2014; 'Missing links in the root-soil organic matter continuum', August 2009; Organizing committee member: 'Trait-Based Methods for Representing Change in Belowground Ecosystems', August, 2017; 39th New Phytologist Symposium. 'Trait covariation: Structural and functional relationships in plant ecology', June 2017; 'DOE workshop on trait methods for representing ecosystem change', November 2015,
Ad-hoc reviewer for: *Annals of Botany; Biogeosciences; Ecology; Ecology Letters; Global Biogeochemical Cycles; Global Change Biology; Global Ecology and Biogeography; Journal of Ecology; Journal of Geophysical Research – Biogeosciences; Nature; New Phytologist; Oecologia; Plant Physiology; Plant and Soil; Polar Science; Proceedings of the National Academy of Sciences of the United States of America; Soil Biology and Biochemistry; Soil Science Society of America Journal; Tree Physiology; National Science Foundation; National Institute for Climate Change Research; Department of Energy, Office of Science.*
Society memberships: American Association for the Advancement of Science, American Geophysical Union, Ecological Society of America.

Collaborators and Co-Editors
ORNL colleagues; NGEE collaborators; Anne Bjorkman (University of Edinburgh); Chris Blackwood (Kent State University); Gregoire Freschet (Universite de Montpellier); Erik Hobbie (University of New Hampshire), J Kattge (Max Planck Institute for Biogeochemistry); Randy Kolka (USFS); M. Luke McCormack (Morton Arboretum, Chicago); Karis McFarlane (LLNL); Stephen Sebestyen (USFS); Isla Myers-Smith (University of Edinburgh); Victoria Sloan (University of Bristol); Hadyn Thomas (University of Edinburgh); Oscar Valverde-Barrantes (Florida International University); Peter van Bodegom (Leiden University, The Netherlands).

Graduate and Postdoctoral Advisors
M.S. Advisor: Scott D. Bridgham (University of Oregon, formerly University of Notre Dame)
Ph.D. co-Advisors: Richard J. Norby (Oak Ridge National Laboratory) and Aimée T. Classen (University of Vermont, formerly University of Tennessee, Knoxville)
Postdoctoral Advisor: Richard J. Norby

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Education and Training

2015	University of Wyoming, Applied Mathematics, Ph.D.
2007	GIK Institute, Pakistan, Computational Mathematics, M.S.
2005	Quaid-i-Azam University, Pakistan, Applied Mathematics, B.S.

Research and Professional Experience

2018-Present	Computational Scientist, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN
2015-2018	Postdoctoral Research Associate, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN
2010	Project Assistant, Institute for Structural Analysis, Graz Technical University, Austria.
2007-2010	Faculty Member, Faculty of Engineering Sciences, GIK Institute, Pakistan.

Selected Publications (5 Years)

Jan, A., E.T. Coon, J.D. Graham, and S.L. Painter. A subgrid approach for modeling microtopography effects on overland flow. Water Resources Research, 2018. Doi:10.1029/2017WR021898

Jan, A., E.T. Coon, S.L. Painter, R. Garimela, and D.J. Moulten. An Intermediate- scale model for the simulation of soil thermal hydrology in low-relief polygonal landscapes, Computational Geosciences 22 (1), 163-177. doi: 10.1007/s10596-017-9679-3

Akbarabadi, M., M. Borges, A. Jan, F. Pereira, and M. Piri. On the Validation of a Compositional Model for the Simulation of CO_2 Injection into Saline Aquifers. Transport in Porous Media, (2017) 1-32. doi: 10.1007/s11242-017-0872-6 [Authors are listed alphabetically]

Akbarabadi, M., M. Borges, A. Jan, F. Pereira, and M. Piri. A Bayesian framework for the validation of models for subsurface flows: synthetic experiments, Computational Geosciences Vol 19(2015), pp. 1231–1250. doi: 10.1007/s10596-015-9538-z [Authors are listed alphabetically]

Awards

Catherine Gibbs Shaw and Shanti Sehgal Award, University of Wyoming, USA (2014)
National Engineering and Scientific Commission (NESCOM) Excellence Award (2007)
Talent Farming Scheme Award: Higher Education Commission, Pakistan (2004)

Synergistic Activities

Worked on IDEAS project to help NGEE-Arctic project implement a computationally advantageous spatial structure for simulating permafrost dynamics
Manuscript reviews: Applied Mathematical Modelling

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Education and Training

2010	North Carolina State University, USA, Civil Engineering, PhD
2006	Indian Institute of Technology Kanpur, India, Technische Universität Darmstadt, Germany, Civil Engineering, MS
2004	Muzaffarpur Institute of Technology, India, Civil Engineering, BS

Research and Professional Experience

2012-Present	Research Staff Member. Oak Ridge National Laboratory, Environmental Sciences Division.
2014-Present	Joint Assistant Professor. University of Tennessee Knoxville, The Bredesen Center for Interdisciplinary Research.
2010-2012	Postdoctoral Research Associate. Oak Ridge National Laboratory, Computer Science and Mathematics Division.
2006-2010	Graduate Research Assistant. North Carolina State University, Department of Civil Engineering.
2005-2006	Visiting Research Fellow, Technische Universität Darmstadt, Germany, Civil Engineering
2004-2005	Graduate Research/Training Assistant, Indian Institute of Technology Kanpur, India

Selected Publications

Langford, Zachary L., Jitendra Kumar, and Forrest M. Hoffman. November 17, 2018. "Wildfire Mapping in Interior Alaska Using Deep Neural Networks on Imbalanced Datasets." Proceedings of the 2018 IEEE International Conference on Data Mining Workshops (ICDMW 2018). Institute of Electrical and Electronics Engineers (IEEE), Conference Publishing Services (CPS). doi:10.1109/ICDMW.2018.00116.

Langford, Zachary L., Jitendra Kumar, and Forrest M. Hoffman. November 18, 2017. "Convolutional Neural Network Approach for Mapping Arctic Vegetation using Multi-Sensor Remote Sensing Fusion." Proceedings of the 2017 IEEE International Conference on Data Mining Workshops (ICDMW 2017). Institute of Electrical and Electronics Engineers (IEEE), Conference Publishing Services (CPS). doi:10.1109/ICDMW.2017.48. Data doi:10.5440/1418854.

Langford, Zachary, Jitendra Kumar, Forrest M. Hoffman, Richard J. Norby, Stan D. Wullschleger, Victoria L. Sloan, and Colleen M. Iversen. September 6, 2016. "Mapping Arctic Plant Functional Type Distributions in the Barrow Environmental Observatory Using WorldView-2 and LiDAR Datasets." Remote Sens., 8(9):733. doi:10.3390/rs8090733.

Kumar, J., Forrest M. Hoffman, W. W. Hargrove, and N. Collier. August 23, 2016. "Understanding the Representativeness of FLUXNET for Upscaling Carbon Flux from Eddy Covariance Measurements." Earth Syst. Sci. Data Discuss., 1–25. doi:10.5194/essd-2016-36.

Bond-Lamberty, Ben, Daniel Epron, Jennifer Harden, Mark E. Harmon, Forrest M. Hoffman, Jitendra Kumar, Anthony David McGuire, and Rodrigo Vargas. June 27, 2016. "Estimating Heterotrophic Respiration at Large Scales: Challenges, Approaches, and Next Steps." Ecosphere, 7(6). doi:10.1002/ecs2.1380.

Tang, Guoping, Fengming Yuan, Gautum Bisht, Glenn E. Hammond, Peter C. Lichtner, Jitendra Kumar, Richard T. Mills, Xiaofeng Xu, Benjamin Andre, Forrest M. Hoffman, Scott L. Painter, and Peter E. Thornton. March 4, 2016. "Addressing Numerical Challenges in Introducing a Reactive

Transport Code into a Land Surface Model: A Biogeochemical Modeling Proof-of-concept with CLM–PFLOTRAN 1.0.” Geosci. Model Dev., 9(3):927–946. doi:10.5194/gmd-9-927-2016.

Kumar, J., Collier, N., Bisht, G., Mills, R. T., Thornton, P. E., Iversen, C. M., and Romanovsky, V. Modeling the spatiotemporal variability in subsurface thermal regimes across a low-relief polygonal tundra landscape. The Cryosphere, 10(5):2241--2274, 2016. doi:10.5194/essd-2016-36.

Kumar, Jitendra, Jon Weiner, William W. Hargrove, Steven P. Norman, Forrest M. Hoffman, and Doug Newcomb. November 17, 2015. “Characterization and Classification of Vegetation Canopy Structure and Distribution within the Great Smoky Mountains National Park using LiDAR.” In Peng Cui, Jennifer Dy, Charu Aggarwal, Zhi-Hua Zhou, Alexander Tuzhilin, Hui Xiong, and Xindong Wu, editors, Proceedings of the 15th IEEE International Conference on Data Mining Workshops (ICDMW 2015), pages 1478–1485. Institute of Electrical and Electronics Engineers (IEEE), Conference Publishing Services (CPS). doi:10.1109/ICDMW.2015.178.

Anderson-Teixeira, Kristina J., et. al. (2015) CTFS-ForestGEO: a worldwide network monitoring forests in an era of global change. *Global Change Biology* (in press). doi:10.1111/gcb.12712.

Warren, Jeffrey M., Paul J. Hanson, Colleen M. Iversen, Jitendra Kumar, Anthony P. Walker, and Stan D. Wullschleger. (2014) Root structural and functional dynamics in terrestrial biosphere models: evaluation and recommendations. *New Phytologist*, Vol. 205 (1):59-48. doi:10.1111/nph.13034.

Hoffman, Forrest M., Jitendra Kumar, Richard T. Mills, and William W. Hargrove. (2013) Representativeness-based sampling network design for the State of Alaska. *Landscape Ecology*, Vol. 28(8):1567-1586, doi:10.1007/s10980-013-9902-0.

Synergistic Activities

Associate Editor: Frontiers in Water, Water and Built Environment

Review Editor: Frontier in Big Data, Data Driven Climate Science

Co-convener: Session “Big Data in Geoscience”, AGU Fall Meeting 2012, 2013, 2014

Co-convener: Workshop “Data Mining in Earth System Science”, International Conference on Computational Science, 2012, 2013, 2014, 2015; IEEE International Conference on Data Mining, 2017, 2018

Reviewer for journals: New Phytologist, Water Resources Research, The Cryosphere, Environmental Management, Journal of Applied Meteorology and Climatology, Journal of Water and Climate Change, Journal of Computing in Civil Engineering, Journal of Geophysical Research, Remote Sensing, Sensors, International Journal of Geo-Information.

Awards

ForWarn Awards for creating first near real-time forest threat early warning system in the continental United States: 1) USDA Forest Service Chief's Honor Award 2014; 2) USDA Forest Service Southern Research Station Director's Partnership Award 2013; 3) NASA Group Achievement Award Federal Laboratory Consortium (FLC) Interagency Partnership Award 2013; 4) Federal Laboratory Consortium (FLC) Southeast Regional Interagency Partnership Award 2012; 5) USDA Forest Service Southern Research Station Directors Award for Science Delivery 2012

DAAD scholarship (Indo-German Academic Exchange Program) for pursuing Master's thesis research at , Technische Universität Darmstadt, Germany (2005-2006)

Graduate and Postdoctoral Advisors

G. Mahinthakumar, Ranji Ranjithan, E. D. Brill (North Carolina State University), Richard T. Mills (Oak Ridge National Laboratory)

Graduate and Undergraduate Advisees

Bharat Sharma (Northeastern University), Shashank Konduri (Northeastern University), Yuping Lu (UT Knoxville), Zachary Langford (UT Knoxville), Hannah Fry (Maryville College), Ankur Roy (UT Knoxville), Aaron Marshall (College of William and Mary)

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Education and Training

1990	University of Tennessee, Knoxville, Nuclear Engineering, PhD
1987	University of Tennessee, Knoxville, Nuclear Engineering, MS
1985	University of Tennessee, Knoxville, Nuclear Engineering, BS

Research and Professional Experience

2014–present	Climate Change Science Institute and Environmental Sciences Division, Oak Ridge National Laboratory
2010–2014	Subsurface Flow and Transport Team, Earth and Environmental Sciences Division, Los Alamos National Laboratory.
2008–2010	Institute Scientist. Geosciences and Engineering Division, Southwest Research Institute.
1998–2008	Various Positions, Geosciences and Engineering Division, Southwest Research Institute.
1993–1998	Senior Research Scientist, Division of Petroleum Resources, Commonwealth Scientific and Industrial Research Organization.
1991–1993	Postdoctoral Fellow, Research School of Physical Sciences, Australian National University.

Selected Publications

Painter, S. L., E. T. Coon, A. L. Atchley, M. Berndt, R. Garimella, J. D. Moulton, D. Svyatskiy, and C. J. Wilson (2016), Integrated surface/subsurface permafrost thermal hydrology: Model formulation and proof-of-concept simulations, Water Resour. Res., 52, 6062–6077, doi: 10.1002/2015WR018427.

Painter, S. L. (2018). Multiscale framework for modeling multicomponent reactive transport in stream corridors. Water Resources Research, 54. https://doi.org/10.1029/2018WR022831

Jan, A., Coon, E. T., Graham, J. D., & Painter, S. L. (2018). A subgrid approach for modeling microtopography effects on overland flow. Water Resources Research, 54, 6153–6167. https://doi.org/10.1029/2017WR021898

Jafarov, E.E., E.T. Coon, D.R. Harp, C.J. Wilson, S.L. Painter, A.L. Atchley and V.E. Romanofsky. 2018. Modeling the role of preferential snow accumulation in through talik development and hillslope groundwater flow in a transitional permafrost landscape. Environ. Res. Lett. 13 105006

Jan, A., Coon, E.T., Painter, S.L. et al. An intermediate-scale model for thermal hydrology in low-relief permafrost-affected landscapes (2018) Comput Geosci 22: 163. https://doi.org/10.1007/s10596-017-9679-3

Olsen, T.A., K. A. Muller, S. L. Painter, and S. C. Brooks. (2018) Kinetics of Methylmercury Production Revisited. Environmental Science & Technology 52 (4), 2063-2070, DOI: 10.1021/acs.est.7b05152

Sjöberg, Y., E. Coon, A. B. K. Sannel, R. Pannetier, D. Harp, A. Frampton, S. L. Painter, and S. W. Lyon. (2016), Thermal effects of groundwater flow through subarctic fens: A case study based on field observations and numerical modeling, Water Resour. Res., 52, 1591–1606, doi: 10.1002/2015WR017571.

Atchley, A. L., E. T. Coon, S. L. Painter, D. R. Harp, and C. J. Wilson (2016), Influences and interactions of inundation, peat, and snow on active layer thickness, Geophys. Res. Lett., 43, 5116–5123, doi: 10.1002/2016GL06855

Atchley, A. L., Painter, S. L., Harp, D. R., Coon, E. T., Wilson, C. J., Liljedahl, A. K., and Romanovsky, V. E. (2015). Using field observations to inform thermal hydrology models of permafrost dynamics with ATS (v0.83), Geosci. Model Dev. Discuss., 8, 3235-3292, doi:10.5194/gmdd-8-3235-2015.
Harp, D. R., Atchley, A. L., Painter, S. L., Coon, E. T., Wilson, C. J., Romanovsky, V. E., and Rowland, J. C.: Effect of soil property uncertainties on permafrost thaw projections: a calibration-constrained analysis, The Cryosphere, 10, 341-358, https://doi.org/10.5194/tc-10-341-2016, 2016.
Coon, E.T., D. Moulton and S.L. Painter, 2015. Managing complexity in land surface and near-surface simulations. Environmental Modeling & Software, 2016
SL Painter and S Karra. 2014. Constitutive model for unfrozen water content in subfreezing unsaturated soils. Vadose Zone Journal
S Karra, SL Painter and PC Lichtner. 2014. Three-phase model for subsurface hydrology in permafrost-affected regions. The Cryosphere.
JD Hyman, CW Gable, and SL Painter. 2014. Conforming Delaunay triangulation of stochastically generated three-dimensional discrete fracture networks: A feature rejection algorithm for meshing strategy. SIAM Journal on Scientific Computing.
SL Painter, JD Moulton, CJ Wilson. 2013. Modeling challenges for predicting hydrologic response to degrading permafrost Hydrogeology Journal, 1-4
A Frampton, SL Painter, G Destouni. 2013. Permafrost degradation and subsurface flow changes caused by surface warming trends. Hydrogeology Journal 21 (1), 271-280.
Painter, S. L. 2011. Three-phase simulations of moisture dynamics in freezing porous media: Model formulation and validation. *Computational Geosciences* 15(1).
Frampton, A., S. L. Painter, S. Lyon, and G. Destouni, 2011. Non-isothermal, three-phase simulations of near-surface flows in a model permafrost system under seasonal variability and climate change. *J. Hydrology* (in press).
Grimm, R., and S. L. Painter. 2009. On the secular evolution of groundwater on Mars. *Geophysical Research Letters*.
Painter, S., and V. Cvetkovic. 2006. Upscaling discrete fracture network simulations: An alternative to continuum transport models. *Water Resources Research*.
Jiang, Y., A. Woodbury, and S. Painter. 2004. Full-Bayesian inversion of the Edwards Aquifer. *Ground Water* 42(5), 724–733.
Painter, S., J. R. Winterle, and A. Armstrong. 2003. Using temperature to test models of flow near Yucca Mountain, Nevada. *Ground Water* 41(5), 657–666.
Painter, S. 1996. Evidence for nonGaussian Scaling Behavior in Heterogeneous Sedimentary Formations. *Water Resources Research* 32, 1183–1195.

Collaborators and Co-Editors
Vladimir Cvetkovic (Royal Institute of Technology, Stockholm), Georgia Destouni, Steve Lyon, Andrew Frampton, Ylva Sjoberg, A. B. K. Sannel (Stockholm University), Bob Grimm (Southwest Research Institute), Carl Gable, Ethan Coon, Cathy Wilson, David Moulton, Dylan Harp, Satish Karra, Peter Lichtner, Jeffrey Hyman, Nataliia Makendonska (LANL), Jan-Olof Selroos (Swedish Nuclear Fuel and Waste Management Company), Paolo Trinchero (AMPHOS-21), Anna Liljedahl, Vladimir Romanovsky (U. Alaska), Jake Graham (Idaho State),

Graduate and Postdoctoral Advisors
Graduate Advisor: Paul Stevens (University of Tennessee); James Lyon (Oak Ridge National Laboratory).
Postdoctoral Advisor: Lincoln Paterson (Commonwealth Scientific and Industrial Research Organization).

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Education and Training

2012	University of Wisconsin-Madison, Atmospheric and Oceanic Sciences, Ph.D.
2009	University of Wisconsin-Madison, Atmospheric and Oceanic Sciences, M.S.
2006	Oberlin College, Physics and Astronomy, B.A.

Research and Professional Experience

2018-Present	Associate Research and Development Scientist, Oak Ridge National Laboratory, Oak Ridge, TN
2018	Assistant Project Scientist, Sierra Nevada Research Institute, University of California, Merced
2015-2018	Associate Research Scholar, Program in Atmospheric and Oceanic Sciences, Princeton University; Biogeochemistry, Ecosystems, and Climate Group, Geophysical Fluid Dynamics Laboratory
2014-2015	Postdoctoral Research Associate, School of Public and Environmental Affairs and Department of Biology, Indiana University
2012-2013	Postdoctoral Research Associate, Princeton Environmental Institute, Princeton University

Selected Publications

B. N. Sulman, E. R. Brzostek, C. Medici, E. Shevliakova, D. N. L. Menge, and R. P. Phillips. Feedbacks between plant N demand and rhizosphere priming depend on type of mycorrhizal association. Ecology Letters, 20, 1043-1053, 2017. doi:10.1111/ele.12802

N. W. Chaney, M. Van Huijgevoort, E. Shevliakova, S. Malyshev, P. C. D. Milly, P. Gauthier, and B. N. Sulman. Harnessing big data to rethink land heterogeneity in earth system models. Accepted. Hydrology and Earth System Sciences. doi:10.5194/hess-2017-603

B. N. Sulman, A. C. Oishi, R. P. Phillips, E. Shevliakova, and S. Pacala. Microbe-driven turnover offsets mineral-mediated storage of soil carbon under elevated CO2. Nature Climate Change, 4, 1099-1102, 2014. doi:10.1038/nclimate2436

B. N. Sulman, A. R. Desai, N. M. Schroeder, D. Ricciuto, A. Barr, A. D. Richardson, L. B. Flanagan, et al. Impact of hydrological variations on modeling of peatland CO2 fluxes: results from the North American Carbon Program site synthesis. Journal of Geophysical Research, 117, G01031, 2012. doi:10.1029/2011JG001862

A. Salazar, B. N. Sulman, and J. S. Dukes. Microbial dormancy promotes microbial biomass and respiration across pulses of drying-wetting stress. Soil Biology and Biochemistry, 116, 237-244, 2018. doi:10.1016/j.soilbio.2017.10.017

L. M. Jacobs, B. N. Sulman, E. R. Brzostek, J. J. Feighery, and R. P. Phillips. Interactions during decomposition between root litter, leaf litter, and SOM affect soil C dynamics. Journal of Ecology, 106, 502-513, 2018. doi: 10.1111/1365-2745.12921

C. A. Pugh, D. E. Reed, A. R. Desai, and B. N. Sulman. Wetland flux controls: How does interacting water tables and temperature influence carbon dioxide and methane fluxes in northern Wisconsin? Biogeochemistry, 137, 15-25, 2018. doi: 10.1007/s10533-017-0414-x

V. Bailey, B. Bond-Lamberty, K. DeAngelis, A. S. Grandy, C. V. Hawkes, K. Heckman, K. Lajtha, R. P. Phillips, B. N. Sulman, K. E. O. Todd-Brown, and M. D. Wallenstein. Effective proxies for key soil processes and properties inform predictions of climate change. Global Change Biology, 24, 895-905, 2018. doi:10.1111/gcb.13926

W. R. Wieder, M. D. Hartman, B. N. Sulman, Y.-P. Wang, C. D. Koven, and G. B. Bonan. Carbon cycle confidence and uncertainty: exploring variation among soil biogeochemical models. Global Change Biology, 24, 1563-1579, 2018. doi:10.1111/gcb.13979
B. N. Sulman, D. T. Roman, K. Yi, L. Wang, R. P. Phillips, and K. A. Novick. High atmospheric demand for water can limit forest carbon uptake and transpiration as severely as dry soil. Geophysical Research Letters, 43, 9686-9695, 2016. doi:10.1002/2016GL069416
K. A. Novick, D. Ficklin, P. C. Stoy, C. A. Williams, G. Bohrer, A. C. Oishi, S. A. Papuga, P. D. Blanken, A. Noormets, B. N. Sulman, R. L. Scott, L. Wang, and R. P. Phillips. The increasing importance of atmospheric demand for ecosystem water and carbon fluxes. Nature Climate Change, 6, 1023-1027, 2016. doi:10.1038/nclimate3114
B. N. Sulman, D. T. Roman, T. M. Scanlon, L. Wang, and K. A. Novick. Comparing methods for partitioning a decade of carbon dioxide and water vapor fluxes in a temperate forest, Agricultural and Forest Meteorology, 226-227, 229–245, 2016. doi:10.1016/j.agrformet.2016.06.002
W. Wieder, S. Allison, E. Davidson, K. Georgiou, O. Hararuk, Y. He, F. Hopkins, Y. Luo, M Smith, B. N. Sulman, K. Todd-Brown, Y.-P. Wang, J. Xia, and X. Xu. Explicitly representing soil microbial processes in earth system models. Global Biogeochemical Cycles, 29, 1782-1800, 2015. doi:10.1002/2015GB005188
B. N. Sulman, A. R. Desai, and D. J. Mladenoff. Modeling soil and biomass carbon responses to declining water table in a wetland-rich landscape. Ecosystems, 16, 491-507, 2013. doi:10.1007/s10021-012-9624-1
R. F. Grant, A. R. Desai, and B. N. Sulman. Modelling contrasting responses of wetland productivity to changes in water table depth. Biogeosciences, 9, 4215-4231, 2012. doi:10.5194/bg-9-4215-2012

Awards

DOE GREF fellowship, Honorable Mention, 2009.
UW Atmospheric and Oceanic Sciences Department award for excellent performance in first year graduate studies, 2008.
John Frederick Oberlin Scholarship, Oberlin College, 2002-2006.

Synergistic Activities

Currently serving as a liaison between the E3SM and NGEE-Arctic projects, tasked with coordinating and integrating new model developments within ELM coming from the biogeochemistry and thermal-hydrology aspects of the NGEE-Arctic Phase 1 and 2 efforts.
American Geophysical Union Biogeosciences Section Executive Committee Early Career Representative, January 2018-present.
American Geophysical Union Biogeosciences Section Early Career Committee, 2017-present.
Manuscript reviews: *Nature Geoscience, New Phytologist, Biogeochemistry, EOS, PLoS ONE, Wetlands, Biogeosciences, JGR, Agricultural and Forest Meteorology, Soil Biology and Biochemistry, Global Change Biology*
Mentored two undergraduate students in an independent research project: "Measuring leaf and root decomposition and associated priming effects across a mycorrhizal gradient", February 2014 – June 2015.

Peter E. Thornton
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Education and Training

1998	The University of Montana, Missoula, MT, Terrestrial Biogeochemistry, PhD
1992	The John Hopkins University, Baltimore, Geography and Environmental Engineering, MD, MA
1990	The John Hopkins University, Baltimore, MD, Biomedical Engineering, BA

Research and Professional Experience

2017-Present	Deputy Director, Climate Change Science Institute, Oak Ridge National Laboratory
2012-Present	Group Leader, Terrestrial Systems Modeling Group, Environmental Sciences Division, Oak Ridge National Laboratory
2009-Present	Lead, Terrestrial Ecosystem and Carbon Cycle Science, Climate Change Science Institute (CCSI), Oak Ridge National Laboratory
2008-Present	Senior Research Scientist, Environmental Sciences Division, Oak Ridge National Laboratory
2001-2008	Scientist, Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO.
1999-2001	Research Associate, The University of Montana, School of Forestry, Numerical Terradynamic Simulation Group, Missoula, MT.

Selected Publications

Ricciuto, D., K. Sargsyan and P. Thornton 2018. The Impact of Parametric Uncertainties on Biogeochemistry in the E3SM Land Model. Journal of Advances in Modeling Earth Systems 10 DOI: 10.1002/2017MS000962.

Xu, X., J. P. Schimel, I. A. Janssens, X. Song, C. Song, G. Yu, R. L. Sinsabaugh, D. Tang, X. Zhang and P. E. Thornton 2017. Global pattern and controls of soil microbial metabolic quotient. Ecological Monographs 87(3): 429-441 DOI: doi:10.1002/ecm.1258.

Metcalfe, D. B., D. Ricciuto, S. Palmroth, C. Campbell, V. Hurry, J. Mao, S. G. Keel, S. Linder, X. Shi, T. Näsholm, K. E. A. Ohlsson, M. Blackburn, P. E. Thornton and R. Oren 2017. Informing climate models with rapid chamber measurements of forest carbon uptake. Global Change Biology 23(5): 2130-2139 DOI: 10.1111/gcb.13451.

Duarte, H. F., B. M. Raczka, D. M. Ricciuto, J. C. Lin, C. D. Koven, P. E. Thornton, D. R. Bowling, C. T. Lai, K. J. Bible and J. R. Ehleringer 2017. Evaluating the Community Land Model (CLM4.5) at a coniferous forest site in northwestern United States using flux and carbon-isotope measurements. Biogeosciences 14(18): 4315-4340 DOI: 10.5194/bg-14-4315-2017.

Yang, X., P. E. Thornton, D. M. Ricciuto and F. M. Hoffman 2016. Phosphorus feedbacks constraining tropical ecosystem responses to changes in atmospheric CO_2 and climate. Geophysical Research Letters 43(13): 7205-7214 DOI: 10.1002/2016GL069241.

Xu, X., F. Yuan, P. J. Hanson, S. D. Wullschleger, P. E. Thornton, W. J. Riley, X. Song, D. E. Graham, C. Song and H. Tian 2016. Reviews and syntheses: Four decades of modeling methane cycling in terrestrial ecosystems. Biogeosciences 13(12): 3735-3755 DOI: 10.5194/bg-13-3735-2016.

Tang, G., J. Zheng, X. Xu, Z. Yang, D. E. Graham, B. Gu, S. L. Painter and P. E. Thornton 2016. Biogeochemical modeling of CO_2 and CH_4 production in anoxic Arctic soil microcosms. Biogeosciences 13(17): 5021-5041 DOI: 10.5194/bg-13-5021-2016.

Tang, G., F. Yuan, G. Bisht, G. E. Hammond, P. C. Lichtner, J. Kumar, R. T. Mills, X. Xu, B. Andre, F. M. Hoffman, S. L. Painter and P. E. Thornton 2016. Addressing numerical challenges in introducing a reactive transport code into a land surface model: a biogeochemical modeling proof-of-concept with CLM–PFLOTRAN 1.0. Geosci. Model Dev. 9(3): 927-946 DOI: 10.5194/gmd-9-927-2016.

Raczka, B., H. F. Duarte, C. D. Koven, D. Ricciuto, P. E. Thornton, J. C. Lin and D. R. Bowling 2016. An observational constraint on stomatal function in forests: evaluating coupled carbon and water vapor exchange with carbon isotopes in the Community Land Model (CLM4.5). Biogeosciences 13(18): 5183-5204 DOI: 10.5194/bg-13-5183-2016.

Kumar, J., N. Collier, G. Bisht, R. T. Mills, P. E. Thornton, C. M. Iversen and V. Romanovsky 2016. Modeling the spatiotemporal variability in subsurface thermal regimes across a low-relief polygonal tundra landscape. The Cryosphere 10(5): 2241-2274 DOI: 10.5194/tc-10-2241-2016.

Xu, X., D. A. Elias, D. E. Graham, T. J. Phelps, S. L. Carroll, S. D. Wullschleger and P. E. Thornton 2015. A microbial functional group-based module for simulating methane production and consumption: Application to an incubated permafrost soil. Journal of Geophysical Research: Biogeosciences 120(7): 1315-1333 DOI: 10.1002/2015JG002935.

Thornton, P. E., Doney, S. C., Lindsay, K., Moore, J. K., Mahowald, N., Randerson, J. T., Fung, I., Lamarque, J. F., Feddema, J. J., and Lee, Y. H., (2009). "Carbon-Nitrogen Interactions Regulate Climate-Carbon Cycle Feedbacks: Results from an Atmosphere-Ocean General Circulation Model." Biogeosciences 6(10): 2099-2120.

Thornton, P.E., Lamarque, J.-F., Rosenbloom, N.A. and Mahowald, N.M., (2007). "Influence of Carbon-Nitrogen Cycle Coupling on Land Model Response to CO_2 Fertilization and Climate Variability." Global Biogeochemical Cycles 21(4): GB4018.

Synergistic Activities

Collaborator on a DOE-sponsored project to improve wetland biogeochemistry and vegetation modeling in a tidal marsh system undergoing warming x CO_2 manipulation.

Core participant for land and biogeochemistry model development and science campaigns in DOE Energy Exascale Earth System Modeling (E3SM) project.

Leads the modeling component of the Next Generation Ecosystem Experiment (NGEE) Arctic, developing coupled surface subsurface models for high-latitude permafrost systems.

Collaborators and Co-Authors

Xiaofeng Xu (San Diego State University), Dan Ricciuto (ORNL), Khachik Sargsyan (Sandia National Laboratory), Alessio Collalti (CMCC, Viterbo, Italy), Herique Duarte (University of Utah), Forrest Hoffman (ORNL), Gautam Bisht (Lawrence Berkeley National laboratory), David Bader (Lawrence Livermore National Laboratory)

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Education and Training

2014	University of Tennessee at Knoxville, Information Science, Interdisciplinary Graduate Minor in Computational Science, M.S.
1989	University of Tennessee at Knoxville, Biology-Ecology concentration, B.A.

Research and Professional Experience

2013 – Present	Scientific Data Curator. Next-Generation Ecosystem Experiments Arctic (NGEE Arctic), Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN
2012 –2013	Technical Information Specialist. U.S. Geological Survey Oak Ridge, TN
2006 – 2011	Biodiversity Informatics Specialist. National Biological Information Infrastructure, Southern Appalachian Information Node, U.S. Geological Survey, Oak Ridge, TN
2003 – 2005	Botanical Research Associate. NatureServe, Arlington, VA
1999 - 2003	Data Management Specialist. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, VA
1990 - 1999	Botanist. Tennessee Valley Authority (TVA), Regional Natural Heritage Project, Norris, TN

Posters, Presentations, and Participation in Current Position

Data Management Best Practices Part 1: Field Data Collection. Department of Energy (DOE), Oak Ridge National Laboratory, Climate Change Science Institute (CCSI) Educational Webinar: 2017. Presentation.

The NGEE Arctic Data Archive: Data Sharing, DOI Services, and Modeling Archive. DOE, Oak Ridge National Laboratory, Climate Change Science Institute (CCSI) Scientific Advisory Board Meeting: 2016. Poster.

NGEE Arctic Data Management. DOE, NGEE Arctic All-hands Meeting: 2014, 2015, 2016, 2017. Presentations, Posters, Training.

Sharing Data Early and Often for Collaboration: The NGEE Arctic Data Archive. DOE, Oak Ridge National Laboratory, Climate Change Science Institute (CCSI) Scientific Advisory Board Meeting: 2015. Poster.

The New Online Metadata Editor for Generating Structured Metadata. American Geophysical Union (AGU): 2014. Poster.

The NGEE Arctic Data Archive -- Portal for Archiving and Distributing Data and Documentation. DOE, Terrestrial Ecosystem Science (TER) and Subsurface Biogeochemical Research (SBR) programs Joint Principal Investigators Meeting: 2014. Presentation.

Member of DOE, Environmental System Science, Cyberinfrastructure Working Groups, 2016 – current.

Journal Publication

Randall, J.M., L.E. Morse, N. Benton, R. Hiebert, S. Lu and **T. Killeffer**. 2008.The Invasive Species Assessment Protocol: A Tool for Creating Regional and National Lists of Invasive Non-Native Plants that Negatively Impact Biodiversity. Weed Science Society of America, vol. 1, issue 1, January-March 2008. http://dx.doi.org/10.1614/IPSM-07-020.1

Other Publications

Killeffer, T. and K. Gravuer. 2011. Post-Border Weed Risk Assessment – The NatureServe Invasive Species Assessment Protocol. Invasive Plant Management Issues and Challenges in the United States - 2011 Overview. (Abstract). American Chemical Society. http://pubs.acs.org/doi/abs/10.1021/bk-2011-1073.ch003

Blockstein, D., M. Collins, J. Edwards, **T. Killeffer**, and D. Schindel. 2011. Creating a Ten-Year Global, Integrative, Multi-Dimensional Biodiversity Initiative. Results of a Workshop. Sponsored by the National Science Foundation, December 1-2, 2009.

Killeffer, T. 2009. Results of Pre-Workshop Questionnaire for Enabling Biodiversity Research: The Roles of Information and Support Networks. Report from the National Council for Science and the Environment.

Hetrick, S., **T. Killeffer**, and J. Hilten, editors. 2007. Biodiversity Data Interaction for an Alliance of All Taxa Biodiversity Inventories: A Workshop to Design Methods, Standards, and Practices for Data-Sharing at the National Level. Proceedings of a Workshop. 04-05 December 2006. Gatlinburg, Tennessee.

Synergistic Activities

Coordinated NGEE-Arctic Data Representatives across 5 institutions
Collaborated with DOE data archive, ESS-DIVE
Organized NGEE Arctic Town Hall session at AGU in 2015
Organized, conducted, and/or participated in field research with government agencies, universities, non-profit organizations, and volunteers
Presented at 30 conferences presentation/poster
Conducted outreach and training at professional conferences through exhibit tables
Attended over 40 professional conferences and training workshops
Developed training materials and conducted training in multiple professional roles
Held memberships and representation on 7 professional and scientific committees
Established and coordinated 2 ad-hoc recovery committees for federally listed plant species
Mentored and supervised 5 interns/staff

Graduate Advisor

Suzie Allard (University of Tennessee at Knoxville) https://www.sis.utk.edu/users/suzie-allard

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Education and Training

1998-2001	Research Associate, Environmental Sciences Department, Brookhaven National Laboratory
1994-1998	Ph.D. Biology, University of Essex, Colchester. Advisors, Christine Raines, Stephen P. Long
1991-1994	B.Sc. (Joint Honours) Biochemistry & Botany University College of North Wales, Bangor. Honours Project Advisor, John Farrar

Research and Professional Experience

2012-present	Member of the Program Faculty in the Department of Ecology & Evolution, Stony Brook University
2008-present	Continuing Scientist, Environmental & Climate Sciences Department, Brookhaven National Laboratory
2006-2008	Scientist, Environmental Sciences Department, Brookhaven National Laboratory
2005-present	Group Leader, Terrestrial Ecosystem Science & Technology, Environmental & Climate Sciences Department, Brookhaven National Laboratory
2003-2006	Associate Scientist, Environmental Sciences Department, Brookhaven National Laboratory
2004-2005	Deputy Division Head, Earth Systems Science Division
2003-2011	Adjunct Assistant/Associate Professor, Department of Crop Sciences, University of Illinois at Urbana Champaign
2001-2003	Assistant Scientist, Environmental Sciences Department, Brookhaven National Laboratory

Selected Publications (>50 Peer Reviewed Publications >4750 citations, h-index 30)

Smith NG, Keenan TF, Prentice IC, Wang H, Wright IJ, Niinemets U, Crous KY, Domingues TF, Guerrieri R, Ishida FY, Kattge J, Kruger EL, Maire V, Rogers A, Serbin SP, Tarvainen L, Togashi HF, Townsend PA,Wang M, Weerasinghe LK, Zhou SX (2018) Global photosynthetic capacity is optimized to the environment. Ecology Letters. In Press.

Lombardozzi D, Smith NG, Cheng SJ, Dukes JS, Sharkey TD, Rogers A, Fisher R, Bonan GB (2018) Triose phosphate limitation in photosynthesis models reduces leaf photosynthesis and global terrestrial carbon storage. Environmental Research Letters. 13, 074025.

Walker AP, Ye M, Lu D, De Kauwe MG, Gu L, Medlyn BE, Rogers A, Serbin SP (2018) The Multi-Assumption Architecture and Testbed (MAAT v1.0): R code for ensembles with dynamic model structure and analysis of epistemic uncertainty from multiple sources. Geoscientific Model Development. 11, 3159-3185.

Rogers A, Serbin SP, Ely KS, Sloan VL, Wullschleger SD (2017) Terrestrial biosphere models underestimate photosynthetic capacity and CO_2 assimilation in the Arctic. New Phytologist. 216, 1090-1103.

Rogers A, Medlyn BE, Dukes JS, Bonan G, von Caemmerer S, Dietze MC, Kattge J, Leakey ADB, Mercado LM, Niinemets Ü, Prentice IC, Serbin SP, Sitch S, Way DA, Zaehle S (2017) A roadmap for improving representation of photosynthesis in Earth System Models. New Phytologist. 213, 22-42.

Lewin KF, McMahon A, Ely KS, Serbin SP, Rogers A (2017) A zero power warming chamber for investigating plant responses to rising temperature. Biogeosciences. 14, 4071-4083.

Wu J, Serbin SP, Xu X, Albert LP, Chen M, Meng R, Saleska SR, Rogers A (2017) the phenology of leaf quality and its within-canopy variation are essential for accurate modeling of photosynthesis in tropical evergreen forests. Global Change Biology. 23, 4814-4827.

Lin et al (2015) Optimal stomatal behavior around the world: synthesis of a global stomatal conductance database. Nature Climate Change 5, 459-464.

Ali AA, Xu C, Rogers A, McDowell NG, Medlyn BE, Fisher R, Wullschleger SD, Reich PR, Vrugt JA, Bauerle WL, Santiago LS, Wilson CJ (2015) Global scale environmental control of plant photosynthetic capacity. Ecological Applications 25, 2349-2365.

Rogers A (2014) The use and misuse of $V_{c,max}$ in Earth System Models. Photosynthesis Research 119, 15-29.

Collaborators and Co-Editors (last 48 months)

Members of the NGEE-Arctic (www.ngee-arctic.ornl.gov) and NGEE-Tropics (http://esd.lbl.gov/research/projects/ngee_tropics) projects. Ainsworth E (USDA-ARS), Bonan G (NCAR), Dietze MC (BU), Dukes JS (Purdue), Gillespie K (Monsanto), Gray S (UIUC), Kattge J (MPI), Kubien D (UNB), Leakey ADB (UIUC), Medlyn BE (Macquarie), Mercado L (Exeter), Niinemets Ü (Estonian University of Life Sciences), Newman L (ESF), Prentice IC (Imperial), Puthuval K (UIUC), Sitch S (Exeter), Strellner R (UIUC), van der Lelie D (RTI International), von Caemerer S (ANU), Way DA (UWO), Zaehle S (MPI), Colin P. Osborne (University of Sheffield), Mark Rees (University of Sheffield), De Kauwe M (Macquarie University).

Graduate and Postdoctoral Advisors &andAdvisees

Christine Raines (University of Essex, UK), Stephen P. Long (UIUC), Elizabeth Ainsworth (USDA-ARS), Kelly Gillespie (Monsanto), Dhiraj Naik (Indian Institute of Advanced Research), Angela Burnett (University of Sheffield, UK).

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Education and Training

2009-2012	B.S. in Biology with Minor in Chemistry, University of New Mexico

Research and Professional Experience

2018-Present	Environmental Science Associate, Brookhaven National Laboratory
2013-2017	Field Research Assistant, Department of Biology, University of New Mexico
2012	Research Assistant, Department of Chemistry, University of New Mexico
2003-2005	Antitank-Assaultman/Automatic Rifleman, United States Marine Corps

Interests
- Plant physiology
- Circuit design & troubleshooting
- Maintenance of scientific equipment
- Building custom scientific equipment

Experience
- Extensive use and maintenance of LI-6400, LI-6800, LI-840, LI-820, TGA-100/200 on-line gas exchange systems
- Experience with light microscopy, spectrophotometer, sterile techniques, titration, pigment assay, enzyme assay
- Regular use of R, Arduino, FreeCAD, KiCAD, PowerPoint, Word, Excel
- Experience using Python, SAS, NI LabVIEW, LTspice, C, C++, BASH
- Use of oscilloscopes, multi-meters, power supplies, basic signal generators, logic analyzers, data acquisition units, soldering tools, hot air rework
- PCB and circuit design
- Analog and digital sensor integration, including analog signal conditioning and filters, data acquisition systems such as NI hardware, Campbell Scientific data loggers and custom analog to digital systems
- Use of hand and power tools

Selected Publications

Stutz SS, Anderson JA, Zulick R, Hanson DT (2017) Inside out: Efflux of carbon Dioxide from leaves represents more than leaf metabolism. *Journal of Experimental Botany* 68: 2849-2857, DOI: 10.1093/jxb/erx155

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Education and Training

2005–2009	*Ph.D.* The University of Melbourne, Australia Thesis: Geochronology of Timor-Leste and seismo-tectonics of the southern Banda Arc
1993–1996	*Bachelor of Science (Honours),* The University of Melbourne, Australia

Research and Professional Experience

2015–present	*Environmental Science Associate* Environmental and Climate Sciences Department, Brookhaven National Laboratory
2014–2015	*Research collaborator* Biological, Environmental and Climate Sciences Department, Brookhaven National Laboratory
2005–2010	*Demonstrator/instructor* School of Earth Sciences, The University of Melbourne
2002–2005	*Geologist* Division of Exploration & Mining, CSIRO (Commonwealth Science and Industrial Research Organisation, Australia)
2001–2002	*Project Scientist* Division of Exploration & Mining, CSIRO
1997–2001	*Exploration Geologist* Normandy Yandal Operations Limited (formerly Great Central Mines Limited)

Selected Publications

Rogers A, Serbin SP, Ely KS, Sloan VL & Wullschleger SD (2017) Terrestrial biosphere models underestimate photosynthetic capacity and CO_2 assimilation in the Arctic. *New Phytologist*. 216, 1090-1103, DOI:10.1111/nph.14740

Lewin KF, McMahon A, Ely KS, Serbin SP & Rogers A (2017) A zero power warming chamber for investigating plant responses to rising temperature. *Biogeosciences*. 14, 4071-4083, DOI: 10.5194/bg-14-4071-2017

Submitted and In Review

Ely KS, Burnett AC, Lieberman-Cribbin W, Serbin SP, Rogers A, (submitted). Spectroscopy can predict key leaf traits associated with source–sink balance and carbon–nitrogen status. Journal Experimental Botany.

Dickman LT, McDowell N, Grossiord C, Collins AD, Wolfe B, Detto M, Wright JS, Goodsman D, Rogers A, Serbin SP, Wu J, Ely, KS, Michaletz S, Xu C, Kueppers L Chambers JQ (in review). Homeostatic maintenance of non-structural carbohydrates during the 2015-2016 El Niño drought across a tropical forest precipitation gradient. Plant, Cell and Environment.

Serbin SP, Wu J, Ely KS, Kruger EL, Townsend PA, Meng R, Wolfe BT, Chlus A, Wang Z, Rogers A (submitted). From the Arctic to the tropics: Capturing the global variation in leaf mass per area with leaf optical properties. New Phytologist.

Wu J, Rogers A, Albert, Ely KS, Prohaska N, Wolfe B, Oliviera R, Saleska S, Serbin S (submitted). Leaf reflectance spectroscopy captures variation in carboxylation capacity across species, growth environment and leaf age in tropical forests. New Phytologist.

Wu J, Serbin S, Ely K, Wolfe B, Dickman L, Grossiord C, Michaletz S, Collins A, Detto M, McDowell N, Wright SJ, Rogers A (in revision). Stomatal conductance response to seasonal drought across two contrasting tropical forests.

Ely, KS, Sandiford, M, Phillips, D, Boger, SD, 2014. Detrital zircon U-Pb and 40Ar/39Ar hornblende ages from the Aileu Complex, Timor-Leste: provenance and metamorphic cooling history. Journal of the Geological Society London, 171, 299-309, DOI:10.1144/jgs2012-065.

Ely, KS, Sandiford, M, Hawke, ML, Phillips, D, Quigley, M & dos Reis, JE (2011). Evolution of Ataúro island: temporal constraints on subduction processes in the Banda Arc. Journal of Asian Earth Sciences 41, 477-493, DOI:10.1016/j.jseaes.2011.01.019.

Ely, KS & Sandiford, M (2010). Seismic response to slab rupture and variation in lithospheric structure beneath the Savu Sea, Indonesia. Tectonophysics 438 (1-2), 112-124, DOI:10.1016/j.tecto.2009.08.027.

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Education and Training

1974	B.Sc. Cornell University, College of Agriculture and Life Sciences, Ithaca, NY

Research and Professional Experience

2003-present	Principal Engineer, Brookhaven National Laboratory
1995-2003	Research Engineer I, Brookhaven National Laboratory
1986-1995	Environmental Sciences Associate I, Brookhaven National Laboratory
1983-1986	Biology Research Associate II, Brookhaven National Laboratory
1979-1983	Biology Research Associate III, Brookhaven National Laboratory
1975-1979	Biology Research Associate IV, Brookhaven National Laboratory
1974-1975	Foreman, Lewin Farms, Calverton, NY

Research Interests

Effects of climate change and environmental pollutants on natural and managed terrestrial ecosystems. Design, construction and management of experiments examining the effects of pollutants, elevated atmospheric CO_2, warming and drought using chamber, greenhouse and field scale techniques in temperate, tropical and arctic environments.

Current Projects

- Development of zero-power warming enclosure.
- Operations management for greenhouse, growth chamber and field experiments for BNL Biology Department.
- Science Steering Committee member for Amazon FACE project, Manaus, Brazil

Relevant Expertise

- Design and deployment of instrumented trams for near surface, remotely sensed measurements for NGEE Arctic.
- Design, operations and management consultant to the EucFACE Experiment, University of Western Sydney, Richmond, New South Wales, Australia, BIFoR FACE facility, University of Birmingham, UK and Amazon FACE, Manaus, Brazil.
- Principle Investigator, site engineer, and operations manager for the BNL/Duke University Forest - Atmosphere Carbon Transfer and Storage (FACTS-1) FACE research facility located in the Duke University Forest in Chapel Hill, NC.
- Lead design engineer for FACE experiments constructed in Eschikon, Switzerland, Braunschweig, Germany, Rhinelander, WI, and Bethel, MN.
- Site manager in charge of engineering, construction and facility operations for the BNL Free-Air Carbon Dioxide Exposure (FACE) experiments established at Yazoo City, MS, Maricopa, AZ and Sardinilla, Panama .

- Responsible for the design and supervision of construction of the Brookhaven National Laboratory Rainfall Exclusion Shelters (BNL RES) and associated rainfall treatment delivery systems located at BNL and at the University of Illinois at Champaign-Urbana.

Other Interests

1978-present	Charter Member, Ex-Chief and Past President of Riverhead Volunteer Ambulance Corps, Inc. Current position: Director.
1978-present	Emergency Medical Technician, State of New York Department of Health, Certificate Number 051283.

Patents

Lewin, K. F. Multi-port valve. U. S. Patent # 5,620,025. Issued April 15, 1997.

Selected Publications (From 57 peer reviewed journal articles and book chapters)

Lewin, K. F., et.al., 2017, A zero-power warming chamber for investigating plant responses to rising temperature. Biogeosciences, 14, 4071–4083. DOI: 10.5194/bg-14-4071-2017.

Talhelm, A.F., et.al., 2014, Elevated carbon dioxide and ozone alter productivity and ecosystem carbon content in northern temperate forests. Global Change Biology. 20, 2492-2504. DOI: 10.1111/gcb.12564.

Kimball, B. A., Conley, M. M. & Lewin, K. F., 2012, Performance and energy costs associated with scaling infrared heater arrays for warming field plots from 1 to 100 m. Theoretical and Applied Climatology. 108:247–265, DOI 10.1007/s00704-011-0518-5

Calfapietra, C., et al., 2010, Challenges in elevated CO_2 experiments on forests. Trends in Plant Science 15, 1, pp 5–10, DOI: 10.1016/j.tplants.2009.11.001

Lewin,K. F., Nagy, J., Nettles, W. R., Cooley, D. M., and Rogers A., 2009, Comparison of gas use efficiency and treatment uniformity in a forest ecosystem exposed to elevated [CO_2] using pure and pre-diluted Free Air CO_2 Enrichment technology. *Global Change Biology* 15: 388–395, DOI: 10.1111/j.1365-2486.2008.01748.x

Ainsworth E.A., et al., 2008, Next generation of elevated [CO_2] experiments with crops: A critical investment for feeding the future world. *Plant, Cell & Environment* 31, 1317-1324

Dickson, R.E., et.al., 2000. Forest atmosphere carbon transfer storage-II (FACTS II) - The aspen free-air CO_2 and O^3 enrichment (FACE) project in an overview. USDA Forest Service North Central Research Station. General Tech. Rep. NC-214. 68 pp.

Hendrey GR, Ellsworth D, Lewin K, Nagy J. (1999) A Free-air CO_2 Enrichment (FACE) system for exposing tall forest vegetation to elevated atmospheric CO_2. *Global Change Biology* 5 (3): 293-309

Lewin KF, Hendrey GR, Nagy J, LaMorte R. (1994) Design and application of free-air carbon dioxide enrichment facility. *Agricultural and Forest Meteorology.* 70, 15-29

Lewin, K. F., Hendrey, G. R., and Kolber, Z. (1992) Brookhaven National Laboratory free-air carbon dioxide enrichment facility. *Critical Reviews in Plant Science* 11(2,3) 135-141

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Education and Training

2013	M.S. in Electrical Engineering Completed
2010	B.S. in Electrical Engineering with Minors in Mathematics and Music Completed, Manhattan College, Riverdale, NY
2007 –2010	Undergraduate coursework towards B.S. in Electrical Engineering
2006 –2007	Undergraduate coursework in Engineering

Research and Professional Experience

2015 - Present	Staff Electrical Engineer, Brookhaven National Laboratory
2011 - 2015	Associate Staff Electrical Engineer, Brookhaven National Laboratory

Interests

- Circuit design & troubleshooting, data interfaces, audio systems, real-time signal processing, sensor systems
- Software/hardware integration
- Computer & embedded systems programming

Experience

- Regular use of NI Labview, Eclipse, MATLAB, Arduino, MS Visual Studio, PowerPoint, Word, Excel, Microchip MPLAB, Diptrace Schematic & PCB Layout
- Experience using FreeCAD, AutoCAD, Maple, Mathcad, PSPICE, Solidworks, Pro Tools, CorelDRAW Graphics Suite
- Use of basic electronics equipment (oscilloscopes, multi-meters, power supplies, basic signal generators, logic analyzers, spectrum analyzers, data acquisition units, soldering tools)
- Use of basic shop machining equipment & measurement tools (hand tools, drill press, scroll/band/table saws, lathe, mill, CNC equipment, micrometers, calipers)
- Programming in BASIC (Q, P, Visual, VBA), C, C++, HTML, Python, Qt framework, SQL, some Java and PHP
- Work with 8051, ARM, AVR, PIC and Basic Stamp controllers
- PCB and circuit design
- Analog and digital sensor integration, including analog signal conditioning and filters, data acquisition systems such as NI hardware, Campbell Scientific data loggers and custom analog to digital systems.
- Control systems design including PID feedback, PWM control, analog/digital & digital/analog interfaces, signal conditioning, timed sequencing
- TCP/IP Networking
- 3D part design and printing
- Basic optical systems
- Basic pneumatic systems construction, control and regulation
- Basic image processing in MATLAB and OpenCV
- Certified FAA UAS Remote Pilot

Selected Publications

Wang, J., Pikridas, M., Pinterich, T., Spielman, S., Tsang, T., McMahon, A., Smith, S. A Fast (2017) Integrated Mobility Spectrometer for rapid measurement of sub-micrometer aerosol size distribution, Part II: Experimental characterization. Journal of Aerosol Science 113. DOI 10.1016/j.jaerosci.2017.05.001.

Lewin, K. F., McMahon, A., Ely K. S., Serbin, S. P., Rogers, A. (2017). A zero power warming chamber for investigating plant responses to rising temperature. Biogeosciences 14(18):4071-4083. DOI 10.5194/bg-14-4071-2017.

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Education and Training

2008-2012	Ph.D. Forest Ecology, University of Wisconsin – Madison
2004-2008	M.S. Forest Ecology & Environ. Monitoring (dual M.S), U. of Wisconsin – Madison
1991-2004	B.A. Telecommunications & GIS Michigan State University, East Lansing, Michigan

Research and Professional Experience

2016-Present	Associate Ecologist, Environmental & Climate Sciences Department, Brookhaven National Laboratory
2015-Present	Member of the Program Faculty in the Department of Ecology & Evolution, Stony Brook University
2014-2016	Assistant Ecologist, Environmental & Climate Sciences Department, Brookhaven National Laboratory
2014-Present	Affiliate Faculty, Department of Sustainability Studies, Stony Brook University
2014-Present	Honorary Associate Fellow, Department of Forest and Wildlife Ecology, University of Wisconsin – Madison
2012-2014	Postdoctoral Research Associate, Department of Forest and Wildlife Ecology, University of Wisconsin – Madison
2011-2013	Postdoctoral Research Associate, Department of Plant Biology, University of Illinois at Urbana-Champaign.

Selected Publications (>40 Peer Reviewed Publications, >750 citations, ISI h-index 17)

Meng R, Wu J, Zhao F, Cook BD, Hanavan RP, Serbin SP (2018). Measuring short-term post-fire forest recovery across a burn severity gradient in a mixed pine-oak forest using multi-sensor remote sensing techniques. Remote Sensing of Environment. 210, 282-296

Fisher RA, Koven CD, Anderegg WRL, Christoffersen BO, Dietze MD, Farrior C, Holm JA, Hurtt G, Knox RG, Lawrence PJ, Longo M, Matheny AM, Medvigy D, Muller-Landau HC, Powel TL, Serbin SP, Sato H, Shuman J, Smith B, Trugman AT, Viskari T, Verbeeck H, Weng E, Xu C, Xu X, Zhang T, Moorcroft P (2018). Vegetation Demographics in Earth System Models: a review of progress and priorities. Global Change Biology. 24, 35-54

Rogers A, Serbin SP, Ely KS, Sloan VL, Wullschleger SD (2017). Terrestrial biosphere models underestimate photosynthetic capacity and CO_2 assimilation in the Arctic.New Phytologist.216, 1090-1103

Wu J, Serbin SP, Xu X, Albert LP, Chen M, Meng R, Saleska SR, Rogers A (2017). The phenology of leaf quality and its within-canopy variation are essential for accurate modeling of photosynthesis in tropical evergreen forests. Global Change Biology. 23, 4814-4827

Rogers A, Medlyn BE, Dukes JS, Bonan G, von Caemmerer S, Dietze MC, Kattge J, Leakey ADB, Mercado LM, Niinemets Ü, Prentice IC, Serbin SP, Sitch S, Way DA, Zaehle S (2017) A Roadmap for Improving Representation of Photosynthesis in Earth System Models. New Phytologist 213, 22-42

Shiklomanov, A.N., Dietze, M.C., Viskari, T., Townsend, P.A., & Serbin, S.P. (2016). Quantifying the influences of spectral resolution on uncertainty in leaf trait estimates through a Bayesian approach to RTM inversion. Remote Sensing of Environment, 183, 226-238.

Serbin SP, Singh A, Desai AR, Dubois SG, Jablonski AD, Kingdon CC, Kruger EL, Townsend PA (2015). Remotely estimating photosynthetic capacity, and its response to temperature, in vegetation canopies using imaging spectroscopy. Remote Sensing of Environment 167, 78-87

Singh, A., Serbin, S.P., McNeil, B.E., Kingdon, C.C., Townsend, P.A. (2015). Imaging spectroscopy algorithms for mapping canopy foliar chemical and morphological traits and their uncertainties. Ecological Applications 25, 2180-2197

Serbin SP, Singh A, McNeil BE, Kingdon CC, Townsend PA (2014). Spectroscopic determination of leaf morphological and biochemical traits for northern temperate and boreal tree species. Ecological Applications. 24(7), 1651-1669

Dietze MC, Serbin SP, Davidson C et al. (2014). A quantitative assessment of a terrestrial biosphere model's data needs across North American biomes. Journal of Geophysical Research-Biogeosciences, 119, 286-300.

Collaborators and Co-Editors (last 48 months)

Members of the DOE NGEE-Arctic (www.ngee-arctic.ornl.gov) and NGEE-Tropics (http://esd.lbl.gov/research/projects/ngee_tropics) projects, Ainsworth E (USDA-ARS), Baines S (SBU), Bonan G (NCAR), Bradley B (Umass Amherst), Cavender-Bares J (U of Minnesota), Chen J (MSU), Cook B (NASA GSFC), Couture J (UW-Madison), Dahlin K (MSU), De Kauwe M (Macquarie University), Dennison, P (U of Utah), Desai, A (UW-Madison), Dietze M (Boston University), Dukes JS (Purdue), Duncanson, L (NASA GSFC), Fassnacht, F (KIT), Fisher, J (NASA JPL), Fox A (NCAR, U Arizona), Gough C (UVA), Hoffman F (ORNL), Kattge J (MPI), Keller, M (USFS), Koven C (LBNL), Kruger E (UW-Madison), Kubien D (UNB), Lawrence D (NCAR), Leakey ADB (UIUC), LeBauer D (UIUC), Lynch H (SBU), Medlyn BE (Macquarie), Mercado L (Exeter), Middleton E (NASA GSFC), Morton D (NASA GSFC), Niinemets Ü (Estonian University of Life Sciences), Pavlick, R (NASA JPL), Prentice IC (Imperial), Saleska S (U of Arizona), Schimel, D (NASA JPL), Schweiger, A (U of Minnesota), Shiklomanov A (PNNL), Smith N (Texas Tech), Smith W (U of Arizona), Stavros, N (NASA JPL), Townsend P (UW-Madison), Ustin, S (UC Davis), Way DA (UWO), Wennberg, P (Cal Tech), Yang X (UVA)

Graduate and Postdoctoral Advisors and Advisees

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Susan S. Hubbard
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Education and Training

1998	University of California at Berkley, Civil and Environmental Engineering, PhD
1992	Virginia Technological University, Geophysics, MS
1990	University of California at Santa Barbara, Geology, BS

Research and Professional Experience

2015-present	Associate Laboratory Director, Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory
2015-present	Adjunct Professor, Environmental Science, Policy and Management, UC Berkeley
2013- 2015	Division Director, Earth Sciences Division, Lawrence Berkeley National Laboratory
2010–2013	Deputy Director, Earth Sciences Division, Lawrence Berkeley National Laboratory.
1998–2002	Scientist, Lawrence Berkeley National Laboratory.
1990–1993	Geophysicist, ARCO Oil and Gas Co.
1985–1987	Geologist, U.S. Geological Survey, Menlo Park, CA.

Selected Publications (full list at http://esd.lbl.gov/about/staff/susanhubbard/publications.html)

Wu, Y. et al. (2018), Depth-Resolved Physicochemical Characteristics of Active Layer and Permafrost Soils in an Arctic Polygonal Tundra Region: Journal of Geophysical Research: Biogeosciences, v. 123, p. 1366–1386, doi: 10.1002/2018jg004413.

Taş, N. et al. 2018, Landscape topography structures the soil microbiome in arctic polygonal tundra: Nature Communications, v. 9, doi: 10.1038/s41467-018-03089-z.

Tran, A.P. et al (2018), Spatial and temporal variations of thaw layer thickness and its controlling factors identified using time-lapse electrical resistivity tomography and hydro-thermal modeling: Journal of Hydrology, v. 561, p. 751–763, doi: 10.1016/j.jhydrol.2018.04.028.

Wu, Y. et al. (2017), Electrical and seismic response of saline permafrost soil during freeze – Thaw transition: Journal of Applied Geophysics, v. 146, p. 16–26, doi: 10.1016/j.jappgeo.2017.08.008.

Dafflon, B. et al (2017), Coincident above- and below-ground autonomous monitoring to quantify co-variability in permafrost, soil and vegetation properties in Arctic Tundra, *Journal of Geophysical Research: Biogeosciences,* doi: 10.1002/2016jg003724

Tran, A.P. et al. (2017) Coupled land surface–subsurface hydrogeophysical inverse modeling to estimate soil organic carbon content and explore associated hydrological and thermal dynamics in the Arctic tundra: The Cryosphere, v. 11, p. 2089–2109, doi: 10.5194/tc-11-2089-2017

Wainwright, H.M. et al. (2016), Mapping snow depth within a tundra ecosystem using multiscale observations and Bayesian methods, *The Cryosphere Discussions*, p. 1–56, doi: 10.5194/tc-2016-168

Dafflon, B. et al (2016), Geophysical estimation of shallow permafrost distribution and properties in an ice-wedge polygon-dominated Arctic tundra region, *Geophysics*, 81(1), WA247–WA263, doi:10.1190/geo2015-0175.1.

Gangodagamage, C. et al (2014), Extrapolating active layer thickness measurements across Arctic polygonal terrain using LiDAR and NDVI data sets, *Water Resources Research*, 1944-7973, doi:10.1002/2013WR014283.

Dafflon, B. et al. (2013), Electrical Conductivity Imaging of Active Layer and Permafrost in an Arctic Ecosystem, through Advanced Inversion of Electromagnetic Induction Data, *Vadose Zone Journal,* v. 12, doi: 10.2136/vzj2012.0161.

Invited, Keynote and Plenary Speaking Engagements. Over 150 invited engagements. Select invited examples include: AGU (2018, 2017, 2016, 2015, 2013, 2010, 2009, 2007, 2006, 2005,2002, 2001); EGU (2015, 2012); GSA (2006, 2010); US Energy Association (2014); CMWR Barcelona (2010); Gordon Conference, Flow in Porous Media (2008)

Awards and Recognitions (partial list):2017, Fellow, American Geophysical Union (AGU); 2018, Honorary Prof, Beijing Normal University 2016, Hal Mooney Award, Distinguished Achievements in Near Surface Geophysics, Society of Exploration Geophysicists (SEG); 2014, Distinguished Alumni, Civil and Environmental Engineering Academy, UC Berkeley; 2014, Soc. for Technical Communication, Distinguished technical communication award; 2013, Outstanding Women @ Berkeley Lab recognition; 2011, Fellow, Geological Society of America (GSA); 2010, Birdsall-Dreiss Distinguished Lecturer, Hydrological Sciences GSA ; 2009, Frank Frischknecht Leadership Award, SEG Near Surface Geophysical Society; 2009, Top Associate Editor Award, Journal of Hydrology; 2008, 'Most Influential Article', SEG TLE

Synergistic Activities and Service to Community (partial list):
Select Advisory Boards: ***Current***: DOE-BER Cyberinfrastructure ESS-Dive, 2017-; International Soil Modeling Consortium, 2017-; EPA UCB Superfund Program 'Exposome', 2016-; NSF Arctic Data Center, 2016-; UC Water Director's Council, 2016-; UCB Civil and Environmental Engineering Dept, 2016-; EPA Superfund Program UCB Project Advisory Board, 2016-; CCST (California Council on Science and Technology) Council; 2015-; Interoperable Design of Extreme-Scale Application Software (IDEAS) Advisory Board, 2015-; Radionuclide Waste Disposal, EPSCoR Program, Clemson Advisory Board. ***Recent Past:*** DOE Biological and Environmental Research Advisory Committee (BERAC), 2010-2015; DOE Advanced Simulation Capability for Environmental Management (ASCEM) Sr. Advisor; Helmholtz Terrestrial Programme Review Committee 2013; Stanford Energy Resources Engineering Department Review Committee 2012; SmartGeo NSF IGERT, Colorado School of Mines Advisory Board 2010; DOE Environmental Management Technical Advisory Committee 2010.

Editorial Boards*:* AE JGR-Biosciences (2010-2015); Co-Editor Vadose Zone Journal (2007-2013), AE Journal of Hydrology (2007-2010); AE Water Res. Research (2001-2005)

Collaborators, Co-Authors, Co-Editors
Arora, Ajo-Franklin, Brodie, Steefel, Leger, Williams, Dou, Dafflon, Falco, Wainwright, Faybishinko, Tokunaga, Tran, Newcomer, Nico, Peruzzo, Otkim, Tas,Ulrich, Uhlamen, Wan (LBNL); Anantharaman, Banfield, Brown, Rubin (UCB), Schmutz (University of Bordeaux), Bales (UC Merced), Boaga (Università degli Studi di Padova),, Bückner (Vienna University of Technology), Cano Pecharroman (Columbia), Cantor (Portland State University), Cassiani (Università degli Studi di Padova), Castelle (UCB), Curtis (Univeristy of Colorado), Doetsch (ETH), Ficklin (Indiana), Fleckenstein (Helmholtz), Flipo (PSL), Franceschi (University of Bordeaux), Jansson (PNNL), Kennedy (National University of Ireland), Kiparsky (UCB), Liljedahl (University of Alaska), Marchesini (LBNL), Mary (Università degli Studi di Padova), McCready (CA Dept. Water Research), Molz (Clemson), Orozco (Vienne University of Technology), Pachepsky (USDA-ARS), Probst (UCB), Romanovsky (University of Alaska), Rowland (LANL), Rubin (UCB), Schmidt (Helmholtz), Schmutz (University of Bordeaux), Shiel (Oregon State University), Steltzer (Fort Lewis College), Thullner (Helmholtz), Wilkins (Ohio State University).

Graduate and Postdoctoral Advisors
Graduate Advisor: Cahit Coruh (Geophysics, MS) and Yoram Rubin (Hydrology, PhD).

Bhavna Arora
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Education and Training

2012	Texas A&M University, Water Management & Hydrologic Sciences, Ph.D.
2006	IIT Kharagpur, Water Resources Development & Management, M.Tech.
2006	IIT Kharagpur, Agriculture & Food Engineering, B.Tech.

Research and Professional Experience

2017-present	Research Scientist, Lawrence Berkeley National Laboratory Current research focuses on investigating model sensitivity and uncertainty analysis, climate feedback impacts, GHG dynamics, and biogeochemical modeling.
2012-2017	Postdoctoral Fellow, Lawrence Berkeley National Laboratory
2006-2012	Research & Teaching Assistant, Texas A&M University
2003-2003	Summer Intern, Indian Agricultural Research Institute

Selected Publications

Arora, B., H. M. Wainwright, D. Dwivedi, L. J. S. Vaughn, J. B. Curtis, M. S. Torn, B. Dafflon and S. S. Hubbard, Evaluating Temporal Controls on Greenhouse Gas (GHG) Fluxes in an Arctic Tundra Environment: An Entropy-Based Approach, *Science of the Total Environment*, DOI: 10.1016/j.scitotenv.2018.08.251, 2019.

Dwivedi, D., B. Arora, C. I. Steefel, B. Dafflon, R. Veersteg, Hot Spots and Hot Moments of Nitrogen in a Riparian Corridor, *Water Resources Research*, DOI: 10.1002/2017WR022346, 2018.

Grant, R. F., Z. A. Mekonnen, W. J. Riley, B. Arora, and M. S. Torn, Mathematical modeling of arctic polygonal tundra with Ecosys: 2. Microtopography determines how CO_2 and CH_4 exchange responds to changes in temperature and precipitation, *Journal of Geophysical Research: Biogeosciences*, DOI: 10.1002/2017JG004037, 2017.

Arora, B., D. Dwivedi, N. F. Spycher, and C. I. Steefel, On modeling CO_2 dynamics in a flood plain aquifer, *Procedia Earth and Planetary Science*, DOI: 10.1016/j.proeps.2016.12.103, 2017.

Arora, B., N. F. Spycher, C. I. Steefel, S. Molins, M. Bill, M. E. Conrad, W. Dong, B. Faybishenko, T. K. Tokunaga, J. Wan, K.H. Williams and S. B. Yabusaki, Influence of Hydrological, Biogeochemical and Temperature Transients on Subsurface Carbon Fluxes in a Flood Plain Environment, *Biogeochemistry*, DOI: 10.1007/s10533-016-0186-8, 2016.

Dwivedi, D., B. Arora, S. Molins, and C. I. Steefel (2016), *Benchmarking Reactive Transport Codes for Subsurface Environmental Problems*, in Groundwater Research on Exploration, Assessment, Modeling and Management of Groundwater Resources and Pollution, D. Thangarajan and V. P. Singh (eds.), CRC Taylor and Francis Group.

Arora, B., B. P. Mohanty, and J. T. McGuire (2015), An integrated Markov Chain Monte Carlo algorithm for upscaling hydrological and geochemical parameters from column to the field scale, *Science of the Total Environment*, DOI:10.1016/j.scitotenv.2015.01.048.

Steefel, C. I., C. A. J. Appelo, B. Arora, D. Jacques, T. Kalbacher, O. Kolditz, V. Lagneau, P. C. Lichtner, K. U. Mayer, J. C. L. Meussen, S. Molins, D. Moulton, H. Shao, J. Simunek, N. Spycher, S. B. Yabusaki, and G. T. Yeh (2015), Reactive transport codes for subsurface environmental simulation, *Computational Geosciences*, DOI:10.1007/s10596-014-9443-x.

Arora, B., B. P. Mohanty, J. T. McGuire, and I. M. Cozzarelli (2013), Temporal dynamics of biogeochemical processes at the Norman Landfill site, *Water Resources Research*, *49*, 1-18, doi: 10.1002/wrcr.20484.

Arora, B., B. P. Mohanty, and J. T. McGuire (2011), Inverse estimation of parameters for multidomain flow models in soil columns with different macropore densities, *Water Resources Research*, 47, W04512, doi: 10.1029/2010WR009451. (**Note:** ***This publication was a featured article in EOS, Transactions of the American Geophysical Union***)

Synergistic Activities

Panelist, DOE Subsurface Biogeochemical Research Program, Washington D.C., May 15-16, 2017.

Primary session convener, Characterizing Spatial and Temporal Variability of Hydrological and Biogeochemical Processes across Scales, AGU Fall Meeting, 2018-2014. Co-convener(s): Haruko Wainwright (LBNL)

Session Co-chair, Modeling the Critical Zone: Integrating Processes and Data Across Disciplines and Scales, AGU Fall Meeting, 2018-17. Co-convener(s): Li Li (Penn State), Harry Vereecken (IBG), and Praveen Kumar (UIUC).

Department Representative, Distinguished Scientist Seminar Series committee, Earth & Environmental Sciences Area, Lawrence Berkeley National Laboratory, 2015-Present.

Recipient, Outstanding Student Presentation Award, AGU Fall Meeting, Hydrology Section, 2010.

Collaborators and Co-Authors

Jonathan Ajo-Franklin (LBNL), Yiwei Cheng (LBNL), Isabelle Cozzarelli (USGS), Li Li (Penn State), Reed Maxwell (CSM), David Moulton (LANL), Carl Steefel (LBNL), Ken Williams (LBNL) and Steven Yabusaki (PNNL).

Graduate and Postdoctoral Advisors

Graduate Advisors: Binayak Mohanty (Texas A&M Univ.) and Jennifer McGuire (Univ. of St. Thomas); *Post-doctoral Advisor*: Nicolas Spycher (LBNL)

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Education and Training

2007	University of Plymouth, UK, Environmental Microbiology, PhD
2004	University of Plymouth, UK, Biogeochemistry, MS
2003	University of Manchester, UK, Marine Biology & Microbiology, BS

Research and Professional Experience

2010-present	Scientist, Climate and Ecosystem Sciences, Lawrence Berkerley National Laboratory
2008-2010	Lecturer, Princeton Environmental Institute, Princeton University
2007-2010	Postdoctoral Researcher, Department of Geosciences, Princeton University

Selected Publications

Maavara T, Lauerwald R, Laruelle G, Akbarzadeh Z, **Bouskill NJ**, Van Cappellen P, Regnier P (2018) Nitrous oxide emissions from inland waters: Are the IPCC estimates too high? Global Change Biology.

Yabusaki SB, Wilkins M, Fang Y, Williams KH, Arora B, Bargar J, **Bouskill NJ**, et al., (2017) Water table dynamics and biogeochemical cycling in a shallow variably saturated floodplain. Environmental Science and Technology.

Bouskill NJ, Baran R, Wood TE, Ye Z, Bowen BP, Lim HC, Nico PS, Van Norstrand J, Zhao J, Silver WL, Northen TR, and Brodie EL. (2016) Belowground Response to drought in a weathered tropical soil. I. Phylogenetic shifts in community composition are borne out at the functional level. Frontiers in Microbiology. 7: 323.

Bouskill NJ, Baran R, Wood TE, Ye Z, Bowen BP, Lim HC, Nico PS, Holman H-Y, Gilbert B, Silver WL, Northen TR, and Brodie EL. (2016) Belowground Response to drought in a weathered tropical soil. II. Functional changes in the microbial community impact carbon composition and CO_2 flux. Frontiers in Microbiology. 7: 323.

Le Roux, X, **Bouskill NJ,** Niboyet A, Field C, Hungate B, Tang J, Poly F. (2016) Functional type controls on response of soil bacteria to global change. Frontiers in Microbiology. 7: 628.

Bouskill NJ, Tang J, Riley WJ (2014) Meta-analysis of high-latitude nitrogen-addition and warming studies uncovers crucial ecological mechanisms overlooked by land models. Biogeosciences. 11: 1.

Mason OU, Scott NM, Gonzalez A, Robbins-Pianka A, Lum BA, Kimbrel J, **Bouskill NJ,** Prestat E, Borglin S, Joyner DC, Fortney JL, Jurelevicius D, Stringfellow WT, Alvarez-Cohen L, Hazen TC, Knight R, Gilbert JA, and Jansson JK. (2014) Metagenomics reveals sediments microbial community resonse to Deepwater Horizon spill. ISME journal. 8: 1464.

Rajeev L, da Rocha UN, Klitgord N, Luning EG, Fortney JL, Axen SD, Shih PM, **Bouskill NJ,** Bowen BP, Kerfeld CA, Garcia-Pichel F, Brodie EL, Northen TR, and Mukhopadhyay A. (2013) Dynamic cyanobacterial response to hydration and dehydration in a desert biological soil crust. ISME journal. 7: 2178.

Bouskill, NJ, Lim, HC, Borglin, S, Salve, R, Wood, T, Silver, WL, Brodie, EL. (2013) Pre-exposure to drought increases the resistance of tropical forest soil bacterial communities to extended drought. ISME journal. 7: 384.

Bouskill, NJ, Tang, J, Riley, WJ, Brodie, EL. (2012) Trait based representation of biological nitrification: model development, testing and predicted community composition. Frontiers in Microbiology. 3: 364.

Synergistic Activities (selected)

Invited speaker/ panelist: University of Tubingen, Germany**,** April 2017; Ecological Society of America, Annual Meeting (2 invited talks), Portland, OR, August, 2017; Terrestrial Phosphorus workshop, Townsend, TN, May, 2016; The Nitrogen Economy Big Idea Workshop, Oak Ridge, TN, August, 2016; Department of Energy workshop on the Terrestrial –Aquatic Interface, Rockville, MD; August 2016. Coastal Nitrogen cycling workshop, Woods Hole, MA, September, 2015. International workshop on Nitrification, Tokyo, Japan, September, 2013.

Workshops: NGEE-Tropics Terrestrial Biogeochemistry Workshop, San Juan, PR, June, 2015. Community Earth System Modeling workshop, Boulder, CO, August, 2015.

Convener: Distinguish Scientist Seminar Series, LBNL;'Biogeochemical and Isotopic Characterization and Modeling of Biologically mediated Processes Across Scales' AGU fall meeting San Francisco, CA (2010); 'Integrating microbial processes into ecosystem models of carbon and nitrogen cycling' AGU fall meeting San Francisco, CA (2010); 'Interpreting variability in the composition of oceanic biological communities and biogeochemical fluxes'. AGU/ ASLO annual meeting. Portland, OR (2010); Environmental Geochemistry and Geoscience seminar series. Dept. Geosciences, Princeton University (2008-2009).

Editor/ Reviewer: Review Editor: Frontiers in Microbiology. **Reviewer:** Ecology, Ecotoxicology Journal, Environmental Microbiology, Environmental Science and Technology, Frontiers in Marine Science, Frontiers in Microbiology, The ISME Journal, Marine Pollution Bulletin, Proceedings of the National Academy of Sciences, Scientific Reports, Soil Biology and Biochemistry

Collaborators, Co-Authors, Co-Editors

Jonathan Ajo-Franklin, Benjamin Bowen, Eoin Brodie, Mark Conrad, Yiwei Cheng, Benjamin Gilbert, Hoi-Ying Holman, Christopher Hubbard, Susan Hubbard, Tayor Maavara, Peter Nico, Trent Northen, William Riley, Rohit Salve, Jinyun Tang, Yuxin Wu, Kenneth Williams, Qing Zhu (All LBNL); Li Li (Penn State University); Whendee Silver, Mary Firestone, Tana Wood (All UC Berkeley); Amal Jayakumar, Bess Ward (Princeton), Damien Eveillard (Nantes), Xavier Le Roux (Lyon), Chris Fields, Chris Francis (Stanford), Bruce Hungate (Northern Arizona University), Jack Gilbert, Nicole Scott (Argonne National Laboratory), Diana Chien (Massachusetts Institute of Technology), Elliott Barnhart (USGS-MT),

Graduate and Postdoctoral Advisors

Graduate Advisors; Timothy Ford, UMass Amherst; Tamara Galloway, University of Exeter, UK.
Postdoctoral Advisor: Bess Ward, Princeton University.

Baptiste Dafflon
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Education and Training

2005–2009	University of Lausanne, Switzerland, Geophysics, PhD
1999–2004	ETH Zurich, Switzerland, Department of Earth Sciences, Geophysics, BSc and MSc

Research and Professional Experience

2016–present	Research Scientist, Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory Current research focuses primarily on the development of comprehensive strategies for advanced monitoring across spatial scales including geophysical data, point-scale measurements, and remote sensing information, and on the integration and inversion of multiple sources of geophysical and hydrological information to improve the estimation of soil properties and the prediction of hydrological and thermal processes and their control on biogeochemical processes.
2013–2016	Project Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory
2011–2013	Post-Doctoral Researcher, Earth Sciences Division, Lawrence Berkeley National Laboratory.
2010–2011	Post-Doctoral Researcher, Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University

Selected Publications

Arora, B., Wainwright, H.M., Dwivedi, D., Vaughn, L.J.S., Curtis, J.B., Torn, M., Dafflon, B., Hubbard S., Evaluating temporal controls on greenhouse gas (GHG) fluxes in an Arctic tundra environment: An entropy-based approach, Science of The Total Environment, 649, 284-299, 2019.

Tran, A.P., Dafflon B., Bisht, G., and Hubbard, S.S., Spatial and temporal variations of thaw layer thickness and its controlling factors identified using time-lapse electrical resistivity tomography and hydro-thermal modeling, Journal of Hydrology, 561, 751-763, 2018.

Bisht, G., Riley, W.J., Wainwright, H.M., Dafflon, B., Yuan, F.M., et al., Impacts of microtopographic snow redistribution and lateral subsurface processes on hydrologic and thermal states in an Arctic polygonal ground ecosystem: a case study using ELM-3D v1.0, Geoscientific Model Development, 11, 1, 61-76, 2018.

Dafflon, B., Oktem, R., Peterson, J., Ulrich, C., Tran, A.P., Romanovsky, V., and Hubbard, S.S., Coincident aboveground and belowground autonomous monitoring to quantify covariability in permafrost, soil, and vegetation properties in Arctic tundra, Journal of Geophysical Research: Biogeosciences, 122(6), 1321-1342, 2017.

Wu, Y.X., Nakagawa, S., Kneafsey, T.J., Dafflon, B., and Hubbard, S., Electrical and seismic response of saline permafrost soil during freeze - Thaw transition, Journal of Applied Geophysics, 146, 16-26, 2017.

Dafflon, B., Hubbard, S.S., Ulrich, C., Peterson, J.E., Wu, Y., et al., Geophysical estimation of shallow permafrost distribution and properties in an ice-wedge polygon-dominated Arctic tundra region, Geophysics, 81, 247-263, 2016.

Wainwright, H.M., Dafflon, B., Smith, L.J., Hahn, M.S., Curtis, J.B., et al., Identifying multiscale zonation and assessing the relative importance of polygon geomorphology on carbon fluxes in an Arctic tundra ecosystem, Journal of Geophysical Research-Biogeosciences, 120, 4, 788-808, 2015.

Dafflon B., Hubbard S.S., Ulrich, C., and Peterson J.E., Electrical conductivity imaging of active layer and permafrost in Arctic ecosystem through advanced inversion of electromagnetic induction data, Vadose Zone Journal, 12(4), doi:10.2136/vzj2012.016, 2013.

Hubbard, S.S., Gangodagamage, C., Dafflon, B., Wainwright, H., Peterson, J., Gusmeroli, A., Ulrich, C., Wu, Y., Wilson, C., Rowland, J., Tweedie, C., and Wullschleger, S.D., Quantifying and relating land-surface and subsurface variability in permafrost environments using lidar and surface geophysical datasets, Hydrogeology Journal, 21(1), 149-169, 2013.

Dafflon B., Wu Y., Hubbard S.S., Birkholzer J., Daley T., Pugh J., Peterson J.E., and Trautz R., Monitoring CO_2 intrusion and associated geochemical transformations in a shallow groundwater system using complex electrical method, Environ. Sci. Techn., 47(1), 314-321, 2013.

Synergistic Activities

Committee member of the AGU Hydrogeophysical group and co-convener of several sessions (in Hydrology and Cryosphere) between 2011 and 2017 at the Fall Meeting of the AGU.

Collaborators and Co-Authors

Bhavna Arora (LBNL), Warren Barrash (BSU), Gautam Bisht (LBNL), Dipankar Dwivedi (LBNL), Susan Hubbard (LBNL), James Irving (UNIL), Bill Riley (LBNL), Vladimir Romanovsky (UAF), Tetsu Tokunaga (LBNL), Margaret Torn (LBNL), Haruko Wainwright (LBNL), Ken Williams (LBNL), Cathy Wilson (LANL), Stan Wullschleger (ORNL).

Graduate and Postdoctoral Advisors

Graduate Advisor: Klaus Holliger (University of Lausanne).
Postdoctoral Advisor: Warren Barrash (BSU), Susan Hubbard (LBNL).

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Education and Training

1996	University of California, Berkeley, Environmental Engineering, PhD
1993	University of California, Berkeley, Environmental Engineering, MS
1988	University of North Carolina, Chapel Hill, Physics, MS
1984	Rensselaer Polytechnic Institute, Troy, NY, Aerospace Engineering, BS

Research and Professional Experience

2000-Present	Staff Scientist, Lawrence Berkeley National Laboratory, Berkeley, CA.
1998-2006	Lecturer, Civil and Environmental Engineering Department, U.C. Berkeley.
1996-1999	Postdoctoral Fellow with Pamela Matson, Stanford Univ. and U.C. Berkeley.

Selected Publications

Bisht, G., W. J. Riley, H. Wainwright, B. Dafflon, F. Yuan, and V. E. Romanovsky (2018b), Impacts of microtopographic snow-redistribution and lateral subsurface processes on hydrologic and thermal states in an Arctic polygonal ground ecosystem: a case study using ELM-3D v1.0, *Geoscientific Model Development*, *11*, https://doi.org/10.5194/gmd-11-61-2018, 61-76.

Keenan, T. F., and W. J. Riley (2018), Greening of the Land Surface in the World's Cold Regions Consistent with Recent Warming, *Nature Climate Change*, *8*, doi:10.1038/s41558-018-0258-y, 825-828.

Maggi, F. M., F. H. M. Tang, and W. J. Riley (2018), The thermokinetic link between substrate, enzyme and microbial dynamics in Michaeli-Menten-Monod kinetics, *International J. of Chemical Kinetics*, https://doi.org/10.1002/kin.21163.

Mekonnen, Z. A., W. J. Riley, and R. F. Grant (2018a), Accelerated nutrient cycling and increased light competition will lead to 21st century shrub expansion in North American Arctic tundra, *JGR-Biogeosciences*, *123*, https://doi.org/10.1029/2017JG004319.

Mekonnen, Z. A., W. J. Riley, and R. F. Grant (2018b), 21st century tundra shrubification could enhance net carbon uptake of North America tundra Arctic tundra under and RCP8.5 climate trajectory, *Environ Res Lett*, *13*, https://doi.org/10.1088/1748-9326/aabf28.

Riley, W. J., Q. Zhu, and J. Y. Tang (2018b), Weaker land-climate feedbacks from nutrient uptake during photosynthesis-inactive periods, *Nature Climate Change*, https://doi.org/10.1038/s41558-018-0325-4.

Xu, X., W. J. Riley, C. D. Koven, and G. Jia (2018), Observed and simulated sensitivities of spring greenup to preseason climate in northern temperate and boreal regions, *JGR-Biogeosciences*, *123*, 10.1002/2017JG004117.

Ghimire, B., W. J. Riley, C. D. Koven, J. Kattge, A. Rogers, P. B. Reich, and I. Wright (2017), A global trait-based approach to estimate leaf nitrogen functional allocation from observations, *Ecol Appl*, DOI:10.1002/eap.1542.

Grant, R. F., A. A. Mekonnen, W. J. Riley, B. Arora, and M. S. Torn (2017a), Microtopography Determines How CO_2 and CH_4 Exchange Responds to Changes in Temperature and Precipitation at an Arctic Polygonal Tundra Site: Mathematical Modeling with Ecosys, *JGR-Biogeosciences*, DOI: 10.1002/2017JG004037.

Grant, R. F., Z. A. Mekonnen, W. J. Riley, H. M. Wainwright, D. E. Graham, and M. S. Torn (2017b), Microtopography Determines How Active Layer Depths Respond to Changes in Temperature and Precipitation at an Arctic Polygonal Tundra Site: Mathematical Modeling with Ecosys, *JGR-Biogeosciences*, 10.1002/2017JG004035.

Muster, S., …, W. J. Riley, C. D. Koven, and J. Boike (2017), PeRL: A Circum-Arctic Permafrost Region Pond and Lake Database, *Earth System Science Data*, *9*, 10.5194/essd-9-1-2017, 1-31.
Tang, J. Y., and W. J. Riley (2017), SUPECA kinetics for scaling redox reactions in networks of mixed substrates and consumers and an example application to aerobic soil respiration, *Geoscientific Model Development*, *10*, https://doi.org/10.5194/gmd-10-3277-2017, 3277-3295.
Zhu, Q., W. J. Riley, and J. Y. Tang (2017), A new theory of plant and microbe nutrient competition resolves inconsistencies between observations and models, *Ecol Appl*, DOI:10.1002/eap.1490.
Xu, X., W. J. Riley, C. D. Koven, D. P. Billesbach, R. Y. W. Chang, R. Commane, E. S. Euskirchen, S. Hartery, Y. Harazono, H. Iwata, C. E. Miller, W. C. Oechel, B. Poutler, N. Raz-Yaseef, M. S. Torn, S. C. Wofsy, and D. Zona (2016a), A multi-scale comparison of modeled and observed seasonal methane emissions in northern wetlands, *Biogeosciences*, doi:10.5194/bg-13-5043-2016.
Zhu, Q., C. M. Iversen, W. J. Riley, I. Slette, and H. Vander Stel (2016a), Root traits explain observed tundra vegetation nitrogen uptake patterns: Implications for trait-based land models, *JGR-Biogeosciences*, *121*, doi:10.1002/2016JG003554, 3101-3112.
Riley, W. J., Maggi, F. M., Kleber, M., Torn, M. S., Tang, J. Y., Dwivedi, D., and Guerry, N.: Long residence times of rapidly decomposable soil organic matter: Application of a multi-phase, multi-component, and vertically-resolved model (BAMS1) to soil carbon dynamics, Geoscientific Model Development, 7, 1335-1355, doi:10.5194/gmd-7-1335-2014, 2014.
Tang, J. Y., and Riley, W. J.: A total quasi-steady-state formulation of substrate uptake kinetics in complex networks and an example application to microbial litter decomposition, Biogeosciences, 10, 8329-8351, Doi 10.5194/Bg-10-8329-2013, 2013.
Tang, J. Y., and Riley, W. J.: Weaker carbon-climate feedbacks resulting from microbial and abiotic interactions, Nature Climate Change, DOI: 10.1038/NCLIMATE2438, 2014b.

Synergistic Activities

External co-chair, NCAR Community Land Model Working Group, 2013 – present.
Technical lead, Terrestrial Earth-System Processes and Energy-Climate Interactions in the Climate and Earth System Modeling SFA, 2009 – present.
Technical lead, Atmospheric Systems Research SFA, 2010 – present.
Contributing author, Intergovernmental Panel on Climate Change Fifth Assessment, 2011 – 2013.
Member, NSF Permafrost Research Coordination Network, 2011 – present.
Participant, International Land Model Benchmarking Project, 2011 – present.

Collaborators and Co-Authors

Gautam Bisht (LBNL), Joe A. Berry (Carnegie Institute of Washington), Nick J. Bouskill (LBNL), Sebastuen C. Biraud (LBNL), Dave Billesbach (U. Neb), Eoin L. Brodie (LBNL), William D. Collins (LBNL), Forrest Hoffman (ORNL), Charlie Koven (LBNL), David M. Lawrence (NCAR), Yiqi Luo (UO), Federico Maggi (AU), Joe R. Melton (EPFL), Umakant Mishra (ANL), Jim Randerson (UC Irvine), Nick Spycher (LBNL), Peter Thornton (ORNL), Margaret S. Torn (LBNL), Stan Wullschlegger (ORNL)

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Education and Training

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Research and Professional Experience

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Selected Publications

Riley W.J., Zhu Q., and Tang J.Y., Weaker terrestrial feedbacks from nutrient uptake during photosynthesis-inactive periods, *Nature Climate Change*, 2018.

Tang J.Y. and Riley W.J., SUPECA kinetics for scaling redox reactions in networks of mixed substrates and consumers and an example application to aerobic soil respiration, *Geosci. Model Dev*., 10, 3277-3295, 2017.

Tang J.Y. and Riley W.J., A generic law-of-the-minimum flux limiter for simulating substrate limitation in biogeochemical models, *Biogeosciences*, 13, 723-735, 2016.

Tang J.Y., On the relationships between Michaelis-Menten kinetics, reverse Michaelis-Menten kinetics, Equilibrium Chemistry Approximation kinetics and quadratic kinetics, *Geosci. Model Dev.,* 8, 3823-3835, 2015.

Tang J.Y., and Riley W.J., Weaker soil carbon-climate feedbacks resulting from microbial and abiotic interactions, *Nature Climate Change*, 5, 56-60, 2015.

Bouskill N, Riley W.J. and Tang J.Y., Meta-analysis of high-latitude nitrogen-addition and warming studies imply ecological mechanisms overlooked by land models, *Biogeosciences*, 11, 6969-6983, 2014.

Tang J.Y. and Riley W.J., Simple formulations and solutions of the dual-phase diffusive transport for biogeochemical modeling, *Biogeosciences*, 11, 3721-3728, 2014.

Tang J.Y. and Riley W.J., A total quasi-steady-state formulation of substrate uptake kinetics in complex networks and an example application to microbial litter decomposition, *Biogeosciences*, 10, 8329-8351, 2013.

Tang J.Y. and Riley W.J., A new top boundary condition for modeling surface diffusive exchange of a generic volatile tracer: theoretical analysis and application to soil evaporation, *HESS*, 17, 873-893, 2013.

Tang J.Y., Riley W.J., Koven C.D. and Subin Z.M., CLM4-BeTR, a generic biogeochemical transport and reaction module for CLM4: theoretical developments and a site-level evaluation, *Geosci. Model Dev., 6, 127-140, 2013.*

Synergistic Activities

Session Chair, with Gustaf Hugelius, ILAMB2016, Soil Carbon and Nutrient Biogeochemistry 2016.

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2016 – present	Research Scientist, Lawrence Berkeley National Laboratory, USA
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2008 – 2010	Postdoctoral research fellow, Vrije Universiteit, Amsterdam, NL
2004 – 2008	Junior research associate, Wageningen University, NL
2006 – 2007	Researcher, Institute of Environmental Genomics, Oklahoma University, USA

Selected Publications

Taş N, Prestat E, Wang S, Wu Y, Ulrich C, Kneafsey T, Tringe SG, Torn MS, Hubbard SS, Jansson JK. 2018. Landscape topography structures the soil microbiome in arctic polygonal tundra, *Nature Communications*, doi: 10.1038/s41467-018-03089-z.

Taş N, Brandt BW, Braster M, van Breukelen B, Röling WFM. 2018. Subsurface landfill leachate contamination affects microbial metabolic potentials and their expression, *FEMS Microbiology Ecology*, doi: 10.1093/femsec/fiy156

Mackelprang R, Taş N, Waldrop M. 2018. Functional response upon permafrost thaw. Book Chapter in "Microbial Life in the Cryosphere" In Press

Müllera O, Bang-Andreasen T, White RA, Elberling B, Taş N, Kneafsey T, Jansson JK, Lise Øvreås. 2018. Disentangling the complexity of permafrost soil, by using high resolution profiling of microbial community composition, key functions and respiration rates, *Environmental Microbiology*, doi: 10.1111/1462-2920.14348

Valdespino-Castillo P, Cerqueda-García D, Espinosa A, Batista S, Merino-Ibarra M, Taş N, Alcántara-Hernández R, Falcon LI. 2018. Microbial distribution and turnover in Antarctic microbial mats highlight the relevance of heterotrophic bacteria in low-nutrient environments, *FEMS Microbiology Ecology*, 94.9: fiy129

Thompson LR, Sanders JG, McDonald D, Amir A, Ladau J, Locey KJ, Prill RJ, Tripathi A, Gibbons SM, Ackermann G, Navas-Molina JA, et al. & The Earth Microbiome Project Consortium*. 2017. A communal catalogue reveals Earth's multiscale microbial diversity. *Nature*, 551:7681 (*contributing author within the consortium)

Mackelprang R, Saleska SR, Jacobsen CS, Jansson JK, Taş N. 2016. Permafrost meta-omics and climate change, *Annual Review of Earth and Planetary Sciences*, 44: 439-462

Schostag M, Stibal M, Jacobsen CS, Bælum J, Taş N, Elberling B, ... & Priemé A. 2015. Distinct summer and winter bacterial communities in the active layer of Svalbard permafrost revealed by DNA- and RNA-based analyses. *Frontiers in Microbiology*, 6:399.

Jansson JK and Taş N. 2014. The microbial ecology of permafrost, *Nature Reviews Microbiology*, 12: 414-425

Taş N, Prestat E, McFarland JW, Wickland K, Knight R, Asefaw Berhe A, Jorgenson T, Waldrop M, Jansson JK. 2014. Impact of fire on active layer and permafrost microbial communities and metagenomes in an upland Alaskan boreal forest. *ISME Journal*, 8: 1904- 1919

Synergistic Activities

Lead PI: DOE - Early Career Research Program. Awakening the sleeping giant: Multi-omics enabled quantification of the microbial controls on carbon cycling in permafrost ecosystems. 2017-present

Member of the editorial board: FEMS Microbiology Ecology, 2014-present; Frontiers in Sustainable Food Systems, 2018-present

Reviewer: ISME Journal, Ecology, Applied and Environmental Microbiology, Journal of Geophysical Research – Biogeosciences, Plos ONE, Peer J, Microbial Ecology, Microbial Biotechnology, BMC Microbiology, Frontiers in Microbiology, Scientific Reports, Soil Biology and Biochemistry, Environmental Microbiology and Environmental Microbiology Reports

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1994-1998	Postdoctoral Fellow, U.C. Irvine and Stanford University

Selected Publications related to proposed project (out of >150), *indicates mentored student or postdoc

Vaughn*, L.J.S. and M.S. Torn. 2018. Radiocarbon measurements of ecosystem respiration and soil pore-space CO_2 in Utqiaġvik (Barrow), Alaska. Earth Syst. Sci. Data, 10, 1943-1957, 2018. https://doi.org/10.5194/essd-10-1943-2018

Arora, B., Wainwright, H.M., Dwivedi, D., Vaughn, L.J., Curtis, J.B., Torn, M.S., Dafflon, B. and Hubbard, S.S. 2018. Evaluating temporal controls on greenhouse gas (GHG) fluxes in an Arctic tundra environment: An entropy-based approach, *Science of the Total Environment,* 649, 284-299, DOI: 10.1016/j.scitotenv.2018.08.251.

Taş, N., E. Prestat, S. Wang, Y. Wu, C. Ulrich, T. Kneafsey, S.G. Tringe, M.S. Torn, S.S. Hubbard, J.K. Jansson. 2018. Landscape topography structures the soil microbiome in arctic polygonal tundra. Nature Communications 9(1): 777. https://doi.org/10.1038/s41467-018-03089-z

Grant, R. F., Mekonnen, Z. A., Riley, W. J., Arora, B., & Torn, M. S. 2017. Mathematical modeling of arctic polygonal tundra with ecosys: 2. Microtopography determines how CO_2 and CH_4 exchange responds to changes in temperature and precipitation. Journal of Geophysical Research: Biogeosciences, 122, 3174–3187. https://doi.org/10.1002/2017JG004037

Raz-Yaseef*, N., J. Young-Robertson, T. Rahn, V. Sloan, B. Newman, C. Wilson, S.D. Wullschleger, M.S. Torn. 2017. Evapotranspiration across plant types and geomorphological units in polygonal arctic tundra. Journal of Hydrology, 553: 816-825, https://doi.org/10.1016/j.jhydrol.2017.08.036.

Kueppers, L.M., Conlisk, E., Castanha, C., Moyes, A. B., Germino, M.J., de Valpine, P., Torn, M.S. and Mitton, J.B. 2016. Warming and provenance limit tree recruitment across and beyond the elevation range of subalpine forest. Glob Change Biology 23 (6): 2383-2395, doi:10.1111/gcb.13561

Hicks Pries*, C.E., C. Castanha, R. Porras, and M.S. Torn. 2017. The whole soil carbon flux in response to warming. Science 2017; eaal1319 DOI: 10.1126/science.aal1319

Raz-Yaseef*, N., Torn, M.S., Wu, Y., Billesbach, D.P., Liljedahl, A.K., Kneafsey, T.J., Romanovsky, V.E., Cook, D.R. and Wullschleger, S.D. 2017. Larger CO_2 and CH_4 emissions from polygonal tundra during spring thaw in northern Alaska. Geophysical Research Letters. Jan 10 2017, 10.1002/2016GL071220

Vaughn*, L.J.S., M.E. Conrad, M. Bill, and M.S. Torn. 2016. Isotopic insights into methane production, oxidation, and emissions in Arctic polygon tundra. Global Change Biology 22(10), pp.3487-3502

Wainwright, HM, B Dafflon, LJ Smith*, MS Hahn*, JB Curtis, Y Wu, C Ulrich, JE Peterson, MS Torn. SS Hubbard. 2015. Identifying multiscale zonation and assessing the relative importance of polygon geomorphology on carbon fluxes in an Arctic Tundra Ecosystem, JGR Biogeosci., 120, 788–808. *doi:* 10.1002/2014JG002799

Castanha, C., M.S. Torn, M.J. Germino, B. Weibel, and L.M. Kueppers. 2013. Conifer seedling recruitment across a gradient from forest to alpine tundra: effects of species, provenance, and site. Plant Ecology & Diversity 6 (3-4) 307-318. DOI: 10.1080/17550874.2012.716087

Schmidt, M.W.I.S, M. S. Torn, S. Abiven, T. Dittmar, G. Guggenberger, I.A. Janssens, M. Kleber, I. Kögel-Knabner, J. Lehmann, D.A.C. Manning, P. Nannipieri, D.P. Rasse, S. Weiner, and S.E. Trumbore. 2011. Persistence of soil organic matter as an ecosystem property. Nature, 478 (7367), 49–56; DOI: 10.1038/nature10386. (Schmidt and Torn are equal co-authors)

Synergistic Activities

President-elect, Biogeosciences, AGU, 2019-2020

PI, AmeriFlux Management Project, 2012-present

PI, Terrestrial Ecosystem Science SFA, Deep soil warming experiment, 2010-present

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International Advisory Board, University Research Priority Program on Global Change and Biodiversity, University of Zurich, Switzerland, 2013-present.

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Collaborators, Co-Authors, and Other Conflicts of Interest, 2014-2018

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Education and Training

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Research and Professional Experience

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Feb. 11-May 14	Postdoctoral Scholar, Lawrence Berkeley National Laboratory

Selected Publications

Wainwright, H.M., A. Seki, S. Mikami and K. Saito, "Characterizing Regional-Scale Temporal Evolution of Air Dose Rates After the Fukushima Dai-ichi Nuclear Power Plant Accident", Journal of Environmental Radioactivity 189 (2018): 213-220.

Wainwright, H.M., A. Liljedahl, J. Peterson, B. Dafflon, C. Ulrich, A. Gusmeroli, S. Hubbard, "Estimation of snow depth within a tundra ecosystem using multiscale observations and Bayesian methods", Cryosphere, 11(2), 857-875, 2017.

Wainwright, H.M., J. Chen, A. Seki and K. Saito, "A multiscale Bayesian data integration approach for mapping radionuclide contamination in the regional scale", Journal of Environmental Radioactivity, 167, 62-69, 2017.

Yabusaki, S.B., **H.M. Wainwright** et al., "Water Table Dynamics and Biogeochemical Cycling in a Shallow, Variably-Saturated Floodplain", Environmental Science & Technology, DOI: 10.1021/acs.est.6b0487, 2017.

Finsterle S., M. Commer, J.K. Edmiston, Y. Jung, M.B. Kowalsky, G.S.H. Pau, **H.M. Wainwright**, and Y. Zhang, "iTOUGH2: A Multiphysics Simulation-Optimization Framework for Analyzing Subsurface Systems", Computers & Geosciences, http://dx.doi.org/10.1016/j.cageo.2016.09.005, 2016.

Wainwright, H.M., A. Flores-Orozco, M. Bücker, B. Dafflon, S.S. Hubbard and K.H. Williams, "Probabilistic mapping of biogeochemical hotspots using induced polarization imaging", Water Resour. Res., 52, 533–551, doi:10.1002/2015WR017763, 2015.

Wainwright, H.M., B. Dafflon, L.J. Smith, M.S. Hahn, J.B. Curtis, Y. Wu, C. Ulrich, J.E. Peterson, M.S. Torn and S.S. Hubbard, "Identifying multiscale zonation and assessing the relative importance of polygon geomorphology on carbon fluxes in an Arctic Tundra Ecosystem", accepted, Journal of Geophysical Research, Biogeosciences, 120 (4), 788-808, 2015.

Wainwright, H.M., J. Chen, D. Sassen and S.S. Hubbard, "Bayesian Hierarchical Approach for Estimation of Reactive Facies over Plume-Scales Using Geophysical Datasets", Water Resources Research, 50, 4564–4584, doi:10.1002/2013WR013842, 2014.

Wainwright, H.M., S. Finsterle, Y. Jung, Q. Zhou and J.T. Birkholzer, "Making Sense of global sensitivity analysis", Computers & Geosciences, ISSN 0098-3004, http://dx.doi.org/10.1016/j.cageo.2013.06.006, 2013.

Wainwright, H.M., S. Finsterle, Q. Zhou, J.T. Birkholzer, "Modeling the Performance of Large-Scale CO_2 Storage Systems: A Comparison of Different Sensitivity Analysis Methods", International Journal of Greenhouse Gas Control, 17, Pages 189-205, ISSN 1750-5836, http://dx.doi.org/10.1016/j.ijggc.2013.05.007, 2013.

Hubbard, S. S., C. Gangodagamage, B. Dafflon, **H.M. Wainwright**, J. E. Peterson, A. Gusmeroli, C. Ulrich, Y. Wu, C. Wilson, J. Rowland, C. Tweedie and S.D. Wullschleger, "Quantifying and relating land-surface and subsurface variability in permafrost environments using LiDAR and surface geophysical datasets", Hydrogeology, Feb2013.doi: 10.1007/s10040-012-0939-y, 2013.

Chen, X., **H. Murakami**, M.S. Hahn, G. Hammond, M.L. Rockhold and Y. Rubin, "Bayesian geostatistical aquifer characterization at the Hanford 300 Area using tracer test data", Water Resour. Res., 48, W06501, doi:10.1029/2011WR010675, 2012.

Murakami, H., X. Chen, M.S. Hahn, Y. Liu, M.L. Rockhold, V.R. Vermeul, J.M. Zachara, and Y. Rubin, "Bayesian approach for three-dimensional aquifer characterization at the Hanford 300 area", Hydrol. Earth Syst. Sci. 7, 2017–2052, 2010.

Synergistic Activities

Japan Atomic Energy Agency, 10/01/2016–09/30/2020, Environmental Restoration related to the Fukushima Nuclear Accident: Integration of Complex Radiation Datasets, $200,000/year (Co-PI, Task Lead)

Department of Energy, Office of Environmental Management, 10/01/2017–09/30/2018, Innovative Monitoring Technologies and Virtual Testbed, $200,000/year (PI)

Lawrence Berkeley National Laboratory LDRD 10/01/2017–09/30/2018, Engineering Ag through Multiscale Sensing and Machine Learning, $180,000/year (Co-PI)

Department of Energy, Office of Science, 05/01/2012 – 09/30/2019, Next Generation Ecosystem Experiment–Arctic, $6,000,000/yr

Department of Energy, Office of Science, 10/01/2013 – 09/30/2019, LBNL Sustainable Systems Science Focus Area 2.0, $6,900,000/yr (Co-PI, Component Lead)

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2007–2008	Acting Deputy Division Leader, Earth and Environmental Sciences.
1999–2007	Technical Staff Member EES; developed OSL geochronology laboratory; PI for multiple large ($1M+) internal and external projects requiring the development and application of hydrology, erosion and contaminant transport experiments and models; Eco-hydrology Team Leader; LANL Water Portfolio Leader.
1988–1999	Senior Research Scientist, Co-founder Cooperative Research Centre for Catchment Hydrology (CRCCH); Program Leader: Erosion Control and Waterway Management. Leader of the Australian National Riparian Zone Program: Chemical and Physical Processes.

Selected Publications

Young-Robertson JM, N Raz-Yaseef, LR Cohen, BD Newman, T Rahn, V Sloan, CJ Wilson, and SD Wullschleger, (2018). Evaporation dominates evapotranspiration on Alaska's Arctic Coastal Plain. Arctic, Antarctic, and Alpine Research 50: e1435931. https://doi.org/10.1080/15230430.2018.1435931

Jafarov, EE, ET Coon, DR Harp, CJ Wilson, SL Painter, AL Atchley, VE Romanovsky VE, (2018) Modeling the role of preferential snow accumulation in through talik development and hillslope groundwater flow in a transitional permafrost landscape. *Environ. Res. Lett, 2018. https://doi.org/10.1088/1748-9326/aadd30*.

Raz-Yaseef, N, J Young-Robertson, T Rahn, V Sloan, BD Newman[3] CJ Wilson, SD Wullschleger, MS Torn, (2017) Evapotranspiration across plant types and geomorphological units in polygonal arctic tundra. J. Hydrol., doi.org/10.1016/j.jhydrol.2017.08.036.

Shelef, E, JC Rowland, CJ Wilson, GE Hilley, U Mishra, GL Altmann, CL Ping (2017), Large uncertainty in permafrost carbon stocks due to hillslope soil deposits. *Geophys. Res. Lett., 44, 6134–6144, doi:10.1002/2017GL073823*.

Throckmorton, HM, BD Newman, JM Heikoop, GB Perkins, X Feng, DE Graham, D O'Malley, VV Vesselinov, J Young, SD Wullschleger, CJ Wilson, (2016) Active layer hydrology in an arctic tundra ecosystem: quantifying water sources and cycling using water stable isotopes. Hydrol. Process., *doi:* 10.1002/hyp.10883.

Atchley, AL, ET Coon, SL Painter, DR Harp, CJ Wilson. (2016) Influences and interactions of inundation, peat, and snow on active layer thickness. Geophysical Research Letters 43, no. 10: 5116-5123.

Painter, SL, ET Coon, AL Atchley, M Berndt, R Garimella, JD Moulton, D Svyatskiy, and CJ Wilson (2016), Integrated surface/subsurface permafrost thermal hydrology: Model formulation and proof-of-concept simulations, Water Resour. Res., 52, *doi:*10.1002/2015WR018427.

Liljedahl AK, J Boike, RP Daanen, AN Federov, GV Frost, G Grosse, LD Hinzman, Y Iijma, JC Jorgenson, N Matveyeva, M Necsoiu, MK Reynolds, VE Romanovsky, J Schulla, KD Tape, DA Walker, CJ Wilson, H Yabuki and D Zona (2016) Pan-arctic ice-wedge degradation in warming permafrost and its influence on tundra hydrology. Nature Geoscience. http://dx.doi.org/10.1038/NGEO2674.

Ali, A, C Xu, A Rogers, RA Fisher, SD Wullschleger, EC Massoud, JA Vrugt, JD Muss, NG McDowell, JB Fisher, PB Reich, CJ Wilson (2016). A global mechanistic model of plant photosynthesis capacity. Geoscientific Model Development, 9, 587-606, doi:10.5194/gmd-9-587-2016.

Harp DR, AL Atchley, SL Painter, ET Coon, CJ Wilson, VE Romanovsky and JC Rowland (2016). Effect of soil property uncertainties on permafrost thaw projections: a calibration-constrained analysis. The Cryosphere 10: 341-358. http://dx.doi.org/10.5194/tc-10-341-2016.

Throckmorton, HM, JM Heikoop, BD Newman, GL Altmann, MS Conrad, JD Muss, GB Perkins, LJ Smith, MS Torn, SD Wullschleger, CJ Wilson. (2015), Pathways and transformations of dissolved methane and dissolved inorganic carbon in Arctic tundra watersheds: Evidence from analysis of stable isotopes, *Global Biogeochem. Cycles*, doi:10.1002/2014GB005044.

Atchley, AL, SL Painter, DR Harp, ET Coon, CJ Wilson, AK Liljedahl, and VE Romanovsky: (2015) Using field observations to inform thermal hydrology models of permafrost dynamics with ATS (v0.83). Geoscientific Model Development, 8, 2701-2722, doi:10.5194/gmd-8-2701-2015.

Heikoop, JM, HM Throckmorton, BD Newman, GB Perkins, CM Iverson, T Row-Chowdhury, V Romanovsky, DE Graham, CJ Wilson, SD Wullschleger (2015) Isotopic identification of soil and permafrost nitrate sources in an Arctic tundra ecosystem, J. Geophys. Res. Biogeosci., 120, doi:10.1002/2014JG002883.

Newman, BD, HM Throckmorton, DE Graham, B Gu, SS Hubbard, L Liang, Y Wu, JM Heikoop, EM Herndon, TJ Phelps, CJ Wilson, SD Wullshleger (2015) Microtopographic and Depth Controls on Active Layer Chemistry in Arctic Polygonal Ground. *Geophysical Research Letters* DOI 10.1002/2014GL062804.

Beighley, E, K Eggert, CJ Wilson, JC Rowland, H Lee, (2014) A hydrologic routing model suitable for climate scale simulations of arctic rivers: application to the Mackenzie River Basin, *Hydrol. Process.*, DOI: 10.1002/hyp.10398.

Chen, M., JC Rowland, CJ Wilson, GL Altman, SP Brumby, (2013) The importance of natural variability in lake areas on the detection of permafrost degradation: A case study in the Yukon Flats, Alaska, *Permafrost and Periglac. Process*, DOI: 10.1002/ppp.1783.

Lewis, K, G Zyvoloski, C Wilson, B Travis, J Rowland, (2012) Drainage subsidence associated with Arctic permafrost degradation. *Journal of Geophysical Research - Earth Surface,* 117, F04019, DOI: 10.1029/2011JF002284.

Xu, C, R Fisher, SD Wullschleger, CJ Wilson, M Cai, NG McDowell, (2012) Toward a Mechanistic Modeling of Nitrogen Limitation on Vegetation Dynamics, *PLos ONE* May 2012 | Volume 7 | Issue 5 | e37914.

Schuur, EAG, many authors…, CJ Wilson, SA Zimov, (2011) High risk of permafrost thaw. *Nature* 480, 32-33, doi:10.1038/480032a

Xu, C, C Liang, S Wullschleger, C Wilson, and N McDowell (2011). Importance of feedback loop between soil inorganic nitrogen and microbial community in the heterotrophic soil respiration response to global warming. *Nature Reviews Microbiology* 9 (3): 222-223.

Collaborators and Co-Editors

David Lawrence (NCAR), Ted Schuur (NAU), Donatella Zona (U.Sheffield), Moritz Langer (AWI), Carli Arendt (NCSU), Christian Andresen (WISC).

2018/19 Post Docs and Students

Post Docs: Elchin Jafarov, Christian Andresen, Nathan Conroy, James Beisman; Post Masters: Nathan Wales; Post Bac: Emma Lathrop, Julian Dann

Adam L. Atchley
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Education and Training

2013	Colorado School of Mines, Hydrological Science and Engineering, PhD
2009	Colorado School of Mines, Hydrological Science and Engineering, MS
2003	Oregon State University, College of Forestry, Natural Resources, BS

Research and Professional Experience

2016–present	Research Scientist, LANL EES Division: LANL PI for SERDP Climate-driven Landscape Disturbance Assessment, Fire Disturbance and Hydrologic Modeling.
2013–2016	Postdoctoral Associate, LANL EES Division: NGEE-Arctic, ATS Model Development.
2010–2013	Graduate Research Assistant, Colorado School of Mines, Geologic Science and Engineering: Groundwater Flow, Reactive Transport And Human Health Risk.

Publications

Atchley, A.L., A.M. Kinoshita, S.R. Lopez, L. Trader, R.S. Middleton. Simulating Surface and Subsurface Water Balance Changes Due to Burn Severity. *Vadose Zone Journal*, *17*(1), 2018.

Jafarov, E., E.T. Coon, D. Harp, C.J. Wilson, S.L. Painter, A.L. Atchley, V. Romanovsky. Modeling the role of preferential snow accumulation in through talik development and hillslope groundwater flow in a transitional permafrost landscape. *Environmental Research Letters*, 2018.

Abolt, C.J., Michael H Young, Adam L Atchley, and Dylan R Harp. Microtopographic control on the ground thermal regime in ice wedge polygons. *The Cryosphere*, 12(6):1957, 1968, 2018.

Bennett, K.E., J.R., Urrego Blanco, A. Jonko, T.J. Bohn, A.L. Atchley, N.M. Urban, R.S., Middleton, Global sensitivity of simulated water balance indicators under future climate change in the Colorado Basin. *Water Resources Research*, *54*(1), pp.132-149, 2018.

Painter, S.L., E.T. Coon, A.L. Atchley, M. Berndt, R. Garimella, J.D. Moulton, D. Svyatskiy, C.J. Wilson. Integrated surface/subsurface permafrost thermal hydrology: Model formulation and proof-of-concept simulations. *Water Resources Research*, *52*(8), pp.6062-6077, 2016.

Harp, D.R., AL Atchley, SL Painter, ET Coon, CJ Wilson, VE Romanovsky, and JC Rowland. Effect of soil property uncertainties on permafrost thaw projections: a calibration-constrained analysis. The Cryosphere, 10(1):341; 358, 2016.

Atchley, A.L., Ethan T Coon, Scott L Painter, Dylan R Harp, and Cathy J Wilson. Influences and interactions of inundation, peat, and snow on active layer thickness. *Geophysical Research Letters*, 43(10):5116; 5123, 2016.

Atchley, A.L., S.L. Painter, D.R. Harp, E.T. Coon, C.J. Wilson, A. Liljedahl, V. Romanovsky. Using Field Observations to Inform Thermal Hydrology of Permafrost Dynamics with ATS (v0.83). *Geoscientific Model Development.* 8, 2701-2722, doi:10.5194/gmd-8-2701-2015.

Atchley, A.L., A. Navarre-Sitchler, R.M. Maxwell. The Effects of Physical and Geochemical Heterogeneity on Hydro-geochemical Transport and Effective Reaction Rates. Contaminant Hydrology: 165, 53-64 doi:10.1016/j.jconhyd.2014.07.008, 2014.

Atchley, A.L., R.M. Maxwell, A. Navarre-Sitchler. Human health risk assessment of CO_2 leakage into overlying aquifers using a stochastic, geochemical reactive transport approach. Environmental Science & Technology: 47(11), 5954-5962, doi: http://dx.doi.org/10.1021/es400316c, 2013.

Atchley, A.L., R.M. Maxwell, A. Navarre-Sitchler. Using streamlines to simulate stochastic reactive transport in heterogeneous aquifers: Kinetic metal release and transport in CO_2 impacted drinking water aquifers. *Advances in Water Resource*: 52, 93-106, 2013.

Benson, D.A., A.L. Atchley, R.M. Maxwell, E. Poeter, H. Ibrahim, A. Dean, J. Revielle, M. Dogan, E. Major. Reply to Comment on "Comparison of Fickian and temporally nonlocal transport theories over many scales in an exhaustively sampled sandstone slab. *Water Resources Research*, 48, W07802, 5pp, doi: 10.1029/2012WR012004, 2012.

Atchley, A.L., and Maxwell, R.M. Influences of subsurface heterogeneity and vegetation cover on soil moisture, surface temperature, and evapotranspiration at hillslope scales. *Hydrogeology Journal*: 19(2), 289-305, doi:10.1007/s10040-010-0690-1, 2011.

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Education and Training

2014	University of Alaska Fairbanks, Ph.D. (Hydrology), Interdisciplinary Studies and Civil and Environmental Engineering, International Arctic Research Center, Water and Environmental Research Center.
2006	University of Victoria, M.Sc. (Hydrology), Water and Climate Impacts Research Center.
1999	University of Victoria: B.Sc. (Geography Co-op, with Distinction), 2000 Graduate

Research and Professional Experience

Current-2018	Scientist, Team Leader (acting), Applied Terrestrial Energy and Atmospheric Modeling (ATEAM), Computational Earth Science, Earth and Environmental Sciences (EES-16), Los Alamos National Lab, Los Alamos, NM
2018-2016	Director's Postdoctoral Fellow, Los Alamos National Lab, Los Alamos, NM
2016-2015	Postdoctoral Researcher, Los Alamos National Lab, Los Alamos, NM
2010-2006	Pacific Climate Impact Consortium (PCIC), Victoria B.C., Hydrologist, Team Lead 2009-2010

Awards and Honors

2013	International Arctic Research Center, October Scientist of the Month
2013	Alaska Weather Symposium, Top Student Presentation
2013	Western Snow Conference, Top Student Presentation
2012	EPSCOR Travel Award, University of Alaska Fairbanks
2011	PYRN Travel Award, University of Alaska Fairbanks
2009/12/15	Northern Research Basin conference, selected Canada/US participant

Grants and Fellowships

2018	LANL Labratory Directed Research and Development Exploratory Research proposal (660K, 3 years)
2018	NOAA Snow Remote Sensing (Experimental Framework for Testing the National Water Model: Operationalizing the Use of Snow Remote Sensing in Alaska, 669K, 2 years)
2017	LANL Labratory Directed Research and Devleopment Early Career Award (416K, 2 years)
2016	Director's Funded Postdoctoral Research Fellowship, Los Alamos National Lab
2013	American Water Resources Association, Alaska Section Scholarship, University of Alaska Fairbanks (2.5K)
2012-2014	Alaska Climate Science Center, Ph.D. Tuition Scholarship and Research Assistantship
2011	Alaska Climate Science Center, Ph.D. Tuition Scholarship and Research Assistantship
2010	National Science Foundation, Ph.D. Tuition Scholarship and Research Assistantship
2010-2012	Natural Sciences and Engineering Research Council of Canada, PGS-D Scholarship, University of Alaska Fairbanks (42K)
2004-2005	Natural Sciences and Engineering Research Council of Canada, Industrial Postgraduate Scholarship, University of Victoria (20.5K)
2004-2004	Northern Scientific Training Program, University of Victoria (3K)

2003 Environment Canada Science Horizons, University of Victoria (18K, Declined)
2003-2005 President's Research Scholarship, University of Victoria (2K)

Selected Publications
Peer Reviewed Journal Articles (19)

2018 Accepted Solander, K.C., **Bennett, K.E.**, Fleming, S.E., Gutzler, D.S., Hopkins, E.M., Middleton, R.S., Accepted. Interactions between climate change and complex topography drive observed streamflow changes in the Colorado River Basin. *Journal of Hydrometerology*.

2018 In Discussion **Bennett, K.E.**, Cherry, J.E., Balk, B., Lindsey, S. **Using MODIS estimates of fractional snow cover area to improve streamflow forecasts in Interior Alaska. In review,** *Hydrology and Earth System Sciences Discussion. https://www.hydrol-earth-syst-sci-discuss.net/hess-2018-96/.*

2018 **Bennett, K.E.**, Bohn, T.J., Solander, K., McDowell, N.G., Xu, C., Vivoni, E., Middleton, R.S. Climate change and climate-driven disturbances in the San Juan River sub-basin of the Colorado River, *Hydrology and Earth System Sciences*. 22 (1), 709-725. https://doi.org/10.5194/hess-22-709-2018.

2018 McDowell, N.G., **Bennett, K.E.**, Michaletz, S., Solander, K.C., Xu, C, Maxwell, R., Allen, C., Middleton, R.S. Predicting chronic climate-driven disturbances and their mitigation. *Trends in Ecology and Evolution*. 33, 1, 15-27. https://doi.org/10.1016/j.tree.2017.10.002.

2017 **Bennett, K.E.**, Urrego Blanco, J., Jonko, A., Bohn, T.J., Atchley, A.L., Urban, N.M., Middleton, R.S.: Global sensitivity of large-scale simulated water balance indicators under future climate change in the Colorado Basin, *Water Resources Research*. 54, 132-149. https://doi.org/10.1002/2017WR020471.

2017 Clark, M.P., Bierkens, M.F.P., Samaniego, L., Woods, R.A., Uijenhoet, R., **Bennett, K.E**., Pauwels, V.R.N., Cai, X., Wood, A.W., Peters-Lidard, C.D. The evolution of process-based hydrologic models: Historical challenges and the collective quest for physical realism, Hydrol. Earth Syst. Sci., 21, 3427–3440. https://doi.org/10.5194/hess-21-3427-2017.

2017 Huntsman, B.M., Faulk, J.A, Savereide, J.W., **Bennett, K.E.** The role of density-dependent and – independent processes in spawning habitat selection by salmon in an Arctic riverscape. PLoS ONE 12(5): e0177467. https://doi.org/10.1371/journal.pone.0177467

2017 Koster, R. D., Betts, A. K., Dirmeyer, P. A., Bierkens, M., **Bennett, K.E.**, Déry, S. J., Evans, J., Fu, R., Hernandez, F., Leung, L. R., Liang, X., Masood, M., Savenije, H., Wang, G., Yuan, X. Hydroclimatic Variability and Predictability: A Survey of Recent Research, Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2017-122.

2017 Solander, K.C., **K.E. Bennett**, R.S. Middleton. Historical shifts in streamflow extremes in the Colorado River Basin, *Journal of Hydrology: Regional Studies*, 12, 363-367. https://doi.org/10.1016/j.ejrh.2017.05.004.

2017 Smith, D.W., Welch, M., **Bennett, K.E.**, Padgham, J. Mohtar, R. Building a WEF Nexus Community of Practice (NCoP). *Current Sustainable/Renewable Energy Reports.* 4: 168. https://doi.org/10.1007/s40518-017-0080-6.

2015 **Bennett, K.E.**, Cannon, A.C., Hinzman, L. Historical trends and extremes in boreal Alaska river basins. *Journal of Hydrology*, *527*, 590-607. doi:10.1016/j.jhydrol.2015.04.065

2015 Wegner, C., **Bennett, K.E.**, de Vernal, A., Forwick, M., Fritz, M., Heikkilä, M., … Werner, K. Variability in transport of terrigenous material on the shelves and the deep Arctic Ocean during the Holocene. Special Issue for Arctic in Rapid Transition (ART) October 2012 Workshop, Sopot, Poland. *Polar Research*. 34. 24964, https://doi.org/10.3402/polar.v34.24964.

2015 **Bennett, K.E.**, Walsh, J.E. Spatial and temporal changes in indices of extreme precipitation and temperature for Alaska. *International Journal of Climatology, 35*(7), 1434–1452. doi: 10.1002/joc.4067.

2014 Semmens, K.A., Ramage, J., Apgar, J.D., **Bennett, K.E.**, Liston, G.E., Deeb, E. Passive microwave remote sensing of snowmelt and melt-refreeze using diurnal amplitude variations.

Chapter 13 in Remote Sensing of the Terrestrial Water Cycle, AGU Books. https://doi.org/10.1002/9781118872086.ch13.

2014 Schnorbus, M., Werner, A.T., **Bennett, K.E.** Impacts of climate change in three hydrologic regimes in British Columbia, Canada. *Hydrological Processes, 28*(3), 1170-1189.

2012 **Bennett, K.E.**, Werner, A.T., Schnorbus, M. Uncertainties in hydrologic and climate change impact analyses in headwater basins of British Columbia. *Journal of Climate, 25*(17), 5711-5730.

2010 **Bennett, K.E.**, Prowse, T.D. Northern Hemisphere geography of ice covered rivers. *Hydrological Processes, Scientific Briefing, 24*(2), 235-240. doi: 10.1002/hyp.7561.

2008 **Bennett, K.E.**, Gibson, J.J., McEachern, P M. Water-yield estimates for critical loadings assessment: comparisons of gauging methods versus an isotopic approach. *Canadian Journal of Fisheries and Aquatic Sciences, 65*(1), 83-99.

2008 Pike, R.G., Spittlehouse, D.L, **Bennett, K.E.**, Eggington, V.N., Tschaplinski, P.J., Murdock, Trevor Q., Werner, A.T. Climate change and watershed hydrology: Part I - Recent and projected changes in British Columbia. Part II - Hydrologic implications for British Columbia. *Streamline Watershed Management Bulletin, 11*(2), 1-13.

Peer Reviewed Books (12)

2018 In Review Shrestha, R.R., **Bennett, K.E.**, Peters, D.L., Yang, D. Hydrologic Extremes in Arctic Rivers and Regions: Historical Variability and Future Perspectives. Book Chapter on Arctic Hydrology. *Arctic Hydrology, Permafrost, and Ecosystem: Linkages and Interactions*. D. Yang and D. Kane (Editors).

2014 **K.E. Bennett.** *Changes in extreme hydroclimate events in interior Alaskan boreal forest watersheds*. Thesis. University of Alaska Fairbanks. http://gradworks.umi.com/36/70/3670470.html

2011 Schnorbus, M., **Bennett, K.E.**, Werner, A., Berland, A.J.R. *Hydrologic Impacts of climate change in the Peace, Campbell and Columbia watersheds, British Columbia, Canada.* Pacific Climate Impacts Consortium, University of Victoria: Victoria, B.C. pp. 157.

2010 Pike, R.G., **Bennett, K.E.**, Redding, T., Werner, A., Spittlehouse, D.L., Moore, R.D., … Campbell, D. Chapter 19: Climate Change Effects on Watershed Processes in British Columbia. In R.G. Pike, T. E. Redding, R. D. Moore, R. D. Winkler & K. D. Bladon (Eds.), *Compendium of forest hydrology and geomorphology in British Columbia.* B.C. Ministry of Forests and Range, For. Sci. Prog., and FORREX Forum for Research and Extension: Victoria, B.C. pp. 699-747.

2010 Schnorbus, M., **Bennett, K.E.**, Werner, A.T. *Quantifying the Water Resources impacts of Mountain Pine Beetle and associated salvage harvest operations across a range of watershed scales: Hydrologic Modeling of the Fraser River Basin.* Information Report B.C.-X-423. Canadian Forest Service, Pacific Forestry Centre: Victoria, B.C. pp. 64.

2009 Rodenhuis, D., **Bennett, K.E.**, Werner, A., Murdock, T.Q., Bronaugh, D. *Climate overview 2007: Hydro-climatology and future climate impacts in British Columbia.* Pacific Climate Impacts Consortium, University of Victoria: Victoria, B.C. pp. 132.

2008 Pike, R.G., Spittlehouse, D.L., **Bennett, K.E.**, Egginton, V.N., Tschaplinski, P.J., Murdock, T.Q., Werner, A.T. *A summary of climate change effects on watershed hydrology*. MFR Extension Note 87. B.C. Ministry of Forests and Range: Victoria, B.C.

2007 Walker, I., Sydneysmith, R., Allen, D., **Bennett, K.E.**, Bodtker, K., Bonin, D., ... Menounos, B. Chapter 8: British Columbia. In D. Lemmen, Warren, F., Lacroix, J., Bush, E. (Eds.), *From impacts to adaptation: Canada in a changing climate 2007.* www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/assessments/285. Accessed April 2014. Natural Resources Canada: Toronto, ON.

2007 Murdock, T.Q., **Bennett, K.E.**, Werner, A.T. *GVRD historical and future rainfall analysis update.* Pacific Climate Impacts Consortium, University of Victoria: Victoria B.C. pp. 52.

2007 Werner, A.T, **Bennett, K.E.**, Runnells, J., Lee, R., Rodenhuis, D. Menounos, B. *Preliminary analysis of climate variability and change in the Canadian Columbia River basin: Focus on* *water resources.* Murdock, T., J. Fraser, and C. Pearce (Eds.). Pacific Climate Impacts Consortium, University of Victoria: Victoria B.C. pp. 57.

2006 **Bennett, K.E.** *Regional hydrologic controls on acid-sensitivity of lakes in boreal Canada, an isotopic perspective.* Masters of Science Thesis, University of Victoria: Victoria, B.C.

2004 Paquet, P.C., Darimont, C., Nelson, J.R, **Bennett, K.E.** *A critical assessment of protection for key wildlife and salmon habitats under the proposed British Columbia Central Coast Land and Resource Management Plan.* Raincoast Conservation Society: Victoria, B.C. pp. 23.

In Preparation (4)

Bennett, K.E., Tidwell, V.C., Llewellyn, D., Behery, S., Barrett, L., Stansbury, M., R.S. Middleton. Threats to Food-Energy-Water Security for a Colorado River Basin Provisioning Watershed. *In prep for the Envionmental Research Letters.*

Bennett, K.E., Cherry, J.E., Hinzman, L. MODIS-derived snow melt timing in boreal warm-permafrost watersheds of Interior Alaska: validation, modeling and comparison. *In prep for Hydrology and Earth System Sciences.*

Bennett, K.E. Hinzman, L. Future changes in extreme events in interior Alaskan river basins.

Solander, K.C., **K.E. Bennett**, Fleming, S., Middleton, R.S. Can we predict future climate impacts on hydrology using historical data?

Invited Talks

Plenary Speaker (1)

2012 Bennett, K.E., Hinzman, L., Cherry, J.E., & Walsh, J.E. Changing Extreme Events in the Arctic and Sub-Arctic Regions of Alaska: Building Science Frameworks to Support Social and Economic Analysis of Climate Change Impacts on Extreme Events. ART-APECS Workshop, Sopot, Poland. 23-26 Oct.

Conferences (14)

2018 Bennett, K.E., Fortin, A., Miller, G., Middleton, R.S., Climate, Snow, and Infiltration Interactions on the Pajarito Plateau in Northern New Mexico. AMS Mountain Meterological Meeting. Santa Fe, NM. 29 Jun.

2018 Bennett, K.E., Fortin, A., Middleton, R.S., Climate, Snow, and Infiltration Interactions on the Pajarito Plateau in Northern New Mexico. Western Snow Conference. Albquerque, NM. 18 Apr.

2017 Bennett, K.E., Bohn, T.J., Solander, K., McDowell, N.G., Xu, C., Vivoni, E., and Middleton, R.S. Impacts of changing temperature, precipitation and land cover change in the Colorado River Basin. UCOWR/NIWR Annual Conference. Fort Collins, CO. 13 Jun.

2017 K.E. Bennett, V. Tidwell, T. Bohn, N. McDowell, C. Xu, C. Wilson, and R. Middleton. Impacts of Climate Change, Climate Extremes, and Climate-driven Disturbances on the Food-Energy-Water Nexus in the Colorado River Basin. Santa Fe Climate Conference. Santa Fe, NM. 6-10 Jan.

2016 Bennett, K.E. Climate change and integrated forest disturbance impacts in the Colorado River basin. Eric Wood Symposium. Princeton, NJ. 2-3 Jun.

2013 Bennett, K.E., Cannon, A.C., & Hinzman, L. Historical Changes and Future Projections of Extreme Hydro-climate Events in Interior Alaskan Watersheds. Paper presented at the 19th International Northern Research Basins Symposium and Workshop, Southcentral Alaska, USA 11-17 Aug.

2011 Bennett, K.E., Cherry, J.E., & Walsh, J.E. Climate change impacts on hydro power reservoir systems and fisheries. PACMAN: Cyberinfrastructure for Discovering Climate Change Impacts in Water Resources Across Alaska and the Hawaiian Islands, Honolulu, HI. 13-14 Jan.

2010 Bennett, K.E., Werner, A.T., & Schnorbus, M. Assessing Hydrologic Impacts on Water Resources in B.C. Pacific Northwest Climate Science Conference, Portland State University, Portland, OR. 15-17 Jun.

2009 Bennett, K.E. Uncertainties in Hydrologic and Climate Change Impact Analyses in a Headwater Basin of the Peace River Watershed. Proceedings and Presentation. Paper presented at the 17th International Northern Research Basins Symposium and Workshop, Iqaluit-Pangnirtung-Kuujjuaq, Canada. 12-18 Aug.

2008 Bennett, K.E., Caya, D., Rodenhuis, D.R., & Smith, D. Monitoring and Prediction of Western Water. Improving Water Security through Integrated Observation and Prediction Networks, Canmore, AB. 8-10 Dec.

2008 Bennett, K.E., & Murdock, T.Q. Changing Precipitation Patterns in British Columbia. B.C. Water and Waste Association, Annual Conference, Whistler, B.C. 30 Apr.

2008 Bennett, K.E., Nelitz, M., Schnorbus, M., Werner, A.T., McGuire, M., Rodenhuis, D.R., & Hamlet, A. PCIC Inputs to Climate Change and Salmon in the Fraser River Basin. Future Forests Ecosystem Initiative, Cranbrook, B.C. 8 Oct.

2008 Bennett, K.E., Werner, A.T., Murdock, T.Q., & Beck, B. Changing Precipitation Patterns in Vancouver, B.C. ACT – Extreme Events: Municipalities Adapting to Climate Change. Simon Fraser University, Vancouver, B.C. 2 Jun.

2005 Bennett, K.E., & Gibson, J.J. Isotopic Estimation of Water Yields for Ungauged Catchments: Linking throughflow, runoff and residence time to landscape response units in the Boreal forest, northeastern Alberta, Canada. 12th IAHS Scientific Assembly, Fos do Iguacu, Brazil. 3-9 Apr.

Meetings and Workshops (12)

2017 K.E. Bennett. The National Water Model LANL-NCAR Workshop. Los Alamos, NM, 10 May.

2017 K.E. Bennett and R. Middleton. FEW Nexus Workshop on Integrated Science, Engineering, and Policy: A Multi Stakeholder Dialogue. College Station, TX. 26-27 Jan.

2016 Bennett, K.E., Middleton, R.S., McDowell, N. Xu, C., Bohn, T. & E. Vivoni. Climate change, forest disturbances and water management impacts and in the San Juan / Chama River System. Climate Research Symposium and Climate Adaptation Roundtable. Santa Fe, NM, 15-16 Nov.

2015 Bennett, K.E. and Cherry, J.E., MODIS Remote Sensing to Examine Snow Melt and Streamflow Properties in Interior Subarctic Boreal Alaskan Watersheds. OCONUS Meeting, Anchorage, AK, USA. 15 May.

2014 Bennett, K.E., Hinzman, L., Walsh, J.E., & Cannon, A.C. Extreme events in Interior Alaskan watersheds. Extreme weather and hydrology: Lessons learned from the western Canadian floods of 2013 and others., Canmore, AB. 11-12 Feb.

2013 Bennett, K.E., Hinzman, L, Cherry, J E, Walsh, J., Hiemstra, C., & Lindsey, S. Estimating historical and future changes in extreme hydro-climate events in Interior Alaskan watersheds. Proving Ground All Hands Telcon Meeting. 14 Jan.

2013 Cherry, J., Bennett, K.E., & Tedesche, M. Hydrology, Hydropower, and Remote Sensing in Alaska. OCONUS Proving Ground Meeting. Anchorage, AK. 17-21 Jun.

2012 Bennett, K.E., Cherry, J.E., Hinzman, L, Walsh, J.E., & Hiemstra, C. Spring Snowmelt Drivers in Interior Alaskan Watersheds. NOAA Satellite Science Week. GOES-R Proving Ground Status, Kansas City, MO. 30 Apr-4 May.

2011 Bennett, K.E. Update to the National Weather Service's River Forecast Center, MODIS Snow Cover Fraction Integration into CHPS. River Forecast Center Meeting, Anchorage, AK. 25 Aug.

2010 Bennett, K.E., Rodenhuis, D.R., Werner, A.T., Murdock, T.Q., & Bronaugh, D. Hydro-climatology and Future Climate Impacts in British Columbia. B.C. Hydro Review of Climate Overview and Hydrology Modeling Workshop, Burnaby, B.C. 20 Apr.

2009 Bennett, K.E., Schnorbus, M., Werner, A.T., Caya, D., & Rodenhuis, D.R. Variable Infiltration Capacity Hydrologic Modeling Project - Recent accomplishments, challenges, and future directions. Hydrology Modeling in Alaska, International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK. 30 Oct.

2009 Bennett, K.E., Schnorbus, M., & Werner, A.T. PCIC Hydrologic Modeling Program: 2050s Projections of Snow Water Equivalent for the Fraser River Basin, CHSH/CWRA Discussion Group Meeting. Dec 8.

Seminar Series (7)

2015 Bennett, K.E. Impacts of changing forest disturbance and climate on streamflow in the Colorado River basin, U.S.A., National Center for Atmospheric Research, CO. 28 Sep.

2015 Bennett, K.E. Changing extreme streamflow patterns in boreal forest watersheds of Alaska. ACCAP Webinar/ LANL EES-16 Brownbag 23 Jun.

2012 Bennett, K.E. Characterizing Spring Snowmelt in the Boreal Forest of Interior Alaska. Pacific Climate Impacts Consortium Seminar Series, University of Victoria, Victoria, B.C. 10 Oct.

2009 Bennett, K.E., Werner, A.T., Schnorbus, M., Nienaber, P., Bronaugh, D., Rodenhuis, D.R., Berland, A.J. Uncertainties in Hydrologic and Climate Change Impact Analyses in a Headwater Basin of the Peace River Watershed. Canadian Center for Climate Modeling and Analysis (CCCma) Seminar, University of Victoria. Victoria, B.C. 12 Nov.

2009 Bennett, K.E., Schnorbus, M., Werner, A.T., Nienaber, P., & Rodenhuis, D.R. Hydrologic Modeling, Applying the Variable Infiltration Capacity Model in B.C. Watersheds. Canadian Center for Climate Modeling and Analysis (CCCma) Seminar, University of Victoria. Victoria, B.C. 15 Jan.

2008 Bennett, K.E. Hydrologic Impacts of Climate Change in B.C. Climate Impacts Group Seminar Series, University of Washington., Seattle, WA. 17 Apr.

2007 Bennett, K.E., & Murdock, T.Q. Historical trends in temperature and precipitation in B.C. Canadian Center for Climate Modeling and Analaysis Seminar, University of Victoria, Victoria, B.C. 18 Oct.

Conference Activity

Sessions Organized (1)

2010 Bennett, K.E., Music, B., Caya, D., & Rodenhuis, D. Uncertainty in climate change impacts to the water cycle (Part 1 and 2). Joint Canadian Meterological and Oceanographic Society - Canadian Geophysical Union. Session 1B03/1C04. Ottawa, ON. 31 May-4 Jun.

Presentations (23)

2017 K.E. Bennett, N. McDowell, C. Xu, and R. Middleton. The sensitivity of the Colorado River basin to temperature, precipitation and land cover change. Canadian Geophysical Union. Vancouver, BC, Canada. 28-31 May.

2016 K.E. Bennett, V. Tidwell, T. Bohn, N. McDowell, C. Xu, C. Wilson, and R. Middleton. On the Edge: the Impact of Climate Change, Climate Extremes, and Climate-driven Disturbances on the Food-Energy-Water Nexus in the Colorado River Basin. American Geophysical Union Fall Meeting. Session GC43C, San Francisco, CA. 12-16 Dec.

2015 Bennett, K.E., Middleton, R., McDowell, N., Xu, C., Wilson, C. Influence of forest disturbance on Hydrologic Extremes in the Colorado River basin. American Geophysical Union Fall Meeting. Session H24B, San Francisco, CA. 14-18 Dec.

2013 Bennett, K.E., Cherry, J.E., Hiemstra, C., & Bolton, B. Comparison of snow melt properties across multiple spatial scales and landscape units in interior sub-Arctic boreal Alaskan watersheds. American Geophysical Union Fall Meeting. Session C44B, San Francisco, CA. 9-13 Dec.

2013 Bennett, K.E., Hinzman, L., Cherry, J., Walsh, J.E., & Lindsey, S. Historical changes and future projections of extreme hydro-climate events in Interior Alaskan watersheds. Alaska Weather Symposium, University of Alaska Fairbanks. Fairbanks, AK. 13 Mar.

2013 Bennett, K.E., Lindsey, S., Hinzman, L., & Walsh, J.E. Historical changes and future projections of extreme hydro-climate events in Interior Alaskan watersheds. AWRA Alaska Section Annual Conference, Anchorage, AK. 6 Mar.

2012 Bennett, K.E., Cherry, J.E., Hinzman, L., Walsh, J.E., Hiemstra, C., & Lindsey, S. Spring Snowmelt Drivers in Interior Alaskan Watersheds. Western Snow Conference, Anchorage, AK. 21-24 May.

2012 Bennett, K.E., Hinzman, L., Cherry, J.E., Walsh, J.E., Hiemstra, C., & Lindsey, S. Estimating historical and future changes in extreme hydro-climate events in Interior Alaskan watersheds. American Geophysical Union Fall Meeting. Session B31I. San Francisco, CA. 3-7 Dec.

2011 Bennett, K.E., Hinzman, L., Cherry, J.E., & Walsh, J.E. Understanding the impacts of changing hydro-climate extremes to hydropower resources in Southeast Alaska. AWRA Alaska Section Annual Conference, Chena Hot Springs, AK. 4-6 Apr.

2011 Bennett, K.E., Hinzman, L., Cherry, J.E., Walsh, J.E., Hiemstra, C., Balk, B., & Lindsey, S. Hydro-climatology of a discontinuous permafrost watershed in Interior Alaska. American Geophysical Union Fall Meeting. Session C54A, San Francisco, CA. 5-9 Dec.

2010 Bennett, K.E., Werner, A.T., & Schnorbus, M. Uncertainties in Hydrologic and Climate Change Impact Analyses in Headwater Basins of British Columbia. Joint Canadian Meterological and Oceanographic Society - Canadian Geophysical Union, Ottawa, ON. 31 May-4 Jun.

2010 Werner, A.T., Bennett, K.E., Schnorbus, M. Sensitivity of Projected Streamflow Changes in a Small Coastal Hybrid Watershed to Selected GCMs, Emissions Scenarios, Model Runs and Downscaling Approaches. Joint Canadian Meterological and Oceanographic Society - Canadian Geophysical Union, Ottawa, ON. 31 May-4 Jun.

2010 Braun, M., Bennett, K.E., Sushama, L., Caya, D. Uncertainties in the assessment of climate change impacts at the watershed level using Canadian RCM projections: The Peace River Basin, B.C. Joint Canadian Meterological and Oceanographic Society - Canadian Geophysical Union, Ottawa, ON. 31 May-4 Jun.

2010 Bennett, K.E., Werner, A.T., Schnorbus, M., & Berland, A.J.R. Climate Change Impacts to Hydro Power Reservoir Systems in British Columbia, Canada: Modeling, Validation and Projection of Historic and Future Streamflow and Snowpack. American Geophysical Union Fall Meeting. Session C13C., San Francisco, CA. 13-17 Dec.

2009 Bennett, K.E., Werner, A.T., Salathé, E.P., Schnorbus, M., Nelitz, M., & D., Rodenhuis. Hydrologic Modeling for Climate Change Impacts Analysis of Shifts in Future Hydrologic Regimes. Joint American Geophysical Union - Canadian Geophysical Union Assembly, Toronto, ON. 24-27 May.

2009 Bennett, K.E., Werner, A.T., Schnorbus, M., Salathé, Jr. E., & Nelitz, M. Regional Impacts of Climate Change in the Cariboo Chilcotin Region. Joint American Geophysical Union - Canadian Geophysical Union Assembly, Toronto, ON. 24-27 May.

2009 Schnorbus, M.A., Bennett K.E., Werner, A.T. Climate change, bark beetles, the dieback of the pine forest, and Fraser River stream flows. 8th University of Washington Program on Climate Change (PCC) Summer Institute, Climate Impacts on the Pacific Northwest: Present, Past, and Future, Friday Harbor Laboratories, San Juan Island, WA. 14-17 Sep.

2009 Schnorbus, M., Bennett, K.E., Werner, A.T. Quantifying the peak flow impacts of mountain pine beetle and salvage harvest in the Fraser River drainage, pp. 22-23 in Mountain Pine Beetle and Water Management. Workshop Proceedings of the Forum for Research and Extension in Natural Resources Society (FORREX), Kelowna, B.C. 2 Jun.

2009 Schnorbus, M.A., Bennett, K.E., Werner, A.T. Quantifying the hydrologic impacts of mountain pine beetle and salvage harvest in the Fraser River basin, British Columbia, Canada. Joint American Geophysical Union - Canadian Geophysical Union Assembly, Toronto, ON. 24-27 May.

2008 Bennett, K.E., Deems, J., & Hamlet, A. Developing a high resolution long term gridded climate surface for British Columbia. Canadian Geophysical Union, Banff, AB. 12-14 May.

2008 Bennett, K.E., Werner, A.T., & Bronaugh, D. Snow Water Equivalent (SWE) Trends in Pacific North America. Canadian Geophysical Union, Banff, AB. 12-14 May.

2006 K.E., Bennett, J.J., Gibson, & McEachern, P. Regional hydrologic, physical and chemical interactions of Boreal Plains lakes systems, NE Alberta, Canada. Canadian Geophysical Union, Banff, AB. 15 May.

2005 Bennett, K.E., & Gibson, J.J. An approach to critical loadings in northern Alberta: Water balance of Boreal landscapes. Canadian Geophysical Union., Banff AB. 12 May.

Posters (6)

2017 Katrina, K.E., Urrego-Blanco, J., Jonko, A., Vano, J., Newman, A., Bohn, T.J., and Middleton, R.S. Colorado River basin sensitivity to disturbance impacts. American Geophysical Union Fall Meeting. New Orleans, LA. 12-16 Dec.

2014 Bennett, K.E., Understanding future projected changes and historical trends in extreme climate and streamflow events in warm boreal permafrost basins of Interior Alaska. American Geophysical Union Fall Meeting. Session C11C, San Francisco, CA. 15-19 Dec.

2011 Schnorbus, M., Bennett, K.E., & Werner, A.T. Quantifying the Hydrological Impacts of the Mountain Pine Beetle and Salvage Harvesting on the Fraser River Basin, British Columbia, Canada. Poster Presentation. American Meteorological Society, Seattle, WA. 22-27 Jan.

2011 Werner, A.T., Bennett, K.E., Schnorbus, M., & Berland, A.J.R. Sensitivity of Projected Streamflow Changes to Future Scenarios in Three Hydrologic Regimes in B.C. Poster Presentation. American Meteorological Society, Seattle, WA. 22-27 Jan.

2009 Bennett, K.E., Werner, A.T., & Schnorbus, M. Uncertainties in Hydrologic and Climate Change Impact Analyses in Major Watersheds in British Columbia, Canada. Poster GC41B-0772. American Geophysical Union., San Francisco, CA. 14-18 Dec.

2008 Bennett, K.E., Bronaugh, D., & Rodenhuis, D.R. Observed SWE Trends and Climate Analysis for Pacific North America. Poster C21C-0578. American Geophysical Union., San Francisco, CA. 15-19 Dec.

Campus Talks (6)

2015 Bennett, K.E. Impacts of changing forest disturbance and climate on streamflow in the Colorado River basin, U.S.A., University of Colorado Boulder, CO. 30 Sep.

2014 Bennett, K.E. The impact of climate change on extreme hydro-climate events in Interior Alaska. University of Alaska Fairbanks Regents Visit to the International Arctic Research Center, Fairbanks, AK. 17 Jan.

2014 Bennett, K.E., Hinzman, L, Walsh, J., & Cannon, A.C. Historical changes in extreme streamflow in Interior Alaskan River Basins. Water and Environmental Research Center, University of Alaska Fairbanks, Fairbanks, AK. 5 Apr.

2013 Bennett, K.E. The impact of climate change on extreme hydro-climate events in Interior Alaskan watersheds. Poster Presentation. Alaska Climate Science Center Young Scientists Gathering, Fairbanks, AK. 1 Nov.

2011 Bennett, K.E. Influence of Climate Change on Regional Hydrologic Trends and Extremes in the Arctic. USGS Alaska Climate Science Center, Fairbanks, AK. 10 Sep.

2011 Bennett, K.E., Hinzman, L, Cherry, J E, Hiemstra, C., & Walsh, J.E. Impacts of changing hydro-climate extremes in Interior Alaska. Review of the Cooperative Institute for Alaska Research (CIFAR), Fairbanks, AK. 27-28 Jul.

Technical Documents

Research Reports (5)

2018 Miller, G., Bennett, K.E., Bruggman, A., Jonko, A. Atchley, A., Middleton, R.S. Pajarito Plateau Climate Impacts (PCI): Estimating the Impacts of Climate and Vegetation Changes on Infiltration. Internal LANL Report. September, 2018. 60 pp.

2017 Pajarito Regional Climate Change Impacts on Water. Internal LANL Report. September 2017. 38 pp.

2014 Heinrichs, T., Cherry, J.E., Bennett, K.E., & Zui, J. CIFAR Annual Report: Cooperative Alaska Research and Satellite Data Services. University of Alaska Fairbanks: Fairbanks, AK. 10 pp.

2006 Bennett, K., Gibson, J.J., Birks, S.J., & Tattrie, K. Isotope tracing of water yield and chemical loadings on acid sensitive aquatic ecosystems in the Alberta Oil Sands Region. 2005 Progress and Summary Report on CEMA Project 2004-0033, Technical Report prepared for the Cumulative Environmental Management Association: Edmonton, AB. 10 pp.

2004 Bennett, K., & Gibson, J.J. Water balance techniques using stable isotopes: Acid sensitive lakes programme, NE Alberta, 2003-2004. Interim Report 1. Cumulative Environmental Management Agency: Edmonton, AB. 23 pp.

Applied Research Reports (7)

2009 Bennett, K.E. Status Report VIC Hydrologic Modeling Project (January 2008 – June 2008). Pacific Climate Impacts Consortium, University of Victoria: Victoria, B.C. 10 pp.

2009 Bennett, K.E., Werner, A.T., Rodenhuis, D.R., & Caya, D. Workplan for Hydrologic Modeling: Implementation of the VIC Hydrologic Model for B.C. Watersheds. Pacific Climate Impacts Consortium, University of Victoria: Victoria, B.C. 10 pp.

2009 Bennett, K.E., Werner, A.T., & Schnorbus, M. Report on Training: Implementation of the VIC Hydrologic Model (January 2008 – June 2008). Pacific Climate Impacts Consortium, University of Victoria: Victoria, B.C. 5 pp.

2009 Bennett, K.E., Werner, A.T., Schnorbus, M., & Berland, A.J.R. Status Report: VIC Hydrologic Modeling Project (July 2008 to December 2008). Pacific Climate Impacts Consortium, University of Victoria: Victoria, B.C. 19 pp.

2009 Nelitz, M., Porter, M., Bennett, K.E., Werner, A.T., Bryan, K., Poulsen, F., & Carr, D. Part II. Summary of results. In ESSA Technologies & Pacific Climate Impacts Consortium (Eds.), Evaluating the vulnerability of freshwater fish habitats to the effects of climate change in the Cariboo-Chilcotin. Fraser Salmon and Watersheds Program, B.C. Ministry of Environment, and Pacific Fisheries Resource Conservation Council: Vancouver, B.C. 20 pp.

2009 Nelitz, M., Porter, M., Bennett, K.E., Werner, A.T., Bryan, K., Poulsen, F., & Carr, D. Part I. Summary of technical methods. In ESSA Technologies & Pacific Climate Impacts Consortium (Eds.), Evaluating the vulnerability of freshwater fish habitats to the effects of climate change in the Cariboo-Chilcotin. Fraser Salmon and Watersheds Program, B.C. Ministry of Environment, and Pacific Fisheries Resource Conservation Council.: Vancouver, B.C. 26 pp.

2007 Abbott, C.L., K.E. Bennett, K. Campbell, Murdock, T.Q., & Swain, H. Workshop Summary Report - Forest Pests and Climate Change Symposium Pacific Climate Impacts Consortium, University of Victoria: Victoria, B.C. 14 pp.

Teaching Experience

University of Alaska Fairbanks, Fairbanks, AK, Guest Lecturer

2012 Spring Snowmelt Drivers in Interior Alaskan Watersheds. Ohio Wesleyan University, Arctic Summer School.

2012 An Example of R Efficient Programming. Introduction to R Class.

2012 Climate change impacts to extreme hydro-climate events in Interior Alaskan Watersheds. IARC Summer School.

Camosun College, Victoria, B.C., Guest Lecturer

2009 Introduction to Physical Geography: Hydrologic Modeling - Applying the Variable Infiltration Capacity Model in B.C. Watersheds. 6 Apr.

2006 Introduction to Physical Geography: Climate Change - Impacts to Hydrology and Water Resources in B.C. 15 Oct.

Training Seminars

2014 Introduction to R. Arctic Region Supercomputing Center Training Series, University of Fairbanks, Fairbanks, AK. 20 Jun.

2013 Intro to R Programming using the Arctic Region Supercomputing Center (ARSC). Arctic Region Supercomputing Center Training Series, University of Fairbanks, Fairbanks, AK, May 21 Mar.

2002 Tree Stewardship Atlas Mapping. Training Seminar for the Canadian Wildlife Service, Delta, B.C. 20 Jun.

2002 3D Bathymetric Mapping Data Collection and Methods. Training Seminar for B.C. Hydro, Burnaby, B.C. 14-16 Oct.

Mentoring Experience

2018 Los Alamos National Lab, Los Alamos, NM. Undergraduate Mentor, Post-masters mentor.

2017-2015 Los Alamos National Lab, Los Alamos, NM. High school, Masters and Post-Masters students

2006-2009 Pacific Climate Impacts Center. Coop students and technicians.

Research Experience

Research Assistantships

2010-2014 Graduate Research Assistant, International Arctic Research Center, University of Alaska Fairbanks

2003 -2006 Graduate Research Assistant, Water and Climate Change Impacts Research Center/Environmental Canada, Department of Geography, University of Victoria

Other Professional Work

2002 -2006 Geostreams Consulting, Victoria B.C., President, GIS Specialist

1999 - 2001 Latitude Geographics Group Ltd., Victoria B.C., Project Manager, GIS Specialist

Collaborators

University of Alaska Fairbanks

National Center for Atmospheric Science (NCAR), visiting scientist 2015-2017

Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL)

Arizona State University

Service Activities

Peer Review

Water Resources Research

Local Environment

Atmosphere-Ocean

Journal of Hydrology (top contributor 2015)

Hydrologic Processes

Climatic Change

Journal of American Water Resources Association

To Profession and Community

Organizing Committee, Seminar Lead, America Meteorological Society, Mountain Meteorological Meeting, Santa Fe, NM, June 2018

Science Café, Los Alamos National Lab, 2016-2018

American Water Resources Association, Alaska Section, Northern Director, 2012-2014

American Water Resources Association, Alaska Section, Board Member, 2012-2014

International Arctic Research Center Seminar Series, Facilitator, University of Alaska Fairbanks, 2011-2012

Media Coverage

2013 NOAA Cooperative Institute "Hot Item" Article. *CIFAR Research Used by National Weather Service to Better Predict Flooding*. http://ci.noaa.gov/InTheNews/HotItems/TabId/722/ArtMID/1835/ArticleID/10123/CIFAR-Research-Used-by-National-Weather-Service-to-Better-Predict-Flooding.aspx. 17 Jun.

Related Professional Skills

Hydrological Modeling

Variable Infiltration Capacity (VIC), SAC-SMA (CHPS/FEWS modeling framework), SNOW17, SWAT, knowledge/training of HEC-RAS, CRHM, WaSiM, and SnowModel.

Statistical Analysis

Data management and statistical analysis of large data sets from hydrologic models, global and regional climate models, meteorological and hydrological data, and remote sensing data.

Programming

Highly proficient in R (R-Project), ArcGIS, Bash, C Shell, Python geoprocessing, cluster and high performance computing environments.

Leadership and Team Work

Leadership training, business and contract management
Ability to work closely with others in a team environment

Professional Memberships

American Geophysical Union, 2007-present
Alaska Water Resources Association, 2011-2015
Permafrost Young Researcher Network, 2012-2015
United States Permafrost Association, 2012-2015

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Education and Training

2009	University of Illinois at Urbana-Champaign, Statistics, MS
2007	Parkland College, Accounting, No Degree
2006	Chinese Academy of Sciences, Ecology, PhD
2003	Northeast Normal University, China, Environmental Sciences, MS
2000	Northeast Normal University, China, Ecology

Research and Professional Experience

2017-present	Research Technologist III, Statistical Modeling and Analysis, Earth and Environmental Sciences Division, Los Alamos National Laboratory. Data management; statistical modeling on snow distribution for Teller site in Alaska; develop interactive application for isotope analysis using stable isotope mixing models.
2013-2017	Economist and Staff Manager, Budget Projection, Medical Assistance Division, Human Services Department of New Mexico. Data management, statistical modeling for budget project, staff management and evaluation.
2010-2013	Postdoc, Data Analysis and Statistical Modeling, Earth and Environmental Sciences Division, Los Alamos National Laboratory. Statistical analysis to characterize the natural variability and detect the long term trend in thermokarst lake areas for Yukon Flats in Alaska.
2010 Jun.-Aug.	Intern, Statistical Modeling, The Travelers Companies. Data management, development of performance evaluation for independent agencies using statistical modeling.
2008-2009	Research Assistant, Data Management and Statistical Modeling. Kinesiology and Community Health Department, University of Illinois at Urbana-Champaign. Statistical modeling to identify factors that affect child dental health and child obesity.

Selected Publications

M. Chen, J. C. Rowland, C. J. Wilson, G. L. Altmann, S. P. Brumby. 2013. The importance of the natural variability of lake areas on detection of permafrost degradation: a case study in the Yukon Flats, Alaska. *Permafrost and Periglacial Processes*. DOI: 10.1002/ppp.1783. 24(3): 224-240.

C. Xu and **M. Chen**. 2013. Section 5.1. Landscape ecosystem. In: Remote Sensing of Natural Resources, G. Wang and Q. Weng (eds). Taylor & Francis Group.

M. Chen, J. C. Rowland, C. J. Wilson, G. L. Altmann, S. P. Brumby. 2012. Temporal and spatial pattern of thermokarst lake area changes at Yukon Flats, Alaska. *Hydrological Processes*. DOI: 10.1002/hyp.9642. 28(3): 837-852.

Y. Zhang, **M. Chen**, W. Zhou, C. Zhuang. 2010. Evaluating Beijing's human carrying capacity from the perspective of water resource constraints. *Journal of Environmental Science.* 22(8): 1297-1304.

M. Chen, C. Xu, R. Wang. 2007. Key Natural Impacting Factors of China's Human Population Distribution. *Population and Environment.* 28(3): 187-200.

M. Chen, R. Wang, L. Zhang, C. Xu. 2006. Temporal and spatial assessment on natural resources use in China using ecological footprint method. *The International Journal of Sustainable Development and World Ecology.* 13(4): 255-268.

J. Feng, **M. Chen**, Z. Li, S. Zhang, H. Zhao, J. Zhou. 2002. Research on Correlation Between Echolocation Sounds and Morphological Features Among Three Kinds of Bats (English Version). *Nature Science Progression.* 12(9): 673-678.

Collaborators

Bob Bolton (UAF), Bob Busey (UAF), Go Iwahana (UAF), James Syme (RAND Corporation)

Dylan R. Harp
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Los Alamos National Laboratory, Earth and Environmental Sciences Division
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Education and Training

2009	University of New Mexico, Civil Engineering, PhD
2006	University of New Mexico, Civil Engineering, MS
2004	University of New Mexico, Civil Engineering, BS, Summa Cum Laude
1994	Southeastern Illinois College, Forestry Technology, AAS

Research and Professional Experience

2010–present	Research Scientist, LANL EES Division: NGEE Arctic Modeling Team Lead; NMSBA Geothermal Project PI; National Risk Assessment Partnership (Task 2 Lead); LYNM Modeling Lead; DTRA Gas Seepage Modeling Lead; DTRA Non-Proliferation (LANL PI).
2009–2010	Postdoctoral Associate, LANL EES Division: Groundwater Flow and Transport at the LANL Site.
2006–2008	Graduate Research Assistant, LANL EES Division: Groundwater Flow and Transport at the LANL Site.
2004–2006	Graduate Research Assistant, University of New Mexico, Department of Civil Engineering: Evaporation from Bare Soil in the Rio Grande Riparian Zone.

Publications

Harp, D.R., John P Ortiz, Sachin Pandey, Satish Karra, Dale Anderson, Chris Bradley, Hari Viswanathan, and Philip H Stauffer. Immobile pore-water storage enhancement and retardation of gas transport in fractured rock. *Transport in Porous Media*, 124(2): 369; 394, 2018.

Charles J Abolt, Michael H Young, Adam L Atchley, and Dylan R Harp. Microtopographic control on the ground thermal regime in ice wedge polygons. *The Cryosphere*, 12(6):1957, 1968, 2018.

Bailian Chen, Dylan R Harp, Youzuo Lin, Elizabeth H Keating, and Rajesh J Pawar. Geologic CO_2 sequestration monitoring design: A machine learning and uncertainty quantification-based approach. *Applied Energy*, 225:332; 345, 2018.

George D Guthrie, Rajesh J Pawar, J William Carey, Satish Karra, Dylan R Harp, and Hari S Viswanathan. The mechanisms, dynamics, and implications of self-sealing and CO_2 resistance in wellbore cements. *International Journal of Greenhouse Gas Control*, 75:162, 179, 2018.

Harp, D.R., Philip H Stauffer, Daniel OMalley, Zunsheng Jiao, Evan P Egenolf, Terry A Miller, Daniella Martinez, Kelsey A Hunter, Richard S Middleton, Jeffrey M Bielicki, et al. Development of robust pressure management strategies for geologic CO_2 sequestration. *International Journal of Greenhouse Gas Control*, 64:43; 59, 2017.

Maruti Kumar Mudunuru, Satish Karra, Dylan Robert Harp, GD Guthrie, and Hari S Viswanathan. Regression-based reduced-order models to predict transient thermal output for enhanced geothermal systems. *Geothermics*, 70:192; 205, 2017.

Elizabeth Keating, Diana Bacon, Susan Carroll, Kayyum Mansoor, Yunwei Sun, Liange Zheng, Dylan Harp, and Zhenxue Dai. Applicability of aquifer impact models to support decisions at CO_2 sequestration sites. *International Journal of Greenhouse Gas Control*, 52:319, 330, 2016.

Adam L Atchley, Ethan T Coon, Scott L Painter, Dylan R Harp, and Cathy J Wilson. Influences and interactions of inundation, peat, and snow on active layer thickness. *Geophysical Research Letters*, 43(10):5116; 5123, 2016.

Harp, D.R., AL Atchley, SL Painter, ET Coon, CJ Wilson, VE Romanovsky, and JC Rowland. Effect of soil property uncertainties on permafrost thaw projections: a calibration-constrained analysis. The Cryosphere, 10(1):341; 358, 2016.

Atchley, A., S.L. Painter, D.R. Harp, E.T. Coon, C.J. Wilson, A. Liljedahl, V. Romanovsky, (accepted for online comment) Using Field Observations to Inform Thermal Hydrology of Permafrost Dynamics with ATS (v0.83). *Geoscientific Model Development.*

Jordan, A. B., Stauffer, P. H., Harp, D. R., Carey, J. W., & Pawar, R. J. (2015). A response surface model to predict CO 2 and brine leakage along cemented wellboreS. *International Journal of Greenhouse Gas Control*, 33, 27-39.

Harp, D. R., Stauffer, P. H., Mishra, P. K., Levitt, D. G., & Robinson, B. A. (2014). Thermal Modeling of High-Level Nuclear Waste Disposal in a Salt Repository. *Nuclear Technology*, 187(3), 294-307.

Harp, D. R., & Vesselinov, V. V. (2013). Contaminant remediation decision analysis using information gap theory. *Stochastic Environmental Research and Risk Assessment*, 27(1), 159-168.

Harp, D.R., & and Vesselinov, V.V. (2013). Accounting for the inuence of aquifer heterogeneity on spatial propagation of pumping drawdown. *Journal of Water Resource andHydraulic Engineering*, 2(3).

Vesselinov, V. V., & Harp, D. R. (2012). Adaptive hybrid optimization strategy for calibration and parameter estimation of physical process models. *Computers & Geosciences*, 49, 10-20.

Harp, D. R., & Vesselinov, V. V. (2012). An agent-based approach to global uncertainty and sensitivity analysis. *Computers & Geosciences*, 40, 19-27.

Harp, D. R., & Vesselinov, V. V. (2012). Analysis of hydrogeological structure uncertainty by estimation of hydrogeological acceptance probability of geostatistical models. *Advances in Water Resources*, 36, 64-74.

Harp, D. R., & Vesselinov, V. V. (2011). Identification of Pumping Influences in Long-Term Water Level Fluctuations. *Groundwater*, 49(3), 403-414.

Harp, D. R., & Vesselinov, V. V. (2010). Stochastic inverse method for estimation of geostatistical representation of hydrogeologic stratigraphy using borehole logs and pressure observations. *Stochastic Environmental Research and Risk Assessment*, 24(7), 1023-1042.

Harp, D. R., Taha, M. R., & Ross, T. J. (2009). Genetic-fuzzy approach for modeling complex systems with an example application in masonry bond strength prediction. *Journal of Computing in Civil Engineering*, 23(3), 193-199.

Harp, D. R., Dai, Z., Wolfsberg, A. V., Vrugt, J. A., Robinson, B. A., & Vesselinov, V. V. (2008). Aquifer structure identification using stochastic inversion. *Geophysical Research Letters*, 35(8).

Harp, D. R., Taha, M. R., Stormont, J. C., Farfan, E., & Coonrod, J. (2007). An evaporation estimation model using optimized fuzzy learning from example algorithm with an application to the riparian zone of the Middle Rio Grande in New Mexico, USA. Ecological Modeling, 208(2), 119-128.

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Education and Training

1996	PhD, Mathematics, University of British Columbia
1990	M. Eng., Physics, McMaster University
1988	B. Eng., Physics, McMaster University

Research and Professional Experience

2015/10 – present	Deputy Group Leader, Applied Mathematics and Plasma Physics, Los Alamos National Laboratory.
2008/12–2015/09	Scientist 4, Team Leader, Mathematical Modeling and Uncertainty Quantification Applied Mathematics and Plasma Physics, Los Alamos National Laboratory.
1998/10–2008/11	Technical Staff Member, Applied Mathematics and Plasma Physics, Los Alamos National Laboratory.

Selected Publications

D. Dwivedi, C. I. Steefel, B. Arora, M. Newcomer, J. D. Moulton, B. Dafflon, B. Faybishenko, P. Fox, P. Nico, N. Spycher, R. Carroll, and K. H. Williams. Geochemical exports to river from the intrameander hyporheic zone under transient hydrologic conditions: East River mountainous watershed, Colorado. Water Resour. Res., 54, 2018.

A. Reisner, L. Olson, and J. D. Moulton. Scaling structured multigrid to 500k+ cores through coarse-grid redistribution. SIAM J. Sci. Comput., 40(4):C581–C604, 2018.

A. Jan, E. T. Coon, S. L. Painter, R. Garimella, and J. D. Moulton. An intermediate-scale model for thermal hydrology in low-relief permafrost-affected landscapes. Computat. Geosci., 22(1):163–177, 2018.

E. T. Coon, J. D. Moulton, and S. L. Painter. Managing complexity in simulations of land surface and near-surface processes. Environmental Modeling & Software, 78:134–149, 2016.

K. Lipnikov, D. Moulton, and D. Svyatskiy. New preconditioning strategy for Jacobian-free solvers for variably saturated flows with Richards equation. Adv. Water Resour., 94:11–22, 2016.

R. A. Bartlett, A. Dubey, X. S. Li, J. D. Moulton, J. M. Willenbring, and U. M. Yang. Testing in CSE Software: Impacts on research credibility, development productivity, maturation, and sustainability. Chapter submitted to Software Engineering for Science, Eds. J. Carver and G. K. Thiruvathukal et al., Chapman and Hall/CRC, 2016.

C. I. Steefel, C. A. J. Appelo, B. Arora, D. Jacques, T. Kalbacher, O. Kolditz, V. Lagneau, P. C. Lichtner, K. U. Mayer, J. C. L. Meeussen, S. Molins, D. Moulton, H. Shao, J. Simunek, N. Spycher, S. B. Yabusaki, and G. T. Yeh. Reactive transport codes for subsurface environmental simulation. Computat. Geosci., 19(3):445–478, 2015.

R. V. Garimella, W. A. Perkins, M. W. Buksas, M. Berndt, K. Lipnikov, E. Coon, J. D. Moulton, and S. L. Painter. Mesh infrastructure for coupled multiprocess geophysical simulations. Procedia Engineering, 82:34–45, 2014.

M. Freshley, T. Scheibe, D. Moulton, V. Freedman, S. S. Hubbard, S. Finsterle, C. I. Steefel, H. Wainwright, G. Flach, R. Seitz, P. Dixon, and J. Marble. Advanced simulation capability for environmental management initial user release. Proceedings of the Waste Management Conference, Phoenix, AZ, March 2–6, 2014.

S. L. Painter, J. D. Moulton, and C. J. Wilson. Modeling challenges for predicting hydrologic response to degrading permafrost. Hydrogeol. J., 21(1):221–224, 2013.

Synergistic Activities

- Executive Committee (Chair): Environmental System Science (ESS) Community Cyberinfrastructure Working Groups, since their creation in spring of 2016.
- Organizing Committee (Member): Copper Mountain Conference on Multigrid Methods, Biennielly in Copper Mountain, CO, since 2002.
- Co-organizer: with Carl Steefel (LBNL) and Tim Scheibe (PNNL), of the Computational Challenges for Mechanistic Modeling of Terrestrial Environments Workshop, DOE Headquarters, Germantown, Maryland, March 26–27, 2014.
- Co-organizer: with Ian Gorton (PNNL), Transforming Water Resource Management with Open-Source Community Tools, The XIX International Conference on Computational Methods in Water Resources (CMWR 2012), University of Illinois at Urbana-Champaign, June 17–21, 2012.

Collaborators (48 months):

External to LANL: Carl Steefel (LBNL), Sergi Molins (LBNL), Dipankar Dwivedi (LBNL), Haruko Wainwright (LBNL), Erin Barker (PNNL), Vicky Freedman (PNNL), Glenn Hammond (SNL), Ethan Coon (ORNL), Scott Painter (ORNL), Ahmad Jan (ORNL), Susan Hubbard (LBNL), Tim Scheibe (PNNL), Mark Freshley (PNNL), Mike Heroux (SNL), Lois Curfman McInnes (ANL), Han Johansen (LBNL), David Bernholdt (ORNL), Reed Maxwell (CSM), Laura Condon (UofA), Stephen Long (UIUC), Jonathan Lynch (PSU), Peter Thornton (ORNL), Eoin Brodie (LBNL), Eric Pierce (ORNL), Deb Agarawal (LBNL), Forrest Hoffman (ORNL), Xianyuan Chen (PNNL), Luke Olson (UIUC), Andrew Reisner (UIUC)

Internal to LANL: Ben Bergen, Markus Berndt, Gian Luca Delzanno, Rao Garimella, Humberto Godinez, Dylan Harp, Vania Jordanova, Qinjun Kang, Eugene Kikinzon, Konstantin Lipnikov, Donatella Pasqualini, Joel Rowland, Danill Svayatsky, Nathan Urban, Cathy Wilson

Graduate and Postdoctoral Advisors:

Postdoctoral: J. E. Dendy, Los Alamos National Laboratory

Ph.D. Uri M. Ascher, University of British Columbia

M. Eng. Michael S. Patterson, Hamilton Regional Cancer Center/McMaster University

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Education and Training

1996	New Mexico Institute of Mining and Technology, Socorro, Geochemistry, PhD
1988	University of Texas at El Paso, Geology, MS
1984	Central Michigan University, Mt. Pleasant, Geology, BS

Research and Professional Experience

2011 - Present	Technical Staff, Earth and Environmental Sciences Division, Los Alamos National Laboratory
2006–2011	Subprogramme Manager and Technical Officer, International Atomic Energy Agency, Isotope Hydrology Section, (on leave from Los Alamos National Laboratory
2002–2005	Ecohydrology Team Leader, Atmosphere, Climate, and Environmental Dynamics Group, Los Alamos National Laboratory
1998–2000	Hydrology and Geochemistry Task and Team Leader, LANL Environmental Restoration Project, Los Alamos National Laboratory
1989–1996	Research Technician, Los Alamos National Laboratory.

Selected Publications

Koger, J. M., B. D. Newman, and T. J. Goering. 2018. Chemostatic behavior of major ions and contaminants in a semiarid spring and stream system near Los Alamos, NM, USA. *Hydrological Processes*, *32*: 1709-1716.

Young-Robertson, J., N. Raz Yaseef, L. Cohen, B. D. Newman, T. Rahn, V. Sloan, C. Wilson, and S. Wullschleger. 2018. Evaporation dominates evapotranspiration on Alaska's Arctic Coastal Plain. *Arctic, Antarctic, and Alpine Research, 50:* e1435931.

Grossiord, C., S. Sevanto, T. E. Dawson, H. D. Adams, A. D. Collins, L. T. Dickman, B. D. Newman, E. A. Stockton, and N. G. McDowell. 2017. Warming combined with more extreme precipitation regimes modifies water sources of trees. *New Phytologist*, 213: 584–596, doi: 10.1111/nph.14192.

Raz Yaseef, N., J. Young, T. Rahn, V. Sloan, B. D. Newman, C. J. Wilson, S. Wullschleger, and M. Torn. 2017. Evapotranspiration across plant types and geomorphological units in polygonal Arctic tundra. *Journal of Hydrology*, 553: 816–825.

Throckmorton, H. M., J. M. Heikoop, B. D. Newman, G. B. Perkins, X. Feng, D. E. Graham, S. D. Wullschleger, L. Hinzman, and C. J. Wilson. 2016. Stable Isotope Hydrology of Polygonal Ground in the Arctic Coastal Plain: Barrow, Alaska. *Hydrological Processes,* DOI:10.1002/hyp.10883.

Cohen, L. R., N. Raz-Yaseef, J. B. Curtis, J. M. Young, T. A. Rahn, C. J. Wilson, S. D. Wullschleger, and B. D. Newman. 2015. Measuring diurnal cycles of evapotranspiration in the Arctic with an automated chamber system. *Ecohydrology,* 8:652–659.

Davis, P., J. Syme, J. Heikoop, J. Fessenden-Rahn, G. Perkins, B. D. Newman, A. E. Chrystal, and S. B. Hagerty. 2015. Quantifying uncertainty in stable isotope mixing models. *Journal of Geophysical* ***Research-Biogeosciences***, 120: 903-923.

Heikoop, J. M., H. M. Throckmorton, B. D. Newman, G. B. Perkins, C. M. Iversen, T. Roy Chowdhury, V. Romanovsky, D. E. Graham, R. J. Norby, C. J. Wilson, and S. D. Wullschleger. 2015. Isotopic identification of soil and permafrost nitrate sources in an Arctic tundra ecosystem, *Journal of Geophysical Research – Biogeosciences*, 120:1000-1017.

Newman, B. D., H. M. Throckmorton, D. E. Graham, B. Gu, S. S. Hubbard, L. Liang, Y. Wu, J. M. Heikoop, E. M. Herndon, T. J. Phelps; C. J. Wilson, S. D. Wullschleger. 2015. Microtopographic and Depth Controls on Active Layer Chemistry in Arctic Polygonal Ground. Geophysical Research Letters in early view.

Newman, B. D., B. P. Wilcox, S. Archer, D. D. Breshears, C. N. Dahm, C. J. Duffy, N. G. McDowell, F. M. Phillips, B. R. Scanlon, and E. R. Vivoni. 2006. The ecohydrology of water-limited environments: a scientific vision. *CUAHSI Hydrology Vision Paper Series*, Water Resources Research, 42, W06302, doi:10.1029/2005WR004141.

Synergistic Activities

Co-lead of Climate Focus Area for LANL's Science of Signatures Leadership Team.

Developed procedure with IAEA colleagues for use of optically based stable isotope analyses of liquid water samples now being used in over 30 laboratories world-wide.

Collaborator on IAEA Global Isotope Monitoring Networks including new web based analysis tools and isotope mapping applications.

Scientific Secretary (co-organizer), 2011 International Symposium on Isotope Hydrology, Marine Ecosystems, and Climate Change Studies, Monaco.

Co-organizer of 2002 AGU Chapman Conference on Ecohydrology of Semiarid Environments, and organizer of 2004 CUAHSI/NSF Ecohydrology Vision Workshop.

Associate Editor, Vadose Zone Journal (2002–2010) and Hydrogeology Journal (2013-present).

Guest Editor, Vadose Zone Journal Special Issue (2005). Guest Editor, Journal of Ecology Special Feature, (2005).

Adjunct professor, Dept. of Earth and Environmental Sciences, New Mexico Institute of Mining and Technology (2006-2009).

Recent Collaborators

Collaborators Pradeep Aggarwal, Luis Araguás-Araguás (IAEA); Kay Birdsell, Jeff Heikoop, Joel Rowland, Phil Stauffer, Kurt Solander, Cathy Wilson (Los Alamos); David Graham, Colleen Iversen, Melanie Mayes, Verity Solmon, Jeff Warren, Stan Wullschleger (Oak Ridge); Kolby Jardine, Robinson Negron-Jaurez (Lawrence Berkely Labs) Alexander Alkholodov, Go Iwahana, Vladimir Romanovsky, Jessie Young-Robertson (U. Alaska-Fairbanks), Ruby Leung, Nate McDowell, Nick Ward (PNNL), Dave Breshears (U. of Arizona); Andrew Campbell, Jesus Gomez (New Mexico Tech); Christopher Duffy (Penn State); Marty Frisbee (Purdue); Bradford Wilcox (Texas A&M); Robert Michel (USGS); Tanna Wood (USFS); Neil Sturchio (U. Delaware).

Graduate Advisors Hector Fuentes (MS/Florida International), Andrew Campbell (Ph.D/New Mexico Institute of Mining and Technology), & Brad Wilcox (Ph.D./Texas A&M).

Postdocs and Students Carli Arendt (Pdoc), Deb Bergfeld (Pdoc), Bridget Bergquist (UGS), Brendon Brady (MS), Lily Cohen (PostBac), Nathan Conroy (Post-Doc), Tina Degaw (UGS), Sam Earman (Ph.D.), Hugo Gutierrez-Jurado (Ph.D.), Jace Koger (post M.S.), Eli Ludwig (GRA), Victor Rodriguez (UGS), Chris Sharp (UGS), Donna Sharp (UGS), Danny Slattery (M.S.), Heather Throckmorton (Pdoc); Leonard Trujillo (UGS), Suchitra Ramani (P-Doc), Nathan Wales (MS, Post-MS).

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Education and Training

1992	Vassar College, Poughkeepsie, NY, Geology, B.A.
1994	University of Nevada, Reno, NV, Hydrology & Hydrogeology, M.S.
2007	University of California, Berkeley, CA, Earth & Planetary Science, Ph.D.
2007-2008	Stanford University, Stanford, CA, GES

Research and Professional Experience

2010 – present	Scientist, Earth & Evironmental Science Div., Los Alamos National Lab
2008 – 2010	Director's Postdoctoral Fellow, Los Alamos National Lab
1998-2000	Hydrogeologist, Gradient Corporation, Cambridge, MA
1994-1998	Hydrogeologist, ABB Environmental Services, Wakefield, MA

Selected Publications

Shelef, E., **Rowland, J.C.**, Wilson, C.J., Hilley, G.E., Mishra, U., Altmann, G., and Ping, C-L., (2017), Large uncertainty in permafrost carbon stocks due to hillslope soil deposits, *Geophysical Research Letters*, 44: 6134-6144, doi:10.1002/2017GL073823.

Rowland, J. C., E. Shelef, P. A. Pope, J. Muss, C. Gangodagamage, S. P. Brumby, and C. J. Wilson (2016), A morphology independent methodology for quantifying planview river change and characteristics from remotely sensed imagery, *Remote Sensing of Environment*, *184*, 212-228.

Rowland, J.C. and Coon, E.T, 2016, From documentation to prediction: how remote sensing and mechanistic modeling are raising the bar for thermokarst research, *Hydrogeology Journal.*

Harp, D., et al. (2016). Effect of soil property uncertainties on permafrost thaw projections: a calibration-constrained analysis. *The Cryosphere* 10(1): 341-358.

Fagherazzi, S., Edmonds, D.A., Nardin, W., Leonardi, N., Canestrelli, A., Falcini, F., Jerolmack, D. Mariotti, G., **Rowland, J.C.**, and Slingerland, R.L., 2015, Dynamics of river mouth depostis: *Reviews of Geophysics*, 53, doi:10.1002/2014RG000451.

Beighley, R. E., Eggert, K., Wilson, C. J., **Rowland, J. C**., and Lee, H., 2014, A hydrologic routing model suitable for climate scale simulations of arctic rivers: application to the Mackenzie River Basin: Hydrological Processes, doi: 10.1002/hyp.10398.

Chen, M., **Rowland, J.C.**, Wilson, C.J., Altmann, G.L., and Brumby, S.P. (2013), The importance of the natural variability of lake areas on the detection of permafrost degradation: a case study in the Yukon Flats, Alaska, *Permafrost and Periglacial Processes*. vol. 24, 224-240, DOI: 10.1002/ppp.1783.

Chen, M., **Rowland, J.C**., Wilson, C.J., Altmann, G.L., & Brumby, S.P. (2012). Temporal and spatial pattern of thermokarst lake area changes at Yukon Flats, Alaska. *Hydrological Processes*, 837-852.

Rowland, J.C., Travis, B.J., and Wilson, C.J., (2011) The role of advective heat transport in talik development beneath lakes and ponds in discontinuous permafrost. *Geophysical Research Letters*: 38: L17504, doi:10.1029/2011GL048497.

Rowland, J. C., Jones, C. E., Altmann, G., Bryan, R., Crosby, B. T., Geernaert, G. L., Hinzman, L. D., Kane, D. L., Lawrence, D. M., Mancino, A., Marsh, P., McNamara, J. P., Romanovsky, V., Toniolo, H., Travis, B. J., Trochim, E., and Wilson, C. J., (2010) Arctic landscapes in transition: Responses to thawing permafrost, *EOS*, vol. 91(26), 229-236, DOI: 10.1029/2010EO260001.

Synergistic Activities
Workshop Lead: DOE Terrestrial Aquatic Interface, September 2016
NGEE Arctic Task Lead for Landscape characterization, structure and heterogeneity
NSF Review Pane: Arctic Sciences, 2018
Session Organizer: AGU Fall meeting 2017: Characterizing Spatial and Temporal Variability of Hydrological and Biogeochemical Processes Across Scales
Special Issue on Subsidence Guest Editor: Hydrogeology Journal 2015.

Collaborators and Other Affiliations
Collaborators: B. Arora (LBNL), V. Bailey (PNNL), B. Bolton (UAF), E. Coon (ORNL), B. Crosby (ISU), N. Falco (LBNL), E. Foufoula-Georgiou (UC Irvine), S. Godsey (ISU), E. Herndon (KSU), G. Hilley (Stanford), S. Hubbard (LBNL), M. Lamb (Caltech), M. Marani (Duke), P. Megonigal (SERC), U. Mishra (ANL), J. Muss (CCRi), C. Richardon (Duke), V. Romanovsky (UAF), J. Shaw (U Ark), E. Shelef (U Pitt), S. Silvestri (Duke), K. Singha (CSM), P. Thornton (ORNL), H. Wainwright (LBNL), K. Williams (LBNL), S. Wullschleger (ORNL)
Advisors: W. Dietrich (UC Berkeley), G. Hilley (Stanford), M. Manga (UC Berkeley), J. Miller(Western Carolina U.), M. Stacey (UC Berkeley).
Advisees: D. Ahrens (UCB), A. Bowles (Stanford), M. Chen (LANL), M. Fratkin (LANL), C. Gangodagamage (NOAA), R. Lauzon (Duke), H. Melenda (CSM), J. Muss (Ccri), A. Piliouras (LANL), R. Sare (Stanford), E. Shelef (U Pitt), J. Schwenk (LANL), S. Stauffer, N. Sutfin (CWU).

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Education and Training

2003	University of Helsinki, Finland, Physics, PhD
1998	University of Helsinki, Material Science, MS

Research and Professional Experience

2018 - Present	Team leader: Atmosphere, Climate, and Ecosystem Sciences, Earth and Environmental Sciences Division, Los Alamos National Laboratory
2012–2018	Research scientist, Earth and Environmental Sciences, Los Alamos National Laboratory
2009–2012	Post-doctoral fellow, Earth and Environmental Sciences, Los Alamos National Laboratory
2007–2009	University lecturer in meteorology, University of Helsinki, Finland
2004-2006	Academy of Finland, Post Doctoral Fellowship -visiting scientist at Dept. of OEB, Harvard University
1998-2004	Teaching assistant, Department of Physics, University of Helsinki, Finland
1997-1998	Research assistant, Accelerator laboratory, University of Helsinki, Finland

Selected Publications

Salmon Y, Lintunen A, Lindfors L, Suhonen H, **Sevanto S**, Vesala T, Hölttä T. 2018. Refilling of xylem embolism under tension: experimental evidence of a rare ability from birch? *Acta Horticulturae* (in press).

McBranch NA, Grossiord C, Adams H, Borrego I, Collins AD, Dickman LT, Ryan MG, **Sevanto S**, McDowell NG. 2018. Lack of acclimation of leaf area:sapwood area ratios in pinon pine and juniper in response to precipitation reduction and warming. *Tree Physiology* doi:10.1093/treephys/tpy066.

Gomez SL, Carrico CM, Allen C, Lam J., Dabli S, Aiken AC, Rahn T, Romonosky D, Chylek P, **Sevanto S**, Dubey MK. 2018. Southwest U.S. biomass burning smoke hygroscopicity: The role of plant phenology, composition and combustion properties. *Journal of Geophysical research –Atmospheres* 123: 5416-5432.

Manrique-Alba A, **Sevanto S**, Adams H, Collins D, Dickman LT, Chirino E, Bellot J, McDowell N. 2018. Stem radial growth and water storage responses to heat and drought vary between conifers with differing hydraulic strategies. *Plant, Cell and Environment* 41: 1926-1934.

Grossiord C, **Sevanto S**, Bonal D, Borrego I, Dawson TW, Ryan MG, Wang W, McDowell NG. 2018. Prolonged warming and drought modify belowground interactions for water among coexisting plants. *Tree Physiology* doi:10.1093/treephys/tpy080.

Grossiord C, **Sevanto S,** Limousin, J-M, McDowell NG, Meir P, Mencuccini M, Pangle R, Pockman W, Salmon Y, Zweifel R. 2018. Manipulative experiments demonstrate how precipitation change could alter controls of plant water use. *Experimental and Environmental Botany*, 152: 19-27. Invited contribution to the Special Issue "Experiments with trees".

Nelson RO, Vogel SC, Hunter J, Watkins EB, Losko AS, Tremsin AS, Borges NP, Cutler TE, Dickman LT, Espy M, Gautier C, Madden AC, Majewski J, Malone MW, Mayo DR, McClellan KJ, Montgomery D, Mosby S, Nelson AT, Ramos K, Schirato RC, Schroeder K,

Sevanto S, Swift AL, Vo L, Williamson T, Winch N. 2018. Neutron imaging at LANSCE – from cold to ultrafast. *Journal of Imaging* 4: 45.

Grossiord C, Gessler A, Reed SC, Borrego I, Collins AD, Dickman LT, Ryan M, Schonbeck L, **Sevanto S,** Vilagrosa A, McDowell NG. 2018. Reductions in tree performance are minimized during hotter droughts by adjustments in nitrogen cycling. *Plant, Cell and Environment* 41: 2627-2637.

Sevanto S, Ryan MG, Dickman LT, Derome D, Patera A, Defraeye T, Pangle RE, Hudson PJ, Pockman WT. 2018. Is desiccation tolerance and avoidance reflected in xylem and phloem anatomy of two co-existing arid-zone coniferous trees? *Plant, cell and Environment* 41: 1551-1564.

Cernusak LA, Ubierna N, Jenkins MW, Garrity SR, Rahn T, Powers HH, Hanson DT, **Sevanto S**, Wong SC, McDowell NG, Farquhar GD. 2018. Unsaturation of vapour pressure inside leaves of two conifer species. *Nature Scientific Reports* 8: 7667.

Frigo J, Ayers H, Hinzey S, Sevanto S, Priocou M, Yang X, McCabe K, Saari A, Sentz K. Kulathumani V. 2018. Novel WSN hardware for long range low power monitoring. *IEEE DCOSS* pp. 89-92.

Sevanto S. 2018. Drought impacts on phloem transport. *Current Opinion in Plant Biology* 43: 76-81.

Leigh A, **Sevanto S**, Close JD, Nicotra AB. 2017. The influence of leaf size and shape on leaf thermal dynamics. Does theory hold up under field conditions? *Plant, Cell and Environment* 40: 237-248.

Synergistic Activities

Guest Associate editor of *Frontier in Plant Science, Functional Plant Ecology* 2018-
Associate editor of *Frontiers in Plant Science, Forest Ecophysiology* 2018-
Associate editor of *Frontiers in Plant Science, Plant biomechanics and modeling* 2011-
Advisory board member for *New Phytologist* 2013-
Editorial board member for *Tree Physiology* 2013-2018
Commentary editor for *Tree Physiology* 2019-
Session Organizer: “Plant-soil interactions under changing climate”, Annual meeting of ESA, New Orleans, LA, Aug 6-10, 2018.
Proposal reviewer for: NSF, *Research Foundation-Flanders (FWO, Belgium), BARD - Binational Agricultural Research and Development Fund US-Israel, Czech Science Foundation, Hawaii Sea Grant College Program*

Recent Collaborators

Jan Carmeliet and Dominique Derome, Zurich Technical University; Annika Hofgaard, Norwegian Institute for Nature Research (NINA); Andrea Leigh Sydney Technical University; William Pockman and David Hanson University of New Mexico; Cheryl Kuske, John Dunbar, Sven Vogel, Jarek Majewski, Michelle Espy, Michael Malone, Emily Schultz-Fellenz (LANL); Gaby Katul Duke University.

<u>Postdocs and Students</u> Tirtha Banerjee (Pdoc LANL), Danielle Ulrich (Pdoc LANL), Bradley Christoffersen (Pdoc LANL), Charlotte Grossiord (Pdoc LANL), Michael Malone (Pdoc LANL), Henry Adams (Pdoc LANL), Turin Dickman (MS UNM), Irina Hannukainen (MS U. Helsinki), Tea Thum (PhD, U. Helsinki), Hanna Lappalainen (PhD, U. Helsinki), Pauli Paasonen (PhD, U.Helsinki), Maarit Raivonen (Pdoc, U. Helsinki)

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Education and Training

2006	Ph. D., Applied Mathematics, University of Houston, Houston, TX
2004	M.S., Applied Mathematics, University of Houston, Houston, TX
2000	M.S., Physics and Applied Mathematics, Moscow Institute of Physics and Technology (Technical University), Moscow, Russia
1998	B.S., Physics and Applied Mathematics, Moscow Institute of Physics and Technology (Technical University), Moscow, Russia

Research and Professional Experience

2010–present	Scientist, Theoretical Division, Los Alamos National Laboratory.
2006–2010	Postdoctoral Fellow, Theoretical Division, Los Alamos National Laboratory.
2003–2006	Research Assistant, University of Houston, Houston, TX
1998–2003	Research Associate, Institute of Numerical Mathematics, Russian Academy of Sciences, Moscow, Russia
1998–2003	Programmer, Russian Research Centre Kurchatov Institute, Institute of High Technologies and Experimental Machine Building (IHTEMB), Moscow, Russia

Selected Publications

G. Kagan, O.L. Landen, D. Svyatskiy, H. Sio, N.V. Kabadi, R.A. Simpson, M. Gatu Johnson, J.A.Frenje, R.D. Petrasso, R.C. Shah, T.R. Joshi, P. Hakel T.E. Weber, H.G. Rinderknecht, D. Thorn, M. Schneider, D. Bradley, and J. Kilkenny. **Inference of the electron temperature in inertial confinement fusion implosions from the hard xray spectral continuum.** Contribution to Plasma Physics, 2018.

D. Svyatskiy and K. Lipnikov. **Consistent nonlinear solver for solute transport in variably saturated porous media.** In Finite Volumes for Complex Applications VIII-Methods and Theoretical Aspects. Springer International Publishing, 2017.

H. Rinderknecht, P. Amendt, M. Rosenberg, C.-K. Li, J. Frenje, M. Gatu Johnson, H. Sio, F. Seguin, R. Petrasso, A. Zylstra, G. Kagan, N. Hoffman, D. Svyatskiy, S. Wilks, V. Glebov, C. Stoeckl, andT. Sangster. **Ion kinetic dynamics in strongly-shocked plasmas relevant to icf. Nuclear Fusion,** 2017**.**

V. Jordanova, GL Delzanno, MG Henderson, H. Godinez, CA Jeffery, E. Lawrence, S.Morley, JD Moulton, LJ Vernon, JR Woodroffe, TV Brito, MA Engel, CS Meierbachtol, D Svyatsky, Y Yu, G Toth, DT Welling, Y Chen, J Haiducek, S Markidis, JM Albert, J Birn, MH Denton, and RB Horne. **Specification of the near-earth space environment with shields. Journal of Atmospheric and Solar-Terrestrial Physics,** 2017**.**

Svyatskiy D. and Lipnikov K**. Second-order accurate finite volume schemes with the discrete maximum principle for solving richards' equation on unstructured meshes.** Advances in Water Resources**,** 104:114-126, 2017

Meierbachtol C.S., Svyatskiy D., Delzanno G.L., Vernon L.J., and Moulton J.D. **An electrostatic particle-in-cell code on multi-block structured meshes**. J. Comput. Phys., 350:796–823, 2017.

Painter S.L., Coon E.T., Atchley A., Berndt M., Garimella R., Moulton D., Svyatskiy D., and Wilson C. J. **Integrated surface/subsurface permafrost thermal hydrology: Model formulation and proof-of-concept simulations.** Water Resources Research, 52(8):6062–6077, 2016.

G. Kagan, H. W. Herrmann, Y.-H. Kim, M. J. Schmitt, S. C. Hsu P. Hakel, N. M. Hoffman, and D. Svyatsky et al. **Kinetic studies of icf implosions.** J. Phys.: Conf. Ser., 717, 2016.

Svyatskiy D., Lipnikov K., and Moulton D. **New preconditioning strategy for jacobian-free solvers for variably saturated flows with richards' equation.** Advances in Water Resources, 94:11–22, 2016.

G. Kagan, D. Svyatskiy, H. G. Rinderknecht, M. J. Rosenberg, A. B. Zylstra, C.-K. Huang, and McDevitt C. J. **Self-similar structure and experimental signatures of suprathermal ion distribution in inertial confinement fusion implosions.** Physical Review Letters, 115:105002, 2015.

G. Kagan, D. Svyatskiy, H. G. Rinderknecht, M. J. Rosenberg, A. B. Zylstra, C.-K. Huang, and McDevitt C. J. **Experimental signatures of suprathermal ion distribution in inertial confinement fusion implosions.** Bulletin of the American Physical Society, 60, 2015.

V Gyrya, K Lipnikov, G Manzini, and D Svyatskiy. **M-adaptation in the mimetic finite difference method**. Mathematical Models & Methods In Applied Sciences, 24(8):1621–1663, 2014.

K. Lipnikov, D. Svyatskiy, and Yu. Vassilevski. **Anderson acceleration for nonlinear finite volume scheme for advection-diffusion problems.** SIAM J. Sci. Comput., 35(2):A1120–A1136, 2013.

K. Lipnikov, D. Svyatskiy, and Yu. Vassilevski. **Minimal stencil finite volume scheme with the discrete maximum principle.** Russian Journal Of Numerical Analysis And Mathematical Modeling, 27(4):369–385, 2012.

L. Jiang, J. Moulton, and D. Svyatskiy. **Analysis of stochastic mimetic finite difference methods and their applications in single-phase stochastic flows.** Computer Methods in Applied Mechanics and Engineering, 217-220:58–76, 2012.

D. Svyatskiy, K. Lipnikov, and J.D. Moulton. **Adaptive strategies in the multilevel multiscale mimetic (M^3) method for two-phase flows in porous media**. Multiscale Modeling and Simulation, 9(3):991–1016, 2011.

D. Svyatskiy, K. Lipnikov, and D. Moulton. **A multilevel multiscale mimetic (m-3) method for an anisotropic infiltration problem.** Int. J. MultiScale Comp. Eng., 9(2):243–256, 2011.

D. Svyatskiy, K. Lipnikov, and G. Manzini. **Monotonicity conditions in the mimetic finite difference method.** In J Fort, J Furst, J Halama, R Herbin, and F Hubert, editors, Finite Volumes For Complex Applications VI: Problems & Perspectives, volume 4, pages 653–661, 2011.

D. Svyatskiy, K. Lipnikov, and G. Manzini. **Analysis of the monotonicity conditions in the mimetic finite difference method for elliptic problems.** J. Comput. Phys., 230(7):2620–2642, 2011.

D. Svyatskiy, K. Lipnikov, and Y. Vassilevski. **A monotone finite volume method for advection-diffusion equations on unstructured polygonal meshes.** J. Comput. Phys., 229(11):4017–4032, 2010.

Awards

2018 -- LANL Distinguished Performance Award
2017 -- R&D 100 Award
2012 -- LANL achievement award
2001 -- Kurchatov prize for outstanding young scientists and engineers.

Graduate and Postdoctoral Advisors

Graduate Advisors: Evgeny Tyrtyshnikov (INM, Russia), Yuri Kuznetsov (University of Houston, TX)
Postdoctoral Advisors: Konstantin Lipnikov, David Moulton (LANL)

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Education and Training

2009	University of Illinois at Urbana-Champaign, Terrestrial Biogeochemistry, PhD
2008	University of Illinois at Urbana-Champaign, Statistics, MS
2000	Northeast Normal University, China, Ecology, BS

Research and Professional Experience

2015–present	Scientist III, Dynamic Vegetation Modeling, Los Alamos National Laboratory. Develop dynamic vegetation models; integration of models, observations, and experiments.
2011–present	Scientist II, Dynamic Vegetation Modeling, Los Alamos National Laboratory. Develop dynamic vegetation models; integration of models, observations, and experiments.
2010–2011	Postdoc, Earth and Environmental Sciences Division, Los Alamos National Laboratory. Coupled a dynamic vegetation model (ED) with an arctic soil hydrological model (ARCHY).
2009–2010	Postdoc. Department of Entomology, North Carolina State University. Uncertainty and sensitivity analysis for a stochastic, spatially explicit simulation models that link insect population dynamics, disease epidemiology, and population genetics aimed to release transgenic mosquitoes to reduce the incidence of human disease.
2004–2009	Research Assistant, Department of Natural Resources and Environmental Sciences. Coupled a forest ecosystem process model (PnET-II) with a forest landscape model (LANDIS-II); Developed general uncertainty and sensitivity analysis methods for models with correlated parameters.

Selected Publications

Goodsman, D.W., Grosklos, G., Aukema, B.H., Whitehouse, C., Bleiker, K.P., McDowell, N.G., Middleton, R.S. and **Xu, C**., 2018. The effect of warmer winters on the demography of an outbreak insect is hidden by intraspecific competition. *Global change biology*, 24(8):3620-3628. doi: 10.1111/gcb.14284

K. Bennett, T. Bohn, K. Solander, N. McDowell, **C. Xu**, E. Vivoni, and R. Middleton.2018. Climate change and climate-driven disturbances in the San Juan River sub-basin of the Colorado River. *Hydrology and Earth System Sciences*, 22, 709-725.

D. Johnson, J. Needham, **C. XU**, et al. Tree survival in the tropics reveals limited demographic diversity. *Nature Ecology and Evolutions*. In Press.

Z.Hu, S.T. Michaletz , D. J. Johnson , N.G. Mcdowell , X. Zhou, **C. Xu.** Plant traits control wood decomposition more than climate at the global scale. *Global Change Biology*. In Press.

N.G. McDowell, K.Bennett, S.Michaletz, K. Solander, **C. Xu**, R.M. Maxwell, C.Allen, R.Middleton. 2018. Predicting chronic climate-driven disturbances and their mitigation. *Trends in Ecology and Evolutions*, 33,15-27

Goodsman, D., Aukema, B, N. McDowell, R. Middleton and **C. XU**. 2018. Seasonally forced stochastic stage and age-structured models: capturing variability using convolutions. *Ecology and Evolutions*.8, 162–175.

Fisher, R. A., Koven, C. D., Anderegg, W. R. L., Christoffersen, B. O., Dietze, M. C., Farrior, C., Holm, J. A., Hurtt, G., Knox, R. G., Lawrence, P. J., Lichststein, J. W., Longo, M., Matheny, A. M., Medvigy, D., Muller-Landau, H. C., Powell, T. L., Serbin, S. P., Sato, H., Shuman, J., Smith, B., Trugman, A. T., Viskari, T., Verbeeck, H., Weng, E., **Xu, C**., Xu, X., Zhang, T. and Moorcroft,

P. 2018. Vegetation Demographics in Earth System Models: a review of progress and priorities. Global. Change Biology. doi:10.1111/gcb.13910

Walker, A.P.; Quaife, T.; van Bodegom, P.M.; De Kauwe, M.G.; Keenan, T.F.; Joiner, J.; Lomas, M.; MacBean, N.; **Xu, C.;** Yang, X.; Woodward, F.I..2017. The impact of alternative trait-based Vcmax spatial-scaling hypotheses on global gross primary production. New Phytologist, 215:1370-1386.

McDowell NG and **Xu C**. 2017. Using traits to uncover tropical forest function. New Phytologist 200: 304-321.

Hu Z, **Xu C**, McDowell NG, Johnson DJ, Wang M, Huang Z, Zhou X. 2017. Linking microbial community composition to C loss during wood decomposition. *Soil Biology and Biochemistry,* 104: 108-116.

Christoffersen, B. O., Gloor, M., Fauset, S., Fyllas, N. M., Galbraith, D. R., Baker, T. R., Rowland, L., Fisher, R. A., Binks, O. J., Sevanto, S. A., **Xu, C**., Jansen, S., Choat, B., Mencuccini, M., McDowell, N. G., and Meir, P.2016. Linking hydraulic traits to tropical forest function in a size-structured and trait-driven model (TFS v.1-Hydro), Geosci. Model Dev., 9 (11), 4227-4255, doi:10.5194/gmd-2016-128.

R. J. Norby, L. Gu, I.C. Haworth, A.M. Jensen, B.L. Turner, A.P. Walker, J. M. Warren, D.J. Weston**, C. Xu**, and K.Winter. Informing models through empirical relationships between foliar phosphorus, nitrogen and photosynthesis across diverse woody species in Panama. New Phytologist, 215: 1425–1437.

Ali, A., **C Xu**, A Rogers, RA Fisher, SD Wullschleger, EC Massoud, JA Vrugt, JD Muss, NG McDowell, JB Fisher, PB Reich, CJ Wilson.2016. A global mechanistic model of plant photosynthesis capacity. Geoscientific Model Development, 9, 587-606, doi:10.5194/gmd-9-587-2016.

N.G. McDowell**,** A.P. Williams, **C. Xu**, W.T. Pockman, L.T. Dickman, S. Sevanto, R. Pangle, J. Limousin, J. Plaut, D. Scott Mackay, J. Ogee, J.C. Domec, C.D. Allen, R.A. Fisher, X. Jiang, J. Muss, D.D. Breshears, S. A. Rauscher, C. Koven. 2016. Multi-scale predictions of massive conifer mortality due to chronic temperature rise. Nature Climate Change 6, 295–300 doi:10.1038/nclimate2873

Fisher R., Muszala S., Spessa A., Verteinstein M., Lawrence, P., **Xu C**., McDowell N., Kluzek E., Koven C., Knox R., Holm J., Rogers B.M., Lawrence D. & Bonan G. (2015). Taking off the training wheels: the properties of a dynamic vegetation model without climate envelopes. Geoscientific Model Development, 8 (11), 3593-3619.

McDowell, NG, Fisher, RA, **Xu, C**, Domec, JC, Hölttä ,T, Mackay, DS, Sperry, JS, Boutz, A, Dickman, L, Gehres, N, Limousin, JM, Macalady, A, Martínez-Vilalta, J, Mencuccini M, Plaut, JA, Ogée J, Pangle, RE, Rasse, DP, Ryan MG, Sevanto, S, Waring, RH, Williams, AP, Yepez, EA, Pockman, WT. 2013. Evaluating theories of drought-induced vegetation mortality using a multimodel–experiment framework. New Phytologist 200: 304-321.

Synergistic Activities

Reviewers for >30 journals and LANL, NSA, NSF and DOE grants

Feb 2011-present, Duty Coordinator of the IUFRO (International Union of Forest Research Organizations) Working Party 4.03.01.

Oct 2012-present, EES computational council, Los Alamos National Laboratory, NM

LANL lead on NGEE tropics

Collaborators

George Z. Gertner (University of Illinois), Alun Lloyd (North Carolina State University), Nathan McDowell (PNNL), Peter Thornton (ORNL), Charlie Koven (LBNL), Rosie Fisher (NCAR), Jackie Shuman (NCAR), Jasper Vrugt (UCI), Jim Randerson (UCI), Alex Hall (UCLA), Brian Aukema (UMN), Yufan Jin (UCDavis), Lara Kuepper (UC Berkeley/LBNL), Jeff Chamber (LBNL)

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Education and Training

2006	University of Alaska Fairbanks, Hydrologic Engineering, PhD
1996	University of Alaska Fairbanks, Geologic Engineering, MS
1991	California Lutheran University, Thousand Oaks, Geology with a Minor in Psychology, B.S.

Research and Professional Experience

2011-present	Research Assistant Professor, International Arctic Research Center, University of Alaska Fairbanks
2009–2011	Postdoctoral Fellow, International Arctic Research Center and Arctic Region Supercomputing Center, University of Alaska Fairbanks.
2006–2008	Postdoctoral Fellow, Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany.
1998–2006	Graduate Research Assistant. Water Research Center, Institute of Northern Engineering, UAF.
1996–1998	Engineer II, EA Environmental, Science, and Technology, Fairbanks, Alaska.
1994–1996	Student Hydrologist, United States Geological Survey (through Environmental Careers Organization), Fairbanks, Alaska.
1992–1994	Graduate Teaching Assistant, University of Alaska, Fairbanks.

Selected Publications

A. Endalamaw, W.R. Bolton, J.M. Young-Robertson, D. Morton, L. Hinzman, and B. Nijssen, "Toward Improved Parameterization of a Meso-Scale Hydrologic Model in Discontinuous Permafrost, Boreal Forest Ecosystem." Hydrology and Earth System Sciences, 21, 4663-4680 (2017).

S. Peckham, M. Stoica, E. Jafarov, A. Endalamaw, and W. Bolton, "Reproducible, Component-Based Modeling With TopoFlow, A Spatial Hydrologic Modeling Toolkit: Reproducible Modeling with TopoFlow." Earth and Space Science, doi: 10.1002/2016EA000237 (2017).

J.M. Young-Robertson, W.R. Bolton, U. Bhatt, J. Cristobal, and R. Thoman, "Deciduous Trees are a Large and Overlooked Sink for Snowmelt Water in the Boreal Forest." Nature Scientific Reports, 6, Art. No. 29506, doi: 10.1038/srep29504 (2016).

Lara, M.J., McGuire, A.D., Euskirchen, E.S., Tweedie, C.E., Hinkel, K.M., Skurikhin, A.N., Romanovsky, V.E., Grosse, G., Bolton., W.R., Genet, H. 2014. Century Time-Scale Change in Peak Season CO_2 and CH_4 Flux in Response to Land Cover Change in Ice-Wedge Polygonal Tundra, on the Barrow Peninsula, Arctic Alaska. *Global Change Biology.* DOI: 10.1111/gcb.12757.

Cable, J.M., Ogle, K., Bolton, W.R., Bentley, L.P., Iwata, H., Harazono, Y., Romanovsky, V.E., Welker, J.W. 2013. Permafrost thaw effects boreal plant transpiration through warmer soil, deeper thaw, and greater soil water storage. *Ecohydrology*. DOI: 10.1002/eco.1423.

Bolton, W.R., Boike, J., Overduin, P.P. 2008. Estimation of Hydrologic Properties in Permafrost Affected Soils Using a Two-Directional Freeze-Thaw Algorithm. In Douglas L. Kane and Kenneth M. Hinkel (Editors), *Proceedings of the Ninth International Conference on Permafrost*, pp.155-158.

Schramm, I., J. Boike, W. R. Bolton, and L. D. Hinzman. 2007. Application of TopoFlow, a spatially distributed hydrological model, to the Imnavait Creek watershed, Alaska. *Journal of Geophysical Research* 112.

W. R. Bolton, L. Hinzman, and K. Yoshikawa. 2004. Water balance dynamics of three small catchments in a Sub-Arctic boreal forest. In *Northern Research Basins Water Balance*, edited by Douglas L. Kane and Daqing Yang. Proceedings of a workshop held at Victoria, Canada, March 2004, IAHS Series of Proceedings and Reports Number 290, 213–223.
Hinzman, L. D., W. R. Bolton, K. C. Petrone, J. B. Jones, and P. C. Adams. 2006. Watershed hydrology and chemistry in Alaska's boreal forest: The central role of permafrost. In *Alaska's Changing Boreal Forest*, edited by F.S. Chappin III, M. Oswood, K. Van Cleve, L.A. Viereck, and D.L. Verbyla, Oxford University Press, Oxford, UK.
Yoshikawa, K., W. R. Bolton, V. E. Romanovsky, M. Fukuda, and L. D. Hinzman. 2002. Impacts of wildfire on the permafrost in the boreal forest of Interior Alaska. *Journal of Geophysical Research* 107, 108(D1).
Jones, J. B. Jr., K. C. Petrone, J. C. Finlay, L. D. Hinzman, and W. R. Bolton. 2005. Nitrogen loss from watersheds of interior Alaska underlain with discontinuous permafrost. *Geophys. Res. Lett.* 32, L02401, doi:10.1029/2004GL021734.
Young, K. L., W. R. Bolton, A. Killingtveit, and D. Yang. 2006. Assessment of precipitation and snowcover in northern research basins. *Nordic Hydrology* 37, 377–391.
Bolton, W. R., J. Boike, and P. P. Overduin. 2008. Estimation of hydraulic properties in permafrost affected soils using a two-directional freeze-thaw algorithm. In *Proceedings of the Ninth International Conference on Permafrost*, edited by Douglas L. Kane and Kenneth M. Hinkel, 155–158.
Bolton, W. R., L. Hinzman, and K. Yoshikawa. 2000. Stream flow studies in a watershed underlain by discontinuous permafrost. In *Proceedings Water Resources in Extreme Environments*, edited by D.L. Kane 31–36.
Hinzman, L. D., N. D. Bettez, W. R. Bolton, F. S. Chapin, M. B. Dyurgerov, C. L. Fastie, B. Griffith, R. D. Hollister, A. Hope, H. P. Huntington, A. M. Jensen, G. J. Jia, T. Jorgenson, D. L. Kane, D. R. Klein, G. Kofinas, A. H. Lynch, A. H. Lloyd, A. D. McGuire, F. E. Nelson, W. C. Oechel, T. E. Osterkamp, C. H. Racine, V. E. Romanovsky, R. S. Stone, D. A. Stow, M. Sturm, C. E. Tweedie, G.L. Vourlitis, M. D. Walker, D. A. Walker, P. J. Webber, J. Welker, K. S. Winker, and K. Yoshikawa. 2005. Evidence and implications of recent climate change in northern Alaska and other Arctic regions. Climatic Change 72(3), 251–298.

Synergistic Activities

North Slope Science Initiative – Science Technical Advisory Panel. 2015 – present. US Department of Interior Federal Advisory Panel.

Establishment of computational methods, with primary focus upon hydrological and thermal processes that are physically correct and numerically accurate for incorporation in an array of modeling platforms.

Recent concentration on accurately quantifying and characterizing ecological processes in an attempt to improve depiction of feedback processes in climate models.

Collaborators and Co-Editors

L. Hinzman (University of Alaska Fairbanks), M. Lara (University of Alaska Fairbanks), H. Genet (University of Alaska Fairbanks), V. Romanovsky (University of Alaska Fairbanks), A.D. McGuire (University of Alaska Fairbanks), T.S. Rupp (University of Alaska Fairbanks), J. Littel (USGS, Anchorage), J. Young-Robertson (University of Alaska Fairbanks), S. Stueffer (University of Alaska Fairbanks), J. Jones (University of Alaska Fairbanks), D. Kane (University of Alaska Fairbanks), P. Marsh (Laurier University, Waterloo, Ontario, Canada), P.P. Overduin (Alfred Wegener Institute, Potsdam, Germany), S. Peckham (University of Colorado), K. Yoshikawa (University of Alaska Fairbanks).

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Education and Training

2010	University of Alaska Fairbanks, Botany, Ph.D.
2000	University of Missouri, Biology, M.S.
1994	College of the Atlantic, Human Ecology, B.A.

Research and Professional Experience

2013-present	Research Assistant Professor, Scenarios Network for Alaska and Arctic Planning, International Arctic Research Center, University of Alaska Fairbanks. Research interests include vegetation ecology, landscape ecology, ecosystem ecology, plant ecology and evolution, biogeography, and land change science. My current research projects investigate the response of high latitude ecosystems to rapid climate change and disturbance through both field and modeling studies.
2010-present	Adjunct Instructor, Biology and Wildlife Department, University of Alaska Fairbanks Teach various courses including *Arctic Environmental Change* (Summer 2012, 2014, 2015, 2016, 2018), *Principles of Evolution* (Spring 2011), and *Introduction to the Flora of Alaska* (Summer 2007, 2011).
2010-2012	Postdoctoral Fellow, International Arctic Research Center, University of Alaska Fairbanks

Selected Publications

Walker, D. A., Epstein, H. E., J. Sibik, U. Bhatt, V. E. Romanovsky, A. L. Breen, S. Chasníková, R. Daanen, L. A. Druckenmiller, K. Ermokhina, B. C. Forbes, G. V. Frost, J. Geml, E. Kaärlejarvi, O. Khitun, A. Khomutov, T. Kumpula, P. Kuss, M. O. Leibman, G. Matyshak, N. Moskalenko, P. Orekhov, J. Peirce, M. K. Raynolds, and I. Timling. 2018. Vegetation of the Eurasia Arctic Transect, Yamal Peninsula and Franz Josef Land, Russia. *Applied Vegetation Science*. In Press.

Genet, H., Y. He, Z. Lyu, A. D. McGuire, Q. Zhuang, J. Clein, D. D'Amore, A. Bennet, A. Breen, F. Biles, E. Euskirchen, K. Johnson, T. Kurkowski, S. Schroder, N. Pastick, T. S. Rupp, Y. Zhang, and Z. Zhu. 2017. The role of driving factors in historical and projected carbon dynamics of upland ecosystems in Alaska. *Ecological Applications* doi.org/10.1002/eap.1641

Ackerman, D. & A. L. Breen. 2016. Infrastructure development may accelerate range expansion of trembling aspen (*Populus tremuloides*, Salicaceae) into the Arctic. *Arctic* 69:130-136.

Walker, D. A., F. J. A. Daniëls, I. Alsos, U. S. Bhatt, A. L. Breen, M. Buchhorn, H. Bültmann, L. A. Druckenmiller, M. E. Edwards, D. Ehrich, H. E. Epstein, W. A. Gould, R. A. Ims, H. Meltofte, M. K. Raynolds, J. Sibik, S. S. Talbot, and P. J. Webber. 2016. Circumpolar Arctic vegetation: A hierarchic review and roadmap toward an internationally consistent approach to survey, archive and classify tundra plot data. *Environmental Research Letters* 11: 055005

Breen, A. L., M. K. Raynolds, I. Timbling, D. F. Murray & D. A. Walker. 2014. Ecology and Evolution of Plants in Arctic and Alpine Environments. Pp. 149-178. In: Rajakaruna, N., B. Boyd & T. Harris. (Eds.) *Plant Ecology and Evolution in Harsh Environments*. Nova Science Publishers, Hauppauge, New York.

Breen, A. L. 2014. Balsam poplar plant communities on the Arctic Slope of Alaska. *Phytocoenologia* 44(1-2): 1-17.

Jones, B. M., A. L. Breen, B. V. Gaglioti, D. H. Mann, Adrian V. Rocha, G. Grosse, C. D. Arp & D. A. Walker. 2013. Identification of unrecognized tundra fire events on the North Slope of Alaska. *Journal of Geophysical Research* 118: doi:10.1002/jgrg.20113

Breen, A. L., D. F. Murray & M. S. Olson. 2012. Genetic consequences of glacial survival: the late Quaternary history of balsam poplar (*Populus balsamifera* L.) in North America. *Journal of Biogeography* 39(5): 918-928.

Rocha, A. V., M. M. Loranty, P. E. Higuera, M. C. Mack, F. Sheng-Hu, B. M. Jones, A. L. Breen, E. B. Rastetter, S. J. Goetz & G. R. Shaver. 2012. The footprint of Alaskan tundra fires during the past half-century: implications for surface properties and radiative forcing. *Environmental Research Letters* 7: 044039. doi:10.1088/1748-9326/7/4/044039

Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. R. Henry L. E. Ahlquist, J. M. Alatolo, M. S. Bret-Harte, M. P. Calef, T. V. Callaghan, A. B. Carroll, et al. 2006. Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences* 103(5): 1342-1346.

Synergistic Activities

Member of the Association of Early Career Polar Scientists, 2008-present

Member of the Editorial Board of *Phytocoenologia*, an International Journal of Plant Community Ecology, 2014-present

Member of the IARPC Terrestrial Ecosystems Working Group, 2016-present

Steering committee member for the Conservation of Arctic Flora & Fauna (CAFF) Arctic Vegetation Archive Working Group, 2012-present

Network Partner for the Peregrine Fund Tundra Conservation Network, 2013-present

Grant reviewer for NSF Division of Polar Programs and Division of Environmental Biology

Manuscript reviewer as requested

Collaborators and Co-Authors (past 48 months)

Daniel Ackerman (University of Minnesota), Inger Alsos (The Arctic University of Norway), Christopher Arp (UAF), Alec Bennet (UAF), Umq Bhatt (UAF), Frances Biles (USDA Forest Service), Robert Bolton (UAF), Marcel Buchhorn (Flemish Institute for Technological Research, Belgium), Helga Bültmann (University of Münster, Germany), Silvia Chasníková (Slovak Academy of Sciences), Joy Clein (UAF), Ronald Daanen (UAF), David D'Amore (USDA Forest Service), Fred Daniëls (University of Münster, Germany), Lisa Druckenmiller (UAF), Mary Edwards (University of Southampton, UK), Howard Epstein (University of Virginia), Ksenia Ermokhina (Russian Academy of Sciences), Dorothee Ehrich (The Arctic University of Norway), Eugenie Euskirchen (UAF), Bruce Forbes (University of Lapland), Gerald Frost (Alaska Biological Research Inc.), Jozef Geml (Naturalis Biodiversity Center, Netherlands), Helene Genet (UAF), William Gould (USDA Forest Service), Yujie He (Purdue University), Stephan Hennekens (Alterra, Netherlands), Teresa Hollingsworth (USDA Forest Service), Rolf Ims (The Arctic University of Norway), Colleen Iversen (ORNL), Kristopher Johnson (USDA Forest Service), Benjamin Jones (UAF), Elina Kaärlejarvi (Umeå University, Sweden), Olga Khitun (Russian Academy of Sciences), Artem Khomutov (University of Tyumen, Russia), Timo Kumpula (University of Eastern Finland), Thomas Kurkowski (UAF), Patrick Kuss (University of Zürich, Switzerland), Marina Leibman (Russian Academy of Sciences), Georgy Matyshak (Lomonosov Moscow State University), A. David McGuire (USGS/UAF), Hans Meltofte (Aarhus University, Denmark), Natalya Moskalenko (Russian Academy of Sciences), Pavel Orekhov (Russian Academy of Sciences), , Neal Pastick (University of Minnesota), Jana Peirce (UAF), Martha Raynolds (UAF), Vladimir Romanovsky (UAF), T. Scott Rupp (UAF), Verity Salmon (ORNL), Julien Schroder (UAF), Jozef Sibik (Slovak Academy of Sciences), Stephen Talbot (US Fish and Wildlife), Ina Timling (UAF), Margaret Torn (LBNL), Donald Walker (UAF), Marilyn Walker (Homer Energy), Patrick Webber (Michigan State University), Stan Wullschleger (ORNL), Yujin Zhang (UAF), Xiaoping Zhu (USDA Forest Service), Qianlai Zhuang (Purdhoe University)

Graduate and Postdoctoral Advisors
Postdoctoral Advisor: Dr. T. Scott Rupp, University of Alaska Fairbanks
Ph.D. Advisor: Dr. Matthew Olson, Texas Tech University
M.S. Advisor: Dr. Candace Galen, University of Missouri Columbia

Undergraduate and Graduate Advisees
None yet.

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Education and Training

2001	University of Alaska Fairbanks, Alaska, Mechanical Engineering, BS

Research and Professional Experience

2004–present	Research Engineer, UAF International Arctic Research Center / Water and Environmental Research Center.
1999–2004	Design Engineer and Field Technical, GW Scientific (Fairbanks, Alaska).
1999–2000	Research Student Assistant, UAF Undergraduate Research Program.

Selected Publications

Saito, K., Iwahana, G., Ikawa, H., Nagano, H., and Busey, R. C.: Links between annual surface temperature variation and land cover heterogeneity for a boreal forest as characterized by continuous, fibre-optic DTS monitoring, Geosci. Instrum. Method. Data Syst., 7, 223-234, https://doi.org/10.5194/gi-7-223-2018, 2018.

Nagai, S., Akitsu, T., Saitoh, T.M. Busey, RC, et al. 8 million phenological and sky images from 29 ecosystems from the Arctic to the tropics: the Phenological Eyes Network. Ecol Res (2018). https://doi.org/10.1007/s11284-018-1633-x

Ikawa, H., Nakai T., Busey RC, Kim YK, Kobayashi H, Nagai S, Ueyama M, Saito K, Nagano H, Suzuki R, Hinzman L, **2015.** Understory CO_2, sensible heat, and latent heat fluxes in a black spruce forest in interior Alaska, Agricultural and Forest Meteorology, Volumes 214–215, 15 December 2015, Pages 80-90, ISSN 0168-1923, http://dx.doi.org/10.1016/j.agrformet.2015.08.247.

Alexeev, V.A., ES Euskirchen, JE Cherry, RC Busey. **2015**. Tundra burning in 2007 – Did sea ice retreat matter?, Polar Science, Volume 9, Issue 2, June 2015, Pages 185-195, ISSN 1873-9652, http://dx.doi.org/10.1016/j.polar.2015.02.002.

Nagai S. Nakai T, Saitoh TM, Busey RC, Kobayashi H, Suzuki R, Muruaoka H, Kim YW. **2013**. Seasonal changes in camera-based indices from an open canopy black spruce forest in Alaska, and comparison with indices from a closed canopy evergreen coniferous forest in Japan. Polar Science v7 issue 2. doi:10.1016/j.polar.2012.12.001

Nakai, T, YW Kim, RC Busey, R Suzuki, S Nagai, H Kobayashi, H Park, K Sugiura, A Ito. **2013.** Characteristics of evapotranspiration from a permafrost black spruce forest in interior Alaska. Polar Science. v7 issue 2. doi:10.1016/j.polar.2013.03.003

Alessa, L., A. Kliskey, D. White, R. Busey, P. Williams, and L. Hinzman. **2008**. Freshwater vulnerabilities and resilience on the Seward Peninsula as a consequence of landscape change. *Global Environmental Change* 18, 256–270.

Busey, R.C., L. D. Hinzman, J. J. Cassano, and E. Cassano. **2008**. Permafrost distributions on the Seward Peninsula: Past, present, and future. *Proceedings 9th International Conference on Permafrost, Fairbanks, Alaska, June 29–July 3, 2008*, 215–220.

Chambers, M. K., D. M. White, M. R. Lilly, L. D. Hinzman, K. M. Hilton, and R. C. Busey. **2008**. Exploratory analysis of the winter chemistry of five lakes on the north slope of Alaska. *Journal of the American Water Resources Association*, doi:10.1111/j.1752-1688.2007.00164.x.

Chambers, M., D. White, R. Busey, L. Hinzman, L. Alessa, and A. Kliskey. **2007**. Potential impacts of a changing Arctic on community water sources on the Seward Peninsula, Alaska. *J. Geophys. Res.* 112, G04S52, doi:10.1029/2006JG000351.

Kliskey, A., L. Alessa, R. Lammers, C. Arp, D. White, L. Hinzman, and R. Busey. An integrated freshwater resilience index for the Arctic. *Environmental Management* (submitted).

Liljedahl, A., L. Hinzman, R. Busey, and K. Yoshikawa. **2007**. Physical short-term changes after a tussock tundra fire, Seward Peninsula, Alaska. *J. Geophys. Res.* 112, F02S07, doi:10.1029/2006JF000554.

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Research Professional II
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Education and Training

2018	University of Alaska Fairbanks, Electrical Engineering, M.S., Thesis: "Design of a Multichannel Outdoor Data Logger for Precise Temperature Measurements"
2008	Far Eastern State Transport University, Electrical Engineering, B.S., Project: "Modernization of the existing cellular network with subsequent transition from 2G to 3G"

Teaching Experience

2014-2016	University of Alaska Fairbanks, Teaching Assistant – "Communication Systems", "Signal Analysis", "Circuit Theory", "Electronic Circuit Design", and "Electrical Machinery", Facilitated the educational process by conducting laboratories and grading assignments
2011-2014	Far Eastern State Transport University, Instructor – "Communication with Mobile Objects", Taught a lecture course

Research and Professional Experience

2017 – Present University of Alaska Fairbanks, Geophysical Institute, Research Professional II

- Support the research process with expertise in such areas as data loggers/sensors (Campbell Scientific), wireless communications, systems administration, data processing.
- Continue developing the prototype of the data logger for precise temperature measurements.

2008 – 2014 Russian Satellite Communications Company (RSCC), Engineer II at the Satellite Communications Center "Khabarovsk"

- Managed iDirect Infiniti and Evolution hubs.
- Participated in the development of ground facilities for the High Throughput Satellite system.

Languages

Russian– native language
English– speak fluently and read/write with high proficiency

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Education and Training

2003	Michigan Technological University, Forest Science, PhD
1997	Johns Hopkins University, Mathematical Sciences, MS
1994	Marymount College, Mathematics, BS

Research and Professional Experience

2018 - present	Associate Professor, University of Alaska Fairbanks
2014-2018	Research Associate Professor, University of Alaska Fairbanks
2009-2014	Research Assistant Professor, University of Alaska Fairbanks
2006 - 2009	Research Associate, University of Alaska Fairbanks
2004-2006	Postdoctoral Fellow, University of Alaska Fairbanks
1997 - 1998	Hydrologist, U.S. Geological Survey, Baltimore, MD
1994-1995	Environmental modeling, Argonne National Laboratory

Selected Publications

Euskirchen, E.S., K. Timm,, A.L. Breen, S. Gray, T.S. Rupp, P. Martin, J. Reynolds, A. Sesser, K. Murphy, J.S. Littell, A.Bennett, W.R. Bolton, T. Carman, H. Genet, B. Griffith, T. Kurkowski, M.J. Lara, S.Marchenko, D. Nicolsky, S. Panda, V. Romanovsky, R. Rutter, C.L. Tucker, A.D. McGuire. *In press.* Co-production of knowledge: Developing the Integrated Ecosystem Model to inform resource management decisions in Arctic Alaska. *Frontiers in Ecology and the Environment.*

Euskirchen, E.S., C.W. Edgar, M.S. Bret-Harte, A. Kade, N. Zimov, S. Zimov. 2017. Interannual and seasonal patterns of carbon dioxide, water, and energy fluxes from ecotonal and thermokarst-impacted ecosystems on carbon-rich permafrost soils in northeastern Siberia. *Journal of Geophysical Research – Biogeosciences.*

Euskirchen, E.S. M.S. Bret-Harte, G.R. Shaver, C.W. Edgar, V.E. Romanovsky. 2017. Long-term release of carbon dioxide from arctic tundra ecosystems in northern Alaska. Ecosystems. doi:10.1007/s10021-016-0085-9

Commane, R., J. Lindaas, J. Benmergui, K.A. Luus, R. Y.-W. Chang, B.C. Daube, S. Dinardo, E.S. Euskirchen, J.M. Henderson, A. Karion, J.B. Miller, S.M. Miller, N.C Parazoo, J.T. Randerson, C. Sweeny, K. Thoning, S. Veraverbeke, C.E. Miller, S.C. Wofsy. 2017. Carbon dioxide sources from Alaska driven by increasing early winter respiration from Arctic tundra. Proceedings of the National Academy of Sciences. 114: 5361–5366, doi: 10.1073/pnas.1618567114

Euskirchen, E.S., A. Bennett, A.L. Breen, H. Genet, M. Lindgren, T. Kurkowski, A.D. Mcuire, T.S. Rupp. 2016. Consequences of changes in vegetation and snow cover for climate feedbacks in Alaska and northwest Canada. Environmental Research Letters. doi:10.1088/1748-9326/11/10/105003

Lara, M.J., A.D. McGuire, E.S. Euskirchen, C. Tweedie, K. Hinkel, A. Skurikhin, V.E. Romanovsky, G. Guido, W. Bolton, H. Genet, 2015. Century time-scale change in peak growing season CO_2 and CH_4 flux in response to change in ice-wedge polygonal tundra, on the Barrow Peninsula in Arctic Alaska. *Global Change Biology*.

Euskirchen, E.S., T.B. Carman, A.D. McGuire. 2014. Changes in structure and function of northern Alaskan ecosystems when considering variable leaf-out times across groupings of species in a dynamic vegetation model. *Global Change Biology*.

Wullshleger, S., H.E. Epstein, E.O. Box, E.S. Euskirchen, S. Goswami, C.M. Iverson, J. Kattage, R. Norby, P.M. van Bodegom, X. Xu. 2014. Plant functional types in Earth System Models: Past experiences and future directions for application of dynamic vegetation models in high-latitude ecosystems. Invited Review, Journal of Botany 114: 1-16.

Euskirchen, E.S. Goodstein, H.P. Huntington. 2013. An estimated cost of lost climate regulation services caused by thawing of the Arctic cryosphere. *Ecological Applications*.

Euskirchen, E.S., A.D. McGuire, F.S. Chapin III, S. Yi, and C.C. Thompson. 2009. Changes in vegetation in northern Alaska under scenarios of climate change 2003-2100: Implications for climate feedbacks. *Ecological Applications*.

Synergistic Activities

Co-chair NEON Technical Working Group Advisory Board Surface-Atmosphere Exchange (2017 – present)

Arctic Boreal Vulnerability Experiment (ABoVE) Science Team (2016 – present)

Steering Committee, Synergies between the National Ecological Observation Network (NEON) and Long Term Ecological Sites (LTER) (July 2015 – present)

Planning Committee, National Academy of Sciences, Understanding Northern Latitude Vegetation Greening and Browning - A Workshop (August 2018 – present)

Working Group Co-Lead, NCEAS Arctic Data Center activity, Reconciling historical and contemporary trends in terrestrial carbon exchange of the northern permafrost-zone (August 2017 – present)

Collaborators and Significant Recent Co-Authors (not including UAF)

Commane, R., Columbia Univ.
Gray, S., USGS
Jones, J., Oregon State Univ.
Kling, G., Univ. Michigan
Littell, J.S., USGS
Miller, C., Jet Propulsion Laboratory
Neumann, Univ. Washington
Oechel, W., San Diego State Univ.
Rastetter, E., Marine Biol. Lab
Salmon, V., Oak Ridge National Lab
Serbin, S., Brookhaven National Lab
Turetsky, M., Univ. of Guelph
Waldrop, M., U.S. Geological Survey
Wilson, E., NASA Goddard
Wullschleger, S., Oak Ridge National Lab
Zimov, N., Northeast Science Station, Russia
Fratterigo, J., U. Illinois
Iversen, C., Oak Ridge National Lab
Kimball, J.S., Univ. of Montana
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Watts, J., University of Montana
Wofsy, S., Harvard Univ.
Zona, D., Univ. Sheffield / San Diego State Univ.
Poulter, B., NASA Goddard

Graduate and Postdoctoral Advisors

Kurt S. Pregitzer, Michigan Technological University (currently: University of Idaho); Jiquan Chen, Michigan Technological University (currently: Michigan State University)
Postdoctoral advisor: A**.** David McGuire, University of Alaska Fairbanks

Graduate and Postdoctoral Advisees

Primary Advisor: Caroline Lundmark (Postdoc, July 2010 – September 2011), Vijay Patil (PhD student, graduated Oct. 2017), Tobey Carmen (M.S. Student, graduated August 2012), Casey Brown (PhD student, graduated May 2016), Rebecca Finger (M.S. Student, graduated Dec. 2014), Mark Lara (Postdoc, March 2013 – August 2016), Colin Tucker (Postdoc, June 2013 – June 2015)
Committee Member: Dana Brown (Ph.D. student, graduated May 2016); Niki Jacobs (Ph.D. student, January 2016 – present); Jason Clark (Ph.D. student, February 2017 – present)

Go Iwahana
University of Alaska Fairbanks, International Arctic Research Center

Professional Preparation

2004	Hokkaido University, Japan, Earth Environmental Science PhD
2000	Hokkaido University, Japan, Earth Environmental Science M.S.
1998	Hokkaido University, Japan, Geophysics, B.S.
	Ph. D. Thesis: "Influence of forest disturbance on the ecosystem energy and water balance in the continuous permafrost zone, Eastern Siberia"

Appointments

2017-current	Research Assistant Professor, International Arctic Research Center, University of Alaska Fairbanks
2015-2016	Research Associate, International Arctic Research Center, University of Alaska Fairbanks
2012-2015	Post-doctoral Research Fellow, International Arctic Research Center, University of Alaska Fairbanks
2009-2011	Assistant Professor, Graduate School of Earth Environmental Science, Hokkaido University, Japan
2006-2009	Assistant Professor, Graduate School of Engineering, Hokkaido University, Japan
2004-2006	Research Fellow of Japan Science Promotion Society

Products (Peer-review papers)

Saito, K., G. Iwahana, H. Ikawa, H. Nagano, and R. C. Busey (2018), Links between annual surface temperature variation and land cover heterogeneity for a boreal forest as characterized by continuous, fibre-optic DTS monitoring, Geosci. Instrum. Method. Data Syst., 7(3), 223-234, doi:10.5194/gi-7-223-2018.

Tsuyuzaki, S., G. Iwahana, and K. Saito (2017), Tundra fire alters vegetation patterns more than the resultant thermokarst, Polar Biology. DOI10.1007/s00300-017-2236-7

Iwahana, G., K. Harada, M. Uchida, S. Tsuyuzaki, K. Saito, K. Narita, K. Kushida, and L. D. Hinzman (2016), Geomorphological and geochemistry changes in permafrost after the 2002 tundra wildfire in Kougarok, Seward Peninsula, Alaska, Journal of Geophysical Research: Earth Surface, 121(9), 1697-1715.

Sato, H., H. Kobayashi, G. Iwahana, and T. Ohta (2016), Endurance of larch forest ecosystems in eastern Siberia under warming trends, Ecology and Evolution, 6(16), 5690-5704.

Iwahana, G., M. Uchida, L. Liu, W. Gong, F. Meyer, R. Guritz, T. Yamanokuchi, and L. Hinzman (2016), InSAR Detection and Field Evidence for Thermokarst after a Tundra Wildfire, Using ALOS-PALSAR, Remote Sensing, 8(3), 218.

Fedorov, A. N., G. Iwahana, P. Y. Konstuntinov, T. Muchimura, R. N. Argunov, P. V. Efremov, L. M.C. Lopez, and F. Takakai (2016), Variability of permafrost and landscape conditions following clear cutting of larch forest in Central Yakutia, Permafrost and Periglacial Processes (Accepted: 1 February 2016)

Lopez Caceres, M. L., F. Takakai, G. Iwahana, A. N. Fedorov, Y. Iijima, R. Hatano, and M. Fukuda (2015), Snowmelt and the hydrological interaction of forest–grassland ecosystems in Central Yakutia, eastern Siberia, Hydrological Processes, 29(14), 3074-3083.

Iwahana, G., et al. (2014), Geocryological characteristics of the upper permafrost in a tundra-forest transition of the Indigirka River Valley, Russia, Polar Science, 8(2), 96-113.

Fedorov, A. N., P. P. Gavriliev, P. Y. Konstantinov, T. Hiyama, Y. Iijima, and G. Iwahana (2014), Estimating the water balance of a thermokarst lake in the middle of the Lena River basin, eastern Siberia, Ecohydrology, 7(2), 188-196.

Zhegusov, Y., S. Ksenofontov, T. Maximov, A. Sugimoto, and G. Iwahana (2013), Environmental Consciousness of Local People of Yakutia Under Global Climate Change, in Causes, Impacts and Solutions to Global Warming, edited by I. Dincer, C. O. Colpan and F. Kadioglu, pp. 251-260, Springer New York.

Iwahana, G., K. Fukui, N. Mikhailov, O. Ostanin, and Y. Fujii (2012), Internal Structure of a Lithalsa in the Akkol Valley, Russian Altai Mountains, Permafrost and Periglacial Processes, 23(2), 107-118.

Konstantinov, P. Y., A. N. Fedorov, T. Machimura, G. Iwahana, H. Yabuki, Y. Iijima, and F. Costard (2011), Use of automated recorders (data loggers) in permafrost temperature monitoring (in Russian), Earth Cryosphere, 15(1), 23-32.

Lopez, M. L., T. Shirota, G. Iwahana, T. Koide, T. C. Maximov, M. Fukuda, and H. Saito (2010), Effect of increased rainfall on water dynamics of larch (Larix cajanderi) forest in permafrost regions, Russia: an irrigation experiment, Journal of Forest Research, 15(6), 365-373.

Lopez C, M. L., E. Gerasimov, T. Machimura, F. Takakai, G. Iwahana, A. N. Fedorov, and M. Fukuda (2008), Comparison of carbon and water vapor exchange of forest and grassland in permafrost regions, Central Yakutia, Russia, Agricultural and Forest Meteorology, 148(12), 1968-1977.

Fukui, K., Y. Fujii, N. Mikhailov, O. Ostanin, and G. Iwahana (2007), The lower limit of mountain permafrost in the Russian Altai Mountains, Permafrost and Periglacial Processes, 18(2), 129-136.

Iwahana, G., T. Machimura, Y. Kobayashi, A. N. Fedorov, P. Y. Konstantinov, and M. Fukuda (2005), The Influence of Forest Clear-cutting on the Thermal and Hydrological Regime of the Active Layer near Yakutsk, Eastern Siberia, Journal of Geophysical Research, 110, G02004.

Brouchkov, A., M. Fukuda, G. Iwahana, Y. Kobayashi, and P. Konstantinov (2005), Thermal Conductivity of Soils in the Active Layer of Eastern Siberia, Permafrost and Periglacial Processes, 16(2), 217-222.

Machimura, T., Y. Kobayashi, G. Iwahana, T. Hirano, L. Lopez, M. Fukuda, and A. N. Fedorov (2005), Change of carbon dioxide budget during three years after deforestation in Eastern Siberian Larch forest, J. Agric. Meteorol., 60(5), 653-656.

Brouchkov, A., M. Fukuda, A. Fedorov, P. Konstantinov, and G. Iwahana (2004), Thermokarst as a short-term permafrost disturbance, Central Yakutia, Permafrost and Periglacial Processes, 15(1), 81-87.

Synergistic Activities

Collaboration with researchers in Japan, Russia and across the U.S. in monitoring of permafrost degradation and paleo-environmental analyses using permafrost

Member of American Geophysical Union

Member of International Permafrost Association

Member of Japan Geoscience Union

Member of Japan Permafrost Association

Collaborators and Co-Editors

H. Eicken (University of Alaska Fairbanks), C. Wilson (LANL), J. Deming (University of Washington), L. Hinzman (University of Alaska Fairbanks), M. Lara (University of Illinois), B. Jones (University of Alaska Fairbanks), K. Saito (JAMSTEC), A. Fedorov (Yakutsk Permafrost Institute), H. Ohno (Kitami Institute of Technology), S. Kim (JPL), B. Busey (University of Alaska Fairbanks), R Muskett (University of Alaska Fairbanks), F. Meyer (University of Alaska Fairbanks), T. Yohokata (National Institute of Environmental Studies), M. Uchida (National Institute of Environmental Studies), T. Sone (Hokkaido University), J. Ahn (Seoul National University), A Brouchkov (Moscow State University), T. Maximov (Institute for Biological Problems in the Cryosphere).

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Education and Training

2001	Lomonosov Moscow State University, Moscow Russia, Geology, PhD
1997	Lomonosov Moscow State University, Moscow Russia, Geocryology, MS
1996	Lomonosov Moscow State University, Moscow Russia, Geocryology, BS

Research and Professional Experience

2014 - Present	Research Associate, Geophysical Institute, University of Alaska Fairbanks
2007 - 2014	Post Doctoral Fellow, Geophysical Institute, University of Alaska Fairbanks
2001 - 2007	Senior Scientist, Laboratory of Soil Cryology, Institute of Physical-Chemical and Biological Problems of Soil Science RAS

Selected Publications

N.N. Romanovskii, H.-W.Hubberten, A.V.Gavrilov, V.E.Tumskoy and **A.L.Kholodov**. Permafrost of the east Siberian Arctic shelf and coastal lowlands //Quaternary Science Reviews, V 23, Issues 11-13, 2004, pp 1359-1369

D.A. Gilichinsky, E. Nolte, A.E. Basilyan, J. Beer, A.V. Blinov, V.E. Lazarev, **A.L. Kholodov**, H. Meyer, P.A. Nikolskiy, L. Schirrmeister, V.E. Tumskoy, Dating of syngenetic ice wedges in permafrost with 36Cl, Quaternary Science Reviews, Volume 26, Issues 11?12, June 2007, Pages 1547-1556

V.E. Romanovsky, D.S. Drozdov, N.G. Oberman, G.V. Malkova, **A.L. Kholodov**, S.S. Marchenko, N.G. Moskalenko, D.O. Sergeev, N.G. Ukraintseva, A.A. Abramov, D.A.Gilichinsky, A.A. Vasiliev - Thermal state of permafrost in Russia. Permafrost and Periglacial Processes. 2010, 21: 106-116.

A. Kholodov, D. Gilichinsky, V. Ostroumov, V. Sorokovikov, A. Abramov, S. Davydov, V. RomanovskyRegional and Local Variability of Modern Natural Changes in Permafrost Temperature in the Yakutia Coastal Lowlands, Northeastern Siberia. // Proceedings of the Tenth International Conference on Permafrost. 2012. pp. 2080-2085

Webb, E.E., Heard, K., Natali, S.M., Bunn, A.G., Alexander, H.D., Berner, L.T., **Kholodov, A.,** Loranty, M.M., Schade, J.D., Spektor, V. and Zimov, N., 2017. Variability in above-and belowground carbon stocks in a Siberian larch watershed. *Biogeosciences*, *14*(18), pp.4279-4294.

Kraev, G., Schulze, E.D., Yurova, A., **Kholodov, A**., Chuvilin, E. and Rivkina, E., 2017. Cryogenic displacement and accumulation of biogenic methane in frozen soils. *Atmosphere*, *8*(6), p.105.

Shmelev, D., Veremeeva, A., Kraev, G., **Kholodov, A.**, Spencer, R.G., Walker, W.S. and Rivkina, E., 2017. Estimation and Sensitivity of Carbon Storage in Permafrost of North-Eastern Yakutia. *Permafrost and Periglacial Processes*, *28*(2), pp.379-390.

Synergistic Activities

2004- 2007: Head of expedition, Beringia, Russian Academy of Sciences
Collaborator and data contributor to the Circumpolar Active Layer Monitoring project (CALM)
Collaborator and data contributor to the Global Terrestrial Network for Permafrost project (GTN-P)
Collaborator and data contributor to the US DoE funded project Next Generation of Ecosystem Experiment (NGEE)
Collaborator of NSF funded project The Polaris

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Education and Training

2000	St. Petersburg State University, Russia, Physics, B.S.
2003	University of Alaska Fairbanks, USA, Mathematics, M.S.
2007	University of Alaska Fairbanks, USA, Interdisciplinary in Geophysics, Ph.D.

Research and Professional Experience

2013-present	Research Assistant Professor, University of Alaska Fairbanks
2008-2013	Research Staff, Geophysical Institute, University of Alaska Fairbanks
2002-2007	Research Assistant, Geophysical Institute, University of Alaska Fairbanks
1998-2000	Research Assistant, Saint Petersburg State University, Russia

Selected Publications

Nicolsky, D.J., V.E. Romanovsky, V.A. Alexeev, and D.M. Lawrence, 2007, *Improved modeling of permafrost dynamics in a GCM land-surface scheme*, Geophysical Research Letters, 34(8): L08501.

Nicolsky, D.J., V.E. Romanovsky and G.G. Panteleev, 2009, *Estimation of soil thermal properties using in-situ temperature measurements in the active layer and permafrost*, Cold Regions Science and Technology Journal, 55, pp. 120-129, doi:10.1016 /j.coldregions.2008.03.003.

Rawlins, M., D.J. Nicolsky, K. McDonald, and V.E. Romanovsky, 2013, *Simulating Soil Freeze/Thaw Dynamics with an Improved Pan-Arctic Water Balance Model*, Journal of Advances in Modeling Earth Systems, 5, 1-17, doi:10.1002/jame.20045.

Nicolsky, D. J., V. E. Romanovsky, S. K. Panda, S. S. Marchenko, and R. R. Muskett, 2016, Applicability of the ecosystem type approach to model permafrost dynamics across the Alaska North Slope, Journal of Geophysical Research: Earth Surface, 121, doi:10.1002/2016JF003852.

Nicolsky, D.J., and V.E. Romanovsky, 2018, Modeling long-term permafrost degradation, Journal of Geophysical Research: Earth Surface, 123, https://doi.org/10.1029/2018JF004655.

Other Publications

Nicolsky, D.J., V.E. Romanovsky, G.S. Tipenko and D.A. Walker, 2008, *Modeling biogeophysical interactions in non-sorted circles in the Low Arctic*, Journal of Geophysical Research, 113, G03S05, doi:10.1029/2007JG000565.

Lawrence, D.M., A.G. Slater, V.E. Romanovsky and D.J. Nicolsky, 2008, *The sensitivity of a model projection of near-surface permafrost degradation to soil column depth and representation of soil organic matter*, Journal of Geophysical Research, 113, F02011, doi:10.1029/2007JF000883.

Nicolsky D.J., V.E. Romanovsky, N.N. Romanovskii, A.L. Kholodov, N.E. Shakhova, and I.P. Semiletov, 2012, *Modeling sub-sea permafrost in the East Siberian Arctic Shelf: The Laptev Sea Region*, Journal of Geophysical Research, 117, F03028, doi:10.1029/2012JF002358.

Jafarov E.E., D.J. Nicolsky, V.E. Romanovsky, and J.E. Walsh, 2013, *The effect of snow: How to better model ground surface temperatures*, Cold Region Science and Technology, 5(4), 659-675.

Shakhova, N., I. Semiletov, I. Leifer, V. Sergienko, A. Salyuk, D. Kosmach, D. Chernykh, C. Stubbs, D. Nicolsky, V. Tumskoy, and O. Gustafsson, 2014, *Massive methane release via ebullition and storms on the East Siberian Arctic Shelf*, Nature Geoscience, doi:10.1038/ngeo2007.

C. D. Koven, E. A. G. Schuur, C. Schädel, T. J. Bohn, E. J. Burke, G. Chen, X. Chen, P. Ciais, G. Grosse, J. W. Harden, D. J. Hayes, G. Hugelius, E. E. Jafarov, G. Krinner, P. Kuhry, D. M. Lawrence, A. H. MacDougall, S. S. Marchenko, A. D. McGuire, S. M. Natali, D. J. Nicolsky, D. Olefeldt, S. Peng, V. E. Romanovsky, K. M. Schaefer, J. Strauss, C. C. Treat, M. Turetsky, 2015, *A*

simplified, data-constrained approach to estimate the permafrost carbon-climate feedback, Philosophical Transactions of the Royal Society A, 373: 20140423.
Melvin, A.M., P. Larsen, B. Boehlert, J. Neumann, P. Chinowsky, X. Espinet, J. Martinich, M.S. Baumann, L. Rennels, A. Bothner, D.J. Nicolsky, and S.S. Marchenko, 2017, *Climate change risks to Alaska public infrastructure: improved estimates of damages and the economics of proactive adaptation*, Proceedings of the National Academy of Sciences, v. 114, no. 2, E122E131.
McGuire, A.D. D.M. Lawrence, C. Koven, J.S. Clein, E. Burke, G. Chen, E. Jafarov, A.H. MacDougall, S. Marchenko, D. Nicolsky, S. Peng, A. Rinke, P. Ciais, I. Gouttevin, D.J. Hayes, D. Ji, G. Krinner, J.C. Moore, V. Romanovsky, C. Schadel, K. Schaefer, E.AG Schuur, Q. Zhuang, 2018, Dependence of the evolution of carbon dynamics in the northern permafrost region on the trajectory of climate change, Proceedings of the National Academy of Sciences Mar 2018, 201719903.

Synergistic Activities

Development and verification of the permafrost modules/models (Geophysical Institute Permafrost Model, Pan-Arctic Water Balance Model, Alaska Integrated Ecosystem Model)
Participation in Swedish-Russian-US Initiative to study Carbon-Climate-Cryosphere Interactions in the Arctic Ocean
Reviewer for Journals of Geophysical Research, Geophysical Research Letters, Cold Region Science and Technology
Use of the permafrost module output to assess the permafrost changes in the 21st century and their impact on existing and future infrastructure in the Alaskan Arctic
Augmentation of the US Array sites with temperature profilers

Collaborators and Other Affiliations

A.Kholodov (UAF), M.Rawlins (UMass), N.Romanovskii (Moscow State University), V.Romanovsky (UAF), I.Semiletov (UAF), N.Shakhova (UAF), K.McDonald (City College of NY), E.Jafarov (NSIDC), V.Tumskoy (Moscow State University), O.Gustafsson (Stockholm University)

Graduate Advisors

Vladimir Romanovsky (Ph.D., University of Alaska Fairbanks)
Alexei Rybkin (M.S., University of Alaska Fairbanks)
Alexander Chirtsov (B.S., University of Alaska Fairbanks)

Graduate Students

Matthew Harris, M.S., Department of Mathematics and Statistics (2013-2015)
Viacheslav Garayshin, Ph.D., Department of Geology and Geophysics (2013-2017)
Matvey Debolskiy, Ph.D., Department of Geology and Geophysics (2015-present)
Jody Gaines, M.S., Department of Mathematics and Statistics (2018-present)

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Education and Training

1996	University of Alaska Fairbanks, Geophysics, PhD
1982	Moscow State University, Geology, PhD
1985	Moscow State University, Mathematics (Honor Diploma), MS
1975	Moscow State University, Geophysics (Honor Diploma), MS

Research and Professional Experience

2006–present	Professor of Geophysics, University of Alaska Fairbanks, Alaska.
1999–2006	Associate Professor of Geophysics, University of Alaska Fairbanks, Alaska.
1998–1999	Research Associate Professor, Geophysical Institute, University of Alaska Fairbanks, Alaska.
1996–1998	Research Associate, Geophysical Institute, University of Alaska Fairbanks, Alaska.
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1985–1992	Associate Professor of Geophysics and Geocryology, Moscow State University.
1980–1985	Science Researcher, Department of Geocryology, Moscow State University, Russia.
1975–1980	Geophysicist, Faculty of Geology, Moscow State University, Russia.

Selected Publications

Nicolsky, D. J. and V. E. Romanovsky (2018). Modeling long-term permafrost degradation, *Journal of Geophysical Research: Earth Surface, 123.* https://doi.org/10.1029/2018JF004655

Romanovsky, Vladimir, Ketil Isaksen, Dmitry Drozdov, Oleg Anisimov, Arne Instanes, Marina Leibman, A. David McGuire, Nikolay Shiklomanov, Sharon Smith, and Donald Walker, 2017. [Changing permafrost and its impacts]. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017, pp. 65-102. Arctic, Monitoring and Assessment Programme (AMAP), Oslo, Norway, Narayana Press, Gylling, DK-8300 Odder, Denmark

Nicolsky, D. J., V. E. Romanovsky, S. K. Panda, S. S. Marchenko, and R. R. Muskett (2017), Applicability of the ecosystem type approach to model permafrost dynamics across the Alaska North Slope, *J. Geophys. Res. Earth Surf.*, **122**: 50-75, doi:10.1002/2016JF003852

Schuur, E.A.G., A. D. McGuire, C. Schädel, G. Grosse, J.W. Harden, D.J. Hayes, G. Hugelius, C. D Koven, P. Kuhry, D. M. Lawrence, S.M. Natali, D. Olefeldt, V.E. Romanovsky, K. Schaefer, M. Turetsky, C. Treat, J. E. Vonk, 2015. Climate Change and the Permafrost Carbon Feedback, *Nature*, Vol. 520: 171-179, doi:10.1038/nature14338.

Romanovsky, VE., Smith, SL., and Christiansen, HH., 2010. Permafrost Thermal State in the Polar Northern Hemisphere during the International Polar Year 2007-2009: a synthesis. *Permafrost and Periglacial Proceses*, 21:106-116.

Romanovsky, VE., Drozdov, DS. Oberman, NG., Malkova GV., Kholodov AL., Marchenko, SS., Moskalenko, NG., Sergeev DO., Ukraintseva, NG., Abramov AA., Gilichinsky, DA., and AA.Vasiliev, 2010. Thermal State of Permafrost in Russia. *Permafrost and Periglacial Processes*, 21:136-155.

Five other significant publications

Cable, W. L., V. E. Romanovsky, and M. T. Jorgenson, Scaling-up permafrost thermal measurements in western Alaska using an ecotype approach, *The Cryosphere*, 10, 2517-2532, 2016

Schaefer, K., H. Lantuit, V. E. Romanovsky, E. A. E. Schuur, R. Witt, The impact of the permafrost carbon feedback on global climate, *Environmental Research* Letters, 9 (2014) 085003 (9 pp), http://dx.doi.org/10.1088/1748-9326/9/8/085003
Smith, SL., Romanovsky, VE., Lewkowicz, AG., Burn, CR. Allard, M., Clow, GD., Yoshikawa, K. & Throop, J., 2010. Thermal State of Permafrost in North America – A Contribution to the International Polar Year. *Permafrost and Periglacial Proceses*, 21:117-135.
Jorgenson, M. T, V. E. Romanovsky, J. Harden, Y. L. Shur, J. O'Donnell, T. Schuur, and M. Kanevskiy, 2010. Resilience and vulnerability of permafrost to climate change, *Canadian Journal of Forest Research*, 40: 1219–1236.
Romanovsky, VE and TE Osterkamp, 2000. Effects of unfrozen water on heat and mass transport processes in the active layer and permafrost, *Permafrost and Periglacial Processes*, 11, 219-239.

Synergistic Activities

Service to the scientific community as a member of the Executive Committee of the International Permafrost Association (IPA), 2008-2018, and as an IPA vice-President, 2012-2018
Service to the scientific community as a member of the US Polar Research Board, 2008-2013
Service to the scientific community as a member of the Editorial Board, Permafrost and Periglacial Processes (PPP) and Cold Region Science and technology (CRST), 2013 – present
Service to the scientific community as a member of the U.S. delegation to IASC (Terrestrial Working Group), 2014 – present, co-Chair of the Terrestrial Working Group, 2017 - present
Service to the scientific community as a member of the Scientific Advisory Board of the Alfred Wegener Institute (AWI), Germany, 2013 – present

Collaborators and Co-Editors

Prof. L.D. Hinzman, Dr. A.D. McGuire, Dr. K. Yoshikawa, N. Molders, D. Nicolsky (U of Alaska), Dr. T.S. Sazonova, Dr. T. Zhang (U of Colorado, Boulder), Prof. F.E. Nelson (U of Delaware, DE), Prof. N.N. Romanovskiy (Moscow State University), Dr. J. Brown (IPA), C. Duguay (U of Waterloo).

Graduate and Postdoctoral Advisors

Prof. S.A. Ushakov, Moscow State University, Prof. B.N. Dostovalov, MSU, Prof. N.N. Romanovskiy, MSU, Prof. V.A. Zakharov, MSU, Prof. T.E. Osterkamp, UAF, Fairbanks.

Postdoctoral and Visiting Research Fellows Supported

L. Farquharson (2017 – present), S. Panda (2011–2015), R. Muskett (2008–2015), A. Kholodov (2007–2014), G. Grosse (2006–2009), R. Daanen (2005–2010), S. S. Marchenko (2003–2008), T. S. Sazonova (2003–2004), D. O. Sergueev (2001–2003), G. S. Tipenko (2000–2005), R. A. Peterson (2000–2001).

APPENDIX

Project Publications A-3
Data Management Plan A-17
Data Publication and Sharing Policy A-19
Software Productivity and Sustainability Plan A-21
Dataset DOIs and Citations A-23

PROJECT PUBLICATIONS

CALENDAR YEAR 2010

Hanson PJ, KE Childs, SD Wullschleger, JS Riggs, WK Thomas, DE Todd and JM Warren. 2010. A method for experimental heating of intact soil profiles for application to climate change experiments. Global Change Biology 17: 1083-1096. http://dx.doi.org/10.1111/j.1365-2486.2010.02221.x

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DATA MANAGEMENT PLAN

Data Types and Sources: The Next-Generation Ecosystem Experiments (NGEE Arctic) project is composed of an array of researchers from multiple science disciplines across multiple national laboratories and universities. The NGEE Arctic project generates diverse datasets from observations, laboratory measurements, experiments, and models across field plot, watershed, regional, and global scales. These data include automated data collected from weather stations and in situ systems, observations from remote-sensing platforms, manual data collection efforts during large campaign-based field work, and discrete datasets generated from chemical, biochemical, and molecular characterizations of soil, water, microbial, and plant samples. Large output files from a suite of fine- to climate-scale models will also be generated by the NGEE Arctic project. The project draws on a wealth of existing data products collected and generated by other national and international monitoring networks and research organizations across the Arctic including the NASA-funded ABoVE field campaign

Content and Format: The NGEE Arctic project leverages existing tools and expertise to provide data management support to the project by adopting a standards-based, open-source approach to ensure interoperability with future data systems and other projects. The ORNL Online Metadata Editor (OME) is a Web-based tool that allows users to create and maintain robust metadata stored as eXtensible Markup Language (XML) files, the preferred metadata output format, with output that conforms to and satisfies widely-adopted metadata standards – specifically Federal Geospatial Data Committee (FGDC) and ISO11915 metadata standards. The OME captures information about the specific data contributors, projects, parameters, time periods, quality assurance, and locations associated with the data. This metadata is the basis for the NGEE Arctic Search and Access Tool for data products. The OME also enables the automatic generation of a unique data citation and Digital Object Identifier (DOI) for each dataset. Users may upload data files plus additional documentation using the OME. The preferred non-proprietary file format for public sharing of tabular data products is the comma separated value (csv) format. For geospatial imagery, GeoTIFF and NetCDF are the preferred formats for raster data and shapefiles or KML for vector products.

Sharing and Preservation: All NGEE Arctic metadata records are available to the public in the NGEE Arctic Data Search and Access Tool. Metadata may be classified as either Planned, Internal, or Public. Planned datasets include metadata only and are listed in order to promote visibility and communication within the NGEE team. Datasets marked Internal are accessible to authenticated NGEE Arctic team members only, and Public datasets are released without restriction to the public and are shared with the ESS-DIVE data center. Descriptive information captured in the OME enables advanced data search options using keywords, geospatial, temporal, contributor name, and scientific task filters. The NGEE Arctic data will be released publicly under a Creative Commons Attribution 4.0 license (CC-BY) license. The NGEE Arctic portal provides a data sharing policy (available in Appendix), data submission guidance, and data citation recommendations plus guidance on data submissions. Early sharing of data within the project is urged because it encourages vital scientific collaboration within the project, identifies planned research, allows access to the data as soon as possible for researchers and modelers, and ensures long-term preservation. All data and associated metadata produced by NGEE Arctic should be made available as soon as feasible but no later than 12 months after acquisition. All public data will be submitted to the DOE's ESS-DIVE data center. At the end of the project, all internal data and associated metadata will be made public and will be transitioned to ESS-DIVE.

Protection: NGEE Arctic will not store personally identifiable or sensitive environmental information in its data system. If any are discovered, it will be removed. Intellectual property rights of investigators are protected by access restrictions and promoted through data citation guidance and DOIs. Stored data are protected from loss by routine and test backup protocols. Cybersecurity planning and infrastructure for the NGEE Arctic data system will be provided as part of the Oak Ridge National Laboratory cyberinfrastructure.

Rationale: The open sharing of NGEE Arctic data among project researchers, the broader scientific community, and the public is critical to meeting the scientific goals and objectives of the NGEE Arctic project and critical to advancing the mission of the Department of Energy (DOE), Office of Science, Biological and Environmental (BER) program. The NGEE Arctic project seeks to understand how surface and subsurface processes and properties are interconnected across permafrost-dominated tundra ecosystems. Ultimately, the NGEE Arctic project is developing a process-rich ecosystem model, extending from the bedrock to the vegetative canopy-atmospheric interface, in which the evolution of Arctic ecosystems can be modeled at the scale of a high-resolution ESM grid cell.

DATA PUBLICATION AND SHARING POLICY

The open sharing of Next-Generation Ecosystem Experiments (NGEE Arctic) data among project researchers, the broader scientific community, and the public is critical to meeting the scientific goals and objectives of the NGEE Arctic project and to advancing the mission of the Department of Energy (DOE), Office of Science, Biological and Environmental (BER) program. The NGEE Arctic project is committed to upholding a rigorous and high-quality data management strategy and the implementation of that strategy in an innovative, cost-effective, data collection, management, distribution, and archival framework. The NGEE Arctic data management policy is consistent with the data policies of the sponsoring program (https://www.energy.gov/datamanagement/doe-policy-digital-research-data-management). We intend this policy to be a clear statement of the importance of full, open, and timely sharing of all data and associated metadata produced by NGEE Arctic. This Policy is applicable to all NGEE Arctic participants, including scientists at Oak Ridge National Laboratory, Los Alamos National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, the University of Alaska Fairbanks, partners at universities and other state and federal agencies, cooperating independent researchers, and to users of NGEE Arctic data products.

Sharing Data: Metadata describing the NGEE Arctic data products is captured in the Online Metadata Editor (OME). Data (including metadata) should be made available as soon as feasible after initial quality checks but no later than 12 months after acquisition. Generally, public release will be concurrent with open literature publication of results. All public data will be submitted to the DOE's ESS-DIVE data center. At the end of the project, all internal data and associated metadata will be made public and will be transitioned to ESS-DIVE. Key data collected by graduate students should not be released publicly at the NGEE Arctic Data Portal prior to submitting their thesis, dissertation, or peer-reviewed publication because to do so can jeopardize the student's academic interests. As a result, data collected specifically for a student's thesis or dissertation are not subject to the public data sharing obligations of this policy until the end of Phase 3 or after the student has completed their degree, whichever comes first. All data supporting a student or postdoctoral associate's work must be submitted to the archive prior to leaving the NGEE Arctic project.

Quality Assurance of Data: Data products submitted to the archive must undergo quality checks and should include estimates of uncertainty. Each data contributor should document the quality assurance checks that have been performed before data sharing. When data products have been updated because of additional quality checks or the discovery of errors, the data should be resubmitted to the Archive as a new version and with documentation of the changes. Data versioning will be facilitated by the OME system.

Credit to Data Contributors and Authors: The NGEE Arctic data will be released publicly under a Creative Commons Attribution 4.0 license (CC-BY) license. Users are free to use, share, and adapt the data for their own use, but they must give appropriate credit to the data authors. When data are used in publications or in modeling or integrative studies, the scientist collecting the data must be credited appropriately, either by co-authorship, citation, or acknowledgement. The NGEE Arctic Data Search and Access Tool provides formal citations and digital object identifiers (DOIs) for all data products. The full citation should be included in any publication that uses the data, and the citation should include all individuals contributing to the data product, the title of the data product, the year of data release, the name of the archive, and the DOI. NGEE Arctic participants who wish to use internally-shared products are required to discuss and develop planned uses and any resulting publications with the data contributors in a collaborative manner. The data contributors must have the opportunity to read the manuscript before submission, and, if appropriate, be offered co-authorship. In cases where unpublished data from other investigators are a minor contribution to a paper, the data are to be referenced by the proper citation and DOI. Where NGEE Arctic datasets are included in papers led by the modeling team, the relevant data contributors should be notified and included in analysis and co-authorship discussions. In all cases each dataset must be properly cited.

Code Sharing: Public release of NGEE Arctic modeling code will be discussed and agreed upon by the modeling team, with the understanding that our goal as a group is to make the developments here available to the larger community as soon as possible. Therefore, we will release code to the public on submission of the primary paper describing the model version. Public release removes the 'rights' of code developers to be automatically considered for co-authorship. However, we encourage users of the released model to consider including those developers to the extent it would benefit the users' analyses.

Disclaimer of Liability: Data and documents available from the NGEE Arctic web site (https://ngee.ornl.gov/) were prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, or any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Further, Oak Ridge National Laboratory is not responsible for the contents of any off-site pages referenced. The complete ORNL disclaimer can be viewed at http://www.ornl.gov/ornlhome/disclaimers.shtml.

Software Productivity and Sustainability Plan

This Software Productivity and Sustainability Plan describes NGEE Arctic's process for developing and modifying software used in the project, consistent with CESD's software policy and procedures. This document is not a description of any technical work related to these tasks, but rather a description of the processes the team will use to accomplish that work. It takes into consideration that the software components used in this project originate outside the project and already have their own distribution protocols, development policies, and Software Productivity and Sustainability Plans.

The following software packages (hereafter collectively addressed as "software," "code," or "packages") may be modified as part of this work:

Advanced Terrestrial Simulator (ATS)	https://github.com/amanzi/ats
Alquimia	https://github.com/LBL-EESA/alquimia
PFLOTRAN	https://www.pflotran.org/documentation/index.html
FATES	https://github.com/NGEET/fates
E3SM	https://github.com/E3SM-Project/E3SM

These codes are open source and are developed independently of the NGEE Arctic project. Participants in the project will follow the existing development policies or Software Productivity and Sustainability Plans for those codes, to the extent practicable, and will augment those plans as needed.

Overall Process

The Test-Driven Development (TDD) software development process will be used throughout Phase 3. This process refers to a style of programming in which three activities are tightly interwoven: coding, testing, and design. TDD has a good track record for improving existing software and is well-suited for scientific software because it focuses on the need to maximize scientific output while ensuring software quality but avoiding unnecessarily formal methods for rigorously modeling and specifying the exact nature of the software products.

Development will be divided into phases, with each phase resulting in a new release. Within each phase, requirements will be determined directly through meetings with NGEE Arctic staff, the broader software development teams, and other interested parties. High-level requirements will then lead to specific test cases that will drive the development through multiple iterations of design and analysis, code development, and testing. The NGEE Arctic modeling team will use the project management tools from teamwork (www.teamwork.com) to communicate requirements and status of ongoing tasks.

Tools and Processes

The NGEE Arctic team will continue to use the existing software version control repositories at each code's hosting sites (i.e. BitBucket for PFLOTRAN, GitHub for the other codes). New development will be undertaken in separate feature branches. All new features will be accompanied by appropriate tests. The NGEE Arctic modeling team will use the project management tool teamwork (www.teamwork.com) to coordinate work internally and to track the ongoing tasks. Issues that affect the larger software communities will be tracked using the tools provided by each code's hosting site.

A pull request will be created to merge feature branches back into the main branch when development of that feature is complete. New stable versions will be distributed from the code hosting sites through tags.

Training

All new developers will be provided training material on scientific software development practices that was produced by the Interoperable Design of Extreme-scale Application Software (IDEAS) project. All new developers will be assigned a mentor from the pool of existing developers for the purposes of practical exposure to the project development practices.

Software Improvement Strategies

The primary software improvement strategy for this project will be the institution of code reviews of the project software products. Code reviews will be conducted internally during each feature development phase to evaluate the overall design and testing strategy. In addition, informal code reviews with the larger software development teams will be undertaken as needed.

Risk Management for Third-Party Tools

ATS and PFLOTRAN rely on a significant number of open-source software dependencies. Those packages will be tested for correct functionality using their own integration tests and by running the suite of tests currently available for ATS and PFLOTRAN. To mitigate risk associated with new versions of software dependencies, the versions used before undergoing any migration to a newer version of the dependencies will be archived to provide a fallback plan. Furthermore, all migration to new major versions of dependencies will only be performed when new features are created for the ATS and PFLOTRAN software.

If the integration tests fail and the stack trace indicates that the failure was in a previously well-behaved dependency, then the development team will know that changes in that dependency have caused the error. In that event, the project team will (1) engage the third-party development team to see whether the loss of capability could be redeveloped or added back, or (2) seek to correct the inconsistency or add the missing capability on its own. In the case where the capability could not be recovered in its original distribution, the project team would seek to find the capability in another third-party dependency before attempting to develop a new piece of software to provide the capability.

Dataset DOIs and Citations

The following lists data records available through the NGEE Arctic data search and download system (http://ngee-arctic.ornl.gov/data) as of December 2018. Planned datasets and records that do not have an assigned DOI are not listed here.

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