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The methane flux along topographical gradients on a glacier foreland in the High Arctic, Ny-Ålesund, Svalbard

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Abstract: In order to examine the relationship between the methane (CH_4) flux and soil factors and vegetation in High Arctic tundra, we investigated the CH_4 flux along topographical gradients on a glacier foreland in Ny-Ålesund, Svalbard (79°N, 12°E). The CH_4 flux rates varied widely among sites even within the same vegetation type, ranging from positive (emission) to negative (absorption) values. High CH_4 emission rates were detected on ridges and in sites with a low soil water content, but there was no significant relationship between CH_4 flux rates and soil factors including soil moisture, pH, soil carbon and nitrogen content. Mean values of CH_4 emission and CH_4 absorption were 0.30±0.33 mg m^{-2} h^{-1} (n=12) and 0.11±0.06 mg m^{-2} h^{-1} (n=11), respectively. These findings suggest that the study area is a small source of CH_4 with a mean flux of 0.11 mg CH_4 m^{-2} h^{-1} (0.083 mg C m^{-2} h^{-1}). It was concluded that carbon flux derived from CH_4 accounts for an extremely small proportion of the total carbon flux from soil in this area.

key words: carbon cycle, High Arctic, methane (CH_4) flux, soil factors, vegetation type

Introduction

Climate change caused by anthropogenic greenhouse gases is predicted to be most pronounced at high latitudes (IPCC, 2001). One of the most important impacts of climate change on Arctic terrestrial ecosystems is accelerated decomposition of organic matter as a result of increasing soil temperature and a longer growing season (Euskirchen *et al*., 2006). Whether Arctic soils act as a source or sink of atmospheric carbon depends on the balance between production and decomposition. If decomposition increases more rapidly than net primary production, the system could be a source of atmospheric carbon.

Methane (CH_4), an effective greenhouse gas, is produced in soils as the end product of anaerobic decomposition of organic matter. Northern wetlands between 50 and 70°N are among the most important sources of atmospheric CH_4 emission (Aselmann and Crutzen, 1989), and in the past few decades, considerable progress has been made with regard to the magnitude and control of CH_4 flow in these wetlands (Bubier and Moore, 1994; Frenzel and Rudolph, 1998; Roulet *et al*., 1992; Schimel, 1995). In contrast, much

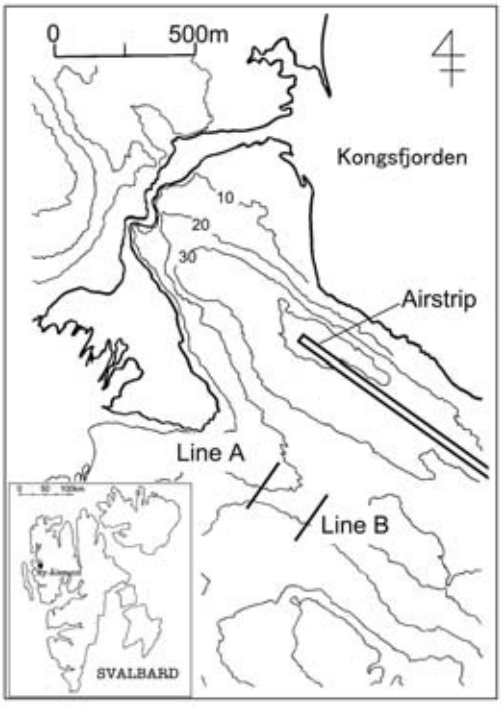

Fig. 1. Study area in Ny-Ålesund, Svalbard.

less attention has been paid to High Arctic regions. Since these regions contain a relatively small area of wetland, their contribution to global CH_4 emission is likely to be small (*cf.* Aselmann and Crutzen, 1989); however, there is evidence that a significant amount of CH_4 is emitted from soil in such regions (Christensen *et al*., 1995, 2000; Moosavi *et al*., 1996; Joabsson and Christensen, 2001). In order to study the carbon cycle in the High Arctic and to predict the response of the cycle to future climate change, evaluation of CH_4 flux on a regional scale is needed.

One difficulty in evaluating the CH_4 flux in the High Arctic is the heterogeneity of habitats (Cannone *et al*., 2004). Since CH_4 flux can vary with topography, vegetation and soil factors (Morrissey and Livingston, 1992; Christensen *et al*., 2000; Coles and Yavitt, 2002), we need to study the effects of each of these factors before evaluating the regional CH_4 flux. The objectives of our study were 1) to clarify the relationship between the CH_4 flux and topographical profile, vegetation and environmental factors in the region, and 2) to estimate the contribution of the CH_4 flux from soil to the carbon cycle in the High Arctic. This study is part of a project aimed at investigating the process and function of carbon cycling in primary succession in Ny-Ålesund, Svalbard (Nakatsubo *et al*., 1998, 2005; Bekku *et al*., 1999, 2004a, b; Uchida *et al*., 2002; Muraoka *et al*., 2002).

Materials and methods

Study site

The study area was located at the front of East Brøgger Glacier in Ny-Ålesund, Svalbard, Norway (79°N, 12°E; Fig. 1). The vegetation of the northern coast of Brøgger peninsula is well developed, and varies with topography, though the whole area lies within the High-Arctic *Drays octopetala* zone. The study area was located in the polar semi-desert vegetation zone of the High Arctic (Longton, 1997). The annual mean air temperature is −5.7°C and annual mean precipitation is 487 mm (Department of Meteorology, Norwegian Polar Institute). Soil temperature at a depth of 1cm during June to August ranged from −0.4 to 15.6°C in 2002 (National Institute of Polar Research, unpublished data).

Measurement of CH_4 flux

The CH_4 flux was measured following the closed chamber method (Bekku *et al*., 1995). In August 2004, 28 chambers were set every 20 m along two line transects of 260 m length (Line A and B), set on the north facing slope near Ny-Ålesund Airport (Fig. 1). Vegetation along the transects could be divided into 4 types (Ohtsuka *et al*., 2006): *Salix* (main dominant species; *Salix polaris*), *Oxyria/Luzula* (*Oxyria digyna* and *Luzula confusa*), *Cardamine* (*Cardamine nymanii*) and bryophytes (no vascular plants).

Each chamber (21 cm in diameter and 14 cm in height) was carefully driven about 4 cm into the soil at least one day before the gas flux measurements. The aboveground parts of vascular plants and the green bryophyte layer within the chamber were removed prior to the simultaneous measurements of CO_2 flux rate (unpublished data). This procedure might influence the CH_4 flux rate because some wetland vascular plants are known to increase CH_4 emission rates by mediating CH_4 transport between sediments and the atmosphere (Schimel, 1995; Frenzel and Rudolph, 1998). In addition, plant-associated CH_4 oxidation has been reported for a wide range of wetland species (King, 1994). However, since there were no wetland vascular plants in the study site and since belowground parts of the plants were left intact, the effect of this procedure on the CH_4 flux rate was assumed to be small.

During the gas flux measurements, the volumetric soil water content at a depth of 5 cm was measured using a time domain reflectometry sensor (TDR; TRIME-FM, IMKO, Ettlingen, Germany). Soil temperatures at depths of 1 and 5 cm, measured with a thermometer (TM-150, Custom, Tokyo, Japan), were within a narrow range of 6 to 8°C except for one plot (4°C at Line A, Plot 9).

Gas samples were collected using 5-m*l* glass vacuum bottle at 20 min intervals over 1 hour. Sampling was performed between the hours of 0900 and 1500 (local time) on 1, 2 and 4 August 2004. Gas samples were brought back to Japan and analyzed with a gas chromatograph (GC-14B, Shimadzu, Japan).

After the CH_4 flux measurements, soil samples within the chamber, 2.5–3 cm depth, were taken. Part of these fresh soil samples was used to measure soil pH [soil: water ratio of 1:2.5 (g/g)], and the rest was dried at room temperature for measurements of the carbon and nitrogen content using a NC analyzer (Sumigraph NC-800, Sumikla Chemical

Analysis Service, Ltd). All plants within the chamber were brought to the laboratory and sorted into species. They were then oven-dried at 70°C for more than 24 h and weighed. Detailed descriptions of the soil and vegetation analysis appeared in Ohtsuka *et al.* (2006).

We conducted all statistical analyses using the Stat View 5.0 software package (SAS Institute, Cary, NC, USA). One-way ANOVA was used to determine differences in aver-

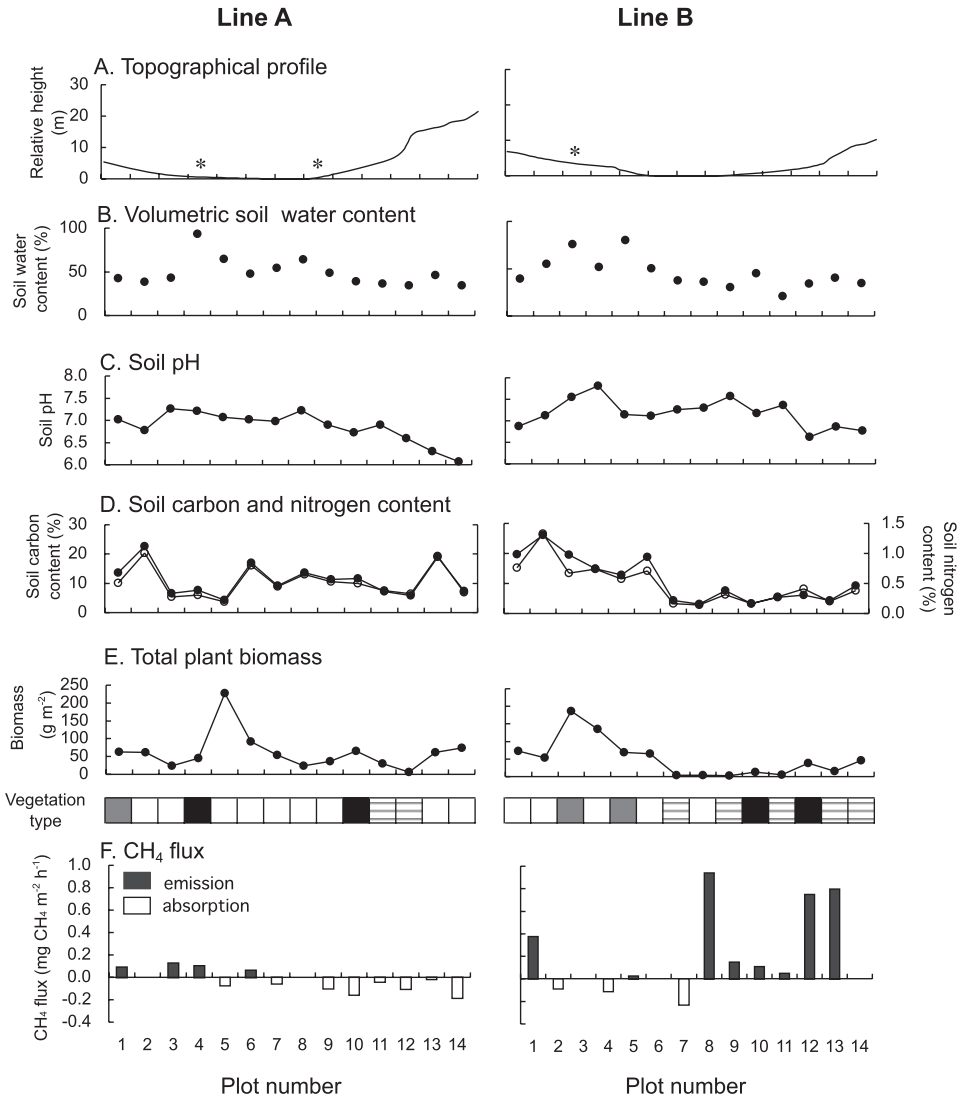

Fig. 2. The topography, soil factors, vegetation and CH_4 flux along the two transect lines.
*: water table was above the ground surface. (D) ●: Nitrogen content, ○: Carbon content.
■: *Cardamine* type, □: *Salix* type, ▤: *Oxyria/Luzula* type, ■: Bryophyte type.

age the CH_4 flux between the different vegetation types.

Results

Figure 2 illustrates the CH_4 flux from soil as well as the topographical profiles and environmental factors along the two line transects (Lines A and B). CH_4 flux rates varied widely among sites, ranging from positive (emission) to negative (absorption) values. The mean CH_4 emission (mean±S.D.) was 0.30±0.33 mg m^{-2} h^{-1} (n=12) and CH_4 absorption was 0.11±0.06 mg m^{-2} h^{-1} (n=11). These data indicate that the study area was a source of CH_4 with a mean flux of 0.11 mg CH_4 m^{-2} h^{-1}.

There was no clear relationship between the CH_4 flux rates and topography. For example, high CH_4 emission rates were detected on the ridge in Line B (Nos. 12 and 13), whereas plots on the ridge in Line A showed negative values (CH_4 absorption). Methane flux rates were generally small in plots on the depression both in Line A and Line B although the rates could be either positive or negative values.

The water table in some plots (No. 4 and No. 8 on Line A and No. 3 on Line B) was above the ground surface. Since soil water content tended to be high on the depression (Fig. 2), plots with a high soil water content generally showed low CH_4 flux rates (Fig. 3a). High CH_4 emission rates were restricted to plots with low soil water content (Fig. 3a) although the opposite was not always true. The relationship between soil water content and CH_4 flux rates was not significant (p>0.05, Fig. 3a), and similarly, there was no significant relationship between soil pH and CH_4 flux (Fig. 3b). In addition, we examined the relationship between CH_4 flux rates and soil carbon and nitrogen contents, and total and vascular plant biomasses, but no significant relationships were observed (data not shown).

The relationships between the CH_4 flux and vegetation types are shown in Fig. 4. The CH_4 flux rates varied widely in each vegetation type, ranging from positive to negative values except in the *Cardamine* type where the number of plots was small (n=2). Although CH_4 emission tended to be high in the *Salix* and Bryophyte types, no significant effect of vegetation type on the CH_4 flow rates was observed (one-way ANOVA, p>0.05).

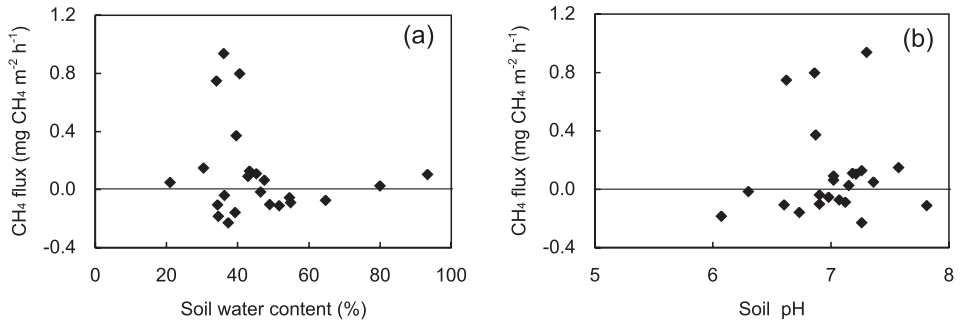

Fig. 3. Relationships between the CH_4 flux and soil factors. (a) Soil water content and (b) soil pH.

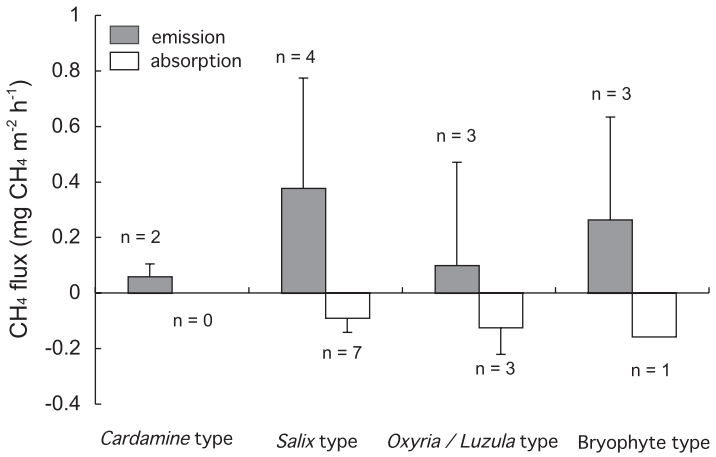

Fig. 4. The mean CH_4 emission and absorption in each vegetation type. Error bar represent the standard deviation.

Discussion

Previous studies have shown that the CH_4 flux is determined by an array of environmental factors, *i.e*. soil temperature (Crill *et al*., 1988; Morrissey and Livingston, 1992), soil water content (Funk *et al*., 1994; Keller and Reiners, 1994; Moosavi *et al*., 1996), the water table (Harriss *et al*., 1982; Sebacher *et al*., 1986; Moore *et al*., 1990; Roulet *et al*., 1992; Kutzbach *et al*., 2004), soil pH and soil organic carbon (Yan *et al*., 2005). Among these, soil moisture is known to have profound effects on CH_4 production by affecting soil aeration (Coles and Yavitt, 2002). Since CH_4 production occurs in anaerobic conditions, it is expected that high CH_4 emission rates are observed in sites with a high soil water content. However, in this study, high CH_4 emission rates were restricted to plots with a low soil water content on a ridge, whereas plots in wet sits on the depression generally showed low flux rates. Furthermore, CH_4 flow rates showed no significant relationship with soil factors such as soil pH, C and N contents.

One possible explanation of the insensitivity of CH_4 flow to these environmental factors is that CH_4 is produced in deep soil layers and that the soil environment in shallow (<5 cm) soil layers has no direct relationship with the production rate. This is in contrast to soil CO_2 production in the area studied by Bekku *et al*. (2004a, b), who reported that CO_2 production occurred mainly in shallow soil layers and had a significant correlation with air temperature and soil temperature at 1 cm depth (Bekku *et al*., 2004a, b). In addition, the CH_4 flux from the soil surface is determined by the balance between CH_4 production and CH_4 oxidation, each of which is controlled by different factors. This might further have complicated the relationship between the CH_4 flux and soil factors. Further studies on the vertical distribution of CH_4 production and CH_4 oxidation activities is therefore needed to clarify this point.

A number of studies have indicated that vegetation has a profound influence on the

Table 1. Mean CH_4 flux in the high latitude ecosystems.

Place	Latitude	Ecosystem	CH_4 flux[a] (mg CH_4 m^{-2} h^{-1})	Soil surface temperature (°C)	Reference
Siberia and European Arctic	67–77°N	Mesic tundra	0.1±0.03[b]	3.5[c]	Christensen *et al.* (1995)
Siberia and European Arctic	67–77°N	Wet tundra	2.0±0.2[b]	5.2[c]	Christensen *et al.* (1995)
Greenland	74°N	Fen, grassland, heath and snowbed	1.9±0.7	12.0–17.5[d]	Christensen *et al.* (2000)
Russia	72°N	Wet tundra	1.2±0.2[b]	1.6–6.7[e]	Kutzbach *et al.* (2004)
Alaska	70°N	Wet coastal tundra	4.9±1.2[b]	2.4–8.6	Sebacher *et al.* (1986)
Alaska	70°N	Wet meadow tundra	1.6±0.8[b]	7.5–13.5	Sebacher *et al.* (1986)
Alaska	68–71°N	Wet meadows	0–11.9[b]	5.5–16.6	Morrissey and Livingston (1992)
Ny-Ålesund	79°N	Polar semi-desert	0.11±0.3	4.2–8.3	This study

[a] mean±standard deviation. [b] original data given by mg CH_4 m^{-2} day^{-1}, [c] mean soil temperature at 2, 4, 8 and 12 cm depths, [d] air temeprature, [e] soil temperature at 15 cm depth.

CH_4 flux (Whiting and Chanton, 1993; Christensen *et al*., 1995, 2000; Stöm *et al*., 2003). Based on the relationships between vegetation and the CH_4 flux, some authors have estimated CH_4 flux rates over large scales using remote sensing indices (Bubier *et al*., 2005). In the present study site, however, application of remote sensing techniques to estimate CH_4 flux seems impractical because the CH_4 flux showed no significant relationship with vegetation types and plant biomass.

Rates of CH_4 flux reported for Arctic ecosystems at high latitudes are extremely variable on a spatial scale (Table 1). For example, Christensen *et al*. (1995), who conducted CH_4 flux measurements along a transect across tundra environments between 67° and 77°N in Siberia and the European Arctic, reported that the mean CH_4 emission was much higher in wet tundra than in mesic tundra though there was large intersite variability. The mean CH_4 flux rate in our study site (0.11 mg CH_4 m^{-2} h^{-1}) was similar to the mean value of the mesic tundra but much smaller than that of the wet tundra reported by Christensen *et al*. (1995).

The mean CH_4 flux rate in our study site corresponded to a carbon flux of 0.083 mg C m^{-2} h^{-1}, which is less than 0.5% of the carbon flux derived from soil respiration near the study site (17.2 mg C m^{-2} h^{-1}, Bekku *et al*., 2004a). It was therefore concluded that the carbon flux derived from CH_4 accounts for an extremely small proportion of the total carbon flux from soil in the study site.

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