Spruce-Peatland Responses Under Climatic and Environmental Change

An *In Situ* Warming by CO_2 Manipulation of a Characteristic High-Carbon Ecosystem

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Summary

Identification of critical environmental response functions for terrestrial organisms, communities, and ecosystems to rapidly changing climate conditions are needed to evaluate ecological consequences and feedbacks. Such research has the most 'real-world' relevance when conclusions are drawn from controlled manipulations operating in natural field settings. We are in the process of developing an experimental platform to address climate change response mechanisms in a *Picea*/*Larix*/*Sphagnum* bog ecosystem located in northern Minnesota. This ecosystem located at the southern extent of the spatially expansive boreal peatland forests is considered to be especially vulnerable to climate change and to have important feedbacks on the atmosphere and climate. The replicated experiment will allow us to test mechanisms controlling vulnerability of organisms and ecosystem processes changes for multiple levels of warming (up to +9°C) combined with elevated CO_2 exposures (800 to 900 ppm). New methods for whole-ecosystem warming at plot scales of 12 to 14-m diameter have been developed for this study. Through the execution of this experiment we plant to quantify thresholds for organism decline or mortality, limitations to regeneration, biogeochemical limitations to productivity, and changing greenhouse gas emissions to the atmosphere. The experiment will allow for the evaluation of responses across multiple spatial scales including: microbial communities, bryophyte populations, various higher plant types, and some faunal groups. Direct and indirect effects of these experimental perturbations will be tracked and analyzed over a decade for the development and refinement of models needed for full Earth system analyses.

A Critical Ecosystem

The experiment will be conducted in a *Picea mariana* [black spruce] – *Sphagnum* spp. forest in northern Minnesota. The experimental site is an ombrotrophic bog within the Marcell Experimental Forest (MEF; N 47° 30.171', W 93° 28.970'). The MEF is within the Laurentian Mixed Forest Province, which is a transitional zone between boreal and broadleaf deciduous forests.

Being located at the southern extent of the spatially expansive boreal peatland forests this forest cover type is considered to be vulnerable to climate change. Because it also stores large amounts of labile carbon in the subtending peat soils, it is also expected to have important feedbacks on the atmosphere and climate through changes in net emissions of CO_2 and CH_4.

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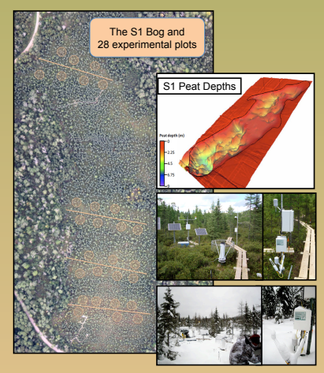
Science Questions

- How vulnerable are peatland ecosystems and their component organisms to atmospheric and climatic change?
- To what degree will changes in plant physiology under elevated CO_2 impact a species' sensitivity to climate or competitive capacity within the community?
- Will full belowground warming release unexpected amounts of greenhouse gases and solutes from high-C-content northern forests?
- What are the critical air and soil temperature response functions for ecosystem processes and their constituent organisms?
- Will ecosystem services (e.g., biogeochemical, hydrological, or societal) be compromised or enhanced by atmospheric and climatic change?



Experimental Design

The SPRUCE experiment is being developed to determine ecological responses for trees, shrubs, bryophytes, microbial communities and whole-ecosystem processes across a broad range of above- and belowground temperature increases, and how those responses to increased temperature will be altered by elevated atmospheric CO_2 concentration. Experimental temperature treatments will range from ambient condition to a +9°C differential from ambient for both air and deep soil. Those treatments will be repeated in combination with ambient or elevated CO_2 atmospheres approaching 800 to 900 ppm. Treatment allocations to 28 available experimental units on the S1 bog are being configured to provide optimal data for characterizing a range of temperature response curves that might develop for plant or ecosystem level phenomenon.

The SPRUCE study will focus primarily on warming with elevated CO_2 acting as an important interacting factor that may negate enhanced decomposition (CO_2 or CH_4 release) from increased photosynthetic allocation of carbon belowground.

Warming Technology

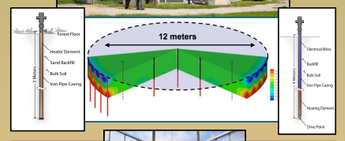
The experiment will employ a combination of large (12-m diameter) open-top aboveground enclosures and a new method for warming soils from the surface down to approximately 2 to 3 meters to achieve the target warming treatments. Belowground warming will be accomplished using circumferential rows of vertical heaters to achieve the target levels of ecosystem warming. Forced–air heating will be used to warm an aboveground encircled treatment space. The final design will represent a compromise between a totally open system (too costly) and a constrained space that still allows substantial exposure of the treatment area to natural radiation, precipitation, and atmospheric deposition.

Elevated CO_2 will be added during daytime hours of the active growing season (May through September) by injection into the heated air streams. Because the warming treatment will reduce the relative humidity of the air entering the open-top chambers, we will outfit all warmed plots with steam-generated humidity control systems under feedback control. Water vapor will be added in the inlet plenum during non-freezing conditions to maintain relative humidity (measured at 2-m above the ground) equal to that in the control chamber.

Because of the routinely high water tables in the *Picea*-*Sphagnum* bog under the current climate, we are contemplating a subsurface flow barrier approximately 2 to 3 m depth outside of the enclosures. We have designed subsurface lateral water flow barriers to 1) maintain hydrological losses via evapotranspiration under extreme warming and to slow vertical flow through the underlying clay aquitard, and 2) prevent the lateral inflow of water into the treated areas.

Prototype Construction

The 12-m diameter prototype in Oak Ridge, Tennessee and diagrams of belowground deep soil heater placement.



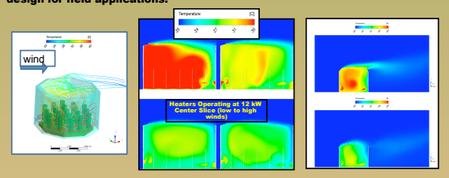
Planned Measurements

1. Plant Growth Responses
   - Vascular plant production, Bryophyte production, leaf and litter production, belowground production
2. Plant Community Composition
   - Tree demography, understory communities (ericaceous shrubs, tree seedlings, forbs, *Sphagnum* spp.)
3. Soil Microbial Community Composition
4. Phenology
5. Microtopography
6. Plant Physiological Responses
   - Photosynthesis and respiration, water relations
7. Biogeochemical Cycling Responses
   - Hydrologic cycle, Element cycles, Carbon stocks
8. Environmental monitoring
9. Mechanistic Modeling

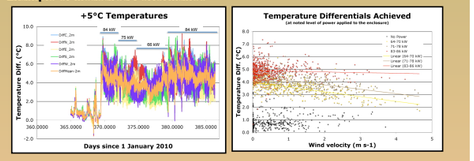
Warming Evaluation and Performance

Complex fluid dynamics modeling was used to design and evaluate likely performance and energy use of the warming technology. Current evaluation of the established prototype is testing those simulations, providing exact performance measures and allowing energy use estimates to be made. Design features of the aboveground warming enclosure are being improved.

Complex fluid dynamics simulations are being used to enhance our system design for field applications.



Example of Measured Performance



In the absence of high winds or intense precipitation events an energy addition at 84 kW allows us to achieve +5°C. Additional variations are driven by solar radiation inputs.

Opportunities for Collaboration

1. Canopy albedo changes
2. Remote sensing of canopy function (NDVI, etc.)
3. Microscale LiDAR
4. Bole respiration
5. Biogeochemical cycling of trace elements (e.g., Hg)
6. Trace gas emissions other than CH_4
7. Mycorrhizal studies
8. N fixation
9. Herbivory
10. Insect populations
11. Amphibian and reptile populations
12. Food web linkages
13. Lichen productivity and decomposition
14. Pests and pathogens (host defenses vs. pathogen virulence)