Soil Respiration and Methane Fluxes in a Black Spruce Forest and Adjacent Thermokarst Wetlands in Interior Alaska

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ABSTRACT

Low-lying forested areas underlain by ice-rich permafrost may develop into thermokarst wetlands when permafrost thaws unevenly and no longer supports the ground above the water table. Inundation of the subsided land leads to tree death and colonization by aquatic vegetation. The objective of our study is to determine whether soil respiration and CH_4 fluxes differ between forested areas having permafrost and adjacent thermokarst wetlands. We measured soil respiration and CH_4 fluxes weekly to bi-weekly during May-September 2003 at a black spruce forest near Fairbanks, Alaska that contains thermokarst wetlands. The forest is underlain by permafrost at depths ranging from 40 to 50 cm, but in several areas thermokarst wetlands have formed due to the melting of permafrost to below 2 m depth. CO_2 and CH_4 fluxes were measured at five locations in thermokarst wetland areas and at five adjacent forested areas having permafrost. Soil temperature and depth to ice were also measured. Soil respiration rates at both the thermokarst and permafrost areas were similar in May, averaging 4.3±2.7 and 3.8±1.1 mmol CO_2 m^{-2} hr^{-1} respectively. Respiration increased through June and July to maximum measured rates of 18.9±5.8 mmol CO_2 m^{-2} hr^{-1} at the thermokarst sites, and to 16.7±3.4 mmol CO_2 m^{-2} hr^{-1} at the permafrost sites. Soil respiration decreased to 4.3±2.2 mmol CO_2 m^{-2} hr^{-1} at the thermokarst sites and to 1.4±0.6 mmol CO_2 m^{-2} hr^{-1} at the permafrost sites at the end of September. Average CO_2 fluxes were greater at the thermokarst sites than at the permafrost sites on 11 of the 14 measurement days. The thermokarst sites emitted CH_4 throughout the growing season, while CH_4 fluxes at the permafrost sites fluctuated between small rates of net emission and net consumption. The maximum average CH_4 flux measured at the thermokarst sites was 0.7±0.2 mmol CH_4 m^{-2} hr^{-1} in early August. The maximum average CH_4 emission rate measured at the permafrost sites was 0.08±0.01 mmol CH_4 m^{-2} hr^{-1} in mid-May, and the maximum average CH_4 consumption rate measured was -0.002±-0.009 mmol CH_4 m^{-2} hr^{-1} in late September.

STUDY SITE

The study site is located about 20 km southwest of Fairbanks, Alaska, and is adjacent to the Bonanza Creek Experimental Forest, a Long Term Ecological Research (LTER) site. This area is typical of the boreal forest of interior Alaska. The study site is near the base of a south-facing slope at approximately 120 m elevation, and appears to be part of the old floodplain of the Tanana River. Small black spruce (*Picea mariana* (Mill.) B.S.P.) and tamarack (*Larix laricina* (Du Roi) K. Koch) trees, dwarf arctic birch (*Betula nana* L.), labrador tea (*Ledum groenlandicum* Oeder), blueberry (*Vaccinium* spp.), feathermosses, and *Sphagnum* mosses grow in areas underlain by permafrost. Within the forested area is a group of wetlands that appears to have been formed by permafrost thaw resulting in uneven ground (Fig. 1). The wetland surfaces are 0.5-1 m below the surrounding area, they contain standing dead black spruce and tamarack trees, and are there are leaning trees at many of the wetland edges. *Sphagnum* mosses are the dominant vegetation, and *Carex* spp. are common. Surface pH of the thermokarst wetlands range from 5.1-5.6. Ten flux measurement locations were established (Fig. 1): five locations within four distinct thermokarst wetlands and five locations in adjacent forested areas having permafrost.

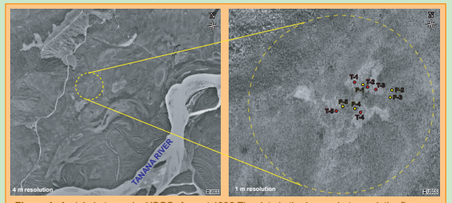

Figure 1. *Aerial photographs,USGS, August 1996.The dots in the lower photo mark the flux measurement locations (red=thermokarst wetland, yellow=permafrost).*

Forested area with permafrost

Thermokarst wetland

METHODS

In early May 2003, ten 0.38 m-diameter collars constructed from PVC were inserted into the soil about 5 cm deep at each of the ten flux measurement sites. Soil respiration (gross CO_2 flux) was measured using an opaque chamber constructed of PVC (height=0.20 m) and fitted with a circulating pump (rate=3 l min^{-1}) and a PP Systems infrared gas analyzer. A rubber gasket on the chamber prevented mixing of atmospheric air with the chamber air. The chamber was placed on a collar and the CO_2 concentration in the chamber was recorded every 15 seconds for 5 minutes. Gas flux was calculated using an equation that included the slope of the linear increase of CO_2 on time as time approached zero, ambient temperature and pressure, chamber plus collar height, and time. Methane flux was measured using a transparent chamber constructed from clear PVC and Lexan, and fitted with a circulating pump and a sample port at the top center of the chamber. The chamber (height=0.23 m) was placed on a collar and a 12 ml sample of chamber air was collected using a syringe connected to the sample port every 4 minutes for 16 minutes. Each sample was immediately transferred from the syringe fitted with a needle to a pre-evacuated 10 ml glass serum vial sealed with a butyl rubber stopper. Samples were analyzed for CH_4 concentration using a gas chromatograph in Boulder, CO. Flux was calculated using the same equation used for CO_2 flux. Soil respiration was measured weekly to biweekly from mid-May to the end of August, and CH_4 flux was measured biweekly over the same period. Fluxes were measured again at the end of September. Soil temperatures at 5, 10, and 15 cm depths were measured at each collar when gas flux was measured. Depth to ice (active layer thickness) was measured at three points next to each collar using a metal rod when gas flux was measured.

RESULTS

Soil Respiration

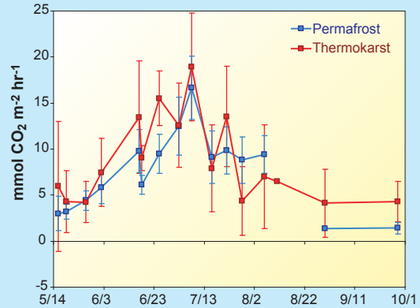

Figure 3. *Soil respiration at permafrost and thermokarst sites, 2003. Each point respresents the mean of five measurements, except for the following dates: 5/16 (2 permafrost, 2 thermokarst), 5/27 (4 permafrost), 6/2 (4 permafrost), 8/6 (4 permafrost, 4 thermokarst), 8/11 (1 thermokarst), 8/30 (1 permafrost, 2 thermokarst), and 9/29 (4 permafrost). The error bars are ± one standard deviation. The mean soil respiration for the entire measurement period is 7.4±4.4 mmol CO_2 m^{-2} hr^{-1} for the permafrost sites, and 8.7±4.9 mmol CO_2 m^{-2} hr^{-1} for the thermokarst sites. Mean soil respiration at the thermokarst sites is significantly greater than mean soil respiration at the permafrost sites (Kruskal-Wallis, p-value=0.38).*

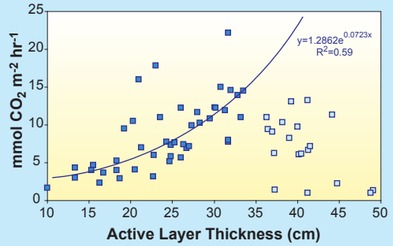

Figure 4. *Permafrost sites soil respiration vs. active layer thickness. Each point represents one measurement. The dark blue points include all fluxes measured when the active layer was less than 35 cm thick. The line and equation represent the relationship between flux and active layer thickness <35 cm. There is no significant correlation between flux and active layer thickness >35 cm.*

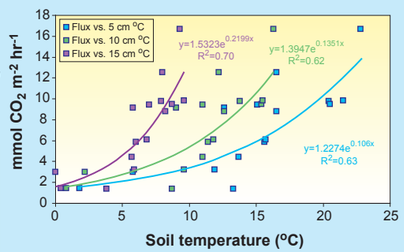

Figure 5. *Permafrost sites soil respiration vs. soil temperature at 5, 10, and 15 cm depths. Each point respresents the mean flux and temperature measured at the permafrost sites (varies from two to five measurements - see Fig. 3 caption). The lines and equations represent the flux-temperature relationships.*

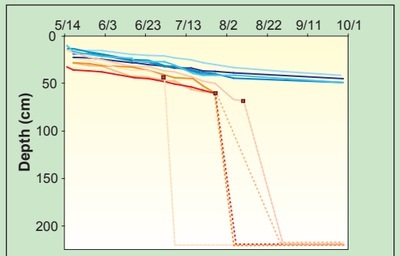

Figure 2. *Active Layer Thickness, 2003. The blue-shaded lines are permafrost sites, and the orange-shaded lines are thermokarst sites. Dotted lines indicate no ice (down to 2.4 m), and the red squares mark the last date when ice was present.*

Dark chamber at permafrost site

Light chamber at thermokarst site (sampling platform in foreground)

RESULTS

Net Methane Flux

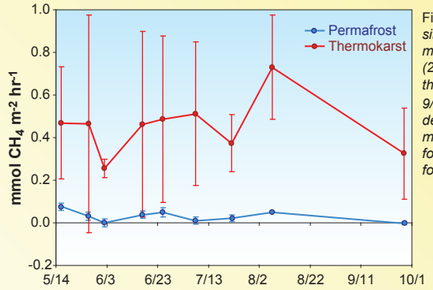

Figure 6. *Net CH_4 flux at permafrost and thermokarst sites, 2003. Each point represents the mean of five measurements, except for the following dates: 5/16 (2 permafrost, 2 thermokarst), 6/2 (3 permafrost, 3 thermokarst), 8/7 (2 permafrost, 2 thermokarst), and 9/29 (2 permafrost). The error bars are ± one standard deviation. The mean net CH_4 flux for the entire measurement period is 0.029±0.026 mmol CH_4 m^{-2} hr^{-1} for the permafrost sites, and 0.44±0.32 mmol CH_4 m^{-2} hr^{-1} for the thermokarst sites.*

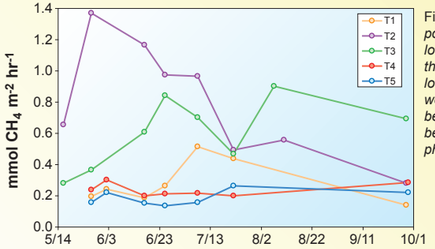

Figure 7. *Net CH_4 flux at thermokarst sites, 2003. Each point respresents one measurement. Sites T2 and T3 are located within the same thermokarst wetland (T2 is near the edge, T3 is in the center), while T1, T4, and T5 are located in separate thermokarst wetlands. The T2/T3 wetland appears to be older than the other wetlands because there are few standing dead trees, shrubs have become established, and there is no open water (see photos below).*

Site T1

Site T2 & T3

Site T4

Site T5

CONCLUSIONS

- Soil respiration at the permafrost and thermokarst wetland sites had a similar seasonal pattern, although total mean respiration was siginificantly greater at the thermokarst sites than at the permafrost sites.

- Soil respiration at the permafrost sites was positively related to active layer thickness to about 35 cm. No relationship was evident at thicknesses <35 cm, probably due to decreasing surface soil temperatures. Permafrost site soil respiration was exponentially related to soil temperatures at 5 cm (Q_{10}=2.9), 10 cm (Q_{10}=3.9), and 15 cm (Q_{10}=9.0).

-Thermokarst wetland soil respiration was not significantly related to active layer thickness or to soil temperature at 5 cm, 10 cm, or 15 cm.

-Net CH_4 flux at the thermokarst wetlands was an average of 18 times greater than at the permafrost sites. There was no apparent seasonal pattern in CH_4 flux at either the permafrost or thermokarst sites. Net CH_4 flux from the thermokarst wetlands was very heterogeneous, possibly reflecting the age of formation and differences in plant communities.

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