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Permafrost in Flux: Tracking Carbon in the Alaskan Tundra

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Ecologists are trying to determine how much of the carbon stored in permafrost may be released as temperatures warm and permafrost thaws.

Interior Alaska around the summer solstice belies any descriptions of America's far north as desolate or inhospitable. In late June, the tundra explodes with life. Mosses and lichens cushion the ground, the bushes—including abundant wild blueberry—begin their frenzied summer growth, and the annual influx of human visitors shifts into high gear. Stampede Road stretches from the Parks Highway, which connects Anchorage and Fairbanks, west toward the northeastern edge of Denali National Park and Preserve. The gravel route gained notoriety when Jon Krakauer's *Into the Wild* brought the story of an ill-prepared young man's demise to national attention. Summer tourists clamber over potholes in rented SUVs or amble on horseback as part of organized rides. And often these travelers stop to talk about Alaska, the tundra, and climate change with that other group of seasonal guests: scientists.

Since 2003, Ted Schuur of the University of Florida Botany Department has been spearheading studies, funded by the National Science Foundation and NASA, in what he's dubbed the "Eight Mile Lake Research Watershed," along Stampede Road. This location north of the little town of Healy is fairly isolated, safe from the barrage of tourists who enter Denali on organized tours and stay at the big hotels that have spawned a commercial strip along the highway south of Healy, just outside the park's entrance. The spectacular views of the Alaska Range give Eight Mile Lake a stunning backdrop, and the proximity to a highway and town makes setting up a summer research project fairly easy. But though Schuur says this site is the most photogenic of any he's ever worked at—and he's studied ecosystems in Hawaii, South and Central America, and Siberia—he did not choose it for its aesthetics or the logistics. What drew him and his colleagues to Eight Mile Lake is a 27-meter-deep hole in the ground.

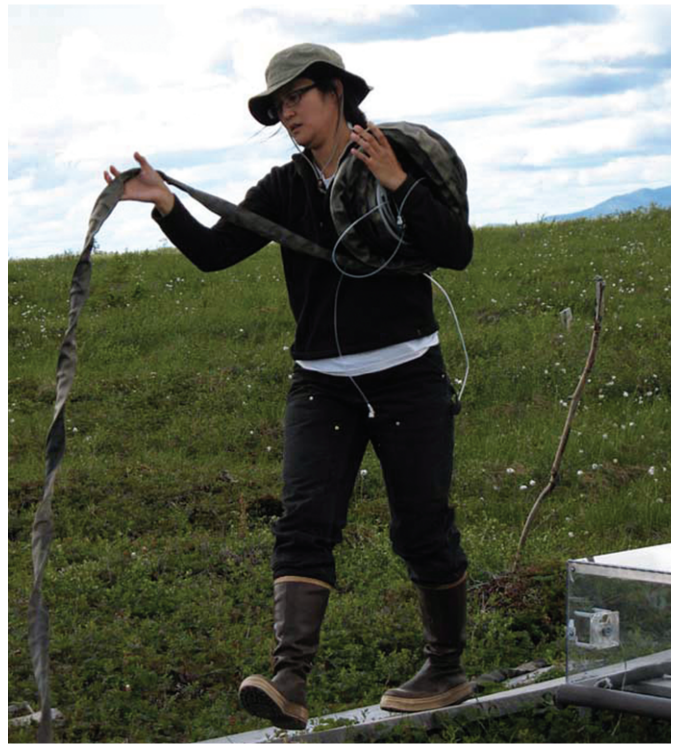
Ted Schuur works on the tundra at Eight Mile Lake, Alaska. Photograph courtesy of Ted Schuur.

In 1985, a geophysicist drilled that hole so he could lower a probe into it once a year and monitor permafrost temperature. Tom Osterkamp's bore hole is one in a network of sites that stretches from Alaska's north slope as far south as permafrost is found. The permafrost temperature has been monitored at most sites for more than two decades.

Permafrost is land that stays at or below 0 degrees Celsius year-round for at least two straight years. It's spotty, or discontinuous, at this latitude—about 64 degrees north. Higher latitudes feature more widespread, continuous stretches of permafrost. When Schuur considered Osterkamp's data and reviewed aerial photos of Eight Mile Lake, he saw warming temperatures and physical indications of permafrost thawing. He recognized that this location offered a unique opportunity to study how the related release of long-frozen carbon would affect the environment. "There are very few locations," he says, "where someone's been there in 1985 watching it warm up and then you come along 20 years later to kind of document what happened."

Documenting change

The bore-hole sites in interior Alaska have averaged a temperature increase of 0.5 to 1.5 degrees Celsius over the period of monitoring. Though the data show what's happened to the one dis-



Boardwalks form a path to the study sites, with the foothills of the Alaska Range visible in the distance. University of Florida graduate student Hanna Lee gathers up cables before moving the auto chambers. Photographs: Amy Mayer.

crete spot where a probe is lowered, the photos and on-the-ground observations made clear that even within the small geographic area of Eight Mile Lake, permafrost warming varies. To understand what's happening on a larger scale, Schuur and his colleagues designed a project that explores how thawing of permafrost—wrought by climate change—affects the carbon balance of the area.

One of the potential consequences of climate warming, according to several models, is that as permafrost thaws, vegetation will change and forests could eventually extend farther north. Initially, much of the currently frozen, stored carbon would be released into the atmosphere. It's unlikely to be offset by the higher carbon uptake from greater plant growth or expansion of forest. In this scenario, the thawing ultimately leads to positive feedback.

But at this point scientists don't assume a positive feedback is unavoidable. The researchers want to quantify and date all the carbon now at play in the ecosystem so they can monitor changes as warming continues. They're employing an interconnected set of experiments, including sophisticated radiocarbon dating techniques.

Each year the permafrost temperature at this bore hole gets measured. Photograph: Amy Mayer.

One labor-intensive effort monitors small plots at three different locations. "When the permafrost thaws in an area where there's lots of ice in the ground, the ice melts, the water drains away," Schuur explains, and the ground surface collapses into the void where the ice used to be. "That's called thermokarst." Ecologists who study thermokarst can tell, relatively speaking, how recently a collapse occurred, or, in other words, how old the thermokarst is. Surveying their watershed, Schuur and his crew selected three areas of permafrost that represented fairly old thawing, newer collapses, and relatively undisturbed tundra. They named them Old Karst, New Karst, and Tussock. "So we used that as a kind of a gradient of thaw with the idea that maybe this is a progression of how your ecosystem will change over time, beyond just at this bore hole."

They've established a method for monitoring the three sites. To traverse the tundra regularly all summer, though, they first had to build a system of boardwalks. Barely above the undulating tussocks, networks of one-by-sixes or one-by-eights lead the scientists and their guests away from the road. Wearing a day pack and rubber boots, I'm able to walk on the one-by-eights with only mild instability, but postdoctoral fellow Jason Vogel says they switched to the skinnier one-by-sixes to further reduce the impact of foot traffic. I slipped off those little boards often during my four days at Eight Mile Lake. But the scientists scurried across them, even when shouldering heavy or awkward equipment.

The researchers regularly schlep out to rotate a set of autochambers between their three sites. Six plexiglass boxes get positioned in a jagged row at a site, with a network of cables snaking between them and connecting to an infrared gas analyzer, a battery, and a data logger. Once hooked up, this system automatically opens and closes the doors on each box, thereby trapping the air from the 50-centimeter by 50-centimeter plots at regular intervals. Each chamber's carbon dioxide concentration and sunlight and moisture levels are monitored and logged. Every week or so the set of boxes must be disconnected, hauled to one of the other sites, and reconnected.

About once a month, another technique is used to trap carbon from each site. The trapped carbon is sent first to a lab in Florida, then to one in California where radiocarbon dating determines its age. That age reflects how long the carbon was stored before being respired back into the atmosphere. In monitoring six plots of tundra at each of the three sites and dating carbon from them, the scientists are gathering information about the age and amount of carbon being exchanged with the atmosphere at each plot.

Understanding whether an ecosystem ultimately contributes greenhouse gases to the atmosphere, receives and stores them, or participates neutrally in the carbon cycle requires accounting for all of the carbon in the system. So although the three autochamber sites offer a data set that compares how areas with older and newer thawing contribute to the carbon cycle during day and night, they account for only one method of carbon exchange.

Visit these Web sites for more information:

www.esrl.noaa.gov/gmd/ccgg/
http://ecology.botany.ufl.edu/ecosystemdynamics/schuur/index.html
www.lter.uaf.edu

Another, simpler experiment involves a bread knife. One hot, clear afternoon, I follow Schuur to a spot adjacent to the autochamber locations. We crouch down and begin filling a plastic bag with all the plants from a 20-centimeter by 20-centimeter quadrat. Then he sinks his bread knife into the ground until he hits the ice and removes the soggy block of tundra that constitutes the active layer, the part of ground that thaws each summer. "Sometimes it's hard to believe on a day when it's sunny and 70 and we're hot in our T-shirts that there's ice 20 centimeters below us," he says.

Despite the warm air, cold wafts up from the ice below. We fill a baggie with the roots from that chunk of soil. Schuur rinses the living plants and roots, places them into separate canning jars, and screws on modified lids equipped with stopcocks. His goal is to isolate the carbon that the plants and roots respire and to date it. He "scrubs" the samples with soda lime to remove the carbon from the ambient air in the jars. The samples continue to respire for a while inside their jars, and the resulting carbon that is captured and dated correlates only with that respiration. Scientists can subtract the age of the carbon that plants are currently respiring from the overall age of carbon in the ecosystem as measured by the autochambers, and get the age of carbon coming from the activity of microbes in the soil. "Our idea," Schuur says, "is that permafrost carbon, once thawed, will be old, and we can detect that signal with our experiments."

Determining the age of the carbon currently at play in the system offers clues about how carbon flux today differs from what it might have been years ago. Schuur says that if the system is in a steady state, some old carbon would always be coming out. "But what we're trying to figure out is, Is more older carbon coming out than would be expected?"

If so, he says, that's cause for further inquiry. Is this old carbon a signal of climate change and, concomitantly, is this ecosystem changing? After five seasons of sending carbon traps crisscrossing the country, Schuur and Vogel finally tabulated some data: old carbon is about 5 to 15 percent of the total ecosystem respiration. Samples from the least thawed sites respired about 5 percent old carbon, Schuur says, while at the most thawed sites that number was as high as 15 percent. As Schuur and Vogel continue to work with their data, they expect to arrive at an approximate figure for how much actual old carbon is reentering the cycle because of permafrost thawing.

Jennifer Harden, an ecologist with the US Geological Survey, is also studying carbon flux in Alaskan permafrost. She hasn't seen Schuur's data, but says isolating old carbon respired by microbes has been a vexing challenge because plant respiration often masks it. If Schuur and Vogel have found a successful way to quantify it, she says, "that sounds like an intriguing change." Harden's current study looks at 18 disparate sites, where she primarily monitors dissolved organic carbon and the carbon in soil organic matter. "Ted's really unique in that he has a long-term study of one site, and our approach is the opposite, in that it's many sites and less time," Harden says.

Her microbial studies on deep permafrost have found that "there's really bioavailable carbon locked in the permafrost layers." But these are among ongoing questions that follow from that conclusion: How much organic carbon is in there? How bioavailable is it? Will it thaw, and if it does thaw, how quickly will that carbon be released? "Every question you address, you partially answer, but three other [ones] come about, and you have to address those questions," she says.

Capturing all the carbon

At Eight Mile Lake and other boreal locations just south of the Arctic, slight variations in altitude mean the difference between forest and tundra. The impacts of thawing permafrost contribute to changes in the topography—the disappearance of lakes and ponds, for example, and the emergence of new vegetation. Several studies in other boreal locations have examined the conditions that cause thermokarst ponds to diminish in size. One factor that makes the Eight Mile Lake project different from many study sites, though, says Schuur, is its upland geography.

Jeremy Jones, another ecologist who studies permafrost, is a senior researcher with the Bonanza Creek Long Term Ecological Research project, near Fairbanks, with which Schuur and Harden are also affiliated. Jones looks at where the carbon in watersheds has come from and how it is exported. He describes other thermokarst sites as appearing as though the top layer of tundra has been pushed aside, leaving a crumpled-carpet appearance along a hillside. In contrast, he says, Eight Mile Lake's thermokarst-dotted landscape has a cottage cheese–like appearance.

At Eight Mile Lake, he says, the thermokarst is "kind of unique." He's more familiar with thermokarst areas that are up to a couple of kilometers long and a few meters wide, much bigger than those at Eight Mile Lake. The difference, he explains, is due to the shallow topography and the gradual slope to the lake. According to Schuur, thawing at Eight Mile Lake leads to water traveling downstream in the watershed rather than pooling at the thaw sites. That means carbon dissolved in that water is leaving the terrestrial study areas.

Jones went to Eight Mile Lake to measure the flow of a particular stream for Schuur, but he found its bed dry. He says monitoring stream flow presents a challenge throughout the area. "The streams flowing in are very small, and they flow through very diffuse channels."

Devising ways to quantify the carbon traveling in water has fallen to Schuur's collaborator, Jim Sickman, of the University of California–Riverside. Sickman says the watershed loses carbon by way of streams and the lake itself. To quantify the net contributions to the atmosphere of carbon released when permafrost thaws, it's necessary to figure out whether the carbon moving in water enters the atmosphere later or is instead stored downstream in aquatic ecosystems. "We are measuring the concentrations of dissolved carbon in the inflow water and outflow water," he says. And they're seeing big differences.

Jim Sickman stands in Eight Mile Lake while installing a lake level gauge. Photograph: Ted Schuur.

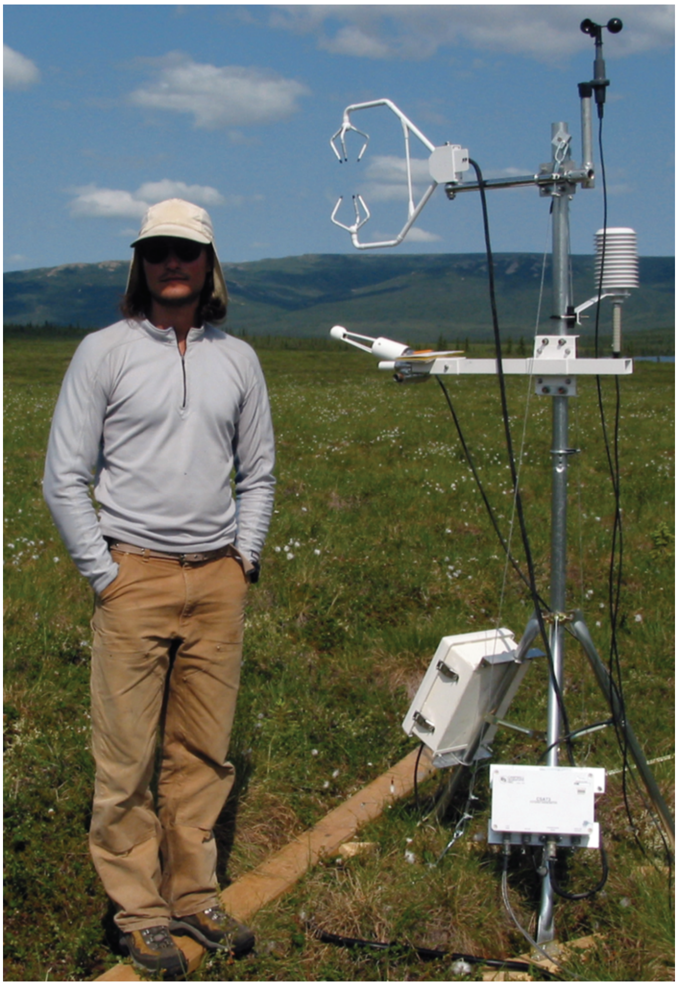
Sickman says the residence time at Eight Mile Lake—the average time it takes for the lake to refill with new water—is one to two years. That's long enough for dissolved carbon to be affected by both biotic and abiotic processes. For example, he says, inflowing waters are supersaturated with carbon dioxide because of respiration in soils, but the water quickly reequilibrates with the atmosphere, similar to the way a soda goes flat when it is left open. More importantly, he says, waters entering the lake are rich in dissolved organic matter (complex molecules derived from decomposition of permafrost and plant materials that give the waters a tea color), and much of this material does not leave the lake by way of the outflow. Sickman and his colleagues are trying to determine whether the organic matter is converted to carbon dioxide and lost to the atmosphere or is stored, long term, in lake sediments.

Other boreal and arctic lakes have much shorter residence times. At Toolik Lake, in northern Alaska, ample phytoplankton production results in higher organic matter in lake outflow than inflow, Sickman says. Eight Mile Lake's long residence time and tea-colored waters reduce its productivity. "I imagine that bacterial productivity is one of the main biological processes going on in the water column," he says. "There's not enough nutrients or light penetration to get really big phytoplankton blooms."

Sickman says the hydrological carbon fluxes his experiments are tabulating won't much affect the interpretation of the data from the individual plots that the auto chambers are monitoring. Rather, he says, "when we move up in scale to the watershed- or river-basin level, the hydrologic fluxes will be more important." In fact, he says, they could switch the overall climate feedback from negative to positive, depending on the fate of organic matter in the lake.

Measuring carbon from plants and soils and in the water starts to pull together a broad picture of what is happening. But there's another medium through which carbon travels. "Eddies of wind are...tumbling across the landscape," Schuur says. "When wind is moving up, it's carrying carbon dioxide...away from your vegetation, and when eddies move down, it's carrying carbon dioxide down," he explains. To quantify the carbon exchange from a study area, then, one must determine whether more carbon came in or went out on the wind.

A large, expensive, complicated device called an eddy covariance tower stands tall above the low vegetation. From Stampede Road, the tower provides the only visual indication that science is happening. Before Schuur's team fixes this tower into place—where it will stay for at least a year—I join Schuur and his field technician Christian Trucco as they walk the radius of the footprint the tower will monitor. It includes an area of unlevel terrain where the ground has visibly subsided. Schuur notes the absence of cottongrass, and says this area represents



Field technician Christian Trucco helped select the location for this eddy covariance tower, which he will maintain through the winter. Photograph: Ted Schuur.

the oldest thermokarst in the study site. “This is definitely the kind of place [to study]—the permafrost has thawed, the vegetation is changing, there [are] big changes in the carbon cycle,” he says. “We want to measure this with our tower.”

The tower draws its calculations from an area with a radius of 200 meters. Eventually, Schuur says, a successful tower could replace the autochambers. For now, he’s hopeful that it will greatly enhance data collecting in winter . For most of the team, the Alaska field season is short—late spring to early fall. But Schuur says some of the summer carbon uptake from plants can be offset by carbon released during fall, winter, and spring. “From our past work and the work of others, what we found is that the three-month growing season when all the plants are alive is really important for carbon moving into the ecosystem. However, that’s balanced by a nine-month winter,” he says. “The plants are asleep, it’s below zero, they’re not growing, but the bacteria still actually eat the soil organic matter. So you can have a lot of carbon loss over the winter.”

Last year, he hired Trucco to stay year-round. Sharp winds made the –35 degrees Celsius temperature feel even colder on the dark winter days when Trucco trudged out to the chambers with spare parts and fresh batteries. With the eddy covariance tower, the effort will be simpler, if not warmer. “It’s an automatic tower, but it essentially needs weekly attention to make sure that the sensors are working or that frost hasn’t covered something up,” Schuur says. Trucco, originally from Colombia’s Caribbean coast, agreed to spend another winter in Alaska.

Pushing ahead of climate change

Schuur and Sickman’s survey of the carbon cycle in the Eight Mile Lake watershed complements what scientists are doing elsewhere in the state and in circumboreal regions. Harden says permafrost researchers begin with the premise that there is a lot of carbon in the deep soils, and it is undergoing change. Those facts were not generally accepted just 10 years ago. Schuur’s work most likely will help contribute new methodologies to permafrost study, she says, and those will be applied at other sites.

To isolate what drives old carbon release, Schuur is developing some strategies to experimentally thaw a chunk of permafrost. Using simple plywood dams to force water pooling and thermokarst formation is one strategy he and Vogel have tested. Adjusting the autochambers so that they actually heat the tundra is another possibility, as is manipulating snowpack with fences to use deeper snow as insulation on some areas of tundra. Schuur recognizes the irony of forcing warming when, ultimately, thawing could have a negative impact.

“Permafrost thawing on the scale of the whole Arctic or high-latitude area is so much bigger than an area that I might affect,” he says, “so I can sort of justify [it this way]: If I change or damage or alter this part of the tundra, I’m doing it so we know more about widespread changes that are being caused by society as a whole.”

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