Next-Generation Ecosystem Experiments – NGEE Arctic

Quarterly Report
June 30, 2010

A progress report submitted to

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Prepared by

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Next-Generation Ecosystem Experiments – NGEE Arctic

Scientists have long recognized the importance of temperature in global change research. The research community has faced, however, many technical and conceptual challenges in the design and interpretation of ecosystem warming experiments. In an effort to overcome some of these constraints, Oak Ridge National Laboratory (ORNL) will work in partnership with other national laboratories and universities to assemble a team of scientists and engineers to prototype concepts for raising air and soil temperatures in large field plots. A priority will be placed on warming permafrost using an array of vertically-installed low-energy heating elements. The performance of this design has been simulated for experimental plots ranging from 3 to 20 m in diameter, and field-tested in 3-m diameter plots in a temperate deciduous forest. We will extend the evaluation of this technology to larger plots suitable for warming permafrost in the arctic tundra. The project involves expertise in modeling heat transfer using computational fluid dynamics models, systems engineering, and global change biology. Engineering plans and field testing a prototype will provide the technology needed as the scientific community plans for next-generation climate change experiments in the arctic tundra. Specific objectives of the NGEE effort include:

- Design a permafrost warming prototype that builds upon current concept of deploying deep-soil heaters in combination with air warming.
- Conduct numerical simulation of above- and belowground ecosystem warming for climatic conditions of Alaska taking into account spatial and temporal variation in climate, soils, and permafrost conditions that exist from the subarctic to arctic regions.
- Deploy optimized permafrost warming prototype at one or more sites in Alaska, taking care to team where appropriate agencies, universities, other national laboratories, and support organizations in the Arctic.
- Monitor performance of the prototype to test for effects of proposed warming on soil and air temperature, and soil water content.
- Educate and inform scientific community on role of manipulative experiments in climate change studies. Develop rationale for future large-scale, long-term ecosystem warming experiment in the Arctic.

Details at a Glance

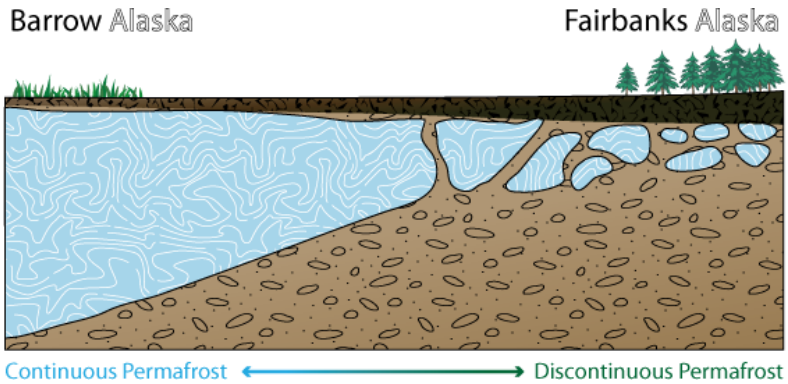
Activities during the April 1 to June 30 quarter include:

- Two sites in Alaska have been identified for deployment of below-ground prototype. One is at the Permafrost Research Station in Fairbanks and another on the Barrow Environmental Observatory, barrow.
- A new low-energy heater has been designed for use in permafrost. The heater casing is longer than previous designs and localizes heat below 3-m.
- Spatial placement of heaters has been optimized for large treatment plots. Wiring diagrams and control/monitoring schemes are being developed.
- Numeric analyses show excellent uniformity of temperature treatments for the permafrost warming concept.
- Fall workshop is being organized to highlight role of experiments in climate change research.
- Press Release on NGEE activities was released by ORNL Communications.

Progress and Accomplishments

Site Selection and Description:

Two sites in Alaska have been identified for deployment and evaluation of a permafrost warming prototype. Given variation in climate, soils, and permafrost characteristics across high-latitude ecosystems, and a desire to monitor prototype performance across this range of conditions, sites have been selected in Fairbanks and Barrow, Alaska. Conditions at these sites are representative of much of the arctic, spanning vegetation from boreal forest to tundra, and discontinuous to continuous permafrost. Subcontracts or Interagency Agreements with the U.A. Army Corp. of Engineers, Cold Regions Research and Engineering laboratory (CRREL; Fairbanks) and the Barrow Arctic Science Consortium (BASC; Barrow) have been established and will assist ORNL in executing the scope of work related to prototype deployment at these two locations.



Site 1 – Fairbanks, Alaska

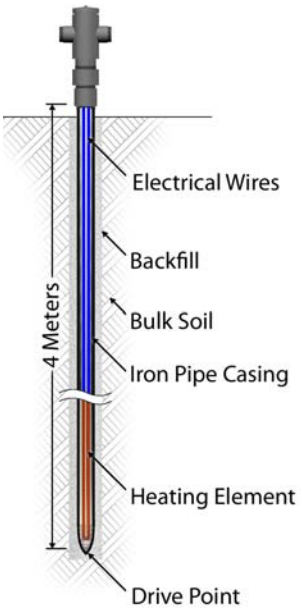
The study site (64.877N, 147.670W) is located 4 km northwest of Fairbanks, Alaska at the U.S. Army Cold Regions Research and Engineering Laboratory Permafrost Research Station. This 50 ha research station was established in 1945 as a location where geotechnical, geophysical, and engineering studies could be performed on permafrost. The site has a comparatively smooth, gentle slope to the west, providing good surface drainage except at the lowest elevations where saturated conditions can exist. Permafrost is characterized as warm, discontinuous, and generally is present to a depth of 60 m with an active layer that varies from 55 to 85 cm. Mean annual temperature at 10 m depth is -0.5^{o}C. Fairbanks has a continental climate, being sheltered from maritime influences by the surrounding mountains. Mean annual air temperature is -3.3^{o}C; mean annual precipitation is 287 mm. Soils consist of tan silt and wind blown loess near the surface and grey silt at depths below 1.4 m. Permafrost moisture contents range from 26 to 41 percent by mass for the frozen silts which makes this relatively low moisture content permafrost. Vegetation is typical of the Alaskan Interior-subarctic taiga forest with white spruce (*Picea glauca* [Moench] Voss), and black spruce (*P. mariana* [Mill] B.S.P) interspersed with

lowbush cranberry (*Vaccinium oxycoccos* L.) and Labrador tea (*Ledum groenlandicum* Oeder). Feather moss and sphagnum moss are present in the understory.

Site 2 – Barrow, Alaska

The study site (71.18N, 156.40 W) is located 10 km east of Barrow, Alaska on the Barrow Environmental Observatory. This 3,021 ha reserve lies within the Alaskan Arctic Coastal Plain, a relatively flat region bordered on the north by the Arctic Ocean and on the south by the foothills of the North Slope. Permafrost at the site is continuous and is present to depths greater than 350 m. Mean annual temperature at 10 m depth is -9.2^{o}C. The active layer is shallow and averages 30 to 50 cm. Barrow has a cold maritime climate that is strongly influenced by proximity to the Arctic Ocean. Winters are long, dry, and cold, and summers are short, moist, and cool. The snow-free period is variable, but generally begins in early June and continues until early September. Mean annual air temperature is -12.6^{o}C; mean annual precipitation is 124 mm with 57 mm coming as precipitation in June, July, and August. Soils are classified as Gelisols and are characterized by an organic-rich surface layer, underlain by a horizon of silty clay to silt loam textured mineral material, and a frozen organic-rich mineral layer. Thirty six percent of the total soil organic carbon is located at depths greater than 100 cm. Sedges and grasses dominate the vegetation. Sedge meadow covers about 75% of the area and contains predominantly sedge (*Carex aquatilis* Wahlenb.), tall cottongrass (*Eriophorum angustifolium* Honckeny), white cottongrass (*E. Scheuchzeri* Hoppe), and Fisher's tundragrass (*Dupontia fisheri* R. Br.).

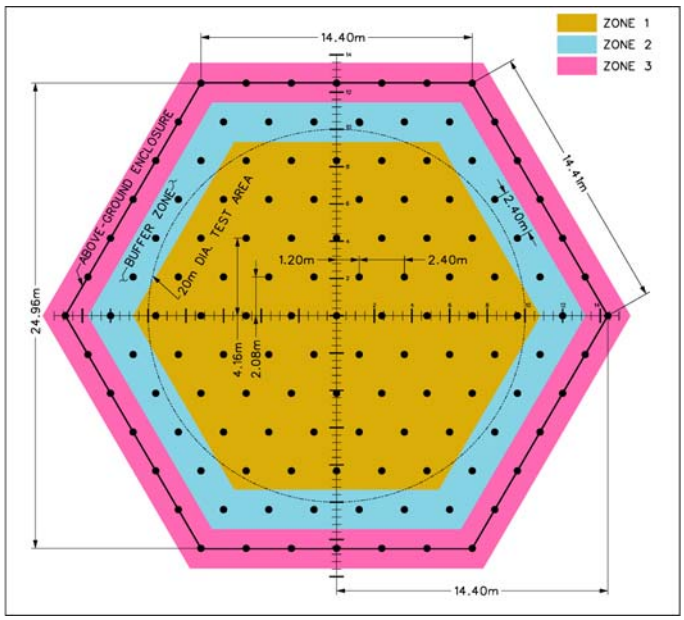
<u>Heater design and plot layout</u>:



The original design of the vertical soil warming heaters as reported by Hanson et al. (in press) has been modified for use in permafrost. Heaters previously deployed in a deciduous forest in east Tennessee were based on a simulated deep-circumferential heating concept that required the installation of vertical heaters just outside the perimeter of the defined soil volume to supply the energy for heating the target soil volume. Each heater casing contained a full-length 60W heating element that was installed from 0 to -3 m within a length of iron pipe. Modifications to this design were made for specific application to permafrost conditions (see diagram). The overall length of the heater casing was increased to 4 m and rather than use a full-length heating element, the element was positioned only in the lower 1 m of the pipe. This positioned the source of heat deep within the soil profile and away from the zone of active biology.

In addition to modification of the original design of the heater, alterations to the plot design were also made. Rather than circular plots,

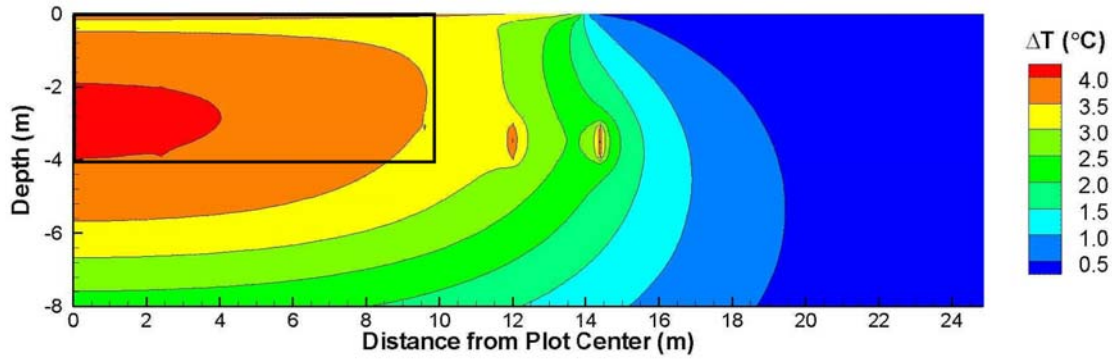
a new hexagonal arrangement of heaters was designed to accommodate a larger plot size (see diagram). Simulations showed that this design allowed temperatures to be raised uniformly in the target soil volume. One hundred and twenty seven heaters are required for this design. They are arranged in three zones, with Zone 2 and 3 representing a buffer zone and Zone 1 encompassing the primary 20-m diameter plot. In practice, heaters in each of these zones will be independently regulated using a reference set-point in a plot distant for the prototype and by monitoring temperature at a depth of 3.5 m. The proportional–integral–derivative controllers (PID) and silicon-controlled rectifiers (SCR) for use in this control system has been used in previous prototypes and electrical diagrams are currently being prepared by ORNL engineers.



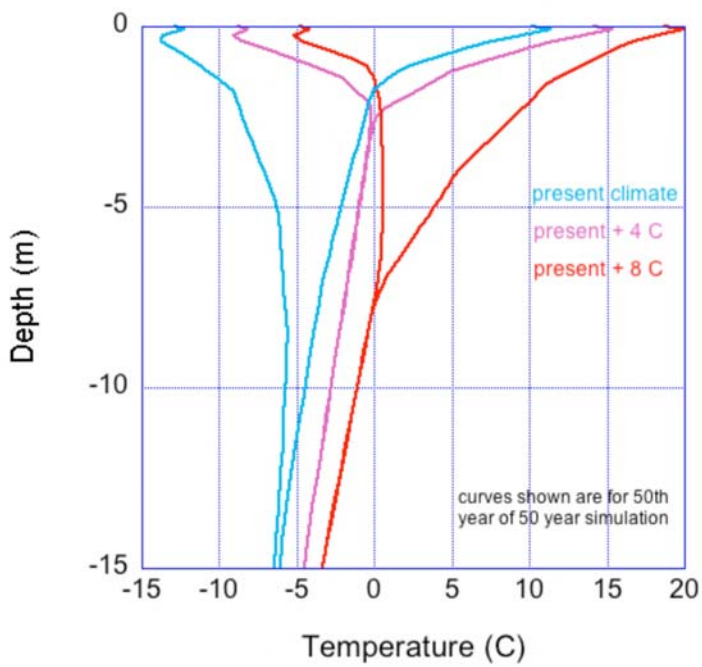
Numeric simulations:

Two activities, one at ORNL and the other at LANL, were undertaken to optimize and evaluate the performance of the new heater and plot layout design. At ORNL, these simulations were conducted with the general-purpose heat conduction code HEATING 7.3. The version of the code used solves steady-state and transient heat transfer dynamics in one-, two-, or three-dimensional Cartesian, cylindrical, or spherical coordinates. The model can include multiple materials, and the thermal conductivity, density, and specific heat of each may be both time- and temperature-dependent. The model considers phase change dynamics.

Results show that low-energy heaters deployed in this hexagonal array, and in combination with a suitable approach to increasing above-ground temperatures, will enable permafrost temperatures to be raised by 4°C above ambient within the target volume. i.e., area highlighted in the black box (see diagram). Although slight “hot spots” are visible in the outer zones of the array, temperature differentials are uniform within the treatment plot itself. Simulations indicate that variation in temperature across the 20-meter treatment plot is less than 0.5^{o}C. In addition, soil temperatures are increased outside the immediate plot area as well, both laterally and with depth. This provides useful insights on separation distance required in a fully-replicated experiment and evidence that our warming treatments will extend to considerable depth.



Simulations conducted at LANL also reveal patterns of permafrost warming with depth for current climate, and for climates where temperatures are simulated to increase 4 and 8°C above ambient (see diagram).



The 'trumpet' plot shows the predicted range of temperatures computed at each soil depth during the last year of a 50 year simulation, for three different climate conditions: present climate, present +4°C, and present +8°C. The profiles in the trumpet plot are results of simulations using the LANL ARCHY code. The surface temperature that drives the dynamics has a daily oscillation as well as a seasonal variation. Shifts in average surface temperature of 4°C and 8°C occur over a 50 year interval in the model. The total model depth is 30 m. This depth is necessary to mitigate influence of surface fluctuations on bottom boundary temperature. Temperature at the bottom boundary is kept at -10°C, and is close to measured temperature at some Alaskan sites for this depth. The soil pores are assumed filled with either liquid or frozen water. The model includes heat conduction and change of phase from ice to water or water to ice, along with latent heat balance. Thermal conductivity is a composite function, computed by weighting the thermal conductivity of soil/rock, water, and ice by their respective volume

fractions. Temperature variation is strongest near the surface, and dampens with increasing depth, partly as a result of the thermal latent heat buffering due to seasonal thawing and freezing, and partly reflecting the heat diffusion time scale. The model has the capability for unsaturated conditions and vapor transport and microbiological activity, but those features were not activated in this set of simulations. The profiles show an expected deepening of the active layer as climate warming occurs. Between the +4°C and +8°C cases, a qualitative change occurs, in that a layer forms at depth (from about 2 - 3 meters depth, to over 7 meters depth) that is thawed year round.

Interactions with other Agencies, Universities, and National Laboratories

U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) – Funded collaborator in Fairbanks, Alaska. Jon Zufelt and Anna Wagner, POCs.

Barrow Arctic Science Consortium (BASC) – Funded collaborator in Barrow, Alaska. Glenn Sheehan, POC.

International Arctic Research Center, University of Alaska – Larry Hinzman, Executive Director of the Center is working with PI on a fall workshop (see page 10 for complete description).

Institute for Northern Engineering, University of Alaska – Discussions are on-going on possible involvement of Daniel White and INE on geophysical considerations of deploying a full global change experiment in the Arctic.

Brookhaven national Laboratory – TBD

Los Alamos National Laboratory – Cathy Wilson, Bryan Travis, Nathan McDowell, and others have been extremely helpful and responsive in a number of areas. Bryan has been central in conducting numeric simulations. Cathy has also been involved in discussions related to co-organization of workshops and writing of publications. A visit to LANL is planned for July 19 at which time we will target activities for the remainder of the FY and into FY11.

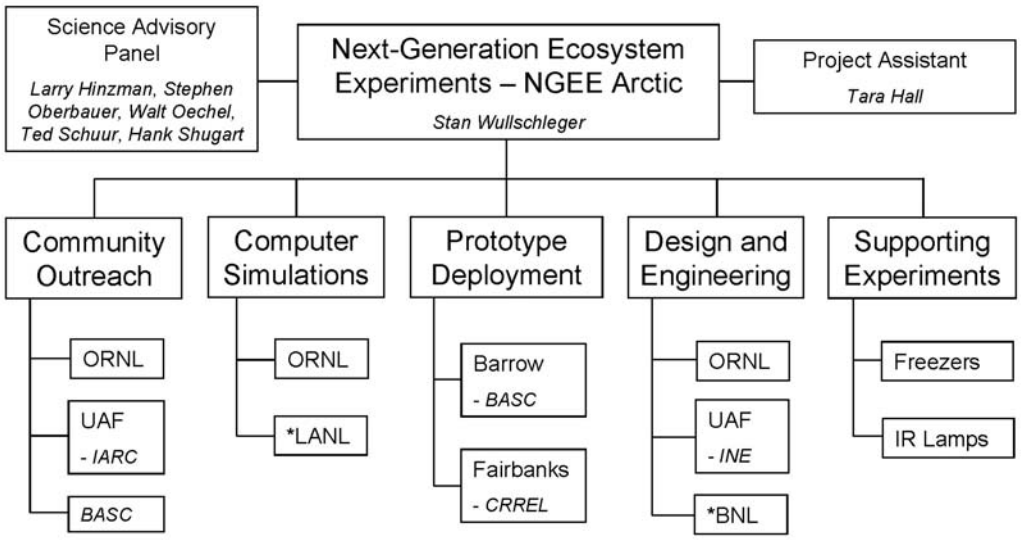
Lawrence Livermore National Laboratory – Current discussions focus on engagement of staff (Karis McFarland) at the Center for Accelerator Mass Spectrometry (CAMS) for 14C analysis. Project will include Ted Schuur (University of Florida) and others TBD, and will be designed to examine influence of deep-soil warming via new heater design on release of old and new carbon from permafrost. Although discussions are to begin soon, this will likely be a FY11 activity.

Chip Miller, Jet Propulsion Laboratory – Leads the NASA Ventures Mission which is designed to examine carbon emissions from high-latitude landscapes; discussions ongoing.

Eric Kasischke, University of Maryland – Lead PI on NASA Arctic-Boreal Vulnerability Experiment (ABoVE). Study focuses on vulnerability of high northern latitude ecosystems and landscapes to climate change; discussions ongoing.

Organizational Structure of NGEE – Arctic

Stan Wullschleger is the PI for the NGEE activity. He is assisted by Tara Hall. A Scientific Advisory Panel has been assembled and will be used as a sounding board for NGEE-related activities. Each of the five advisors has a history in climate change research in the Arctic and/or in modeling the response of terrestrial plants and ecosystems to a changing environment. NGEE activities will be undertaken in many areas. The immediate focus is on prototype deployment, but other areas are being pursued as well, including community outreach, computer simulations, design and engineering, and small-scale experiments in support of field-scale activities.



List of Scientific Advisors and Biosketches

Larry Hinzman is the Director of the International Arctic Research Center and is a Professor of Civil and Environmental Engineering at the University of Alaska Fairbanks. His primary research interests involve permafrost hydrology. He has conducted hydrological and meteorological studies in the Alaskan Arctic continuously for over 25 years while frequently collaborating on complementary research in the Russian and Canadian Arctic. His research efforts have involved characterizing and quantifying hydrological processes and their inter-dependence with climate and ecosystem dynamics. Larry's academic degrees were earned from South Dakota State University, Purdue University and the University of Alaska Fairbanks in Chemistry, Soil Science, Agronomy and Soil Physics. He has served as a member of the Polar Research Board, the U.S. Representative to the International Permafrost Association and is a member of several national and international committees and working groups. He currently serves on the U.S. SEARCH (Study of Environmental Arctic Change) Observing Change Panel, the Alaska Governor's Sub-cabinet Economic Activities Technical Working Group, and on the advisory board for the Alaska Center for Ocean Science Education Excellence.

Steven Oberbauer is a Professor in the Department of Biological Sciences, Florida International University. He has a Ph.D. in botany from Duke University. Steven's research interests include ecophysiology, phenology, and productivity of vascular plants, particularly in tropical forests and tundra, and the effects of disturbance on resource availability. Steven conducts research in two

important biomes. In the Arctic, he is actively involved in research to understand the sensitivity of carbon stored in cold soils as peat to increased temperatures. With climate warming, that carbon could be released to the atmosphere as carbon dioxide or methane, creating a positive feedback for further warming. He is involved in research to understand disturbance in tropical forests and the role that these ecosystems play in removing carbon dioxide from the atmosphere through photosynthesis. Steven has authored more than 60 peer-reviewed publications.

Walter C. Oechel is a Distinguished Professor of Biology at San Diego State University, along with the Coordinator for the Joint Doctoral Program in Ecology with the University of California Davis, Director of the Global Change Research Group, and Academic Director of the Field Stations Program. He received his Ph.D. in Physiological Plant Ecology (Life Sciences) from the University of California, Riverside. His research currently focuses on developing and understanding the predictive capability of the interconnections of terrestrial, atmospheric, and marine systems on global change. He focuses primarily in the Arctic (Alaska, Russia), the Pacific Basin (including Baja California Sur, Mexico, Indonesia), and the semi-arid ecosystems of Italy and San Diego. He incorporates small research aircraft, eddy covariance towers, soil measurements, remote sensing, and modeling in his research programs.

Ted Schuur is an Associate Professor in the Department of Biology at the University of Florida as well as a Research Associate in the Institute for Arctic Biology at the University of Alaska Fairbanks. He is an ecologist who studies interactions between terrestrial carbon cycling and climate change. In particular, he uses geochemical techniques for measuring natural abundance radiocarbon in ecosystem pools and fluxes to trace the sources of carbon emissions to the atmosphere. One of his major research interests is to understand feedbacks to atmospheric CO_2 from warming temperature, thawing permafrost and changing fire regimes in high latitudes ecosystems. His work on this topic has included over a decade of research in boreal and arctic Alaska and northeastern Siberia. He has received new investigator awards from NASA and the Andrew W. Mellon Foundation for his work on carbon and nutrient cycling in terrestrial ecosystems, and a CAREER grant from the National Science Foundation for research and education centered on the use of radiocarbon in ecology and earth system science. He is a native of Michigan and graduated with a BS from the University of Michigan in 1991. He received a PhD from the University of California-Berkeley in 1999 and held a National Science Foundation Postdoctoral Fellowship in Bioinformatics at the University of California-Irvine before arriving in Gainesville, FL in 2001.

Herman H. ("Hank") Shugart, Jr. is the W.W. Corcoran Professor of Environmental Sciences and the Director of the Center for Regional Environmental Studies at the University of Virginia. He received his Ph.D. in Zoology from the University of Georgia. Hank is a systems ecologist whose primary research interests focus on the simulation modeling of forest ecosystems. He has developed and tested models of biogeochemical cycles, energy flow and secondary succession. In his most recent work, he uses computer models to simulate the growth, birth and death of each tree on small forest plots. The simulations describe changes in forest structure and composition over time, in response to both internal and external sources of perturbation. The models are applied at spatial scales ranging in size from small forest gaps to entire landscapes and at temporal scales of years to millennia. He is the author of more than 300 publications including 11 books, 60 book chapters and 90 papers in peer-reviewed journals.

Publications and Presentations

Publications: Two publications are relevant to the NGEE – Arctic activity.

Hanson, P.J., K.W. Childs, S.D. Wullschleger, J.S. Riggs, W.K. Thomas, D.E. Todd, and J.M. Warren. 2010. A method for experimental heating of intact soil profiles for application to climate change experiments. Global Change Biology (in press).

Wullschleger S.D. and M. Strahl. 2010. Climate Change: A Controlled Experiment. March, pg. 78-83.

Presentations:

Wullschleger SD. Experimental manipulation of permafrost temperature in the Arctic tundra: Engineering and design in support of climate change research. Presented April 15, 2010 at the Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH.

Wullschleger SD. Experimental manipulation of permafrost temperature in the Arctic tundra: Engineering and design in support of climate change research. Presented April 20, 2010 at the International Arctic Research Center and the Institute for Northern Engineering, University of Alaska, Fairbanks.

Wullschleger SD. Experimental manipulation of permafrost temperature in the Arctic tundra: Engineering and design in support of climate change research. Presented May 14, 2010 at the Barrow Arctic Science Consortium (BASC), Barrow, Alaska.

Wullschleger SD. Experimental manipulation of permafrost temperature in the Arctic tundra: Engineering and design in support of climate change research. Presented June 17, 2010 at the Climate Change Science Institute, Oak Ridge National Laboratory.

Workshop – Manipulative Experiments in High-Latitude Ecosystems

This 2-day workshop is tentatively scheduled for late-September or early October, 2010. It will be held at the International Arctic Research Center, University of Alaska, Fairbanks. The workshop will address what long-term observations and models indicate about the response of arctic ecosystems to a changing climate (Day 1). Armed with that information participants will be asked on Day 2 to discuss how experiments can best be designed to address issues related to ecosystem response, permafrost degradation, and the range of negative and positive feedbacks likely to arise as a result of global warming. This information will be evaluated in the content of a Department of Energy (DOE, Office of Science) sponsored deployment of an ecosystem warming prototype in Fairbanks and Barrow, and recommendations sought for how ORNL and other partners should proceed with the design, construction, and operation of a possible replicated climate change experiment in the near future.

Press Release – Climate change scientists turn up the heat in Alaska

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Climate change scientists turn up the heat in Alaska

OAK RIDGE, Tenn., June 25, 2010 -- Scientists at the Department of Energy's Oak Ridge National Laboratory are planning a large-scale, long-term ecosystem experiment to test the effects of global warming on the icy layers of arctic permafrost.

While ORNL researchers have conducted extensive studies on the impact of climate change in temperate regions like East Tennessee, less is known about the impact global warming could have on arctic regions.

"We're beginning to take these lessons learned and start applying them to sensitive and globally important ecosystems, such as the arctic," said Stan Wullschleger of the Environmental Sciences Division. "The arctic regions are important to the topic of global warming because of the large land area they occupy around the world and the layer of permanently frozen soil, known as permafrost."

Wullschleger and a team of architects, engineers and biologists from ORNL and other national laboratories design, simulate using computers and then field test large-scale manipulative experiments that purposely warm a test area in order to evaluate ecosystem response to projected climate conditions.

"Evidence is emerging that the arctic is experiencing a greater degree of warming than the rest of the globe," Wullschleger said. "There is growing concern that this warming is already affecting a wide range of physical and ecological processes in the arctic, including permafrost degradation. Manipulative experiments will help us study these processes and their consequences in great detail."

In the arctic study for the Department of Energy's Office of Science, researchers seek to develop specially designed above-and below-ground warming technologies to heat multiple plots of land about 20 meters in diameter. ORNL researchers hope to eventually have replicated plots with treatments that include heating in combination with elevated carbon dioxide.

"The way we design and arrange the above- and below-ground heaters will allow us to warm the air and soil in a manner representing future conditions and then study the consequences of that warming," Wullschleger said.

Wullschleger and others working on the project hope to discover whether carbon stored in permafrost will be released as the soil warms. This could have major consequences for climate.

Before work can begin, a team of engineers and architects must adapt the heater technology that has been used on the Oak Ridge Reservation to study temperate region plants like maple and oak trees to Alaska's harsh winters and icy soil.

"We're developing a prototype because we haven't tested the equipment under arctic conditions before. In parts of Alaska, temperatures will drop to minus-40 degrees Fahrenheit," Wullschleger said.

Results from the prototype tests, modeling simulations, and other scientific analyses will be used to determine the location of the long-term ecosystem experiment.

Wullschleger is collaborating with the U.S. Army Cold Regions Research and Engineering Laboratory in Fairbanks and the Barrow Arctic Science Consortium in Barrow, Alaska. The team plans to hold workshops in collaboration with the International Arctic Research Center at the University of Alaska to get the science community involved in details of the planned experiment.

"That will be a major undertaking, and it will involve the support of the larger scientific community. We want to ensure, right from the beginning, that others are able to contribute to the development of this grand activity," Wullschleger said.

ORNL is managed by UT-Battelle for the Department of Energy's Office of Science.