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Support for Next-Generation Ecosystem Experiments (NGEE Arctic) Field Campaign Report

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June 2019

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Acronyms and Abbreviations

ABoVE	Arctic-Boreal Vulnerability Experiment
ARM	Atmospheric Radiation Measurement
AVIRIS-NG	Airborne Visible InfraRed Imaging Spectrometer-Next Generation
ESM	earth system model
NASA	National Aeronautics and Space Administration
NDVI	normalized difference vegetation index
NGEE	Next-Generation Ecosystem Experiments
PRI	photochemical reflectance index
ZPW	Zero-Power Warming

Contents

Acronyms and Abbreviations iii
1.0 Summary 1
2.0 Results 1
3.0 Publications and References 4
4.0 Education and Outreach 5

Figures

1 Observations and synthesis activities inform the improved representation of above- and below- ground plant traits in terrestrial biosphere models. 2
2 A Zero-Power Warming (ZPW) chamber. 3
3 Advertising poster for public event to commemorate the 20-year anniversary of the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) observatory in Utqiaġvik, Alaska. 5

1.0 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-rich arctic system processes and feedbacks to climate. This is achieved through experiments, observations, and synthesis of existing data sets that strategically inform model process representation and parameterization, and that enhance the knowledge base required for model initialization, calibration, and evaluation. One question of special interest to the NGEE Arctic project addresses how above- and below-ground plant functional traits might 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. We characterized the variation in above- and below-ground plant traits in response to varying edaphic and environmental conditions in Utqiaġvik (formerly Barrow), Alaska. 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.

2.0 Results

Model representation of photosynthesis, and particularly plant traits used to parameterize photosynthesis models, has repeatedly been demonstrated to be a significant source of model uncertainty. Previously, model representation of arctic photosynthesis relied on data and understanding from a variety of terrestrial ecosystems, including temperate grasslands. We have worked for several years to improve model representation of tundra plant photosynthesis in models, deepened our understanding of arctic photosynthetic physiology, and provided new characterization of tundra plant photosynthetic traits and their temperature response functions. 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.

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 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. 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 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. We have also coordinated closely with the NASA Arctic-Boreal Vulnerability Experiment (ABoVE) airborne campaign team to collect high-resolution spatial and spectral Airborne Visible InfraRed Imaging Spectrometer-Next Generation (AVIRIS-NG) imagery over the NGEE Arctic sites. We are using these airborne spectral observations to develop watershed-scale functional trait maps based on our new arctic algorithms.

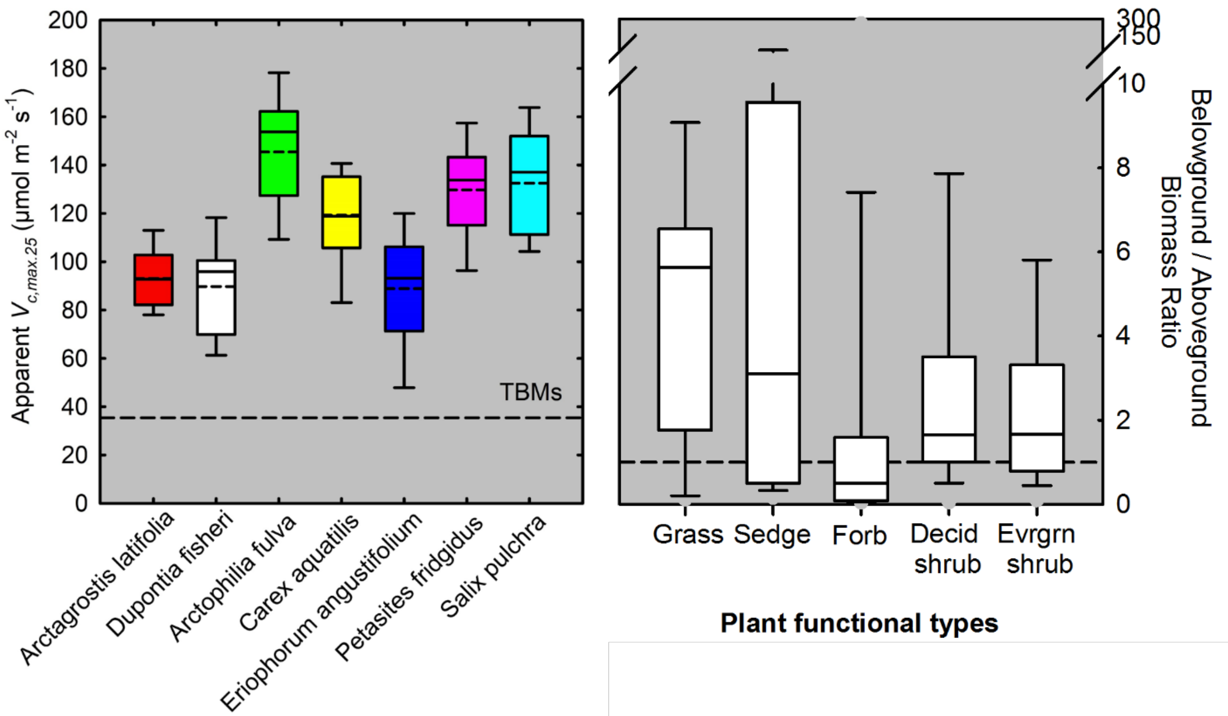

Figure 1. Observations and synthesis activities inform the improved representation of above- and below-ground plant traits in terrestrial biosphere models. (a) Apparent maximum carboxylation rate normalized to 25ºC (apparent $V_{c,max.25}$) measured in seven species located on the Barrow Environmental Observatory, Utqiaġvik, Alaska. (b) Below- to above-ground biomass ratio of plant functional types across tundra ecosystems. Dashed lines in a, b represent current terrestrial biosphere model representation of these plant traits.

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 below ground compared to above ground, with clear implications for ecosystem C storage and nutrient cycling. However, data are limited on below-ground plant structure and function across the vast array of tundra ecosystems. We improved our understanding of below-ground 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. 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.

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. This is highly relevant in the Arctic where warming has been, and is projected to be, markedly greater than the global mean. 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. We designed and evaluated a novel Zero-Powered Warming (ZPW) chamber that is capable of elevating and modulating air temperature by ~4°C (Figure 2) and began a multiyear warming experiment.

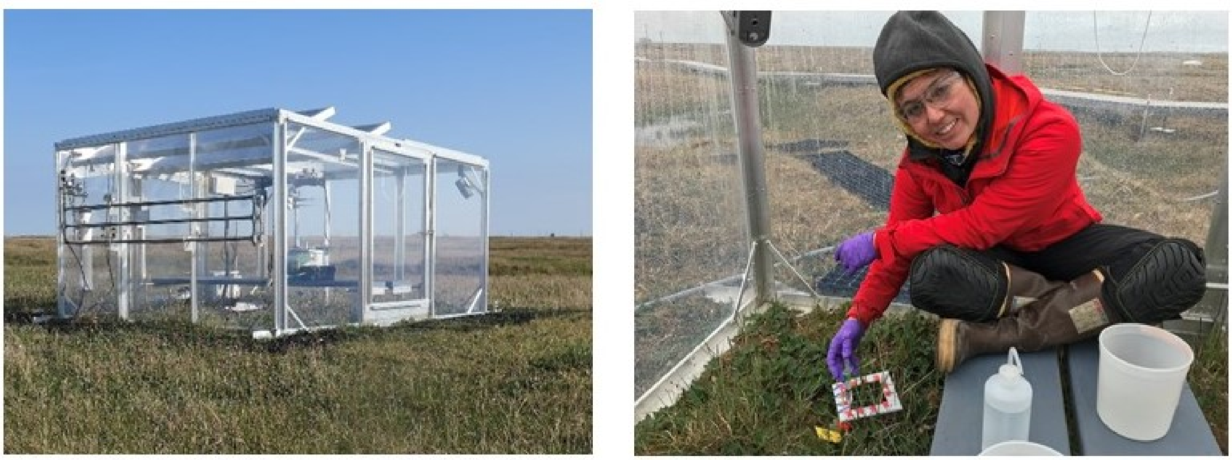

Figure 2. A Zero-Power Warming (ZPW) chamber. The chamber is warmed passively by solar radiation. The combination of an internal and an external heat exchanger modulates venting of the chamber, which enables the air temperature to be elevated by about 4ºC.

We initiated a replicated warming experiment (n=5) on the Barrow Environmental Observatory. 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 two years focused on the plant species *Petasites frigidus* and *Arctagrostis latifolia*, and we plan to continue this experiment in future years 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 plans also include measurements of root respiration to improve our understanding and modeling of linkages between above- and below-ground physiology. In addition, the experiment includes passive monitoring of leaf phenology (visual imagery), greenness (normalized difference vegetation index [NDVI]), and health (photochemical reflectance index [PRI]) throughout the thaw season.

3.0 Publications and References

Iversen, CM, VL Sloan, PF Sullivan, E Euskirchen, AD McGuire, RJ Norby, AP Walker, JM Warren, and SD Wullschleger. 2015. “The unseen iceberg: plant roots in arctic tundra.” *New Phytologist* 205(1): 34– 58, http://dx.doi.org/10.1111/nph.13003

Lewin, KF, AM McMahon, KS Ely, SP Serbin, and A Rogers. 2017. “A zero-power warming chamber for investigating plant responses to rising temperature.” *Biogeosciences* 14(18): 4071–4083, http://dx.doi.org/10.5194/bg-14-4071-2017

Norby, RJ, VL Sloan, CM Iversen, and J Childs. 2019. “Controls on fine-scale spatial and temporal variability of plant-available inorganic nitrogen in a polygonal tundra landscape.” *Ecosystems* 22(3): 528– 543, https://doi.org/10.1007/s10021-018-0285-6

Rogers, A. 2014. “The use and misuse of Vcmax in Earth System Models.” *Photosynthesis Research* 119(1-2): 15–29, http://dx.doi.org/10.1007/s11120-013-9818-1

Rogers, A, BE Medlyn, and JS Dukes. 2014. “Improving representation of photosynthesis in Earth System Models.” *New Phytologist* 204(1): 12–14, http://dx.doi.org/10.1111/nph.12972

Rogers, A, BE Medlyn, JS Dukes, G Bonan, S von Caemmerer, MC Dietze, J Kattge, ADB. Leakey, LM Mercado, U Niinemets, IC Prentice, SP Serbin, S Sitch, DA Way, and S Zaehle. 2017a. “A roadmap for improving the representation of photosynthesis in Earth system models.” *New Phytologist* 213(1): 22– 42, http://dx.doi.org/10.1111/nph.14283

Rogers, A, SP Serbin, KS Ely, VL Sloan, and SD Wullschleger. 2017b. “Terrestrial biosphere models underestimate photosynthetic capacity and CO_2 assimilation in the Arctic.” *New Phytologist* 216(4): 1090–1103, http://dx.doi.org/10.1111/nph.14740

Rogers, A, SP Serbin, KS Ely, and SD Wullschleger. 2019. “Terrestrial biosphere models need to account for decreased quantum yield and convexity at low temperature or they will overestimate Arctic CO_2 assimilation.” *New Phytologist* (in press), https://dx.doi.org/10.1111/nph.15750

Wullschleger, SD, HE Epstein, EO Box, ES Euskirchen, S Goswami, CM Iversen, J Kattge, RJ Norby, PM 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): 1–16, http://dx.doi.org/10.1093/aob/mcu077

Zhu, Q, CM Iversen, WJ Riley, IJ Slette, and HM Vander Stel. 2016. “Root traits explain observed tundra vegetation nitrogen uptake patterns: Implications for trait-based land models.” *JGR Biogeosciences* 121(12): 3101–3112, http://dx.doi.org/10.1002/2016JG003554

4.0 Education and Outreach

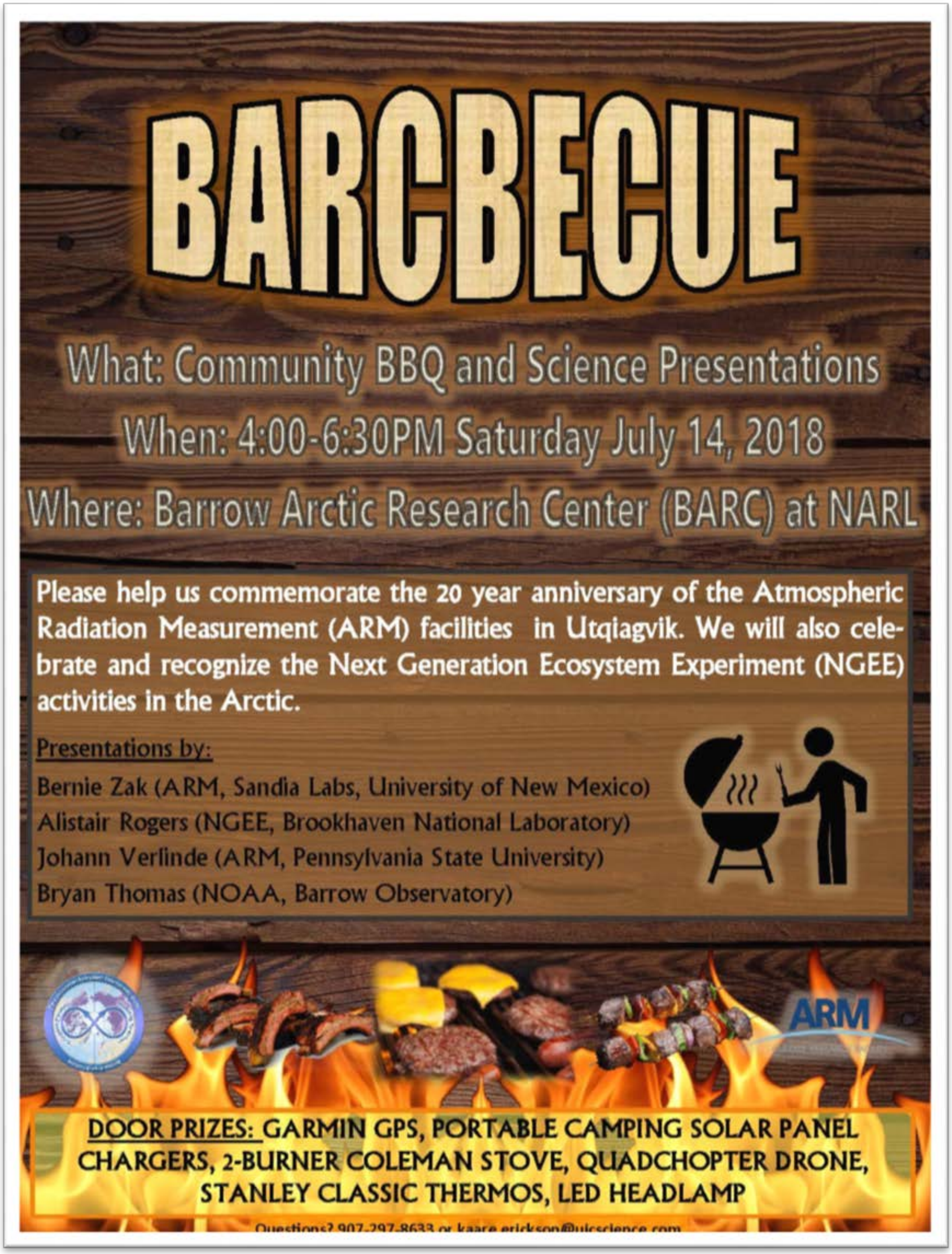

Figure 3. Advertising poster for public event to commemorate the 20-year anniversary of the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) observatory in Utqiaġvik, Alaska.

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