Characteristics of Methane Exchange in a Black Spruce Forest Over Permafrost in Interior Alaska

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Introduction

Methane is an important greenhouse gas with a warming potential 20 times higher than carbon dioxide on a 100-year time scale (*Rodhe* [1990]). Currently, methane contributes about 18 % of radiative forcing (*Forster et al.* [2007]). In order to accurately predict future climate changes, it is necessary to quantify the methane exchange between the land and the atmosphere and understand the mechanisms responsible for seasonal and interannual variation of the exchange.

The boreal forest is a major terrestrial ecosystem occupying approximately 10 % of the earth's land surface (*Dixon et al.* [1994] and *FAO* [2006]). Upland forest ecosystems are generally thought to be net sinks of methane due to the dominance of methane oxidization in the aerated soil. However, it is also known that forests switch to act as methane sources when the soil is in an anaerobic condition (*Megonigal and Guenther* [2008]). Due to this variability over time and a lack of studies based on continuous observation of forest ecosystems, the role of the boreal forest as a methane sink or source is relatively poorly understood.

Since 2003, we have observed methane flux continuously using the aerodynamic gradient technique in a black spruce forest. In this poster, we show the variation of methane exchange over seven years and discuss what environmental variables and vegetation physiology have major controlling effects on the exchange.

Site, Observation and Flux Calculation

The data were obtained in a black spruce forest (64° 52'N, 147° 51'W, Fig. 1) on discontinuous permafrost in Fairbanks, Alaska, USA. The forest is 120 years old (*Vogel et al.* [2005]). The tree density is 4500 trees ha^{-1}. The ground is covered with mosses (e.g., *Sphagnum capillifolium* and *Calliergon stramineum*), sedges (*Carex* species), and shrubs (e.g., *Vaccinium uliginosum* and *Betula glandulosa*). The soil pH is between 5 and 6.

In this forest, concentration of methane was observed at 8 and 2 m from January 2003 to April 2006, and at 8, 4, 2, and 1 m since May 2006. Fluxes of momentum, sensible heat, water vapor, and CO_2 were observed using the eddy covariance technique. Micrometeorology such as radiation, air temperature, relative humidity, rainfall, soil temperature, and soil water content were also observed at and around the tower.

Figure 1: A black spruce forest at the observation site.

Table 1. Snowfall and rainfall in each year. The unit is mm.

	Snowfall (Jan-Apr)	Rainfall	Snowfall (Sep-Dec)
2003	23.4	223.1	56.7
2004	23.5	124.1	51.1
2005	38.0	237.1	4.4
2006	32.6	203.2	2.6
2007	30.0	273.6	22.6
2008	50.5	224.5	42.2
2009	55.9	170.4	27.9

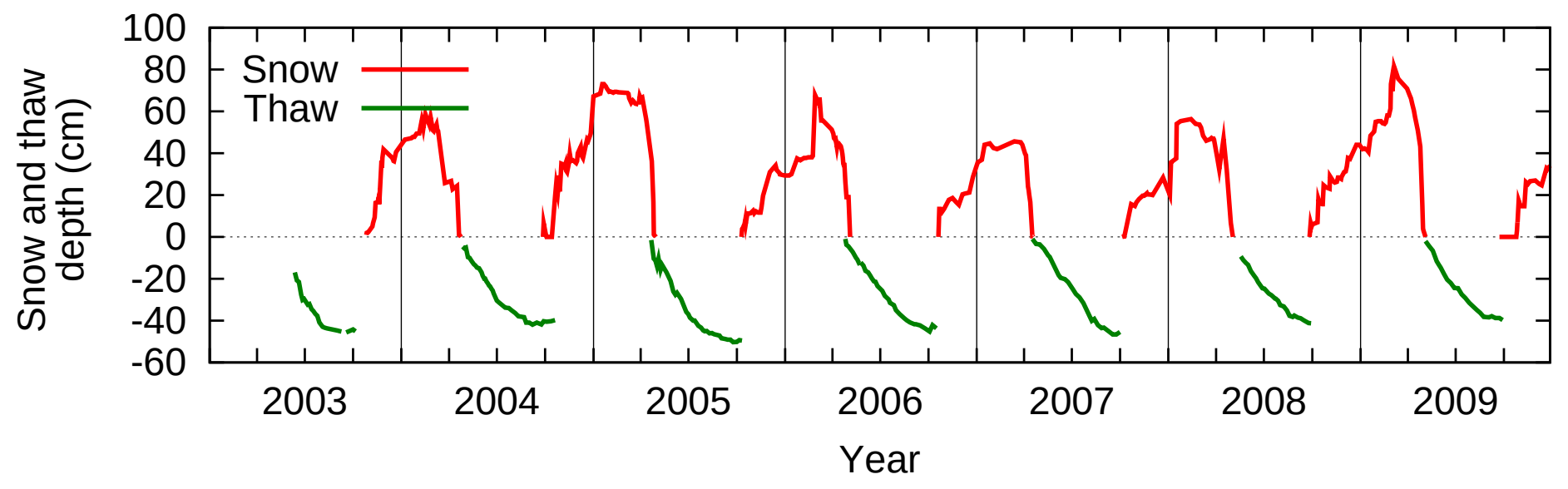

Figure 2: Seasonal variations of snow and thaw depth

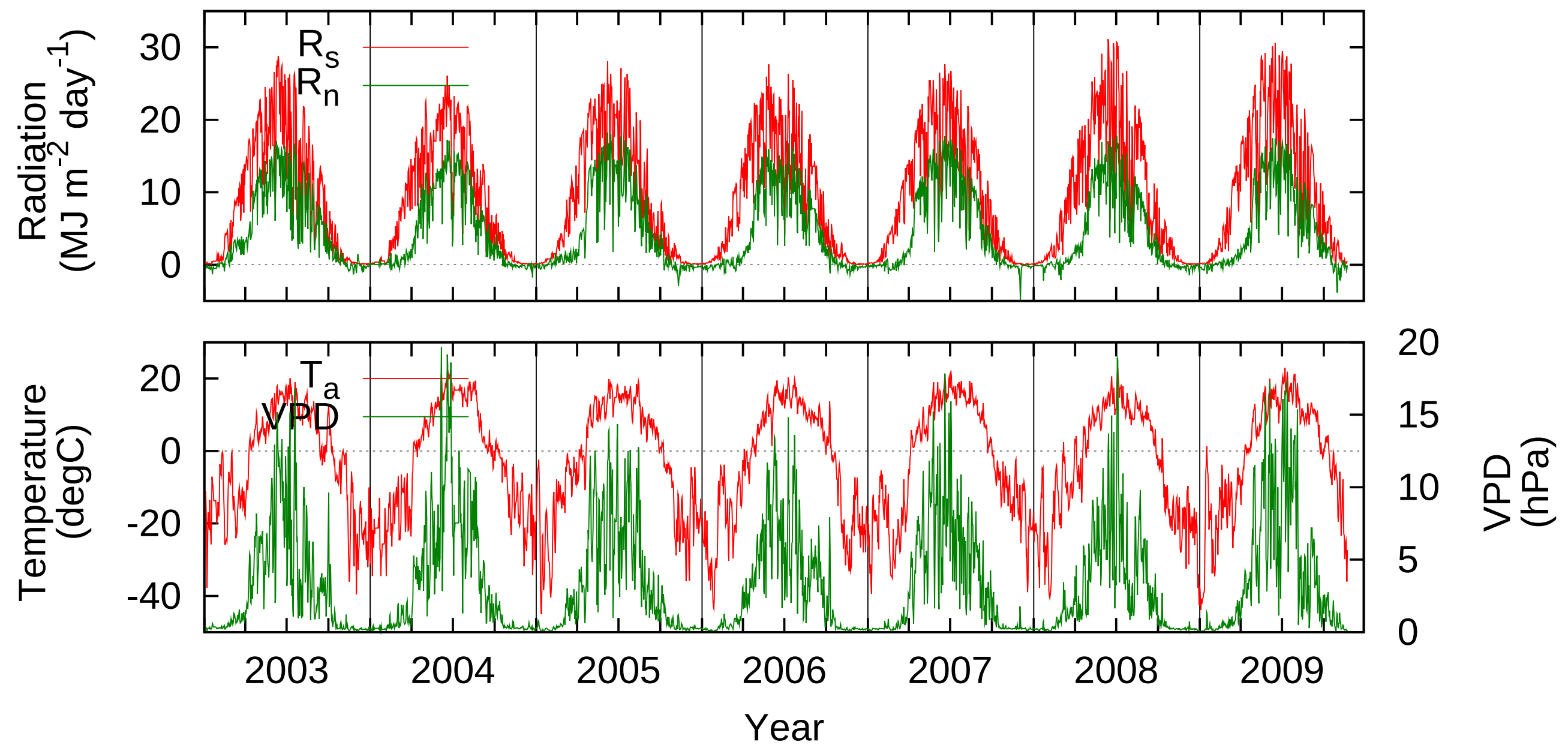

Figure 3: Meteorological variables observed over seven years.

Methane flux was calculated with the aerodynamic gradient method using the observed gradient of methane concentration and the flux-gradient relationship for methane. The flux-gradient relationship for methane was obtained in late summer 2009 by conducting the eddy covariance and the profile observation. Storage in the atmosphere between the observation height and the ground was taken into account to obtain the net exchange between the ecosystem and the atmosphere.

Results and Discussion

The forest generally acted as a net methane sink over the observation period (Fig. 4); the daily exchange rate averaged for the snow-free period in each year ranged from -0.02 to $-1.51\,\mathrm{mgCH_4\,m^{-2}\,day^{-1}}$ (Table 2).

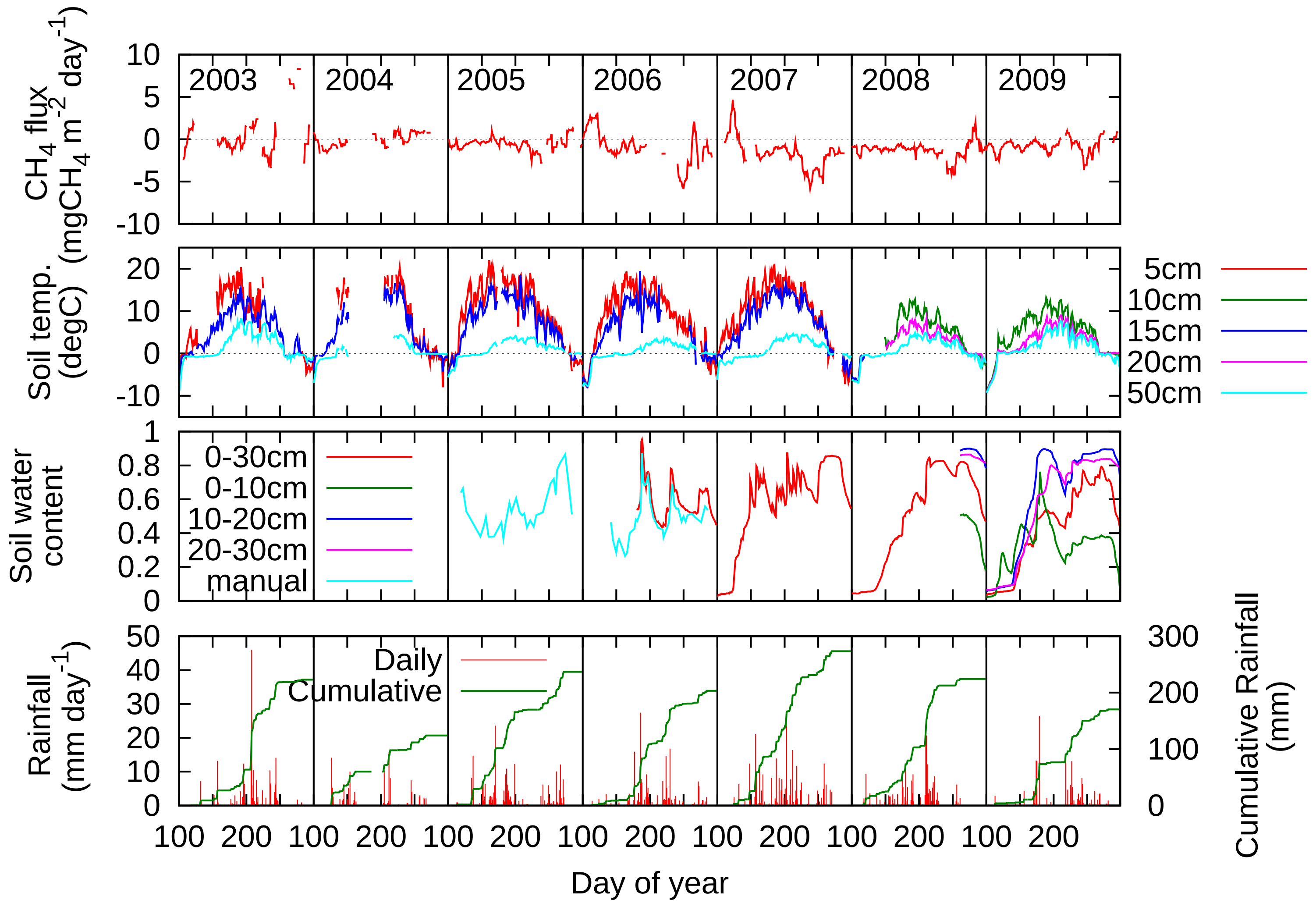

Figure 4: Seasonal variations of methane flux, soil temperature, soil water content, and rainfall during the snow-free period.

Table 2. Methane flux and soil water content averaged for the snow-free period in each year.

Year	Methane flux ($\mathrm{mgCH_4\,m^{-2}\,d^{-1}}$)	Soil water content
2003	-0.02	–
2004	-0.15	–
2005	-0.56	0.55
2006	-0.69	0.58
2007	-1.51	0.57
2008	-1.16	0.50
2009	-0.82	0.43

Uptakes of methane were observed when rainfall did not occur for several days and soil water content decreased, shown as plateaus of cumulative rainfall in Fig. 4. These uptakes are due to methane oxidation in the aerated soil. The uptakes occurred even when soil water content averaged for 0–30 cm depth was as high as 0.6. Hence, drying of the surface soil is important for determining the exchange.

Large methane uptake tended to be observed in late summer (around DOY 250), although the soil moisture condition was preferable for methane production. This is probably due to lower photosynthesis in this period (Fig. 5), which limited the supply of labile organic matter to the soil from the roots (e.g., *Whiting and Chanton* [1993]; *Updergraff et al.* [2001]; *Vann and Megonigal* [2003]), leading to low methane production. In addition to this, when the surface soil becomes dry, methane is efficiently oxidized in the surface soil.

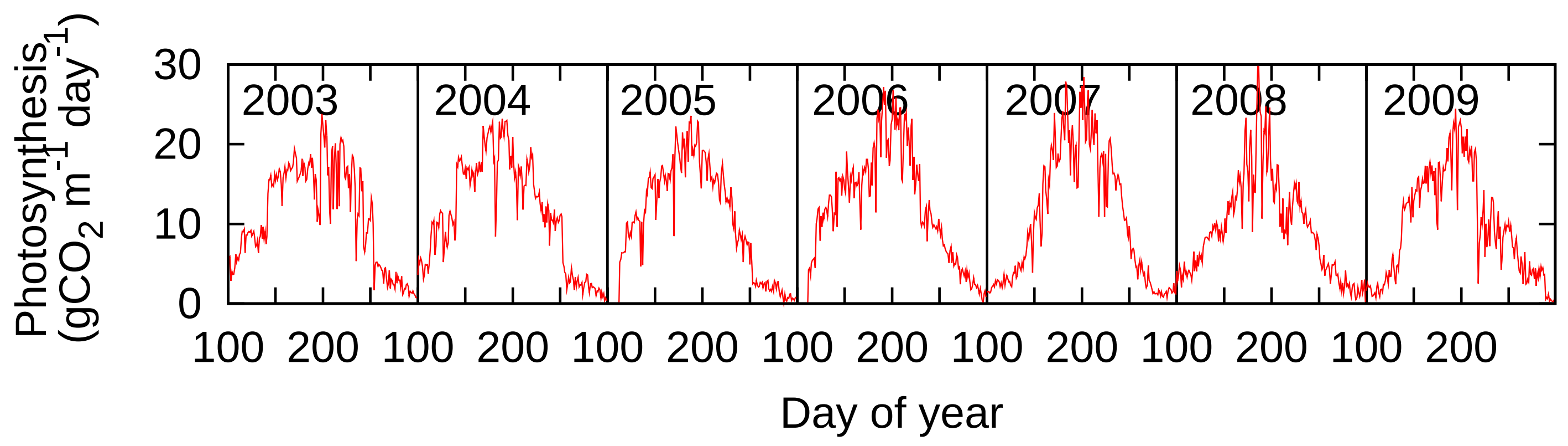

Figure 5: Seasonal variations of gross photosynthesis rate, based on a preliminary data analysis.

Methane emission events were observed in the period after heavy rain and snowmelt. The heavy rain event enhanced anaerobic soil conditions by reducing the diffusion of oxygen into the soil, leading to net methane emission of 0 to $2.0\,\mathrm{mgCH_4\,m^{-2}\,day^{-1}}$. Permafrost inhibits deep percolation of soil water and thus helps to form a saturated water condition in the soil, allowing methane to be produced. In spring, methane emissions were observed in 2003, 2006, and 2007. These emissions are attributable to anaerobic saturated soil conditions caused by snowmelt water. The maximum rate of emission ranges from 2.0 to $4.7\,\mathrm{mgCH_4\,m^{-2}\,day^{-1}}$. This variability may be influenced by depth of soil thawing.

Conclusions

- This black spruce forest generally acts as a sink for methane during snow-free periods under the current climate.
- Drying of the surface soil and supply of labile organic matter can be important variables that control the methane exchange in this forest.
- The forest switches to act as a methane source when oxygen availability in the soil is reduced after heavy rain events and snowmelt.

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