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October 13-14, 2010

Climate Change Experiments in High-Latitude Ecosystems

International Arctic Research Center, University of Alaska, Fairbanks




Workshop Summary

Next-Generation Ecosystem Experiments

Oak Ridge National Laboratory,
Los Alamos National Laboratory and
Brookhaven National Laboratory

Climate Change Experiments in High-Latitude Ecosystems
International Arctic Research Center, University of Alaska, Fairbanks

Workshop Summary

A two-day climate change workshop was held October 13-14, 2010 at the International Arctic Research Center, University of Alaska, Fairbanks. The workshop, sponsored by the Department of Energy (DOE), Office of Science, Biological and Environmental Research, was attended by 45 subject matter experts from universities, DOE national laboratories, other federal agencies, and non-government organizations. Through a series of presentations and discussion sessions, participants highlighted the role of manipulative experiments and observations in understanding plot to landscape-scale processes that were unique to northern ecosystems. Speakers emphasized the sensitivity of boreal forests and Arctic tundra to atmospheric and climatic change in the coming decades. All participants were asked to consider how field studies could contribute data and insights to regional and global climate models. In addition, workshop participants identified critical needs for future global change research in the Arctic. Despite the known challenges of conducting fundamental research in cold regions, participants recommended a concerted effort to address mechanisms underlying greenhouse gas fluxes from warming and thawing permafrost. Tree line migration and shrub advancement into the tundra were also areas where integrated experiments and observations were needed. Research to address vulnerability of Arctic ecosystems to global change should be designed to characterize chemical, physical, and biological processes in sufficient detail so that representations in current climate models can be improved and that new mechanisms can be identified for future inclusion into regional and global climate models.

Given the need to quantify ecosystem-climate interactions in a warming Arctic, a framework was discussed for a new generation of manipulative experiments and observations in tundra and boreal forests driven by the need to address major uncertainties in water, energy and carbon cycle processes. The goal would be to improve modeling and prediction of ecosystem responses and feedbacks to climate change, especially warming in these key regions. Technologies for warming air and soil were presented, along with computer simulations of their potential performance. Estimates of energy costs associated with operating such experiments were also presented. A future workshop will focus on the science, technology, and resource requirements of a DOE-sponsored Next-Generation Ecosystem Experiment (NGEE) project. This project will bring together an inter-disciplinary team of scientists and engineers from national laboratories and strategic partners in support of climate change research in the Arctic.

Our thanks to all those who contributed to the success of this workshop including administrative assistance provided by Tara Hall (ORNL) and Dorothy Parkerson (IARC) and especially to the tireless support provided by Events Coordinator Tohru Saito (University of Alaska, Fairbanks).

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Discussion Questions

Discussion Session #1: Models

A. What are the greatest uncertainties and sensitivities in current-generation ecosystem or climate models?

- Geophysical dynamics and thermal characteristics of permafrost and the active layer, and interactions with temperature and local hydrology
- GHG fluxes from thawing permafrost, wetlands, and thermokarst lakes as driven by rising temperatures, subsidence, and changes in local and regional hydrology
- Physical climate-ecosystem feedbacks, e.g., shifts in plant species composition, snow pack dynamics, surface energy balance, and albedo
- Climate-biogeochemistry feedbacks, e.g., carbon and nitrogen biogeochemistry and interactions with temperature, water, and elevated CO_2 that impact GHG fluxes, plant and ecosystem NPP, and vegetation dynamics
- Microbial dynamics, e.g., improved representation of how functional microbial groups respond to changes in temperature, hydrology, and nutrients; also better descriptions for how temperature, soil water, and aqueous chemistry control anaerobic decomposition, methanogenesis, and methanotrophy at scales applicable to climate models
- Organic matter distribution and biological activity with soil depth; susceptibility of stored carbon to decomposition and loss as CO_2 or CH_4 as a function of temperature, water content, oxygen concentrations, pH, and redox potential
- Interaction of disturbance (e.g., fire, thermokarst) and temperature on GHG fluxes and surface energy balance feedbacks to climate
- Geomorphologic processes that deposited soils and soil carbon in arctic regions; wind-blown deposition and cryoturbation are among processes not in current models

B. What are the processes, impacts, or responses that the scientific community would most like to see better represented in predictive models?

- Improved understanding of species competition or change (i.e., mortality) in response to a changing climate, including temperature, water and CO_2 concentration, and better representation of plant functional types in dynamic vegetation models
- Interactions among temperature, hydrology, soil physical properties (e.g., organic matter content, mineralogy), soil chemistry (e.g., pH, redox potential, O_2 content), and functional microbial dynamics in the balance between CO_2 and CH_4 production and efflux as a result of thawing permafrost
- Better characterization of the nitrogen cycle and interaction with the carbon cycle; need better information on seasonality of nitrogen dynamics, including availability, forms, immobilization, mineralization, and use by plants and microbes
- Improved representation of geophysical thresholds and consequences (e.g., subsidence, thermokarst, hydrologic consequences) in the Arctic at the landscape scale

- Better characterization of belowground plant processes and carbon cycling, e.g., the role of aerenchyma in affecting rhizosphere O_2 concentrations, CH_4 fluxes, and labile carbon inputs

C. Are there scientific or technical limitations that constrain our ability to resolve these uncertainties or characterize and quantify critical processes, impacts, and responses?

- Conceptual models abound, but mechanisms responsible for the many linkages are often not well-characterized in experiments and observations; thus, it is difficult to link current results from observations and experiments to regional or global climate models; i.e., process representation in the models and appropriate measurements for development and testing are often lacking
- Insufficient data are available to develop and test models; isolated measurements from short-term experiments or observations are not adequate; need continuous datasets, especially for important processes that can help constrain, test, and benchmark models
- It was unclear what amount of mechanistic information on carbon and nitrogen cycling that is relatively well developed for fine scales is necessary for coarser scale regional and global modeling
- Assuming data are available, model-data comparisons do not always test relationships with both coupled and un-coupled simulations; results may be misleading or, at best, insights incomplete

Discussion Session #2: Observations

D. What are observational studies telling us about changes in rates and magnitudes of processes, impacts, or responses in high-latitude terrestrial ecosystems?

- Climate-induced changes in species composition in tundra and boreal forests is a slow (i.e., decadal scale) and subtle process; in some locations, largely those affected by abrupt disturbances (e.g., fire and thermokarst), however, vegetation change can occur relatively rapidly (i.e., years)
- Warming of permafrost in the Arctic will result in subsidence and release of old carbon, either from depth or from thermokarst margins; this can and likely will happen quickly; build it into experiment
- Need year-round observation or measurement of processes; data collected only within a given season may be misleading and will likely provide an incomplete picture of what is happening
- Inter-annual variation in, for example, precipitation can be considerable; however, yearly variation in precipitation is not the same as a controlled experimental manipulation of local hydrology

E. How can we use these results to help define what we need to include, measure, and characterize in a controlled field experiment?

- Need high temporal and spatial resolution measurements to quantify the strength and timing of the carbon cycle; must understand pool size, dynamics, temperature and soil water interactions, nutrient limitations, and how fast stored carbon can move to atmosphere as either CO_2 or CH_4

- Sampling strategy should include plans to measure seasonality of plant growth, root production, exudation, and nitrogen availability; in what is described as a N-limited ecosystem, temporal changes in pools, processes, and fluxes are important
- Must understand that ecosystems, especially arctic ecosystems, are highly coupled systems; cannot just measure one or a couple processes; must consider linkages among biological and physical processes and properties of the larger system
- Emphasize continuous measurements of critical processes (e.g., CO_2 and CH_4 flux and isotopes) and ecosystem properties (e.g., albedo); automated equipment may provide this capability and ensure data availability to validate and constrain models for key parameters

Discussion Session #3: Experiments

F. What are the strengths and limitations of current generation lab and field experiments for measuring and quantifying climate-driven processes, impacts, and feedbacks?

- Sophisticated and complex experiments have been conducted in the Arctic; availability of power, infrastructure, and logistical support are challenges, but these have not kept large-scale and long-term experiments from being successful executed (e.g., BioComplexity Experiment and ITEX)
- Small-scale experiments have been conducted with specific objectives in mind; thus, such experiments may be forced to compromise; e.g., hard to passively warm soils beneath small plots due to thermal mass of soil and water
- Short-term experiments have focused more on phenology and timing of events, and less on underlying mechanisms; summer measurements often miss critical winter events that alter our understanding of inter-annual budgets
- Many experiments have not measured ecosystem processes in a way that makes the data easily translated into improvements in current model structures; conceptualizations, as formulated in model structure, are often more complex and contain more necessary parameters than can be measured empirically with observations and experiments

G. What lessons have been learned about variation in patterns or processes over space and time that should be considered in the design of a climate change experiment?

- Considerable inter- and intra-annual natural variation exists; this can contribute to conclusions drawn from long-term experiments; a decade-long experiment will benefit from several years of unusual weather (e.g., wetter or drier)
- Thermokarst and subsidence are a natural consequence of warming in the Arctic; plan for it to happen, because it will
- Spatial variation and heterogeneity are obvious in the Arctic; topography is important and drives local to regional hydrology; mechanisms to explain why patterns are observed at the scale of landscapes is often lacking
- The heterogeneous nature of the landscape, both aboveground and in the subsurface, places a premium on site characterization, including measurements that encompass

geophysical and thermal properties of the permafrost and active layer, local and regional hydrology, and species composition; it also suggests that an experiment include large treatment differences, a high degree of replication, and minimal plot-to-plot variation

Discussion Session #4: NGEE and a Path Forward

H. Does this group have a preferred approach or design that would enable us to achieve our science goals and objectives?

- Not all processes can be addressed; identify and focus on the big ones; especially those unique to the Arctic; permafrost, warming, hydrology, GHG fluxes, vegetation changes, surface energy balance, albedo, biogeochemistry in N-limited ecosystems, and CN feedbacks
- Timing is everything; initial response is not necessarily long-term response; commit to decade-long experiment
- Make sure that data are collected in an intensive manner; otherwise, data will be sparse and not well connected to process-level information; easy to match models to such results, however, this is not always useful
- The three most important variables to include in an experimental design are temperature, hydrology, and CO_2 concentration; location, engineering challenges, and cost of a replicated experiment will ultimately determine treatment combinations of these variables
- No consensus was reached on plot size; plot size should be adjusted to meet experimental objectives and with the recognition that other investigators will want to use resource once operational
- Observational studies conducted in parallel with an experiment will be required to fully understand and scale results to landscapes and beyond; observational studies will also be required to understand important disturbance effects like fire and insect infestations; these observations are already underway within the LTER network and new initiatives like CARVE, ABoVE, and NEON, but none of these networks include a large-scle manipulation such as proposed with NGEE

Workshop Conclusions:

Goal: Understand vulnerability of Arctic ecosystems and feedbacks with climate change; quantify mechanisms through process-level studies tied to GCM-scale process representations; characterize spatial variation in mechanisms through observations; use fundamental knowledge to improve representation of ecosystem dynamics, biogeochemistry, hydrology, and land-atmosphere feedbacks in regional and global models to reduce uncertainty and improve prediction of climate impacts and climate change in high latitude ecosystems.

Approach: A manipulative experiment combined with a distributed observational component are both necessary to achieve these goals. The target ecosystem would be continuous permafrost with high soil carbon stocks, with observations and low-level manipulations in other high latitude ecosystems. The manipulative experiment would ideally include elevated temperature and CO_2 concentration, with manipulation of hydrology (e.g., water table). Manipulation of these variables alone and in combination will enable explicit evaluation of model uncertainties and improved representation of the chemical, physical, and biological processes that drive high-latitude ecosystem response and feedbacks to climate change in those models. The observational component of the overall approach is crucial. It will be required to link process level understanding realized through the manipulative experiment to landscape and regional scales. This component will also be critical to capture consequences and understand the processes that precipitate large-scale disturbance effects such as fire and thermokarst. Data collected and insights derived in the experimental and observational components of the approach will provide much needed data to address not only model uncertainties and sensitivities, but also provide information to test models and their predictions of climate impacts and climate change in the Arctic.

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Workshop Description

Boreal forests and arctic tundra have emerged as important biomes for the study of climate change. These are among the largest and coldest of all biomes and are perceived by many as vulnerable to changes in temperature, elevated CO_2, and precipitation. Warming, in particular, is expected to be greatest in northern latitudes with consequences for tundra, boreal, and peat land ecosystems. *Observational evidence* suggests that warming of the Arctic is underway and there is growing concern that temperature increases are already affecting many physical and ecological processes in high-latitude ecosystems. *Models* also predict changes at regional to global scales; permafrost degradation, changes in local and regional hydrology, carbon and methane emissions, and the expansion of shrubs into tundra represent important feedbacks on climate.

Manipulative *experiments* can help understand the vulnerability of boreal and tundra ecosystems to climate warming and elevated CO_2 concentrations. Previous attempts to manipulate the environment of ecosystems in arctic and subarctic regions have focused on warming plant and soils at small spatial scales. Today, it is increasingly clear that manipulating the environment at the ecosystem scale is required to resolve uncertainties in climate models, yet the requirements of conducting field experiments represent logistical and engineering challenges beyond those typically encountered in ecological research. New approaches will be required to address the questions being asked of the scientific community especially as we continue to move toward large-scale and long-term experiments.

In light of the many questions that surround the response of high-latitude ecosystems to global climate change, it is important that we focus on how experiments can address and resolve uncertainties regarding impacts and feedbacks. The workshop will highlight conclusions from observational studies and model simulations about the response of arctic ecosystems to a changing climate. Participants will be asked to identify the greatest uncertainties or sensitivities in current-generation ecosystem or climate models, and to elaborate on what processes, impacts, or responses they would most like to see better represented in predictive models. Armed with that information participants will explore the scientific and technical limitations that potentially constrain our ability to resolve these uncertainties or characterize and quantify critical processes, impacts, or responses. Finally, participants will be asked to consider how field experiments can best be designed to address issues related to plant, microbial, and ecosystem dynamics; CO_2 and CH_4 production associated with permafrost degradation; fate and transformation of soil carbon with deepening of the active layer; landscape processes; local and regional hydrology; and the many land-atmosphere feedbacks that are likely to arise as a result of global warming. This information will be discussed and evaluated in the context of a Department of Energy, Office of Science, Biological and Environmental Research sponsored Next-Generation Ecosystem Experiments (NGEE) project.

Climate Change Experiments in High-Latitude Ecosystems
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Agenda

Wednesday, October 13, 2010

7:30 and 7:45 am: Buses pick up participants at Pike's Waterfront Lodge

7:45 to 8:30 am: Continental breakfast (International Arctic Research Center, UAF)

8:30 to 9:10 am: Welcome and opening remarks
- Workshop organizers: Larry Hinzman and Stan Wullschleger
- DOE/BER Sponsor: Gary Geernaert
- Statement of workshop goals and objectives – Stan Wullschleger

Plenary Presentations (Moderator, Larry Hinzman)
9:10 to 9:35 am: Dave McGuire, University of Alaska Fairbanks
9:35 to 10:00 am: Ted Schuur, University of Florida

Break: 10:00 to 10:20 am

Regional and Global Climate Models (Moderator, Rich Norby)
10:20 to 10:40 am: John Walsh, University of Alaska Fairbanks
10:40 to 11:00 am: David Lawrence, National Center for Atmospheric Research
11:00 to 11:20 am: Bill Riley, Lawrence Berkeley National Laboratory
11:20 to 11:40 am: Peter Thornton, Oak Ridge National Laboratory
Discussion: 11:40 to noon

Lunch: Noon to 1:30 pm (Guest Speaker, Walter Oechel, San Diego State University)

Observations (Moderator, Alistair Rogers)
1:30 to 1:50 pm: Matthew Sturm, CRREL
1:50 to 2:10 pm: Douglas Kane, University of Alaska Fairbanks
2:10 to 2:30 pm: Eugenie Euskirchen, University of Alaska Fairbanks
2:30 to 2:50 pm: Mikhail Mastepanov, Lund University, Sweden
2:50 to 3:15 pm: Break
3:15 to 3:35 pm: Mike Weintraub, University of Toledo
3:35 to 3:55 pm: Eric Kasischke, University of Maryland
3:55 to 4:15 pm: Mark Ivey, Sandia National Laboratory
Discussion: 4:30 to 5:30 pm

5:45 pm: Buses depart IARC for Pike's Waterfront Lodge

Dinner: 6:30 to 8:30 pm: Pike's Waterfront Lodge (Guest Speaker – Dan O'Neill)

Climate Change Experiments in High-Latitude Ecosystems
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Agenda

Thursday, October 14, 2010

7:30 and 7:45 am: Buses pick up participants at Pike's Waterfront Lodge

7:45 to 8:30 am: Continental breakfast (International Arctic Research Center, UAF)

8:30 to 9:00 am: Summary of recommendations from modeling and observation sessions

Experiments (Moderator, Cathy Wilson)
- 8:30 to 8:50 am: John Yarie, University of Alaska Fairbanks
- 8:50 to 9:10 am: Gus Shaver, Marine Biological Laboratory
- 9:10 to 9:30 am: Douglas Goering, University of Alaska Fairbanks
- 9:30 to 9:50 am: Steve Oberbauer, Florida International University
- 9:50 to 10:15 am: Break
- 10:15 to 10:35 am: Dustin Bronson, University of Wyoming
- 10:35 to 10:55 am: Craig Tweedie, University of Texas at El Paso
- 10:55 to 11:15 am: Robert Hollister, Grand Valley State University
- 11:15 to 11:35 am: Paul Hanson, Oak Ridge National Laboratory

Discussion: 11:35 am to noon

Lunch: Noon to 1:30 pm

Next-generation ecosystem experiments: NGEE Arctic
- 1:30 to 2:00 pm: Soil prototype – Stan Wullschleger, Oak Ridge National Laboratory
- 2:00 to 2:30 pm: Air warming simulations – Rod Linn, Los Alamos National Laboratory
- 2:30 to 3:00 pm: Power generation – Keith Lewin, Brookhaven National Laboratory

Break: 3:00 to 3:20 pm

Discussions: 3:20 to 4:00 pm

4:00 to 4:20 pm: *EOS* article – Daniel Hayes, Oak Ridge National Laboratory

4:20 to 4:40: Conclusions and path forward – Stan Wullschleger and Larry Hinzman

5:00 pm: Adjourn – Buses depart for Pike's Waterfront Lodge

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Deliverables and Discussion Questions

1. Recommendations based on models, observations, and previous field experiments as to the scientific questions that remain unresolved and how providing answers to those questions might shape the design, determine the location, or dictate the treatments of a future large-scale, long-term climate change experiment in the Arctic.

Discussion Session #1: Models

a) What are the greatest uncertainties or sensitivities in current-generation ecosystem or climate models?
b) What are the processes, impacts, or responses that the scientific community would most like to see better represented in predictive models?
c) Are there scientific or technical limitations that constrain our ability to resolve these uncertainties or characterize and quantify critical processes, impacts, and responses?

Discussion Session #2: Observations

d) What are observational studies telling us about changes in rates and magnitudes of processes, impacts, or responses in high-latitude terrestrial ecosystems?
e) How can we use these results to help define what we need to include, measure, and characterize in a controlled field experiment?

Discussion Session #3: Experiments

f) What are the strengths and limitations of current generation lab and field experiments for measuring and quantifying climate-driven processes, impacts, and feedbacks?
g) What lessons have been learned about variation in patterns or processes over space and time that should be considered in the design of a climate change experiment?

Discussion Session #4: NGEE and a Path Forward

h) Does this group have a preferred approach or design that would enable us to achieve our science goals and objectives?

2. Plans for a follow-on workshop in early spring that would take recommendations and solicit input from ecologists, engineers, and architects as to the technical challenges of executing a large, replicated climate change experiment in Alaska.

3. *EOS* publication that highlights the workshop and summarizes the science needs and resource requirements for a possible temperature x CO_2 global change experiment in the Arctic.

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