National Park Service
U.S. Department of the Interior

Denali National Park and Preserve

Permafrost Thaw and Carbon Balance


Photo credit: Ted Schuur

When permafrost thaws in ice-rich areas, it creates localized land surface subsidence called thermokarst. Researchers are comparing the net carbon balance at sites representing a gradient of permafrost thaw—minimal thaw, moderate thaw, and extensive thaw (shown in photo).

[Thawing] of the Arctic permafrost is a "wild card" that could dramatically worsen global warming by releasing massive amounts of greenhouse gases...

United Nations
Environment Programme

Subarctic environments, such as Denali National Park and Preserve's tundra and boreal forest ecosystems, have undergone drastic changes over the past few decades, likely as a result of a changing climate—increasing temperatures. Because Denali lies at the southern limits of permafrost, the average temperature of the park's permafrost hovers just below freezing, making it particularly sensitive to thawing with small increases in temperature.

Warmer temperatures are expected to thaw permafrost, which will affect ecosystems locally. But, one of the most far reaching consequences of climate change in northern ecosystems may be the secondary effects of thawing permafrost on the carbon cycle.

Net balance of C

More than 50% of global terrestrial carbon (C) is stored in permafrost regions as soil organic matter. Carbon naturally enters any terrestrial ecosystem by photosynthesis, since plants take in carbon dioxide (CO_2) from the atmosphere as they grow. Carbon returns to the atmosphere mainly as CO_2 from the metabolic respiration of plants, animals, and microbes (bacteria). Ecosystem carbon balance is the difference between carbon uptake and emissions.

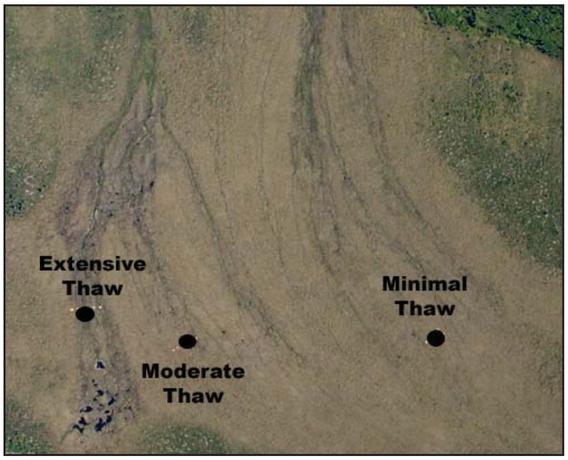
When carbon uptake by plant growth is greater than carbon emissions by metabolic respiration, the ecosystem is a carbon sink, meaning that atmospheric C is stored in biota and soils. When carbon emissions are greater than carbon uptake, the ecosystem is a carbon source, meaning that carbon from the ecosystem is released (from biota and soils) to the atmosphere.

Potential effects of thawing permafrost

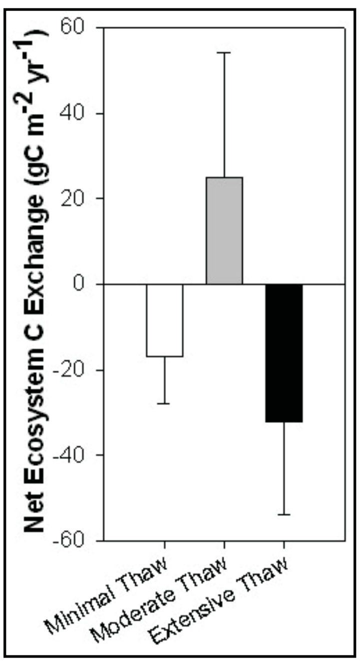
Permafrost thaw associated with climate warming can lead to two different impacts that change ecosystem carbon balance to a sink or a source.

Warming increases plant growth and it promotes the invasion of shrubs and trees into tundra landscapes. Both of these processes can increase the amount of C stored in plant biomass, thus reducing the amount of C in the atmosphere.

At the same time, permafrost thaw, and the associated environmental changes (e.g., ground surface collapse or subsidence), may stimulate the microbial decomposition of soil organic matter. This decomposition can decrease the amount of stored C by releasing more CO_2 into the atmosphere. These metabolic by-products (CO_2 and CH_4) are the same "greenhouse gases" involved in climate change. Thus, when permafrost thaws, the thawing may affect the cycling of C to or from the atmosphere, which can create additional global-scale impacts.



Researchers selected three tundra sites to measure carbon balance near Denali (identified in the 2003 aerial landscape photo). The dark areas represent the shrubby vegetation growing where there is permafrost thaw and ground subsidence.



Net ecosystem carbon balance, as monitored from 2004 to 2006 for three sites (minimal thaw (white bar), moderate thaw (gray), and extensive thaw (black)) outside the northeast park border. Positive values indicate where tundra represents a carbon sink and negative values where tundra represents a carbon source.

Studying the effects of permafrost thaw on C

To learn more about climate change effects related to permafrost thaw that may be occurring in Denali, Dr. Ted Schuur, at the University of Florida, selected three sites just outside the northeastern boundary of the park (see aerial photo at left). The three sites represent a gradient of disturbance created by permafrost thaw: (1) a typical tussock tundra site with permafrost minimally disturbed, (2) a site with moderate evidence of permafrost thaw, and (3) an extensively disturbed site where permafrost thaw has created substantial changes in the landforms when the ground surface sinks or subsides.

At each site, Schuur and his research group measured soil temperature and moisture using sensors connected to a data-logger, to monitor physical changes in the environment associated with permafrost thaw. They surveyed vegetation biomass, species composition, and net difference vegetation index (NDVI) to detect biological changes resulting from thaw. They also measured CO_2 fluxes over a small area of tundra, using a portable chamber and automated chamber system connected to an infra-red gas analyzer, to monitor changes in ecosystem C balance.

Carbon balance was monitored intensively during the growing season (i.e., summer) and periodically during the non-growing seasons, in order to capture daily and seasonal changes in carbon balance. During non-growing season, plants cannot photosynthesize, but microorganisms release CO_2 to the atmosphere even under freezing conditions and account for important carbon emissions over the course of a year.

Preliminary results: C balance at three sites

At the minimally-disturbed tundra site (white bar in graph at right), the ecosystem carbon balance was close to neutral, neither gaining nor losing carbon.

The site with moderate permafrost thaw (gray bar) was a carbon sink, because increased C sequestered in plants through plant growth and shrub invasion (carbon uptake) exceeded the release of C through soil organic matter decomposition (carbon emissions).

At the site with extensive permafrost thaw (black bar), the ecosystem was a carbon source. At this site, the seasonally-thawed soil layer, or active layer, extended as deep as a meter (three feet) or more—

Photo credit: Laura Gutierrez

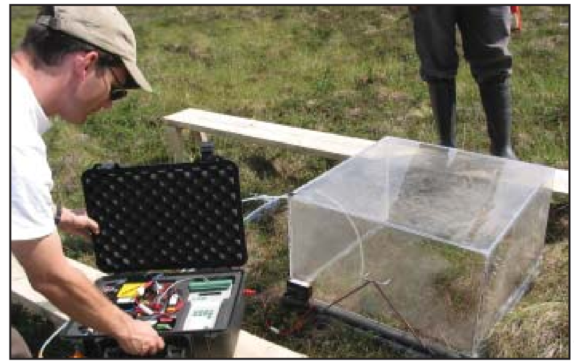


Photo credit: Jason Vogel

Graduate student Hanna Lee uses a point frame to estimate plant biomass and species composition at the moderately disturbed tundra site (upper photo).

Dr. Ted Schuur measures CO_2 emissions from soil and plants using a portable chamber connected to an infra-red gas analyzer (lower photo).

twice the depth of the active layer in the minimally-thawed site. A deeper thaw depth exposed more soil organic matter to decomposition and stimulated the activity of decomposers, thus releasing more soil carbon to the atmosphere. Even though plant growth was high in this site, carbon uptake by plants was overwhelmed by emissions from decomposition.

What's happening as permafrost thaws?

The researchers are able to infer from the measurements at the three sites that, in the early stages of permafrost thaw (moderate thaw), there is a net ecosystem uptake of C, but in the later stages of thaw (extensive thaw), there is a net emission of C from the ecosystem to the atmosphere.

The net release of C to the atmosphere in landscapes where there is advanced permafrost thaw adds to the existing problem of increasing greenhouse gases in the atmosphere. This C release from permafrost thaw may create a dramatic feedback that accelerates climate change.

For more information

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