Next-Generation Ecosystem Experiments–Arctic

ngee-arctic.ornl.gov

Advancing the predictive power of Earth system models through understanding of the structure and function of Arctic terrestrial ecosystems

An important challenge for Earth system models (ESMs) is to accurately represent land surface and subsurface processes and their complex interactions. This is true for all regions of the world, but is especially important for high-latitude Arctic ecosystems that are characterized by ice-rich landscapes where topography, hydrology, vegetation, and biogeochemistry are inexplicitly linked. To address this challenge, the Environmental System Science (ESS) program within the Department of Energy's (DOE) Office of Biological and Environmental Research (BER) is supporting a next-generation ecosystem experiments project in the Arctic (NGEE–Arctic).

The NGEE approach seeks to improve the representation of critical environmental processes in ESMs by focusing on systems that are globally important, climatically sensitive, and understudied or inadequately represented in models. In this approach, modeling and process research are closely and iteratively connected so that model structure and computational requirements are considered in the development of process studies whose outcomes, in turn, are designed to directly inform, challenge, and improve the predictive power of numerical models.

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. A similar initiative under way in the tropics (NGEE–Tropics) is examining how tropical forest ecosystems will respond to environmental and atmospheric change.

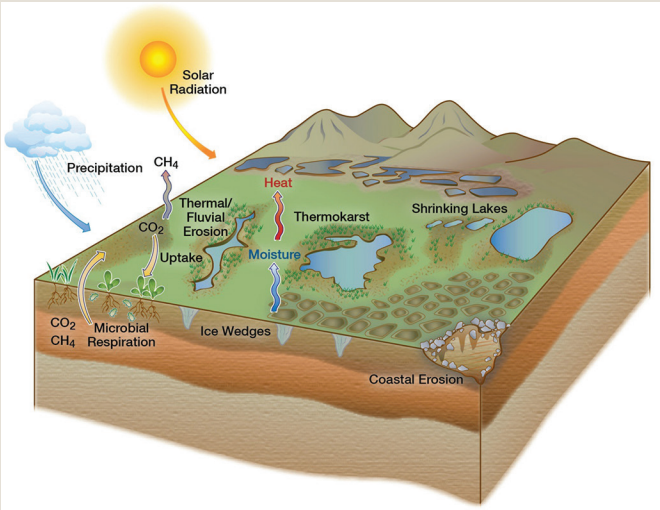
Key NGEE–Arctic Science Questions

The NGEE–Arctic project seeks to understand how surface and subsurface processes and properties are interconnected across permafrost-dominated tundra ecosystems. Related research experiments and modeling efforts on Alaska's North Slope and Seward Peninsula are designed to answer the following questions:

- How does landscape structure and organization control the storage and flux of carbon, water, and nutrients in a changing climate?
- What will control rates of carbon dioxide (CO_2) and methane (CH_4) fluxes across a range of environmental conditions?
- How will warming and potentially permafrost thaw affect above- and belowground plant functional traits, and what are the consequences for carbon, water, and nutrient fluxes?

Knowledge derived from these studies will help answer two integrated questions concerning the Arctic's future:

- What controls the current distribution of Arctic shrubs, and how will shrub distributions and associated feedbacks to the atmosphere shift in the 21st century?
- Where, when, and why will the Arctic become wetter or drier, and what are the implications for future terrestrial ecosystems throughout Alaska and around the world?



Landscapes in Transition. *A mechanistic understanding of what controls the coupled nature of hydrology, biogeochemistry, and vegetation dynamics is needed for system-wide prediction of permafrost dynamics. NGEE–Arctic research activities are designed to identify and quantify the mechanisms underlying processes that control carbon and energy transfer in the Arctic biosphere, as well as how those processes play out in a changing Arctic landscape.*

Integration Across Scales

Variations in landscape structure and organization—including ridges, valleys, and watershed basins—provide the organizing framework for integrating process studies and observations from the pore or core scale (micron to tens of centimeters) to plot (meter to tens of meters) and landscape (kilometer) scales. Multiscale research activities organized around these components are designed to help determine whether the Arctic is, or in the future will become, a negative or positive feedback to anthropogenically forced climate change. These activities include landscape heterogeneity, soil biogeochemistry, plant traits and shrub dynamics, and watershed hydrology.

Permafrost Landscapes. *Degradation of ice-rich permafrost causes subsidence and increased variability in topography across the Arctic landscape. Associated changes in hydrology, vegetation, and biogeochemistry create "hot spots" (i.e., locations within an ecosystem that exert a disproportionately large influence on the flow and processing of nutrients) for CO_2 and CH_4 fluxes.*

Climate Feedbacks. *Landscape topography on Alaska's North Slope determines the distribution of water and vegetation across the Alaskan tundra and thus influences feedbacks to climate. Surface and pore water geochemistry experiments* ***(inset)****, including isotopic analyses, are important indicators for fluxes of CO_2 and CH_4 from degrading permafrost.*

Landscape heterogeneity research considers how vegetation, biogeochemistry, and hydrology are influenced by regional landforms such as ridges, valleys, and drainage basins. A key challenge is simplifying the variations in landscape properties and processes for input into models, while still retaining those fine-scale features that have the strongest influence on important ecosystem feedbacks to climate.

Soil biogeochemistry focuses on temperature, moisture, and nutrient variations and the influence of these variations on microbial dynamics and soil organic matter decomposition. Given the need to improve predictions of net carbon exchange in Arctic systems, assessing geochemical and hydrological influences on CO_2 and CH_4 fluxes under a range of environmental conditions is critical.

Plant traits and shrub dynamics provide an important link among plant communities, tundra biogeochemistry, and biophysical feedbacks to the atmosphere. NGEE–Arctic research efforts have greatly improved model representation of plant traits regulating photosynthesis for Arctic vegetation types and led to new approaches for collecting plant traits using remotely sensed data. Further research is focused on better understanding and modeling the expansion of deciduous shrubs throughout the Arctic landscape.

Watershed hydrology research activities focus on determining the spatial distribution and temporal dynamics of soil saturation and inundation and, in turn, surface and subsurface ecosystem responses, CO_2 and CH_4 fluxes, and the local- to regional-scale energy balance. These observations are important for identifying key model improvements required to enhance prediction of past, present, and future distributions of snow, soil moisture and inundation, and surface and subsurface water flow in the Arctic landscape.

Connecting Observations to Models

This comprehensive suite of NGEE–Arctic process studies and observations is being strongly linked to model development and application requirements for improving process representation, initializing multiscale model domains, calibrating models, and evaluating model predictions. A fundamental challenge for the NGEE–Arctic modeling activity is to relate new process knowledge gained at fine and intermediate spatial scales to states and fluxes relevant for integration in ESMs. Consequently, a nested hierarchy of models is being engaged at fine, intermediate, and global scales, connecting process studies to models and models to each other in a quantitative upscaling and downscaling framework.

The overall objective is general knowledge and understanding through direct observation and fine-grained simulation of Arctic tundra ecosystems and the mechanisms that regulate their form and function. Specifically, this generalization is providing improved representation of Arctic tundra states and dynamics in the land model component of a coupled ESM.

Leveraging NGEE–Arctic Investments

Led by Oak Ridge National Laboratory, the NGEE–Arctic project's collaborative effort includes scientists at Los Alamos National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, University of Alaska Fairbanks, and partners at universities and other state and federal agencies. In addition to ESS, other BER programs involved in the NGEE–Arctic project include:

- Atmospheric Radiation Measurement Climate Research Facility
- Atmospheric System Research program
- Climate and Earth System Modeling programs, including the Accelerated Climate Modeling for Energy (ACME) project and International Land Model Benchmarking project (ILAMB)
- Environmental Molecular Sciences Laboratory
- Genomic Science program
- Subsurface Biogeochemical Research program

NGEE–Arctic also is affiliated with other federal and international monitoring projects, including the National Aeronautics and Space Administration's Arctic-Boreal Vulnerability Experiment (ABoVE) and Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE).

All NGEE–Arctic data generated from observations, experiments, and models are made available at **ngee-arctic.ornl.gov**. These data include automated data collected from weather stations and trace-gas systems; observations from remote-sensing platforms; large campaign-based field work collections; and discrete datasets generated from chemical, biochemical, and molecular characterizations of soil, ice, water, and microbial or plant samples. BER provides research funding to leverage the NGEE investment through regular Funding Opportunity Announcements posted at **www.grants.gov**.

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