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# Annual cycle of methane emission from a boreal fen measured by the eddy covariance technique

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ABSTRACT

The northern wetlands are one of the major sources of methane into the atmosphere. We measured annual methane emission from a boreal minerotrophic fen, Siikaneva, by the eddy covariance method. The average wintertime emissions were below 1 mg $m^{-2}$ $h^{-1}$, and the summertime emissions about 3.5 mg $m^{-2}$ $h^{-1}$. The water table depth did have any clear effect on methane emissions. During most of the year the emission depended on the temperature of peat below the water table. However, during the high and late summer the emission was independent on peat temperature as well. No diurnal cycle of methane flux was found. The total annual emission from the Siikaneva site was 12.6 g $m^{-2}$. The emissions of the snow free period contributed 91% to the annual emission. The emission pulse during the snow melting period was clearly detectable but of minor importance adding only less than 3% to the annual emission. Over 20% of the carbon assimilated during the year as carbon dioxide was emitted as methane. Thus methane emission is an important component of the carbon balance of the Siikaneva fen. This indicates need of taking methane into account when studying carbon balances of northern fen ecosystems.

## 1. Introduction

Methane ($CH_4$) is a powerful greenhouse gas, which accounts for about 20% of the increase in global radiative forcing since the pre-industrialized era. The atmospheric concentration of methane has strongly increased during the industrialized era, but the growth rate has been decreasing lately (Houghton et al., 1996; Wuebbles and Hayhoe, 2002; Dlugokencky et al., 2003).

Major sources of methane into the atmosphere include both biogenic and anthropogenic ones, such as rice paddies, termites, ruminants, fossil fuels, biomass burning, landfills and wetlands (Prather et al., 1995). The northern wetlands commonly are sinks of carbon (Minkkinen et al., 2002; Aurela et al., 2004) but are also the largest natural source of methane into the atmosphere (Prather et al., 1995). Fens are peat-forming wetlands, which, in addition to atmospheric deposition, receive water and nutrients as run-off from surrounding mineral soils (Ingram, 1983). They cover 0.3–0.5 $\times$ $10^6$ $km^2$ in boreal and arctic zones in Eurasia and North America (Gore, 1983; Botch et al., 1995).

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Methane is the end product of anaerobic decomposition by methanogenic microbes, Archaea. In wetlands methane is produced below the water table in anaerobic conditions, where fresh root litter and exudates of the deep-rooting plants provide substrates for methanogens (Schütz et al., 1991; Chanton et al., 1995). Methane is released to the atmosphere via diffusion through the peat, via aerenchymatous vascular plants or via ebullition. A significant part of the methane diffusing through the upper aerobic part of the peat layer is oxided by methanotrophic bacteria before reaching the surface (Le Mer and Roger, 2001; Pearce and Clymo, 2001; Whalen 2005). In sedge-dominated wetlands, most of methane is released through vascular plants (Frenzel and Rudolph, 1998; Ding et al., 2004), thus bypassing the aerobic peat layer where methane oxidation takes place.

Much of the experimental work on the methane emissions from wetlands has been conducted by chamber techniques (e.g. Moore et al., 1990; Huttunen et al., 2003; Bubier et al., 2005) while micrometeorological flux measurement methods, such as the eddy covariance technique, have been used less frequently (see however, Suyker et al., 1996; Hargreaves and Fowler, 1998; Kim et al., 1998a,b; Kormann et al., 2001; Hargreaves et al., 2001). The advantages of the micrometeorological methods are the minimal disturbance on the measured surface and the possibility to measure long, more or less continuous, time series.

However, no continuous annual methane emission measurements by the eddy covariance technique from northern wetlands have been reported previously.

Many longer term eddy covariance flux studies have concentrated on the carbon dioxide exchange instead of total carbon balance (Joiner et al., 1999; Aurela et al., 2001, 2004; Nordstroem et al., 2001), partly because the instrumentation for methane flux measurements have been expensive to purchase and operate, and demanded active maintenance in the field. In addition the methane emitted by wetlands has sometimes been regarded to be important only for the greenhouse warming potential balance, but not so much for the carbon balance of the ecosystem (Harding et al., 2001), even though there is evidence on methane being a significant component of the carbon balance (Suyker et al., 1996, 1997; Corradi et al., 2005). Minkkinen et al. (2002) estimated the annual methane emissions from different boreal peatland types in Finland to vary between near zero and 22 g-C $m^{-2}$ $yr^{-1}$, whereas the total carbon accumulation, including carbon dioxide uptake, methane emission and dissolved carbon flows, varies between 17 and 26 g-C $m^{-2}$ $yr^{-1}$.

The aims of this study were to determine the annual ecosystem scale methane emission from a boreal fen and the seasonal variation of the emission using the micrometeorological eddy covariance technique. In addition, we aim to assess the importance of methane for the carbon and greenhouse gas balances of the fen, and to estimate the contribution of wintertime emission and the springtime emission pulse to the annual methane balance. Also we studied the influence of environmental parameters, such as peat temperatures at different depths and water table depth, on the methane emission.

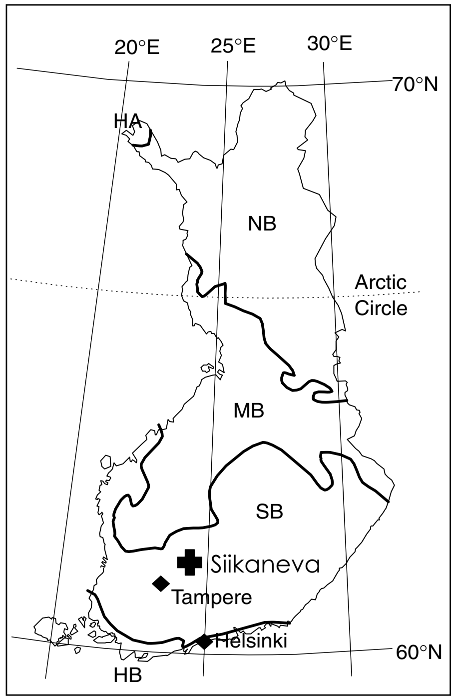


*Fig. 1.* Location of the measurement site, Siikaneva. The two-letter codes indicate climatic vegetation zones after Solantie (1990). HB = hemiboreal; SB = south boreal; MB = middle boreal; NB = north boreal; HA = hemiarctic.

## 2. Methods

The measurement site is located at the eastern end of the Siikaneva fen, which is a boreal oligotrophic fen located in Ruovesi in Southern Finland (Fig. 1, 61°50′N, 24°12′E, 162 m a.s.l.). The peat depth at the measurement site is up to four meters and has accumulated since the end of the last ice age, in about 9000 yr. The vegetation at the site is dominated by peat mosses [*Spaghnum balticum* (Russow) Russow ex C.E.O. Jensen, *S. majus* (Russow) C.E.O. Jensen, *S. papillosum* Lindb.], Sedges (*Carex rostrata* Stokes, *C. limosa* L., *Eriophorum vaginatum* L.) and Rannochrush (*Scheuchzeria palustris* L.). The site has a relatively flat topography with no pronounced string and hollow structures. The homogenous fetch extends some 200 m in the north and south and several hundred meters in east and west.

The annual mean temperature during 1971–2000 at Hyytiälä weather station, located 5 kilometres from Siikaneva, was 3.3°C and the annual precipitation 713 mm (Drebs et al., 2002). The mean daily maximum temperature reached 20°C during summer months (Fig. 2), whereas during winter the temperatures were well below zero degrees. Late summer and early fall were on the average rainier than the first half of the year. Weather

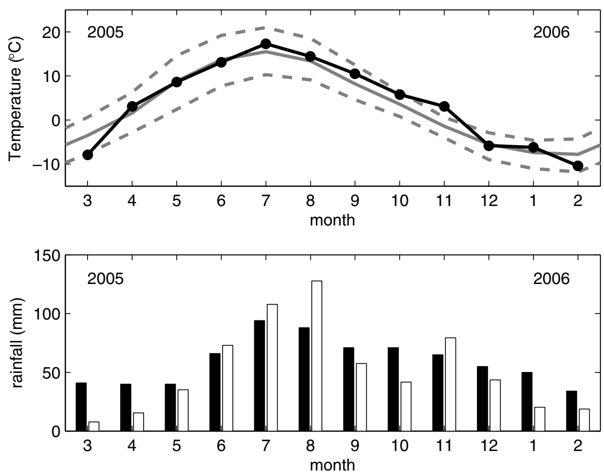


*Fig. 2.* Upper panel: Mean monthly temperatures (solid grey line) and means of daily maxima and minima (dashed grey line) during 1971–2000, and monthly mean temperatures during the measurement period (solid black line and dots) at the Hyytiälä weather station. Lower panel: Mean monthly precipitation during 1971–2000 (black bars) and precipitation during the measurement period (white bars) at the Hyytiälä weather station. The statistics from 1971 to 2000 are from Drebs et al. (2002).

conditions during the measurement period (March 2005–February 2006) show that the latter part of the 2005 was warmer than the 30-yr average, while March 2005 and February 2006 were considerably colder (Fig. 2). Precipitation was higher than average during the summer 2005. In the spring of 2005 the snow and peat melted in the beginning of April and in the fall the permanent snow cover fell in the early December. In March 2005 the thickness of the frozen peat layer varied between 5 and 30 cm and snow depth was 20–30 cm. In the February 2006 the frozen layer varied between 6 and 18 cm and the snow depth was 40–50 cm.

The methane fluxes were measured using the eddy covariance technique. Methane concentrations were measured at a rate of 10 Hz by a tunable diode laser absorption spectrometer (TDL, TGA-100, Campbell Scientific Inc., USA) and the three-dimensional wind vector at the rate of 10 Hz by an acoustic anemometer (USA-1, METEK, Germany). Also carbon dioxide and water vapour fluxes were measured by eddy covariance technique utilizing the same acoustic anemometer and a closed path infrared gas analyser (IRGA, Li-Cor 7000). The acoustic anemometer was placed 3 m above the peat surface and the air intake of the TDL was located 20 cm from the anemometer. The air drawn into the TDL passed first through a diffusion drier (Nafion PD-1000). After the drier the air stream was split and 14 L $\mathrm{min}^{-1}$ directed to the TDL sample cell via 10 m tube with inner diameter of 4 mm. 3 L $\mathrm{min}^{-1}$ was used as sheat flow in the diffusion drier. The high-frequency performance of the TDL has been presented by Laurila et al. (2005) together with details of flux calculation and correction of high-frequency damping. The fluxes were calculated as half-hour covariances using block averaging. The wind vector was rotated prior to flux calculations to force half-hourly averages of vertical and crosswind components of the wind vector, $\overline{w}$ and $\overline{v}$, to zero. The high-frequency losses were corrected for using empirically determined transfer function (Laurila et al., 2005). The data collected during weak turbulence have been removed from further analysis by filtering out all half-hour flux values with friction velocity, $u^* = \sqrt{-\overline{u'w'}}$, below 0.2 m $\mathrm{s}^{-1}$. The use of this rather conservative cut-off limit removes 44% of the annual data. In total 6266 half-hourly flux values remained for the further analysis after data associated with technical problems and low turbulence had been removed.

A set of meteorological and soil parameters were recorded continuously. These included air temperature and humidity, precipitation, photosynthetical photon flux density, net radiation, peat temperature at depths of 5, 10, 20, 35 and 50 cm and water table depth. The vascular green area (VGA) of vegetation was followed during the summer by methods described by Wilson et al. (2006).

## 3. Results and discussion

The eddy covariance measurement system at the Siikaneva fen was operated continuously during a full annual cycle. Apart from a few system malfunctions we obtained a continuous data set covering all parts of the annual cycle. After data recorded during system malfunctions had been removed 13 982 half-hourly flux values remained, which equals to 80% data coverage. Of these, 6266 half-hourly flux values remained for the further analysis after data associated low turbulence had been removed.

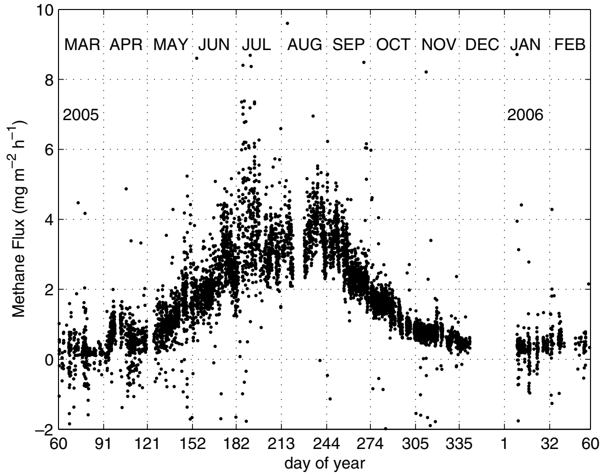


*Fig. 3.* Annual cycle of measured half-hourly methane fluxes. Positive sign indicates upward flux, i.e. emission from the fen.

The study site acted as a source of methane throughout the year (Fig. 3). The fluxes were at their highest in the summer and lowest, but still on average positive during the late winter. The half-hourly fluxes show a relatively large variation with even some negative values. These negative values are recorded mostly during wintertime and appear to be due to the relatively large random uncertainty of a single half-hourly flux value when measuring low fluxes. The emission pulse during the snow melting period was clearly visible in April. The data filtering as well as some technical problems created gaps in the data series and hence we needed to consider methods to fill in the gaps in order to be able to calculate the annual methane emission from the fen.

Despite the large variation in the half-hourly fluxes, we observed no systematic diurnal variation in methane fluxes measured at Siikaneva. This can be shown by normalizing the half-hourly flux values by dividing each half-hour flux value with the median flux of the corresponding day. A seasonal median of the normalized fluxes was then found for each half-hour time period of the diurnal cycle. Only days with data coverage better than 75% were taken into account in these calculations. Figure 4 shows the diurnal cycle of the median normalized fluxes during June–September period. No diurnal cycle was found during any period. In some earlier studies on wetlands and other ecosystems systematic variation have been observed (Suyker et al., 1996; Kim et al., 1998a,b) while in others not (Kormann et al., 2001). The lack of a diurnal cycle allowed us to calculate the average flux for each day directly from the measurements as

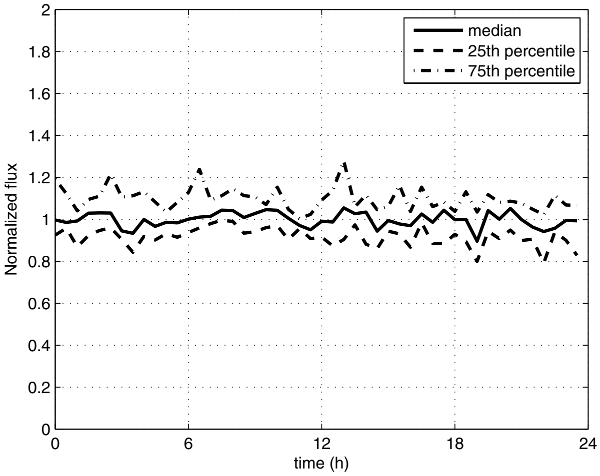


*Fig. 4.* Hourly medians, and 25th and 75th quartiles, of methane fluxes normalized by the daily median flux. Only data from July to September with daily data coverage better that 75% are used for the analysis.

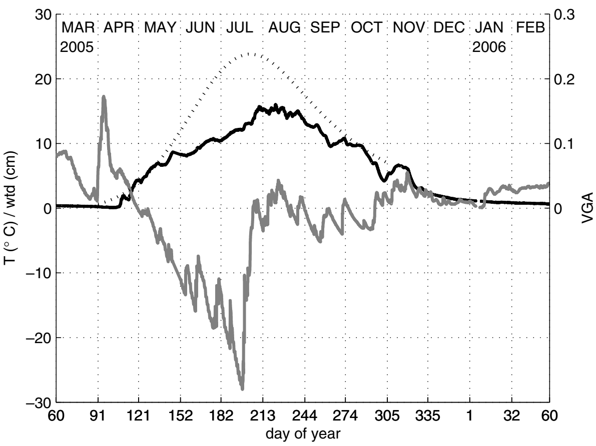


*Fig. 5.* Peat temperature at 35 cm depth (solid black line), water table depth (solid grey line), and aerenchymatous vascular green area (VGA, dashed black line) during the measurement period.

the missing data increase only the random uncertainty, but do not lead to any systematic error.

In order to fill in the data gaps for the days when no measurements were available we investigated the dependence of the daily average fluxes on the environmental parameters. As peat temperature and water table depth have previously been shown to affect methane fluxes (Suyker et al., 1996; Hargreaves and Fowler, 1998; Kim et al., 1998a,b; Hargreaves et al., 2001; Huttunen et al., 2003; Bubier et al., 2005), we concentrated on these two parameters. The annual cycle of water table depth and peat temperature are shown in Fig. 5.

As the dependence of the methane emission on the peat temperature is likely to be exponential (Kim et al., 1998a), we correlated the logarithm of the daily average fluxes with peat temperatures recorded a depths of 5, 20, 35 and 50 cm. Only

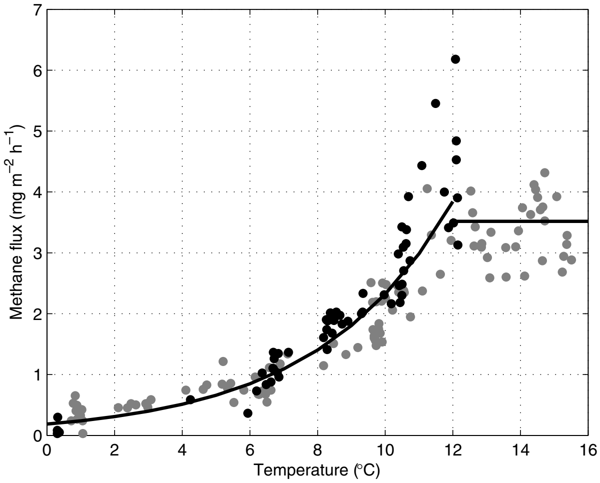


*Fig. 6.* Daily average methane fluxes against peat temperature at 35 cm depth, together with the line indicating the temperature dependence. Black dots represent data obtained before day 200 of year 2005 and grey ones those obtained after that.

the days with data coverage better than 33% was used in this analysis. However, as the spring pulse of the methane emission in April did not seem to depend on the peat temperature (Figs. 3 and 5) we did not use the data from April in our analysis. The correlation coefficients, $r$, between the logarithm of the flux and the peat temperatures varied between 0.87 and 0.89, with best correlation between the logarithm of daily average flux and peat temperature at the depth of 35 cm ($T_{-35cm}$). Also this depth stayed below the water table during the whole year (Fig. 5). As the behaviour of the flux seems to be exponential only in lower temperatures (Fig. 6), an exponential curve was fitted only to the data with $T_{-35\mathrm{cm}} < 12°\mathrm{C}$. This results in an equation

$$F = a \exp\left[bT_{-35\mathrm{cm}}\right], \qquad (1)$$

where $a = 0.19$ mg m$^{-2}$ h$^{-1}$ and $b = 0.25°\mathrm{C}^{-1}$. In the peat temperatures above 12°C the emission seemed to be independent of the peat temperature and the average emission was 3.5 mg m$^{-2}$ h$^{-1}$. This exponential eq. (1) described the behaviour of the fluxes when $T_{-35\mathrm{cm}} < 12°\mathrm{C}$, both before and after the high summer period, sufficiently well for our purposes. This curve can be used for the gap-filling but may not be generalized to other situations, especially as the conditions at the Siikaneva site were far colder than the typical temperature optimum of about 25°C for the methane production (Dunfield et al., 1993; Nozhevnikova et al., 2001; Metje and Frenzel, 2005). If we assume that the peat temperature well below water table at the depth of 35 cm was the major environmental parameter behind the variation of the methane emission, the lack of diurnal cycle of the emission can be explained by the lack of significant diurnal cycle of the peat temperature at this depth.

The dependence of the flux on the water table depth was less obvious, (Fig. 7a). The peculiar structure is most likely a

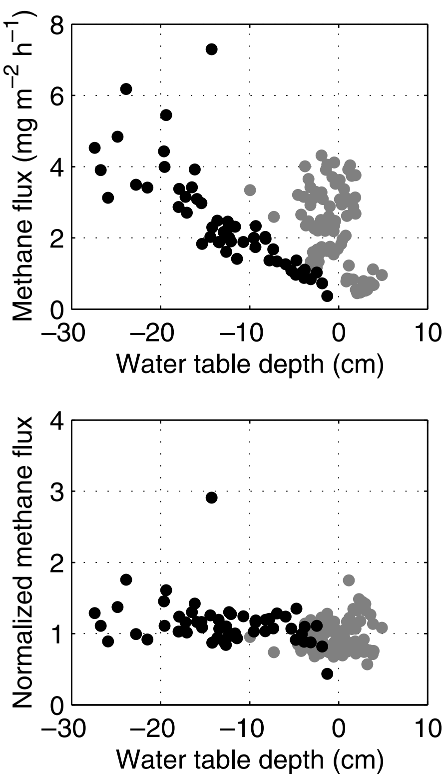


*Fig. 7.* Upper panel: Daily average methane fluxes against water table depth. Lower panel: Daily average methane fluxes normalized by dividing by the emission calculated using the temperature dependence. Black dots represent data obtained before day 200 of year 2005 and grey ones those obtained after that.

by-product of the decreasing water table depth in the early summer with concurrent increase in the peat temperature (Fig. 5). In the latter part of the summer the water level did not show any major variation. In order to focus on the relation between the methane flux and water level we removed the effect of the temperature on the emission by dividing the measured emission with the emissions calculated with the temperature dependence described above (eq. 1). This normalized emission was very weakly anticorrelated with the water table depth before the day 200 and not correlated after that (Fig. 7b). Looking at the Figs. 3 and 5, we can see that during the low water table depth in early July the methane fluxes were very high, with a drop in the fluxes coinciding with the sudden rise in the water table depth in mid-July. Previously also Moore et al. (1990) have observed an increase in fluxes simultaneously with a long period of sustained drop in water table level. This was interpreted as ebullition, triggered by decrease in hydrostatic head. In many reported cases of the positive dependence of the methane emission on the water table depth, water table depth explained the spatial variation of the emission rather than the temporal variation (Hargreaves and Fowler, 1998; Bubier et al., 2005). Also the longer-term effects of water table depth have been reported by Huttunen et al. (2003) and Bubier et al. (2005). In contrast, Hargreaves et al. (2001) have reported independence of the methane emission on the water table depth. Suyker et al. (1996) explained the increasing trends in the methane emission with the sharp increases in the water table depth with 12 day lag. Our data did not show similar behaviour. Also no significant dependence of the measured flux on the wind direction was found. The lack of positive correlation between methane emission and water table depth can be explained by the relatively small range of water table depths during the measurement period (Shannon and White, 1994). The water table depth was never more than 30 cm below the peat surface and the sedges are reported to have rooting depths down to 230 cm, although 90% of the root biomass is located in the uppermost 30 cm (Saarinen, 1996). Thus the aerenchyma of the sedges could effectively transport methane from the peat to the atmosphere even during the lowest water table depths, and the aerobic peat surface layer where methane oxidation would be more efficient, would be bypassed. The lack of a diurnal cycle in the emission indicates the passive diffusion to be the mechanism responsible for the transport of methane into the atmosphere via aerenchyma of the sedges (Shannon et al., 1996; Popp et al., 1999; Chasar et al. 2000).

The independence of the methane emission on peat temperature during the high and late summer may have been caused by limited substrate availability (Bergman et al., 1998; Chasar et al., 2000; Wagner et al., 2005). The maximum in the methane emission occurred in the early July, after which the emission was diminished and stayed independent of the peat temperature until mid-September. This drop in the emission occurred at the same time when the green area of the vascular plants reached its maximum, before vegetation started to senesce (Figs. 3 and 5). In the case where the growth of the methanogenic microbe population exceeds the growth in the available substrates, the methane production would be diminished. This might explain the behaviour of the methane emission during the high summer months with high emission in the beginning with subsequent drop.

As we cannot draw final conclusions on the factors controlling the methane emission from the Siikaneva fen, we compared annual emissions calculated by three different gap-filling methods. (i) In the first method the missing daily average emissions were calculated using the temperature regression described above (eq. 1). As the emission during the spring pulse is independent of the peat temperature, this period was gap-filled separately by linear interpolation. (ii) In the second method also the high and late summer period (July–mid-September), was gap-filled by the linear interpolation. (iii) In the third method the whole year was gap-filled using linear interpolation. In all calculations measured data were used for the days with the data coverage better than 33%, which results 177 daily averages based on measured data. The time series resulting from gap-filling by the method (ii) is shown in Fig. 8.

The annual emissions of methane from the Siikaneva site, calculated using the gap-filling methods (i), (ii) and (iii), were 12.56,

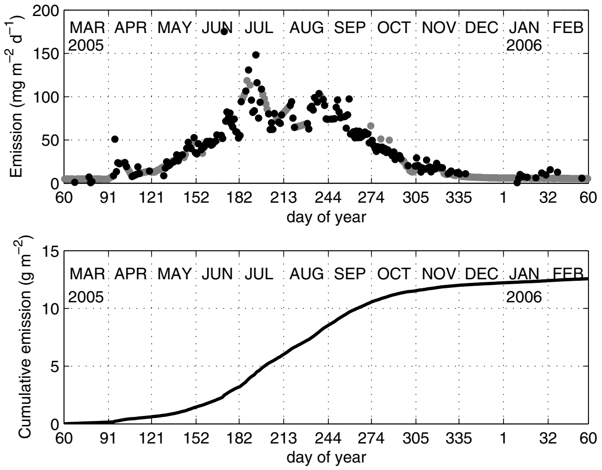


*Fig. 8.* Upper panel: Yearly cycle of the gap-filled daily methane emissions. Black dots are daily emissions calculated from measured data and grey dots those obtained by gap-filling using the method (ii) (see text). Lower panel: Cumulative methane emission calculated from the gap-filled data.

12.57 and 12.63 g m$^{-2}$, respectively. Thus the calculated annual methane emission is rather insensitive to the gap-filling method used. The annual emission used in the further analysis is based on the gap-filling method (ii) and thus the uncertainty of the annual emission was estimated for this method. The uncertainty estimation was carried out in three parts. First, we estimated the uncertainty associated with the daily emissions based on the direct measurements. As the daily emissions were calculated as the average of the measured half-hourly flux values, and we assumed that all diurnal variation is of random nature, we calculated the uncertainty of each daily average as the standard error of the mean. In the second phase we estimated the uncertainty associated with the gap-filling by the temperature dependent algorithm. The uncertainty of a single daily average calculated by this algorithm was estimated by the root–mean–square difference of the measured daily averages and the ones given by the temperature algorithm. Finally, the uncertainty associated with gap-filling by the linear interpolation was estimated. In order to roughly quantify this uncertainty, we used linear interpolation for time periods for which measured data exist, and calculated root–mean–square differences between measured data and result of linear interpolation. This approach provided an individual estimate for each measurement-based daily emission value, $\Delta E_i$., and a single values for the daily emissions estimated by temperature algorithm, $\Delta E_T = 18$ mg m$^{-2}$ d$^{-1}$ and for those obtained by linear interpolation, $\Delta E_I = 17$ mg m$^{-2}$ d$^{-1}$. Using these values we can estimate the uncertainty of the annual methane emission by standard error propagation

$$\Delta E_{\mathrm{annual}} = \sqrt{\sum_{i}^{N_m} (\Delta E_i)^2 + N_T\,(\Delta E_T)^2 + N_I\,(\Delta E_I)^2}, \qquad (2)$$

*Table 1.* Annual balances of carbon dioxide and methane, expressed as mass, carbon balance and greenhouse warming potential with 100-yr time horizon (GWP$_{100}$). Positive sign indicates the upward flux, i.e. the fen is losing carbon. The annual figure for carbon dioxide is for the year 2005.

| | Balance (g m$^{-2}$) | Carbon balance (g-C m$^{-2}$) | GWP$_{100}$ balance (g-CO$_2$-eq. m$^{-2}$) |
|---|---|---|---|
| Carbon dioxide | −156 | −42.5 | −156 |
| Methane | +12.6 | +9.4 | +264 |

where $N_m$, $N_T$ and $N_I$ refer to the numbers of days with measurement-based daily emission, 177, and those with values gap-filled with temperature algorithm and linear interpolation, 139 and 49, respectively. Assuming the errors are normally distributed we obtain the 99% confidence interval by multiplying $\Delta E_{\mathrm{annual}} = 0.38$ g m$^{-2}$ by 2.58, yielding 1.0 g m$^{-2}$. This, however, does not take into account all the sources of uncertainties present in the surface layer flux measurements. For example, the choice of the flux calculation procedure can lead to systematic differences of over 10% in the flux values. Even more difficult is to quantify the effect of the possible violations on the basic assumptions of the method.

The annual methane emission from Siikaneva site, 12.6 g m$^{-2}$ yr$^{-1}$, is lower than the average methane emission of 30 g m$^{-2}$ yr$^{-1}$ from Finnish oligotrophic treeless fens estimated by Minkkinen et al. (2002) and the average emission of 21 g m$^{-2}$ from Eurasian fens estimated by Huttunen et al. (2003). Compared to the annual carbon dioxide balance of the site (Table 1) the carbon emitted annually as methane, 9.4 g C m$^{-2}$, is a significant part of the total carbon balance of the fen. The effect of the methane emission on the radiative forcing can be estimated by using its greenhouse warming potential (GWP), expressed as $CO_2$-equivalents. Using the greenhouse warming potential of 100-yr time horizon (GWP$_{100}$, Albritton et al., 1996), the greenhouse warming potential of the annual methane emission is 264 g $CO_2$-eq. m$^{-2}$. It is noteworthy that the estimated effect of the methane emission from wetlands on the radiative forcing, against that of the carbon sequestration, depends strongly on the time horizon used for the calculations (Whiting and Chanton, 2001). The change of radiative forcing due to any change in the fluxes of carbon dioxide and methane would be likely dominated in the short-term by the effects caused by methane. However, the sustained carbon sequestration since the end of the last glacial has more than compensated the methane emissions, as discussed by Frolking et al. (2006).

The annual methane emission was dominated by the emission during the seven-month long snow-free period, with wintertime emissions contributing considerably less (Table 2). In the April, as the snow and ice melted, the emission of methane was

*Table 2.* Contribution of seasonal methane fluxes to the annual emission, and the excess emission during the snow melt period (see text)

| Season | Period (day of year/year) | Length of the period (days) | Emission (g $m^{-2}$) | Percentage |
|---|---|---|---|---|
| Winter | 60/2005 – 91/2005 and 335/2005 – 59/2006 | 122 | 0.72 | 5.7% |
| Snow melt (excess) | 92/2005 – 118/2005 | 27 | 0.43 (0.27) | 3.4% (2.2%) |
| Snow free period | 119/2005 – 334/2005 | 216 | 11.4 | 90.9% |
| Annual total | 60/2005 – 59/2006 | 365 | 12.6 | 100% |

considerably higher than what would be predicted by the peat temperature. This spring-time emission pulse, previously observed by Hargreaves et al. (2001), is a result of release of methane accumulated below the ice during the winter months. Even though there is an emission of the methane throughout the winter, the resistance in the emission path is higher during the winter due to the frozen surface and snow on top of the fen, and the collapsed structure of the aerenchymatous plants after senescence, which leads to increased methane concentrations in the peat. The effect of spring pulse on the total annual methane balance was investigated by calculating the expected emission during the pulse using the regression between emission and the peat temperature obtained above. Subtracting the expected emission from the actual measured emission gave us the excess emission during the spring pulse to be 0.27 g $m^{-2}$, which is 2.1% of the annual emission (Table 2). Thus, at least at this site with relatively short and mild winter, the omission of the spring pulse does not have a significant effect on the annual balance. Furthermore, the annual balances derived from soil enclosure measurements, which cannot usually catch this phenomenon reliably, would not be significantly affected by the omission. At sites with longer winter period and thicker snow and ice cover, such as the Kaamanen mire in the Finnish Lapland studied by Hargreaves et al. (2001), the spring pulse may have a more pronounced effect on annual methane emission.

## 4. Conclusions

We operated the eddy covariance measurement system for methane continuously during a full annual cycle on a boreal fen in Southern Finland. Despite few data gaps due to technical problems, the data cover all parts of the annual cycle. The system proved to be able to measure even the low methane fluxes during the winter and was able to capture the emission pulse during the snow-melting period.

Methane emission showed to be an important part of the carbon balance of the boreal fen, as over 20% of the carbon accumulated as carbon dioxide during the year was emitted as methane. Thus methane emission is significant not only for the greenhouse warming potential balance, but also as a component of the carbon balance of the fen. Most of the methane was emitted during the snow-free period, whereas the emission during the winter had a smaller significance. The emission pulse during the snow melt was of minor importance to the annual emission.

No diurnal pattern of the methane emission was found. Peat temperature exerted an expected control on the measured methane emission during a large part of the year. In contrast, no clear effect of water table depth on the emission was found. This is consistent with the theory of aerenchyma of the sedges acting as the main transport route of the methane from the peat into the atmosphere. No relationship between the temperature and methane emission was observed during the warmest period of the year.

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