Next-Generation Ecosystem Experiments – NGEE Arctic

Quarterly Report
March 31, 2012

A progress report submitted to

Mike Kuperberg
Program Manager
Department of Energy, Office of Science, Biological and Environmental Research

Prepared by

Stan D. Wullschleger
Environmental Sciences Division
Oak Ridge National Laboratory

Cathy J. Wilson
Earth and Environmental Sciences Division
Los Alamos National Laboratory

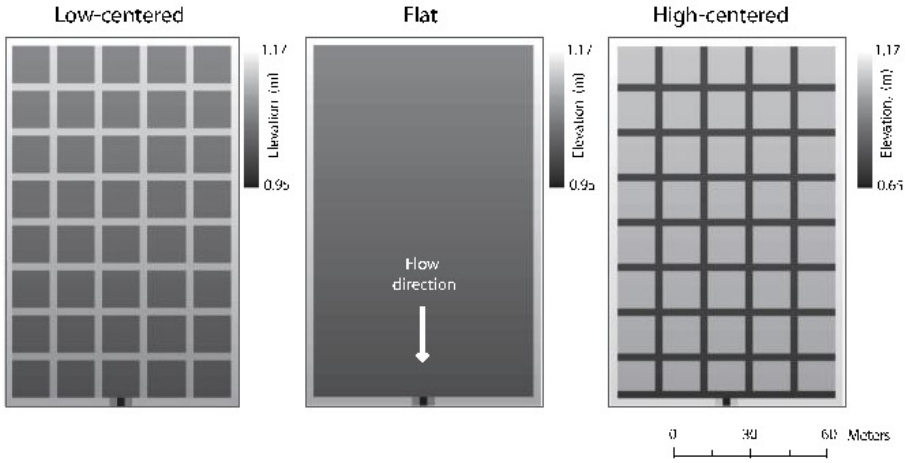
Susan S. Hubbard
Earth Sciences Division
Lawrence Berkeley National Laboratory

Contents

Item	Page
Ice-Wedge Polygon Type Controls Low-Gradient Watershed-Scale Hydrology	2
Details at a Glance	2
Progress and Accomplishments	3
Interactions with other Agencies, Universities, and National Laboratories	8
Publications, Presentations, and Posters	8
Press Releases and News Clips	9
Appendix	10

Ice-Wedge Polygon Type Controls Low-Gradient Watershed-Scale Hydrology

Ice-wedge polygons are ubiquitous to landscapes underlain by permafrost. High- and low-centered polygons are typical but surprisingly, their role on hydrologic fluxes and stocks is not well quantified. Led by Anna Liljedahl, scientists working at the University of Alaska Fairbanks performed hydrologic analyses using the physically-based model WaSiM-ETH that was forced by data from Barrow, Alaska, (1999 to 2009) to assess the effect of ice-wedge polygon type on watershed-scale hydrology. Low-centered polygons, through elevated rims, reduced runoff while increasing evapotranspiration and surface water storage. The high-centered polygon landscape produced more than twice the runoff than the low-centered polygons, while storage and runoff drastically decreased. It is evident that microtopography plays an important role on the watershed-scale hydrologic fluxes and stocks of low-gradient arctic wetlands. A shift from low-centered to high-centered polygon dominated landscape results in drastic changes to watershed-scale water storage, runoff, and evapotranspiration. Low-centered polygons promote extensive ponding, while high-centered polygons enhance runoff. Carbon cycle processes including CO_2 and CH_4 flux from these landscapes will depend on the degree of ponding and resulting oxic and anoxic status of surface soils. Therefore, to understand the connections between carbon, water, and energy budgets in these dynamic landscapes it is necessary to account for the role of geomorphology in regulating tundra microclimate in order to reduce the uncertainty in present and future pan-Arctic hydrologic fluxes and stocks.



Schematic digital elevation models used in the hydrologic analysis of a low-centered polygon, a flat surface, and high-centered polygon. The surface has a general slope of 0.03 % as determined by airborne Lidar surveys of a vegetated drained lake basin near Barrow, Alaska.

Details at a Glance

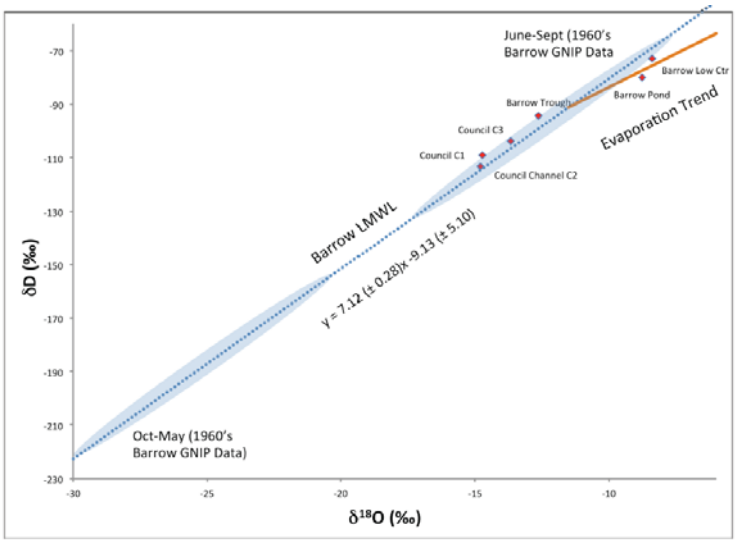
Activities during the January 1 to March 31, 2012 quarter include:

- Isotopic and geochemical chanaracterization of water in hydro-geomorphologic features
- Tundra hydrogeochemical properties characterized using Bayesian fusion approach
- NGEE Arctic partners with UMIAQ LLC for logistical support on the North Slope
- Meta-analysis conducted on root distribution and dynamics for Arctic ecosystems
- Model of nitrogen allocation improves estimates of plant gas exchange and productivity

Progress and Accomplishments

Isotopic and geochemical characterization of water in hydro-geomorphic features:

Oxygen and deuterium isotope measurements of water can help delineate spatial and temporal dynamics of water fluxes in a landscape. These measurements can help to characterize sources of water (e.g. snowmelt, melting permafrost), flow and mixing of different water sources, and processes such as evaporation. Measurement of chemical constituents that vary in concentration according to the oxygenation status of water can help characterize processes responsible for important carbon and nitrogen transformations such as mineralization of organic matter to ammonia, nitrate, CO_2, and methane. To determine how useful water isotopic data would be for the NGEE Arctic project, scientists from LANL (Heilkoop, Perkins, and Wilson) and UAF (Liljedahl, Kim, and Hinzman) collected and analyzed a small set of pilot samples from two proposed NGEE research sites in Barrow and Council, Alaska.



Water isotope data plotted against the local meteoric water line for Barrow.

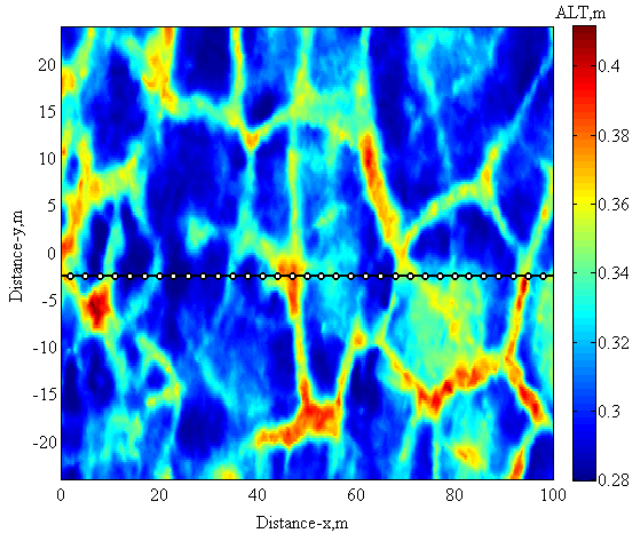
The isotope data were plotted with respect to the local meteoric water line for Barrow as given by the IAEA Global Network of Isotopes in Precipitation (GNIP; data are exclusively from the 1960s; Council samples are shown on this line for comparison sake only). Samples that plot along this line have likely experienced little evaporation and depending on where they fall along the line it is possible to determine relative proportions of winter versus summer precipitation. In contrast, samples that fall to the right of the line suggest that substantial evaporation has occurred. Two interesting observations are noted. The samples from the Barrow pond and low centered polygon may fall along an evaporation trend (here assumed to have a slope of 5) and the waters seem to be dominated by summer precipitation. Barrow locals informed Anna Liljedahl that the summer of 2011 was particularly rainy. The Barrow trough sample was isotopically distinct from the other two Barrow waters, suggesting less evaporation and perhaps a greater degree of mixing of summer precipitation and winter snowmelt. There appears to be sufficient isotopic variation to help determine water sources, storage, mixing, and flow paths. The presence of an evaporative signal suggests that oxygen and deuterium isotopes could be an excellent tracer

of water derived from different sources of standing water including polygonal ground, evaporative ponds and lakes. Low nitrate and sulfate concentrations, along with somewhat elevated soluble iron and manganese, suggest that these waters are reducing, consistent with the high organic content in these waters and studies of surrounding anaerobic peat soils. These results further confirm that aqueous geochemistry measurements can help constrain redox states responsible for organic matter degradation and processes such as methanogenesis.

The proposed summer 2012 synoptic survey of surface water and active layer water will help to better constrain the nature and causes of isotopic and geochemical variation in water in the BEO and when combined with the wealth of other studies being carried out at various temporal and spatial scales will help improve process understanding of a degrading permafrost system.

Tundra hydrogeochemical properties characterized using multi-scale Bayesian fusion approach:

Recent findings suggest that warming climate has a significant impact on the Arctic ecosystems, which could in turn cause feedback to the climate system. Developing a predictive understanding of this feedback system requires characterization of various subsurface properties, such as active layer thickness (ALT), soil moisture, temperature and geochemical parameters. Such characterization is challenging due to the need to sample over large spatial areas in high resolution, and the spatial heterogeneity influenced by microtopography, soil texture and vegetation. To address this challenge, Haruko Wainwright (post-doctoral research associate) and others at LBNL, LANL, ORNL, and the University of Texas El Paso have developed a multiscale data fusion method to estimate subsurface hydrogeochemical properties and state distributions, using datasets that sample different properties over various measurement support scales, such as point measurements, surface geophysical data and remote sensing data. Using their approach, based on a hierarchical Bayesian model, these scientists were able to integrate multiscale, multi-type datasets and generate uncertainty associated with their parameter estimates. Estimates of ALT were derived spatially from point measurements and spatial information contained within geophysical datasets and Lidar imagery.



Active layer thickness in the 2-D domain as estimated for polygon ground in Barrow, Alaska using a Bayesian approach to data assimilation.

Although the current example model is still simple, the results suggested that effective combination of point, geophysical and remote-sensing data can provide high-resolution information about important subsurface properties needed to parameterize both 2D/3D landscape and reactive transport models. As future work, we will improve the ALT estimation and extend the methodology to estimate other subsurface properties including ground ice using various combinations of datasets.

NGEE Arctic partners with UMIAQ, LLC for logistical support on the North Slope:

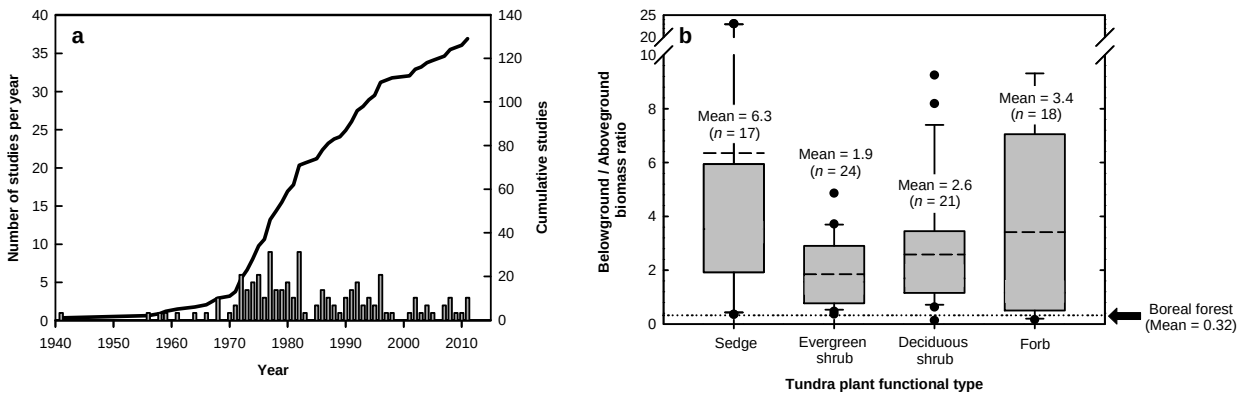
Project Director Stan Wullschleger (ORNL) and Chief Scientist Larry Hinzman (UAF) travelled to Anchorage, Alaska in January to discuss logical support needs with the UIC-owned UMIAQ, LLC. UMIAQ was established in 2006 to meet the growing service demands of resource development activities in Alaska. In August 2010, UMIAQ's services expanded when it merged with UIC subsidiary LCMF, a professional services firm that has provided architectural design, civil and mechanical engineering, and surveying services since 1982. UMIAQ's expanded suite of services offers clients a comprehensive source for their design and regulatory consulting needs. The UMIAQ team knows the politics, culture, land use, regulations, and engineering and design conditions as they pertain to industrial and community development in arctic and subarctic Alaska. In addition, they offer a distinct advantage to firms not based in Alaska by providing reliable local knowledge and expertise.

The one-day meeting between NGEE and UMIAQ focused on lodging, vehicle, laboratory space, and technical support needs for the 2012 field season in Barrow, Alaska. After the meeting, Wullschleger continued to Barrow where he met with UMIAQ Business and Facility Managers to future assess capabilities and infrastructure that would be available to the NGEE research team. An ORNL subcontract is currently being reviewed by UMIAQ representatives. This will be in place prior to a planned April field trip to Barrow.

Larry Hinzman with UMIAQ Project Manager and Marvin Hanson and Project Coordinator Dominique Fox.

Meta-analysis conducted on root distribution and dynamics in Arctic ecosystems:

Colleen Iversen at Oak Ridge National Laboratory, along with co-authors at ORNL and the University of Alaska, Anchorage, is leading a synthesis of rooting distributions and dynamics in the Arctic. The goals of the synthesis are three-fold: (1) summarize the state of knowledge regarding rooting dynamics in arctic ecosystems, and quantify data where possible, (2) provide information that will improve understanding of the role of roots in a number of important ecosystem processes that are currently included (implicitly or explicitly) in models used to simulate carbon and nutrient cycling in the Arctic, and (3) identify priority areas for future research on rooting dynamics in the Arctic. A literature search indicated less than 150 published studies on roots in arctic ecosystems, and that interest in this topic has waned since the mid-1970s (see Figure). However, a synthesis of available data indicates that root dynamics in the Arctic may be a particularly important aspect of ecosystem carbon and nitrogen cycling, as the belowground to aboveground ratios of tundra plant functional types are six to twenty times greater than those in the boreal forest (see Figure). This information will be used by NGEE scientists to guide field measurements of rooting distribution and dynamics for the 2012 field season and for initial parameterization of plant functional types in ecosystem models.

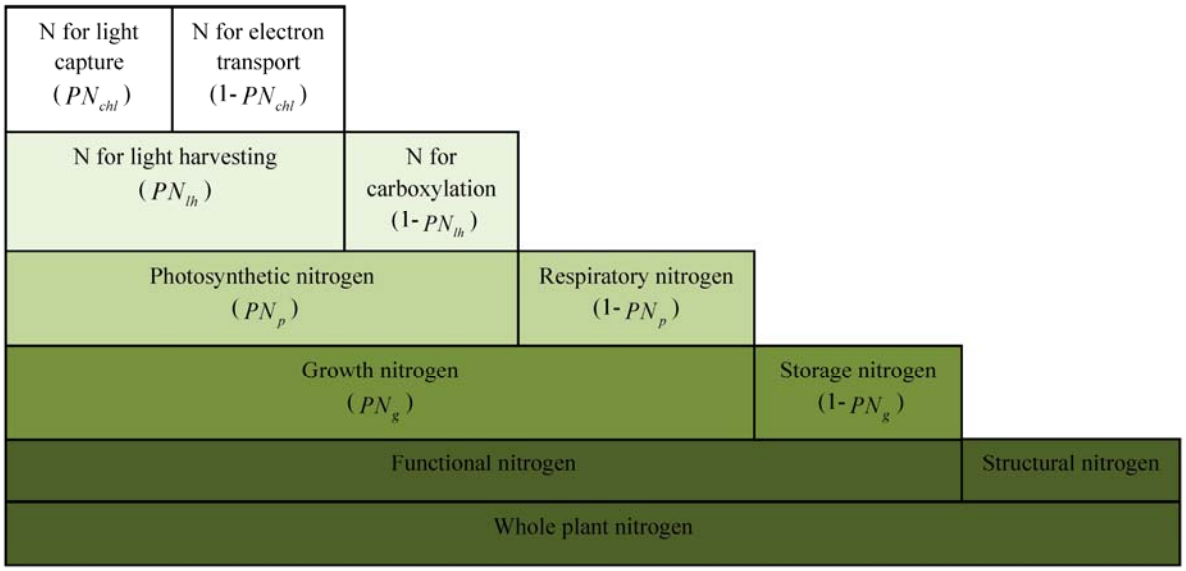


A literature survey of root distribution and dynamics in the Arctic shows number of publications since the mid-1900s and a comparison of root: shoot ratios for contrasting Arctic ecosystems.

Model of nitrogen dynamics improves estimates of gas exchange and ecosystem productivity:

Nitrogen is a dominant regulator of vegetation dynamics, net primary production, and terrestrial carbon cycles; however, most ecosystem models use a rather simplistic relationship between leaf nitrogen content and photosynthetic capacity without taking into consideration differences in light intensity, growing temperature and CO_2 concentration. To account for this known variability in nitrogen-photosynthesis relationships, we developed a mechanistic nitrogen allocation model based on simultaneous optimization among light capture, electron transport, carboxylation, respiration and storage. The model is able to predict photosynthetic capacity acclimation to elevated CO_2 concentration, reduced growing temperature and radiation, and shows good agreement when evaluated against published $V_{c,max}$ (maximum carboxylation rate) and J_{max} (maximum electron transport rate) data. Sensitivity analysis of the model for herbaceous plants, deciduous and evergreen trees infers that elevated CO_2 concentrations lead to lower allocation of nitrogen to carboxylation but higher allocation to storage. Higher growing

temperatures cause lower allocation of nitrogen to carboxylation, due to higher nitrogen requirements for light capture pigments and for storage. Lower levels of radiation have a much stronger effect on allocation of nitrogen to carboxylation for herbaceous plants than for trees, resulting from higher nitrogen requirements for light capture for herbaceous plants. As far as we know, the model developed in this paper is the first model of complete nitrogen allocation that simultaneously considers nitrogen allocations to light capture, electron transport, carboxylation, respiration and storage, and the responses of each to altered environmental conditions. We expect that our model can potentially improve our confidence in simulations of carbon-nitrogen interactions and the vegetation feedbacks to climate in Earth system models.



The allocation starts from the bottom to top. The whole plant nitrogen is first divided into functional nitrogen and structural nitrogen. Functional nitrogen is then divided into growth nitrogen and storage nitrogen. The growth nitrogen is further divided into photosynthetic nitrogen and respiratory nitrogen, with the photosynthetic nitrogen divided into nitrogen for light harvesting and nitrogen for carboxylation (nitrogen in Calvin Cycle enzymes). Finally, nitrogen allocated for light harvesting is divided into nitrogen for light capture (mainly nitrogen in proteins of phosystems I, II and chlorophyll a/b complexes) and nitrogen for electron transport (mainly nitrogen in proteins of thylakoid bioenergetics). The parameter in the parenthesis indicates the proportion of nitrogen invested for its category in the same row.

Interactions with other Agencies, Universities, and National Laboratories

NGEE Arctic Chief Scientist Larry Hinzman participated in the U.S. Arctic Observing Network (AON) Coordination Workshop, 20-22 March 2012 at the Captain Cook Hotel, Anchorage, Alaska. The overall goal of the workshop was to coordinate U.S. activities to observe and monitor the Arctic. The workshop was organized around Study of Environmental Arctic Change (SEARCH) 5-Year Science Goals and Objectives focusing on sea ice, permafrost, land-ice, and society/policy.

Publications, Presentations, and Posters

Publications:

Graham D.E., M.D. Wallenstein, T.A. Vishnivetskaya, M.P. Waldrop, T.J. Phelps, S.M. Pfiffner, T.C. Onstott, L.G. Whyte, D. Gilichinsky, D.A. Elias, R. Mackelprang, N.C. VerBerkmoes, R.L. Hettich, D. Wagner, S.D. Wullschleger and J.K. Jansson (2011) Microbes in thawing permafrost: The unknown variable in the climate change equation. The ISME Journal 6:709-712.

Xu C., R. Fisher, C.J. Wilson, SD. Wullschleger, M. Cai and N.G. McDowell. 2012. Toward a mechanistic modeling of nitrogen limitation on vegetation dynamics. PLoS ONE (in press).

Presentations:

Allesio, G., L. Hinzman, S. Hubbard, B. Dafflon, S. Wullschleger, and A. Arendt. 2012. Exploring the Alaskan cryosphere with ground penetrating radar. American Water Resources Association, Alaska Section Annual Conference. March 5-7, 2012. Juneau, AK.

Hubbard S.S., C. Gangodagamage, B. Dafflon, H. Wainwright, C. Ulrich, A. Gusmeroli, Y. Wu, J. Doetsch, J.E. Peterson, C. Wilson, C. Tweedie, and S.D. Wullschleger. 2012. Quantifying and relating subsurface and land-surface variability in permafrost environments using surface geophysical and LIDAR datasets. European Geophysics Union (EGU) General Assembly. April 22-27, Vienna, Austria.

Thornton, P.E. 2012. Multi-scale modeling approach to improve Arctic tundra ecosystem and climate system prediction. CESM Land Model/Biogeochemistry Working Group, February 27-March 2, 2012, Boulder, CO.

Wullschleger, S.D. 2012. Next-Generation Ecosystem Experiments. Strategies to Promote Integrated Data-Model Approaches to Terrestrial Ecosystem Study. March 19-21, 2012. Bethesda, MD.

Wullschleger, S.D. 2012. Omics in the Arctic: Genome-enabled contributions to carbon cycle research in high-latitude ecosystems. Seventh Annual Genomics of Energy and Environment meeting. March 20-22, 2012. Walnut Creek, CA.

Xu C., R. Fisher, C.J. Wilson, SD. Wullschleger, M. Cai and N.G. McDowell. 2012. Toward a mechanistic modeling of nitrogen limitation on vegetation dynamics. CESM Land Model/Biogeochemistry Working Group, February 27-March 2, 2012, Boulder, CO.

Workshops Attended:

Alaska Section, American Water Resources Association, March 5-7, 2012, Juneau, AK. Web site: http://state.awra.org/alaska/ameetings/2012am/program.shtml

Strategies to Promote Integrated Data-Model Approaches to Terrestrial Ecosystem Study. March 19-21, 2012. Bethesda, MD.

Joint Genome Institute (JGI), Genomics of Energy & Environment, 7th Annual DOE JGI User Meeting, March 20 - 22, 2012, Walnut Creek, California.
Web site: http://www.jgi.doe.gov/meetings/usermeeting/

Strategies to Promote Integrated Data-Model Approaches to Terrestrial Ecosystem Study. March 19-21, 2012. Bethesda, MD.

Posters:

None

Upcoming Meetings:

European Geophysics Union, General Assembly, April 22-27, 2012, Vienna, Austria.
Web site: http://meetings.copernicus.org/egu2012/

Tenth International Conference on Permafrost, June 25-29, 2012, Salekhard, Russia.
Web site: http://www.ticop2012.org/

Press Releases and News Clips

J. Madeleine Nash, San Francisco, CA, January 6, 2012

March 2, 2012 (Radio, Susan Hubbard): http://www.ucop.edu/sciencetoday/article/27380

Appendix

Multiscale Bayesian Fusion Approach using Geophysical and Remote Sensing Data for Characterizing Arctic Tundra Hydrogeochemical Properties

H.M. Wainwright, S.S. Hubbard, B. Dafflon, C. Ulrich & Y. Wu

Lawrence Berkeley National Laboratory, Berkeley, CA, USA

C. Gangodagamage, J. Rowland & C. Wilson

Los Alamos National Laboratory, Los Alamos, NM, USA

C. Tweedie

University of Texas at El Paso, El Paso, TX, USA

S.D Wullschleger

Oak Ridge National Laboratory, Oak Ridge, TN, USA

Introduction

Recent findings suggest that warming climate has a significant impact on the Arctic ecosystems, which could in turn cause feedback to the climate system. A new Department of Energy project, called the Next-Generation Ecosystem Experiments (NGEE Arctic; http://ngee.ornl.gov/), has been initiated to address how permafrost thaw and degradation– and the associated changes in landscape evolution, hydrology, soil biogeochemistry and plant community dynamics– affect this feedback.

Developing a predictive understanding of this feedback system requires characterization of various subsurface properties, such as active layer thickness (ALT), soil moisture, temperature and geochemical parameters. Such characterization is challenging due to the need to sample over large spatial areas in high resolution, and the spatial heterogeneity influenced by microtopography, soil texture and vegetation [Zona et al., 2011].

This work presents a multiscale data fusion method to estimate subsurface hydrogeochemical properties and state distributions, using datasets that sample different properties over various measurement support scales, such as point measurements, surface geophysical data and remote sensing data. The proposed method, based on a hierarchical Bayesian model, allows us to integrate multiscale, multi-type datasets consistently to quantify uncertainty associated with the estimates. We demonstrate our approach using co-located datasets collected at the Barrow Environmental Observatory, Barrow, Alaska.

Methodology

Data Collection Strategy

To improve predictive capabilities and process understanding, NGEE Arctic includes intensive subsurface-surface characterization efforts that involve various types of point, geophysical and remote-sensing data. At the Barrow site our datasets include (a) airborne high-resolution LiDAR data; (b) surface-based ground penetrating radar (GPR), electrical resistivity tomography, spectral induced polarization, and electromagnetic data; and (c) point-based soil temperature, moisture, geochemistry, texture and ALT measurements along and in the vicinity of several ~500m transects across the polygonal ground.

Each dataset offers both advantages and limitations; together, the datasets offer the possibility of providing high-resolution information over large spatial extents. The point-based measurements are invasive and typically sparse, yet they provide direct information about the subsurface properties and states. They are also used to establish the correlations among subsurface properties, geophysical attributes and surface features for calibrating geophysical and remote sensing data. The high-resolution surface geophysical datasets are non-invasive and spatially extensive; integration of these datasets increases the spatial coverage and potentially reveals the fine-scale property variability and spatial correlation structure. The remote-sensing data can further increase the spatial coverage and improve the estimation over a large area through the subsurface-surface correlations. Integration of these disparate datasets requires an understanding of relationships among different hydrogeochemical-geophysical-physical variables and a framework that can honor all datasets and their interdependencies.

Bayesian hierarchical model

The Bayesian hierarchical model consists of three main statistical models; (1) data model: $p(\text{data}|\text{process},\boldsymbol{\beta})$, (2) process model: $p(\text{process}|\boldsymbol{\alpha})$ and (3) prior model: $p(\boldsymbol{\alpha},\boldsymbol{\beta})$, where $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are the model parameters [Wikle et al., 2001]. The process model describes the spatial-temporal patterns of the subsurface properties, conditioned on $\boldsymbol{\alpha}$. Although it is usually not feasible to develop a complete physical model to create such patterns (e.g., depositional processes, polygonal-ground evolution), we can often approximate the patterns using simple functions such as polynomial and cosine functions. The data model connects the patterns created by the process model and the actual data for given $\boldsymbol{\beta}$ and measurement errors. The data can be a direct measurement or a function of the subsurface properties; for example, spatial averaging for low-resolution datasets.

The overall model – a series of conditional models – is flexible and expandable to include complex physical processes or observations. For example, the process model can include multiscale physical processes by having additional hierarchical structures [Ferreira et al., 2007]. Once all the conditional models are developed, we can estimate the joint posterior distribution of the parameters and process $p(\text{process},\boldsymbol{\alpha},\boldsymbol{\beta}|\text{data})$, using Bayesian estimation algorithms such as the Markov-chain Monte-Carlo (MCMC) method.

Demonstration

ALT Estimation

Here we show one example of our data integration; ALT estimation based on the point probe, surface GPR and LiDAR elevation data. For the GPR data, the arrival time of the signal

reflected at the bottom of active layer was converted to ALT using the velocity estimated by the common-midpoint surveys.

First, we developed a process model for ALT (m):

$$\mathrm{ALT} = f(dh, w) + \varepsilon_a, \quad (1)$$

where f is a function, dh is the microtopography (i.e., deviation of elevation from the trend), w is the indicator for the presence of surface water, and ε_a is the residual random component representing additional spatial variability. Although the LiDAR data provides the elevation, we included it as an explanatory variable, since the topography is a dominant control over the subsurface properties [Zona et al., 2011], and also the elevation is quite accurate and spatially exhaustive in the domain of interest. The same argument can be applied for the surface water.

We define the data model for each point data z_p as:

$$z_p = \mathrm{ALT} + \varepsilon_p, \quad (2)$$

where ε_p is the measurement error. The data model for each GPR data point z_g is:

$$z_g = g(\mathrm{ALT}) + \varepsilon_g, \quad (3)$$

where ε_g is the measurement error, and g is a function connecting the actual ALT to the one from the surface GPR.

Based on the exploratory data analysis, we assumed a 2nd-order polynomial for $f(dh,w)$: $f(dh,w)=[dh^2\ dh\ 1\ w]\bullet[\alpha_2\ \alpha_1\ \alpha_0\ \alpha_w]^T$, and a linear model for g(ALT): g(ALT)=0.94ALT+0.04. We also assumed that ε_a is a multivariate Gaussian distribution with exponentially decaying spatial correlation (correlation length 11.0m, standard deviation (STD) 0.19m and nugget fraction 0.56). Table 1 shows the other fixed parameters.

Using MCMC-Gibbs sampling, we computed the posterior distribution of $\boldsymbol{\alpha}=\{\alpha_2\ \alpha_1\ \alpha_0\ \alpha_w\}$ and ALT at the prediction locations; $p(\{\mathrm{ALT}\},\boldsymbol{\alpha}\square\{z_p\},\{z_g\})$ (the curly bracket denotes ALT and data at multiple locations). Although the current model is fairly simple, we can extend it by adding more explanatory variables (e.g., surface vegetation), considering spatially variable $\boldsymbol{\alpha}$, and jointly estimating the currently fixed parameters.

Table 1. Assumed distributions and parameters.

	Value	Unit
Distribution of $\{\varepsilon_p, \varepsilon_g\}$	Independent normal	
STD of $\{\varepsilon_p, \varepsilon_g\}$	{0.01, 0.07}	{m, m}
Prior distribution of $\boldsymbol{\alpha}$	Independent normal	
Prior mean of $\boldsymbol{\alpha}$	{0.88,-0.25,0.26,0.10}	{m^{-1}, , m, m}
Prior STD of $\boldsymbol{\alpha}$	{0.10,0.10,0.10,0.10}	{m^{-1}, , m, m}

Results

Figure 1(a) shows the ALT data from the point probe and the surface GPR. Along this 100m transect, we had point data every 3m and GPR data every 0.2 to 0.4m. The surface GPR not only provides fairly accurate ALT but also captures the fine-scale heterogeneity missed by the point data. The multiple peaks of the ALT profile correspond to trough locations on the surface in the moderately high-centered polygons.

In Figure 1(b), the estimated ALT and uncertainty bounds from our estimation method are compared with the point data. Although the estimate is a simple function of microtopography and surface ponding, it shows good agreement to the point data. Figure 1(c) shows the estimated ALT in the 2-D domain including the point and GPR data, based on the estimated $\boldsymbol{\alpha}$ and LiDAR elevation data. It suggests that, by collecting sparse point and geophysical ALT data, this method can estimate ALT over a large area based on topography. We can see the polygonal-ground feature by large ALT at the troughs.

Summary and Future Work

In this paper, we described a multiscale hierarchical Bayesian method for integrating multiscale, multi-type datasets. As the first example, we illustrated how the method can be used with the GPR and LiDAR data to estimate ALT over a large area. Although the current example model is still simple, the results suggested that effective combination of point, geophysical and remote-sensing data can provide high-resolution information about important subsurface properties needed to parameterize both 2D/3D landscape and reactive transport models. As future work, we will improve the ALT estimation and extend the methodology to estimate other subsurface properties including ground ice using various combinations of datasets.

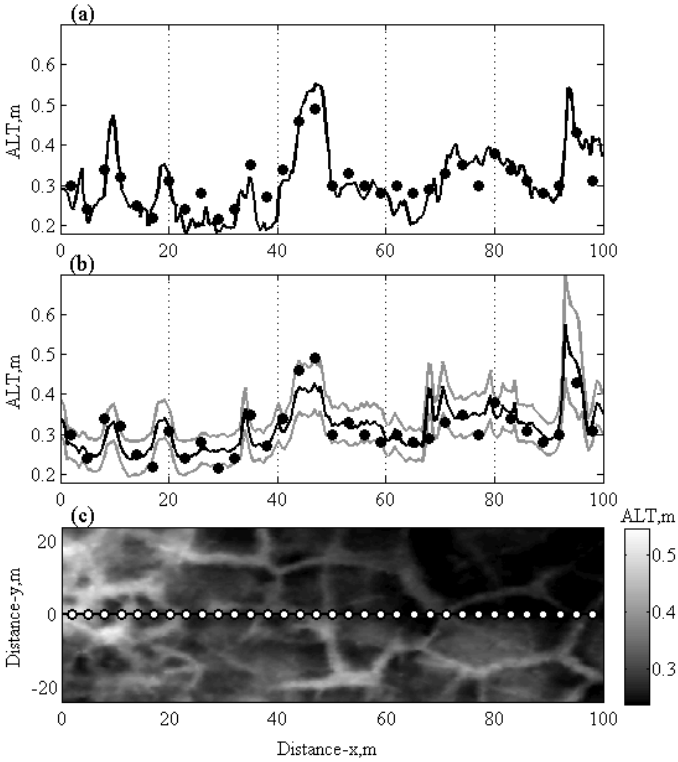


Figure 1. (a) ALT from the point probe (dots) and from the surface GPR (bold line), (b) Estimated ALT (black line), 99% confidence interval (gray lines) and point data (dots), and (c) Estimated ALT in the 2-D domain. The white dots in (b) are the point data locations, and the GPR line.

References

Ferreira, M.A.R. & Lee., H.K.H. 2007. Multiscale modeling: a Bayesian perspective, Springer.

Wikle, C.K., Milliff, R.F., Nychka, D. & Berliner, L.M. 2001. Spatiotemporal hierarchical Bayesian modeling: tropical ocean surface winds, Journal of the American Statistical Association, 96(454):382-397.

Zona, D., Lipson, D.A., Zulueta, R.C., Oberbauer, S.F. & Oechel, W.C. 2011. Microtopographic controls on ecosystem functioning in the Arctic Coastal Plain, J. Geophys. Res., 116

Acknowledgement

Research sponsored by the U.S. Department of Energy, Office of Science, Biological and Environmental Research.

Next-Generation Ecosystem Experiment (NGEE Arctic): A New Project Focused on Improved Climate Prediction

Larry D. Hinzman
International Arctic Research Center, University of Alaska, Fairbanks, AK, USA

Cathy J. Wilson and Joel C. Rowland
Los Alamos National Labratory, Los Alamos, NM USA

Susan S. Hubbard, Margaret S. Torn and William J. Riley
Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Stan D. Wullschleger, David E. Graham, Liyuan Liang, Richard J. Norby and Peter E. Thornton
Oak Ridge National Laboratory, Oak Ridge, TN, USA

Alistair Rogers
Brookhaven National Laboratory, Upton, NY, USA

Introduction

The Arctic may be the most climatically sensitive regions on Earth. High latitudes have experienced the greatest regional warming in recent decades and are projected to warm twice as much as the rest of the globe by the end of the twenty-first century. These areas are uniquely characterized by the presence of permafrost, defined as ground that has been continuously frozen for two or more years. Recent observations suggest that rapid permafrost degradation is increasingly common in the Arctic and is linked to warmer temperatures (Jorgenson et al. 2006). Permafrost degradation is expected to drive changes in climate forcing through biogeochemical and biophysical feedbacks. Biogeochemical feedbacks are dominated by the potential to release a large amount of currently stored carbon back into the atmosphere as CO_2 and CH_4 (Schuur et al. 2009), whereas biophysical feedbacks include terrestrial energy budgets that are changing in response to warming in high-latitude ecosystems (Chapin et al. 2005). These biogeochemical and biophysical processes will take place in an environment undergoing dramatic geomorphic change and landscape reorganization (Rowland et al. 2010). Thawing of ice-rich permafrost can lead to subsidence and deformation of land surfaces that range from localized depressions to deep and extensive thermokarst events. These landscape features, along with thermal erosion, gully formation, and drainage network expansion, are dramatically changing topography, surface and subsurface hydrology, and vegetation structure in the Arctic on time scales of years to decades.

Identifying Critical Ecosystem-Climate Feedbacks

The mechanisms responsible for biogeochemical and biophysical change in the Arctic have been unpredictable and difficult to isolate due to a large number of interactions among individual components of the system. The U.S Department of Energy through their Biological and Environmental Research (BER) program have sponsored a new Next-Generation Ecosystem Experiments (NGEE Arctic) project. The goals of this project are to improve model prediction of climate by quantifying the complex physical, chemical, and biological behavior of terrestrial ecosystems in Alaska. The project will focus on interactions that drive ecosystem-climate feedbacks through greenhouse gas fluxes and changes in surface energy balance associated with thawing permafrost and threshold-dominated permafrost degradation and thermokarst formation, and the many processes that arise as a result of these landscape dynamics. The ultimate deliverable of the NGEE Arctic project is a high-resolution terrestrial system model that is able to simulate coupled thermal, hydrological, geomorphic, biogeochemical, and vegetation processes as needed to predict the evolution of a warming Arctic landscape and its feedback to the global climate system. This vision includes field observations; laboratory experiments; modeling of critical and interrelated water, nitrogen, carbon, energy dynamics; and important interactions from the molecular to the landscape scale that drive feedbacks to the climate system.

The NGEE Arctic project will use observations and models to quantify the response of physical, ecological, and biogeochemical processes to climatic change across molecular to landscape scales. Our approach addresses how permafrost degradation in a warming Arctic, and the associated changes in landscape evolution, hydrology, soil biogeochemical processes, and plant community succession, will affect feedbacks to the climate system. Field and lab research will focus on interactions that drive ecosystem-climate feedbacks through greenhouse gas fluxes and changes in surface energy balance. These feedbacks will arise due to gradual thawing of permafrost and thickening of the seasonal active layer. Feedbacks will also occur as a result of the threshold-dominated processes of permafrost degradation and thermokarst formation and through the many processes that are influenced as a result of these landscape-scale dynamics. Our approach will consider how components of complex systems are linked and the interplay in space and time that determines system behavior. Fundamental knowledge gained in these investigations will be used to improve representation of ecosystem dynamics, subsurface biogeochemistry, and land-atmosphere processes in regional and global models, and will reduce uncertainty and improve prediction of climate change in high-latitude ecosystems.

Phase 1 – Implementing Our Approach on the North Slope

The research scope of NGEE Arctic Phase 1 is designed to address our overarching science question through a series of integrated field observations, lab experiments, and modeling activities. Permafrost degradation and its impact on water, nitrogen, carbon, and energy-related processes will be investigated

across a hierarchy of scales, including the pore/core, plot, and landscape scales. Field research will be conducted in Alaska initially on the North Slope (Barrow) but in other important regions as they become identified. Modeling efforts will focus on application of existing models to evaluate their predictive capability across a range of spatial scales, from single-column to plot to landscape scales. Model results will be compared with laboratory experiments and field observations. We will simulate permafrost degradation in a warming Arctic using the land surface component of a major climate prediction model as well as several high-resolution process-resolving models of subsurface physical and biological dynamics. These efforts will (1) quantify how surface and subsurface processes interact to influence permafrost degradation and hydrology, (2) resolve biogeochemical mechanisms that control rates of CO_2 and CH_4 flux, (3) characterize the role of nitrogen availability in shrub expansion and plant productivity, (4) identify mechanisms underlying changes in ecosystem net energy budgets due to vegetation dynamics, and (5) quantify prediction skill for existing models.

Phase 2 – Expanding to Other Regions of the Arctic

Insights gained in Phase 1 will be used to address the challenge of extrapolating or scaling process studies to larger grid scales of climate models and to sharpen our focus on physical, chemical, and biological processes that shape the structure and function of Arctic ecosystems. Phase 2 will expand to include process-level studies at plot to landscape scales in other regions of Alaska and with collaboration with international partners throughout the Arctic. Modeling efforts will focus on design and implementation of a new Arctic process-resolving land simulator for inclusion in regional and global climate models, building on strengths and improving on the weaknesses of existing models as identified in Phase 1. Our ultimate goal throughout the NGEE project will be to develop a high-resolution, process-rich land model, extending from the bedrock to the top of the vegetative canopy, with which the evolution of the structure and function of the Arctic landscape and its ecosystems in a changing climate can be simulated on the scale of an Earth System Model (30x30km) grid cell.

Understanding the Importance of Spatial and Temporal Scales

The research scope of the NGEE project is designed to characterize critical ecosystem-climate feedbacks and incorporate process knowledge into models that, in turn, can simulate impacts of climate change in high-latitude systems. Permafrost degradation and its impact on water, nitrogen, carbon, and energy-related processes will be investigated across the pore/core, plot, and landscape scale (Figure 1). Although the characteristic lengths and interrogation approach will vary depending on the process being studied, some generalities about these three scales of investigation can be made. Pore/core-scale investigations will focus on processes that operate at the micron to tens of centimeter length scales, typically using homogeneous soil samples and controlled lab conditions. At this scale, biogeochemical processes are determined more by sediment characteristics, such as grain size and porosity; thus intact cores will be studied. Investigations at the plot-scale allow us to interrogate those processes in the presence of natural heterogeneity, including spatial and temporal variations in thermokarst, snow and active layer thickness, and soil texture, which will in turn impact moisture distribution, vertical and lateral flow, and solute (including electron) transport affecting subsurface biogeochemical reaction, vegetation, and energy balance. Representative length scales for plot investigations range from meters to tens of meters. Landscape-scale investigations, operating at representative length scales of kilometers, allow us to consider the impact of factors such as topography, geomorphology, and large-scale drainage on carbon, nitrogen, and energy partitioning and to explore the how processes occurring over smaller length scales contribute to the integrated GHG flux signature as is needed to inform climate models. Research conducted across these scales will ensure quantification of fundamental process coupling while developing insights on scale transitions and macroscopic rules that govern terrestrial Arctic system behavior.

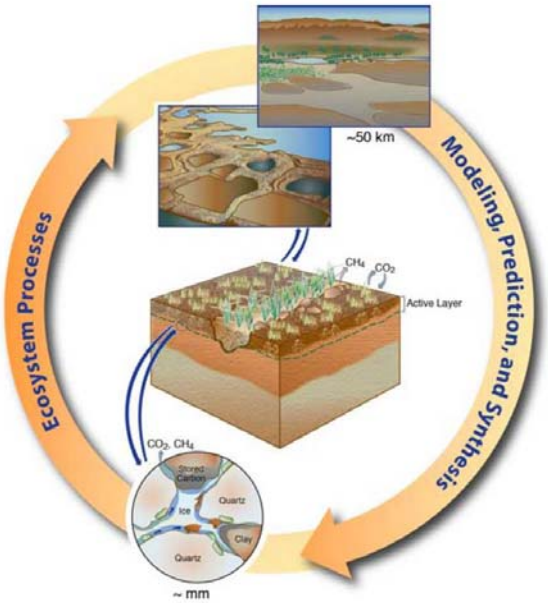


Figure 1. Multi-scale approach of the NGEE Arctic project.

References

Jorgenson, M.T., Y.L. Shur & E.R. Pullman. 2006. Abrupt increase in permafrost degradation in Arctic Alaska. Geophysical Research Letters 33: L02503, doi:10.1029/2005GL024960.

Rowland, J.C., C.E. Jones, G. Altmann et al. 2010. Arctic landscapes in transition: Responses to thawing permafrost. Eos 91: 229–-230.

Schuur, E.A.G., J.G. Vogel, K.G. Crummer, H. Lee J.O. Sickman & T.E. Osterkamp. 2009. The effect of permafrost thaw on old carbon release and net carbon exchange from tundra. Nature 459: 556–59, doi:10.1038/nature08031.

Acknowledgement

Research sponsored by the U.S. Department of Energy, Office of Science, Biological and Environmental Research.

Geophysical Research Abstracts
Vol. 14, EGU2012-**PREVIEW**, 2012
EGU General Assembly 2012
© Author(s) 2012

Quantifying and Relating Subsurface and Land-surface Variability in Permafrost Environments using Surface Geophysical and LIDAR Datasets.

S.S Hubbard (1), C. Gangodagamage (3), B. Dafflon (1), H. Wainwright (1), C. Ulrich (1), A. Gusmeroli (4), Y. Wu (1), J. Doetsch (1), J.E. Peterson (1), C. Wilson (3), C. Tweedie (5), and S.D. Wullschleger (2)

(1) Lawrence Berkeley National Lab, Earth Science, Berkeley, United States (sshubbard@lbl.gov, +1-510-486 5686), (3) Los Alamos National Laboratory, NM, (4) University of Alaska at Fairbanks, AK, (5) University of Texas at El Paso, TX, (2) Oak Ridge National Laboratory, TN

A new U.S. Department of Energy project, called the Next-Generation Ecosystem Experiments (NGEE), has recently been initiated to address how permafrost thaw and degradation - and the associated changes in landscape evolution, hydrology, soil biogeochemical processes, and plant community dynamics - affect feedbacks to the climate system. Quantifying subsurface properties and states that govern permafrost dynamics is challenging due to the need to sample over large spatial regions in high resolution and with minimal disturbance to the ecosystem. Here, we explore the use of remotely sensed, high resolution topographic and surface geophysical data together with point-based soil measurements to characterize active layer and shallow permafrost variability, topographic variability, and their linkages. This quantification represents a first step towards improved initialization and parameterization of climate models in poorly understood, but globally important terrestrial ecosystems. Our study is performed within the Arctic Coastal Plain in Alaska in the Barrow Environmental Observatory.

The data were collected along and in the vicinity of several ∼500m transects and included (a) high resolution LIDAR measurements; (b) surface-based ground penetrating radar, electrical resistivity and phase data, and electromagnetic data; and (c) point-based soil temperature, moisture, geochemistry and texture as well as active layer thickness measurements. The presentation will describe the acquisition, inversion and analysis of the different datasets. It will also describe the approaches used to explore relationships between the geophysical attributes (including electrical conductivity, electrical phase, and radar travel time, velocity and amplitude) to subsurface and surficial properties and states.

Interpretation of the data leads to three main findings. First, advanced assessment of the LIDAR data in terms of permafrost degradation metrics indicates that the land surface can be delineated into three distinct classes of polygonal ground along the transects: high-centered, moderately-low centered, and a region of low-centered polygonal ground. Secondly, analysis of the geophysical and point measurements reveals that there are distinct geophysical responses to active layer and shallow permafrost heterogeneities. Finally, we find that the geophysically-defined subsurface zonation corresponds with the three surficially-identified classes of polygonal ground. These findings document the potential of surface geophysical methods for quantifying subsurface controls on permafrost degradation. Furthermore, if linkages between subsurface and land-surface variabilities (such as documented here) are common in permafrost environments, our study suggests that integration of surface geophysical and LIDAR datasets should permit estimates of properties and states that influence ecosystem feedbacks to climate to be transferred from below to above ground and across scales.

Meeting of the Alaska section of the American Water Resource Association

Exploring the Alaskan cryosphere with Ground Penetrating Radar

A. Gusmeroli, L. Hinzman, S. Hubbard, B. Dafflon, S. Wullschleger, A. Arendt and T.S. Rupp

The hydrological system in Alaska is heavily affected by the presence of seasonal and perennial ice. Snow and ice melt contributes majorly to river run-off whereas permafrost may act as a barrier for water infiltration. Ground penetrating radar (GPR) can be used to characterize these systems. GPR transmits electromagnetic waves from the surface within the subsurface; such waves are partially reflected when they meet inhomogeneities in electrical properties; the reflected energy travels back to the surface and a receiver registers the signal. The travel time from the reflectors is measured and the subsurface can be characterized. In this presentation we will illustrates recent applications of GPR to study the Alaskan cryosphere. Examples will include snow depth profiling; snow water-content estimation; soil thaw depth measurements; river and lake ice profiling; glacier-bed imaging and determination of the glacier thermal regime. Two detailed case study will be analyzed. In one we used multi-frequency GPR to reconstruct the spatial variation of the active layer thickness at the time of maximum thaw in the Arctic tundra near Barrow. In the second case the GPR was used to complement the Synthetic Aperture Radar (IFSAR) inference of the thermal properties of the Kahiltna Glacier in the Alaska Range. GPR is a powerful tool to characterize the cryospheric components of the hydrological cycle.

Omics in the Arctic: Genome-enabled Contributions to Carbon Cycle Research in High-Latitude Ecosystems

Stan D. Wullschleger
Environmental Sciences Division
Oak Ridge National laboratory
Oak Ridge, TN 37831-6301
Email: wullschlegsd@ornl.gov

A decade or more into the 21st Century and society continues to look to the biological sciences for creative solutions to several pressing concerns; energy security, climate change, and the sustainable use of otherwise limited supplies of Earth resources. Of these, the role of plants and microbial communities in climate change and the technologies required to underpin this science, is particularly compelling. It is one that illustrates not only the highly-coupled nature of basic biological processes that will determine the trajectory of climate in our changing world, but also the molecular-scale approaches that must be employed if we are to merge processes-level knowledge with predictive models.

Gaining a quantitative and predictive understanding of the Earth's climatic system will require that biologists characterize complex interactions between terrestrial ecosystems and the fundamental processes that underlie the global carbon cycle. It is already known that vast amounts of carbon fixed initially by plants and then degraded by microbial communities, enter and leave plant-soil systems. The magnitude of these pools and a first-order understanding of exchange rates are well-known for most ecosystems, but the kinetics and controls on the processes that drive carbon flux into leaves through photosynthesis, the incorporation of that carbon into complex biological compounds, and the turnover and transfer of organic matter into soil carbon pools remain highly uncertain. How best to quantify and represent these processes in models is also uncertain and will require an ambitious research agenda that links atmospheric science, ecology, biogeochemistry, and knowledge not only of structural, but functional activities encoded in the genomes of plant and microbes communities. This is a formidable challenge, but one that can be met by emerging systems biology research that targets the behavior of plants and microbial communities and their collective contribution to climate at multiple scales.

Many questions need to be addressed as we characterize critical ecosystem-climate feedbacks in poorly understood yet globally-important ecosystems. Among the biomes of the world this is especially true in nitrogen-limited Arctic ecosystems where carbon stored in frozen soil or permafrost is at risk of release to the atmosphere due to warmer temperatures. As permafrost thaws throughout an annual cycle, giving rise to increasing rates of organic matter decomposition and liberating nitrogen as part of the mineralization process, there may also be shifts in plant growth and community composition. The past 50 years have seen a steady increase in plant productivity for the Arctic as shrubs (e.g., Salix, Betula, Alnus spp.) invade the tundra. The mechanisms responsible for this rapid migration of plants remain unresolved.

The Department of Energy through their Office of Science, Biological and Environmental Research (BER) program has recently launched the Next-Generation Ecosystem Experiments (NGEE Arctic) project. The goals of the NGEE Arctic project will be described, as will opportunities that await input from the plant and microbial biologist. In particular, molecular biologists working closely with climate scientists can help bridge the knowledge gap between genome- and global-scale phenomena. Several questions relevant to ecosystem-climate feedbacks in the Arctic as identified. Special attention is given not only to microbial-mediated processes, but also to less appreciated questions for the plant biologist where the emphasis lies on understanding mechanisms of nitrogen acquisition in temperature-limited environments; plant adaptation to extreme climates; and population structure of plant communities along transition zones (i.e., ectones) in boreal and tundra ecosystems. Incorporation of insights derived from these studies into models will also be discussed.

Improved Climate Prediction through Process-Rich Understanding of Arctic Terrestrial Ecosystems

Stan D. Wullschleger, Oak Ridge National Laboratory
David E. Graham, Oak Ridge National Laboratory
Larry D. Hinzman, University of Alaska Fairbanks
Susan S. Hubbard, Lawrence Berkeley National Laboratory
Liyuan Liang, Oak Ridge National Laboratory
Richard J. Norby, Oak Ridge National Laboratory
Alistair Rogers, Brookhaven National Laboratory
Joel C. Rowland, Los Alamos National Laboratory
Peter E. Thornton, Oak Ridge National Laboratory
Margaret S. Torn, Lawrence Berkeley National Laboratory
William J. Riley, Lawrence Berkeley National Laboratory
Cathy J. Wilson, Los Alamos National Laboratory

Characterized by vast amounts of carbon stored in permafrost and a rapidly evolving landscape, the Arctic has emerged as an important focal point for the study of climate change. These are sensitive systems, yet the mechanisms responsible for those sensitivities are not well understood and many remain uncertain in terms of their representation in Earth System models. Increasing our confidence in climate projections for high-latitude regions of the world will require a coordinated set of investigations that target improved process understanding and model representation of important ecosystem-climate feedbacks. The Next-Generation Ecosystem Experiments (NGEE Arctic) seeks to address this challenge by quantifying the physical, chemical, and biological behavior of terrestrial ecosystems in Alaska. Initial research will focus on the highly dynamic landscapes of the North Slope where thaw lakes, drained thaw lake basins, and ice-rich polygonal ground offer distinct land units for investigation and modeling. The project will focus on interactions that drive critical climate feedbacks within these environments through greenhouse gas fluxes and changes in surface energy balance associated with permafrost degradation, and the many processes that arise as a result of these landscape dynamics. The overarching goal of the NGEE Arctic project is to reduce uncertainty in climate prediction through improved representation of Arctic tundra processes. A focus on scaling based on process understanding and geomorphological units will allow us to deliver a *process-rich ecosystem model, extending from bedrock to the top of the vegetative canopy, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the scale of a high resolution Earth System Model grid cell (i.e., 30x30 km grid size).* This vision includes mechanistic studies in the field and in the laboratory; modeling of critical and interrelated water, nitrogen, carbon, and energy dynamics; and characterization of important interactions from molecular to landscape scales that drive feedbacks to the climate system. A suite of climate-, intermediate- and fine-scale models will be used to guide observations and interpret data, while process studies will serve to initialize state variables in models, provide new algorithms and process parameterizations, and evaluate model performance. The NGEE Arctic project will also develop innovative communication and data management strategies as we work both within a multi-disciplinary team environment and with the larger scientific community to chart a course for an improved process-rich, high-resolution Arctic terrestrial simulation capability.

Process Studies and Observations in the Arctic to Inform a Hierarchical Scaling Framework for Improved Climate Predictability

Cathy J. Wilson, Los Alamos National Laboratory
David E. Graham, Oak Ridge National Laboratory
Larry D. Hinzman, University of Alaska Fairbanks
Susan S. Hubbard, Lawrence Berkeley National Laboratory
Liyuan Liang, Oak Ridge National Laboratory
Richard J. Norby, Oak Ridge National Laboratory
William J. Riley, Lawrence Berkeley National Laboratory
Alistair Rogers, Brookhaven National Laboratory
Joel C. Rowland, Los Alamos National Laboratory
Peter E. Thornton, Oak Ridge National Laboratory
Margaret S. Torn, Lawrence Berkeley National Laboratory
Stan D. Wullschleger, Oak Ridge National Laboratory

A fundamental goal of the Next-Generation Ecosystem Experiments (NGEE Arctic) project is to improve climate prediction through process understanding and representation of that knowledge in Earth System models. Geomorphological units, including thaw lakes, drained thaw lake basins, and ice-rich polygonal ground provide the organizing framework for our model scaling approach for the coastal plains of the North Slope of Alaska. A comprehensive suite of process studies and observations of hydrology, geomorphology, biogeochemistry, vegetation patterns, and energy exchange and their couplings will be undertaken across nested scales to populate the hierarchical modeling framework and to achieve a broader goal of optimally informing process representations in a global-scale model. A central focus of this challenge is to advance process understanding and prediction of the hydrologic and thermal responses and feedbacks to thermokarst development in ice-rich ground and how climate driven changes will control the spatial and temporal availability of water for biogeochemical, ecological, and physical feedbacks to the climate system. Field activities to inform model development will be carried out across a gradient of polygonal ground nested within a drained thaw lake basin age gradient near Barrow, Alaska. Geophysical characterization of these sites will be essential as we describe critical surface-subsurface variability and interactions, as will assessments of fine-scale topography that controls local hydrology. We will investigate greenhouse gas (e.g., CO_2 and CH_4) fluxes from the decomposition of buried organic matter as a function of hydrologic variability in the landscape, with the assumption that physical and chemical factors are represented appropriately at each modeling scale. Process studies that have the greatest potential for reducing prediction uncertainty were prioritized, including studies focused on: improving the mechanistic understanding of permafrost degradation and its influence on water distribution; quantifying mechanisms and rates associated with organic carbon decomposition in Arctic soils; and developing response functions relating plant community composition and phenology to resource gradients created by high-centered and low-centered polygons and other thermokarst features. Additional studies will be used to parameterize a plant physiological model of carbon-nitrogen interactions, including measurements of active-layer nitrogen availability, litter feedbacks to soil carbon-nitrogen cycling, and plant use of available nitrogen. A metric of effectiveness for our scaling approach will be the degree to which prediction at each successive scale is improved as the result of iterative scaling.

Developing a Hierarchical Scaling Framework for Modeling a Dynamic Arctic Landscape in a Changing Climate

Peter E. Thornton, Oak Ridge National Laboratory
William J. Riley, Lawrence Berkeley National Laboratory
Charles D. Koven, Lawrence Berkeley National Laboratory
Forrest M. Hoffman, Oak Ridge National Laboratory
Richard T. Mills, Oak Ridge National Laboratory
Scott L. Painter, Los Alamos National Laboratory
A.D. McGuire, University of Alaska Fairbanks
David E. Graham, Oak Ridge National Laboratory
Larry D. Hinzman, University of Alaska Fairbanks
Susan S. Hubbard, Lawrence Berkeley National Laboratory
Liyuan Liang, Oak Ridge National Laboratory
Richard J. Norby, Oak Ridge National Laboratory
Alistair Rogers, Brookhaven National Laboratory
Joel C. Rowland, Los Alamos National Laboratory
Margaret S. Torn, Lawrence Berkeley National Laboratory
Cathy J. Wilson, Los Alamos National Laboratory
Stan D. Wullschleger, Oak Ridge National Laboratory

An important challenge for Earth System models is to properly represent the land surface. This can be problematic, yet failure to identify and appropriately account for complexities at the landscape scale can compromise climate predictions. The Next-Generation Ecosystem Experiments (NGEE Arctic) project will address this challenge for sensitive and rapidly changing ecosystems of the Arctic tundra through a combination of direct observation and process-resolving simulation in this vast and remote landscape. A distinguishing characteristic of the Arctic tundra, especially the coastal plains of the North Slope is the existence of recognizable and quantifiable landscape units which are repeated over large domains, and which occur at multiple spatial scales. Previous landscape-scale classification efforts using remote-imagery have identified active thaw lakes and drained thaw lake basins, and ice-rich polygonal ground as three common landscape units that occur over large parts of the Arctic tundra. We will use this information to deliver improved climate predictions for the Pan-Arctic region. Our scaling approach will build on the hypothesis that the transfer of information across spatial scales can be organized around these discrete geomorphological units for which processes are represented explicitly at finer scales, with information passed to coarser scales through sub-grid parameterization of Earth System models. By extending an already well-established framework for fractional sub-grid area representations to allow dynamic sub-grid areas and hydrological and geophysical connections among sub-grid units, we expect to be able to characterize permafrost dynamics and the influence of thermokarst at multiple spatial scales in Arctic tundra landscapes. Our fundamental scaling approach will be to identify processes likely to have the largest influence on climate, based on current knowledge of the Arctic tundra system, and then to define a connected (nested) hierarchy of modeling necessary to resolve those processes. This approach allows us to begin immediately to integrate new process knowledge into a climate prediction-scale land model, while establishing a quantitative framework connecting this scale to more process-rich models implemented at finer spatial resolution and over smaller spatial domains. The consequence for NGEE Arctic is that model application efforts can begin immediately and in parallel across multiple modeling scales.