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Shifting environmental controls on CH₄ fluxes in a sub-boreal peatland

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Abstract

We monitored CO₂ and CH₄ fluxes using eddy covariance from 19 May to 27 September 2011 in a poor fen located in northern Michigan. The objectives of this paper are to: (1) quantify the flux of CH₄ from a sub-boreal peatland, and (2) determine which abiotic and biotic factors were the most correlated to the flux of CH₄ over the measurement period. Net daily CH₄ fluxes increased from 70 mg m⁻² d⁻¹ to 220 mg m⁻² d⁻¹ from mid May to mid July. After July, CH₄ losses steadily declined to approximately 50 mg m⁻² d⁻¹ in late September. During the study period, the peatland lost 17.4 g CH₄ m⁻². Both abiotic and biotic variables were correlated with changes in CH₄ flux. When the different variables were analyzed together, the preferred model included mean daily soil temperature at 20 cm, daily net ecosystem exchange (NEE) and the interaction between mean daily soil temperature at 20 cm and NEE ($R^2 = 0.47$, p value < 0.001). The interaction was important because the relationship between daily NEE and mean daily soil temperature with CH₄ flux changed in conjunction with changes in daily NEE. On days when daily NEE was negative, 25 % of the CH₄ flux could be explained by changes in NEE, however on days when daily NEE was positive, there was no correlation between daily NEE and the CH₄ flux. In contrast, daily mean soil temperature at 20 cm was poorly correlated to changes in CH₄ when NEE was negative (17 %), but the correlation increased to 34 % when NEE was positive. The interaction between daily NEE and mean daily soil temperature at 20 cm indicates shifting environmental controls on the CH₄ flux throughout the growing season.

1 Introduction

Peatlands are a critical component in the global carbon (C) cycle because they represent a long-term sink of atmospheric carbon dioxide (CO₂) (Gorham, 1991; Roulet, 2000). Today, soil C stocks in peatlands are estimated to represent 224 to 455 Pg (1 Pg = 10¹⁵ g), equal to 12–30 % of the global soil C pool (Botch et al., 1995; Clymo

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et al., 1998; Gorham, 1991; Lappalainen, 1996; Moore et al., 1998; Zoltai and Martikainen, 1996). Moreover, peatland ecosystems currently sequester an estimated 76 Tg (10^{12} g) $C^{-1} yr^{-1}$ (Vasander and Kettunen, 2006; Zoltai and Martikainen, 1996). Peatlands are also a significant source of methane (CH_4) because of the anaerobic conditions in the often saturated peat (Roulet, 2000). However, because many of the world's peatlands are located in northern climates where temperature and precipitation are expected to experience rapid change (IPCC, 2007; Räisänen, 1997), the fate of the stored carbon in peatlands is now in question (e.g. Frolking et al., 2011).

Methane is produced when CO_2 , or simple carbon substrates, such as acetate, are reduced under anaerobic conditions by obligate anaerobes (Valentine et al., 1994). Past research has identified both water table position (e.g. Bubier et al., 1993; Hargreaves and Fowler, 1998; Pelletier et al., 2007; Roulet et al., 1992) and soil temperature (e.g. Lai, 2009; Long et al., 2010; Rinne et al., 2007) as important abiotic variables that influence the production of CH_4 . Water table position is an important driver because of the low solubility and rate of molecular diffusion of atmospheric oxygen in water, thereby limiting aerobic respiration production, and facilitating CH_4 production (e.g. Liblik et al., 1997; Moore et al., 1998; Silvola et al., 1996). Soil temperature is also important as temperature influences the rate of CH_4 production by methanogens (e.g. Valentine et al., 1994). However, the change in CH_4 production as a function of abiotic drivers can be modified by peat quality, with greater carbon lability resulting in higher temperature responses (Moore and Knowles, 1989; Updegraff et al., 1995). Hence, past work on ecosystem CH_4 production in peatlands have reported a strong correlation between net ecosystem productivity (NEP) and CH_4 efflux (Lai, 2009). As plant production increases, it is theorized, that a greater quantity of labile carbon for CH_4 is made available via root exudates or plant litter (e.g. Joabsson and Christensen, 2001; Waddington et al., 1996; Whiting and Chanton, 1993). While all of these abiotic and biotic drivers are important, throughout the year, one driver may exert a greater influence on CH_4 production. For example, in northern latitudes, CH_4 production in peatlands is strongly influenced by soil temperature (Christensen et al., 2004; Turetsky et al.,

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2008b), whereas at the more southern limits, biological processes that produce CH₄ may be less sensitive to changes in temperature (Johnson et al., 2013; White et al., 2008). In addition to temperature, water table position and NEP, CH₄ emission have also been found to respond to nutrient levels, pH, abundance of other terminal electron
5 acceptors, vegetation community structure and oxidation potential (Bubier, 1995; Liblik et al., 1997; Moore and Knowles, 1989; Segers, 1998; Silvola et al., 1996; Valentine et al., 1994).

In peatlands, the response of CH₄ fluxes to abiotic and biotic drivers have primarily been studied using chamber techniques (Lai, 2009). This technique can provide
10 comparisons between sites, but it typically does not continuously capture the flux of CH₄ over the course of a whole day unless automated chambers are used. Typically researchers monitor the flux of CH₄ during a specified period of time (e.g. 1000 h to 1600 h) and then maybe quantify the diurnal fluxes over a few select days. Chambers also provide limited spatial representation of the site as the measurements are often
15 limited to fewer than 20 locations within the peatland (Lai, 2009). The eddy covariance technique provides an ideal method for quantifying the flux of CH₄ continuously and it integrates the flux of CH₄ from the site.

We deployed an eddy covariance tower in a *Sphagnum* dominated peatland located in Northern Michigan, USA to understand the importance of different abiotic and biotic
20 factors in controlling CH₄ efflux from peatlands. The peatland is located at the southern limit of the sub-boreal peatlands. This region is expected to experience 3–5 °C change in temperature by 2100 (IPCC, 2007). Unlike high latitude peatlands, there have been fewer studies reporting the factors controlling CH₄ fluxes from peatlands at their southern limit. The objectives of this project were to: (1) quantify the flux of CH₄
25 from a sub-boreal peatland, and (2) determine which abiotic and biotic factors were the most important in controlling the flux of CH₄ over the growing season. Because the substrate quality is low in poor fens, we hypothesize that the NEP has a greater control on CH₄ efflux relative to peat temperature during the growing season when NEP is positive.

2 Methods

2.1 Study site

The study site is located within the boundaries of Seney National Wildlife Refuge (NWR). Seney NWR is relatively flat with a southeast slope of 1.9 m km^{-1} , and is part of the 3797 km^2 Manistique Watershed (USFWS, 2009). Seney NWR is covered by open peatlands, lowland swamps, and upland forests (USFWS, 2009). Underlying deposits include sand over Ordovician sandstone, limestone, and dolomite. Dominant vegetation at the study site consists of a ground cover of *Sphagnum* sp. (*S. angustifolium*, *S. capillifolium*, *S. magelanicum*), with an overstory of vascular species. The dominant vascular vegetation consists of *Carex oligosperma*, *Eriophorum vaginatum*, and *Ericaceae* (e.g. *Chamaedaphne calyculata*, *Ledum groenlandicum*, *Kalmia polifolia*, and *Vaccinium oxycoccus*). Upland areas are generally mixed hardwood forests with varying tree species, including American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), red pine, eastern white pine, jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) B.S.P.) and balsam fir (*Abies balsamea* (L.) Mill.) (USFWS, 2009). Hydrology, fire, and human disturbance interact with the surficial geology to influence the plant communities at Seney NWR (Bork et al., 2013; Drobyshev et al., 2008a, b). In the 1930s and 1940s, the refuge constructed a number berms and road networks for the establishment of ponds for wildlife. The study site is located in the southern portion of Seney NWR and has greater than 200 m of continuous fetch in the dominant wind sector, with only 100 m from the lateral wind sectors. The site is classified as a poor fen and has a pH of 3.77 ± 0.02 and has an average microtopographical variation of $0.30 \pm 0.08 \text{ m}$. The climate is strongly influenced by Lake Superior and Lake Michigan, with an annual precipitation of 810 mm. Temperatures in the area range from -37°C to 36°C , with an average temperature of 5°C (USFWS, 2009; Wilcox et al., 2006).

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USA) mounted 0.7 m above the surface. WT levels were measured hourly in 1.5 m deep wells using self-logging Levellogger Junior pressure transducers (Solinst, Georgetown, ON (Solinst)). WT measurements were corrected for changes in atmospheric pressure using a Barologger Gold barometric logger (Solinst).

2.3 High-frequency data processing and corrections

Prior to calculating half-hour covariances, high-frequency EC measurements were subjected to a spike detection algorithm analogous to that presented in Vickers and Mahrt (1997), where spikes were identified when a measurement exceeded the recursive mean by a standard deviation of 2.6 (also derived recursively). The mean was constructed as a recursive digital filter (Kaimal and Finnigan, 1994):

$$\tilde{c}_t = \left(1 - \frac{\Delta t}{\tau_f}\right) \tilde{c}_{t-1} + \frac{\Delta t}{\tau_f} c_t \quad (1)$$

where c_t is the measured value at time t , Δt is the incremental time step between measurements (0.1 s), and τ_f is the RC filter time constant (60 s). The cut-off for spike detection is lower than the typical 3–5 SD range reported by others (e.g. Baldocchi et al., 1997; Humphreys et al., 2006; Vickers and Mahrt, 1997) because, given the above time constant, the recursive mean is more responsive to coherent transient departures from the long-term mean compared to block averaging.

Sonic anemometer wind vectors were mathematically rotated based on the tilt correction algorithms presented by Wilczak et al. (2001), also known as the planar fit method. The planar fit method helps to address the problem of over-rotation in sloping terrain associated with the more commonly used method of Tanner and Thurtell (1969) as outlined by Foken et al. (2004).

Before calculating energy and mass fluxes, a time lag was introduced into the appropriate mass or energy time series in order to maximize the average covariance with the rotated vertical wind speed. Due to the large amount of noise in the CH₄ signal, the lag was restricted to 5 s, where Detto et al. (2011) show a relatively constant time

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lag of 0.9 s for a LI-7700. In the absence of a definitive peak cross-correlation within ± 5 s, the previous time lag was used. In addition to flux loss that results from the asynchrony in the measured time series due to finite instrument processing times, spectral transfer functions were used to correct for high-frequency spectral losses that result from sensor separation, line and volume averaging, and digital filtering. Frequency response corrections were calculated according to the analytical solutions presented in Massman (2000) and applied to despiked, rotated, and lagged covariances.

Errors in EC flux measurements associated with variations in air density due to changing temperature and humidity were corrected based on the method outlined by Webb et al. (1980), and took the following general form:

$$F_x = F_{x0} + \mu \frac{E}{\rho_d} \frac{\rho_x}{1 + \mu\sigma} + \kappa \frac{H}{\rho_a} \frac{\rho_x}{C_p T_a} \quad (2)$$

where F_x and F_{x0} are the corrected and uncorrected flux of x (CO₂ and CH₄), μ is the ratio of the molar mass of air and water, E and H are the mean WPL-corrected latent and sensible heat fluxes, ρ is density where the subscripts “a”, “d”, and “v” represent mean values for ambient air, dry air, and water vapour respectively, $\sigma = \rho_v/\rho_a$, T_a is air temperature, and κ is 1 for CO₂ and equal to the WPL-H multiplier in the LI-7700 manual which corrects for temperature and pressure spectroscopic effects. The sensible heat flux used in the WPL correction is itself dependent on air density fluctuations when measured using a sonic-anemometer. Sonic temperatures were thus corrected using the method of Kaimal and Finnigan (1994).

2.4 Quality assurance and gap filling

Half-hour flux measurements were rejected based on a number of statistical and physical environmental conditions. Basic statistical criteria for rejection of fluxes were based on second, third, and fourth-moment statistics. The thresholds for skewness and kurtosis were based both on those presented by Vickers and Mahrt (1997) and measured empirical probability distributions. A site dependent friction velocity (u^*) threshold of

$\sim 0.08 \text{ ms}^{-1}$ was used as a basic rejection criterion for removing measurements made under conditions without well developed turbulence. Although data was not explicitly rejected during periods of rainfall, data during this period was often rejected as a result of the aforementioned statistical criteria. Finally, half-hourly CO_2 fluxes were rejected if nighttime ($\text{PPFD} \leq 10 \mu\text{mol m}^{-2} \text{ s}^{-1}$) measurements indicated uptake. Negative half-hourly CH_4 fluxes were similarly rejected.

A comprehensive data quality flagging system was also used to identify half-hours with high-quality, questionable, and bad data (Foken et al., 2004). Data quality was assessed based on integral turbulence characteristics, stationary (Foken and Wichura, 1996), and wind direction, where wind-sectors down-wind of the tower were considered inappropriate.

In order to calculate growing season net CO_2 fluxes, missing data was filled using an artificial neural network (ANN). ANNs have been shown to be suitable for gap-filling EC CO_2 flux data (Moffat et al., 2007) where standard meteorological and soil variables were used as driving variables. Day and night time gaps were modelled separately, where the disparity in available data for these two time periods would result in a bias towards daytime conditions during ANN calibration and validation. Due to poorer correlation with measured environmental variables, a simple look-up table based on peat temperature and moisture was used to fill missing CH_4 flux data.

2.5 Statistics

Statistics were completed in JMP 1.0 (SAS Institute Inc., Cary, NC, USA). To compare individual abiotic and biotic variables with changes in CH_4 production we used linear and non-linear regressions. When creating a model to indentify the combined explanatory power of the different variables and their interactions, we used multiple linear regression.

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3 Results

3.1 Meteorological variables

From 19 May to 27 September 2012, mean daily air temperature rose from approximately 10 °C in mid May, to maximum of approximately 25 °C in late July (Fig. 1a). Mean daily soil temperature at 20 cm rose from below 10 °C in May to above 17 °C in early August (Fig. 1b). During the measurement period, precipitation totaled 290 mm (Fig. 1c). June received the most precipitation (97 mm), but each month received at least 47 mm of rainfall. WT position steadily declined throughout the measurement period, falling from 5 cm below the surface in late May, to approximately 40 cm below the surface in mid September (Fig. 1d). WT position responded to precipitation events, particularly those in excess of 20 mm.

3.2 Seasonal and diurnal CH₄ and CO₂ fluxes

Net daily CH₄ and daily net CO₂ flux (NEE) followed a similar pattern during the measurement period (Fig. 2). From 19 May to 27 September, daily NEE increased from -1 gm⁻² d⁻¹ in mid May, to a peak of -7.7 gm⁻² d⁻¹ in late July (Fig. 2a). Daily NEE steadily declined after late July. After the beginning of September, daily NEE ranged from approximately -4.4 to 3.4 gm⁻² d⁻¹. CH₄ losses to the atmosphere increased from 70 mgm⁻² d⁻¹ to 220 mgm⁻² d⁻¹ from mid May to mid July. After July, CH₄ losses steadily declined to approximately 50 mgm⁻² d⁻¹ in late September. The mean net daily CH₄ efflux was 152, 192, 130 and 66 mgm⁻² d⁻¹ for June, July, August and September, respectively. The peatland lost 17.4 gm⁻² of CH₄ during the study period. Diurnally, NEE followed a typical trend, with mean diurnal NEE during the study period ranging from 2.0 μmolm⁻² s⁻¹ at night to -3.8 μmolm⁻² s⁻¹ during midday (Fig. 3a). In contrast, there was little diurnal variation in magnitude of the net diurnal CH₄ flux over the study period. Mean diurnal net CH₄ effluxes ranged between 90 and 112 mgm⁻² s⁻¹ (Fig. 3b). However, there was more variability in the net CH₄ flux at night.

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3.3 Environmental and biological controls of CH₄ fluxes

Individually, mean daily soil temperature at 20 cm, mean daily air temperature, WT position and daily NEE were all correlated with changes in net daily CH₄ flux (Figs. 4–6). Over the entire measurement period, both mean daily air temperature ($R^2 = 0.25$, p value < 0.0001) and mean daily soil temperature at 20 cm ($R^2 = 0.24$, p value > 0.0001) were significantly correlated with net daily CH₄ fluxes (Fig. 4a and b). The Q_{10} values for CH₄ emissions for mean daily soil temperature at 20 cm and mean daily air temperature were 2.0 and 1.7, respectively. WT position also controlled CH₄ emissions. When the WT position was within 30 cm of the surface, the net daily CH₄ flux remained high (Fig. 4c). However, once the WT position dropped below 30 cm, the net daily CH₄ flux declined. This may occur, in part, because the deeper WT positions correlated to later in the season when mean daily air temperatures were low (Fig. 1). To correct for this, we used the Q_{10} value to adjust the net daily CH₄ fluxes to what the flux would be predicted to be at 15 °C. The difference between the predicted flux and the actual flux were then compared to the changing WT position (Fig. 5). When changes in mean daily air temperature are accounted for using the Q_{10} value, decreases in WT position were significantly associated with a decline in net daily CH₄ fluxes, but the explanatory power was weak ($R^2 = 0.06$; p value < 0.01) (Fig. 5). Lastly, as daily NEE became more negative, net daily CH₄ fluxes to the atmosphere increased (Fig. 6). From 19 May to 27 September 2012, changes in daily NEE explained 28 % of the changes in net daily CH₄ fluxes measured the same day ($R^2 = 0.28$, p value < 0.0001). While mean daily air temperature, mean daily soil temperature at 20 cm depth, WT position and daily NEE were all individually associated with changes in net daily CH₄ fluxes, the individual R^2 values were very low, thereby suggesting that multiple regression would better explain the changes in the net daily CH₄ flux.

When the different variables were analyzed together, stepwise forward linear regression using either AIC or BIC found mean daily air temperature, daily NEE and the interaction between mean daily air temperature and daily NEE was the preferred model

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choice ($R^2 = 0.48$, p value < 0.0001). However, the model that included daily NEE, mean daily soil temperature at 20 cm and the interaction between daily NEE and mean daily soil temperature at 20 cm had an R^2 of 0.47 (p value < 0.001). Given the nearly identical R^2 , the more direct biological connection between soil temperature and CH₄ flux, and the strong correlation between mean daily soil temperature and mean daily air temperature ($R^2 = 0.65$), we chose to proceed with a model that included mean daily soil temperature and daily NEE. Because of the significant interaction between daily NEE and mean daily soil temperature, we analyzed the relationship between the net daily CH₄ efflux to both daily NEE and daily mean soil temperature on days when daily NEE was negative and positive (Fig. 7). Net daily CH₄ fluxes were strongly correlated to daily NEE when daily NEE was negative ($R^2 = 0.25$, p value < 0.001) (Fig. 7a). However, when daily NEE was positive, there is no correlation between daily NEE and net daily CH₄ fluxes ($R^2 = 0.00$, p value > 0.75) (Fig. 7b). In contrast, a relationship between mean daily soil temperature and net daily CH₄ fluxes only explain 17 % of the variance in net daily CH₄ is when daily NEE was negative (p value < 0.001) (Fig. 7c), but when daily NEE was positive, changes in mean daily air temperature explain 34 % of the change in net daily CH₄ fluxes (p value < 0.001) (Fig. 7d).

4 Discussion

4.1 Growing season CH₄ fluxes

Daily CH₄ fluxes during the growing season for bogs and poor fens often range from less than 20 mg m⁻² d⁻¹ (e.g. Moore and Knowles, 1990; Roulet et al., 1992; Shannon and White, 1994) to greater than 200 mg m⁻² d⁻¹ (e.g. Moore et al., 1994). The CH₄ effluxes in this study are on the upper end of the reported fluxes for bogs and poor fens, with fluxes ranging from 100 mg m⁻² d⁻¹ to greater than 225 mg m⁻² d⁻¹. From 19 May to 27 September, fluxes totaled 17.4 g m⁻², suggesting that these sites are a significant source of CH₄ during the spring and summer months. During the winter months, the

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WT position typically rises and the deep snow pack prevents freezing. The combination of a high WT position and above freezing temperatures could promote CH₄ fluxes from the peatland throughout the winter. For example, past work in a restored wetland in Denmark (Herbst et al., 2011) and sub-arctic peatland in Greenland (Jackowicz-Korczynski et al., 2010) demonstrate that when the soils do not freeze, CH₄ efflux can still be maintained between 1 and 10 mg m⁻² d⁻¹. If the site maintained a CH₄ flux between 5 and 50 mg m⁻² d⁻¹ during the period outside the measurement period, this peatland would average between 17.6 and 18.6 g m⁻² yr⁻¹.

4.2 Varying controls on CH₄ fluxes

Past work demonstrates that air temperature and soil temperature are strongly correlated to changes in CH₄ efflux (e.g. Godin et al., 2012; Lai, 2009; Segers, 1998). In our study, both mean daily air and soil temperatures at 20 cm depth were correlated to changes in CH₄ flux (Fig. 4a, b). Past work has found Q_{10} values to range between 1.5 to 16 (Lai, 2009). Our Q_{10} values ranged between 1.7 and 2.0 for mean daily soil and air temperatures, respectively, which is on the lower end of previous measurements. WT position remained favourable for CH₄ emission for much of the measurement period, ranging between 10 and 40 cm below the surface, thereby allowing temperature to influence CH₄ production. The sensitivity of the CH₄ efflux to changing temperature may have been partially mitigated by the low pH or low quality substrate. Past work has demonstrated that most methanogenic bacteria have an optimum CH₄ production at a pH between 6 and 8, with production declining at a pH more typical of a poor fen or bog (Garcia et al., 2000; Williams and Crawford, 1984). Furthermore, decreases in substrate quality tended to reduce the Q_{10} value (Dunfield et al., 1993; Valentine et al., 1994).

As WT position increased from 10 to 30 cm below the surface, CH₄ efflux increased. Initially this may appear to contradict literature demonstrating that shallower water tables result in greater CH₄ efflux (Bubier et al., 1993; Hargreaves and Fowler, 1998;

Pelletier et al., 2007; Roulet et al., 1992). However, after adjusting for the effect of temperature, WT position was weakly, but significantly correlated to changes in CH₄ flux. Past work has also demonstrated that lowering WT positions can be associated with greater CH₄ efflux (e.g. Bellisario et al., 1999; Treat et al., 2007). The association between lower WT position and higher CH₄ efflux could result from higher substrate temperatures, as in this study, or because the lower WT position reduces pressure, thereby allowing gas bubbles to be released (Kellner et al., 2004; Strack et al., 2005).

4.3 Substrate quality

Past research has shown that substrate quality and availability controls CH₄ fluxes if the WT position is sufficiently high (e.g. Basiliko and Yavitt, 2001; Coles and Yavitt, 2002; Godin et al., 2012; Yavitt and Seidmann-Zager, 2006). Our results strongly support this past work. Throughout the growing season, days with high daily NEE were associated with increased emissions of CH₄. The peat at this study site is primarily composed of *Sphagnum* moss which decomposes slowly (Hajek et al., 2011; Turetsky et al., 2008a; van Breemen, 1995). However, during the summer months, plant productivity increases considerably as daily NEE increases to $-7.7 \text{ g m}^{-2} \text{ d}^{-1}$. This increase in plant productivity may input higher quality carbon into the system, thereby priming either CO₂ respiration in oxic sites and CH₄ production in anoxic locations. Measurements of dissolved organic carbon (DOC) at this site in 2011 found that DOC peaked during the summer months, suggesting that there may have been more available labile carbon (Hribljan, 2012). Furthermore, past chamber-based work has consistently supported a trend of increasing CH₄ production with increasing NEE (e.g. Alm et al., 1997; Bellisario et al., 1999; Waddington et al., 1996; Whiting and Chanton, 1993). Our results build upon past work as the data from the eddy covariance tower suggests the influence of daily NEE and mean daily soil temperature at 20 cm depth on CH₄ fluxes depends on the amount of CO₂ that is sequestered. On days where daily NEE is above zero, mean daily soil temperature exerts a much larger influence on CH₄ efflux (Fig. 7d), but when daily NEE is negative, then daily NEE is strongly associated with

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changes in CH₄ efflux (Fig. 7a, c). This suggests that the input of more labile carbon by the plant roots is priming the system to produce more CH₄. The CH₄ below the water table may diffuse to the surface or may pass the oxic zone through the aerenchyma tissue of the sedges (Joabsson et al., 1999; Waddington et al., 1996). In contrast, on days when there is little carbon fixation, then the influence of abiotic factors, such as soil temperature, exerts more of an influence.

5 Conclusions

This peatland is located at the southern-limit of sub-boreal peatlands and the CH₄ losses during the growing season are high, relative to other peatlands. The losses of CH₄ were correlated to both changes in mean daily soil temperature at 20 cm, daily NEE and the interaction between mean daily soil temperature and daily NEE. The influence of the two variables changed when NEE was negative or positive. When daily NEE was negative, ecosystem carbon uptake had a greater influence on CH₄ fluxes than when daily NEE was positive. When daily NEE was positive, the correlation between mean daily soil temperature at 20 cm depth increased. The interaction between NEE and mean daily soil temperature has implications for the loss of CH₄ from this peatland under future climate conditions. As NEE varies because of a warmer climate, the changes in NEE may counteract or reinforce some of the effects increased soil temperature will have on CH₄ fluxes. Furthermore, changes in the temperature and hydrology of this system may alter the vegetation, which will subsequently affect NEE, and the pathway for CH₄ to the atmosphere.

References

Alm, J., Talanov, A., Saarnio, S., Silvola, J., Ikkonen, E., Aaltonen, H., Nykanen, H., and Martikainen, P. J.: Reconstruction of the carbon balance for microsites in a boreal oligotrophic pine fen, Finland, *Oecologia*, 110, 423–431, 1997.

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- Baldocchi, D., Valentini, R., Running, S., Oechel, W., and Dahlman, R.: Strategies for measuring and modelling carbon dioxide and water vapour fluxes over terrestrial ecosystems, *Glob. Change Biol.*, 2, 159–168, 1996.
- Baldocchi, D. D., Vogel, C. A., and Hall, B.: Seasonal variation of carbon dioxide exchange rates above and below a boreal jack-pine forest, *Agr. Forest Meteorol.*, 83, 147–170, 1997.
- Basiliko, N. and Yavitt, J. B.: Influence of Ni, Co, Fe, and Na additions on methane production in Sphagnum-dominated Northern American peatlands, *Biogeochemistry*, 52, 133–153, 2001.
- Bellisario, L. M., Bubier, J. L., Moore, T. R., and Chanton, J. P.: Controls on CH₄ emissions from a northern peatland, *Global Biogeochem. Cy.*, 13, 81–91, 1999.
- Bork, S. P., Pypker, T. G., Corace III, R. G., Chimner, R. A., MacLean, A. L., and Hribljan, J. A.: A case study in large-scale wetland restoration at Seney National Wildlife Refuge, Upper Michigan, USA, *Am. Midl. Nat.*, 169, 286–302, 2013.
- Botch, M. S., Kobak, K. I., Vinson, T. S., and Kolchugina, T. P.: Carbon pools and accumulation in peatlands of the former Soviet Union, *Global Biogeochem. Cy.*, 9, 37–46, 1995.
- Bubier, J. L.: The relationship of vegetation of methane emission and hydrochemical gradients in northern peatlands, *J. Ecol.*, 83, 403–420, 1995.
- Bubier, J. L., Moore, T. R., and Roulet, N. T.: Methane emissions from wetlands in the midboreal region of Northern Ontario, Canada, *Ecology*, 74, 2240–2254, 1993.
- Christensen, T. R., Johansson, T. R., Akerman, H. J., Mastepanov, M., Malmer, N., Friborg, T., Crill, P., and Svensson, B. H.: Thawing sub-arctic permafrost: Effects on vegetation and methane emissions; *Geophys. Res. Lett.*, 31, L04501, doi:10.1029/2003GL018680, 2004.
- Clymo, R. S., Turunen, J., and Tolonen, K.: Carbon accumulation in peatland, *Oikos*, 81, 368–388, 1998.
- Coles, J. R. P. and Yavitt, J. B.: L Control of methane metabolism in a forested northern wetland, New York State, by aeration, substrates, and peat size fractions, *Geomicrobiol. J.*, 19, 293–315, 2002.
- Detto, M., Verfaillie, J., Anderson, F., Xu, L. K., and Baldocchi, D.: Comparing laser-based open- and closed-path gas analyzers to measure methane fluxes using the eddy covariance method, *Agr. Forest Meteorol.*, 151, 1312–1324, 2011.
- Drobyshev, I., Goebel, P. C., Hix, D. M., Corace III, G., and Semko-Duncan, M. E.: Interactions among forest composition, structure, fuel loadings and fire history: a case study of red pine-dominated forests of Seney National Wildlife Refuge, Upper Michigan, *Forest Ecol. Manag.*, 256, 1723–1733, 2008a.

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- Drobyshev, I., Goebel, P. C., Hix, D. M., Corace III, G., and Semko-Duncan, M. E.: Pre- and post-European settlement fire history of red pine dominated forest ecosystems of Seney National Wildlife Refuge, Upper Michigan. *Can. J. Forest Res.*, 38, 2497–2514, 2008b.
- Dunfield, P., Knowles, R., Dumont, R., and Moore, T. R.: Methane production and consumption in temperate and sub-arctic peat soils – response to temperature and p H, *Soil Biol. Biochem.*, 25, 321–326, 1993.
- Foken, T. and Wichura, B.: Tools for quality assessment of surface-based flux measurements, *Agr. Forest Meteorol.*, 78, 83–105, 1996.
- Foken, T., Gockede, M., Mauder, M., Mahrt, L., Amiro, B. D., and Munger, J. W.: Post-field data quality control, in: *Handbook of Micrometeorology: a guide for surface flux measurement and analysis*, edited by: Lee, X., Massman, W., and Law, B., Kluwer, Dordrecht, 181–208, 2004.
- Frolking, S., Talbot, J., Jones, M. C., Treat, C. C., Kauffman, J. B., Tuittila, E. S., and Roulet, N.: Peatlands in the Earth's 21st century climate system, *Environ. Rev.*, 19, 371–396, 2011.
- Garcia, J. L., Patel, B. K. C., and Ollivier, B.: Taxonomic phylogenetic and ecological diversity of methanogenic Archaea, *Anaerobe*, 6, 205–226, 2000.
- Godin, A., McLaughlin, J. W., Webster, K. L., Packalen, M., and Basiliko, N.: Methane and methanogen community dynamics across a boreal peatland nutrient gradient, *Soil Biol. Biochem.*, 48, 96–105, 2012.
- Gorham, E.: Northern peatlands: role in the carbon cycle and probable responses to climatic warming, *Ecol. Appl.*, 1, 182–195, 1991.
- Hajek, T., Ballance, S., Limpens, J., Zijlstra, M., and Verhoeven, J. T. A.: Cell-wall polysaccharides play an important role in decay resistance of Sphagnum and actively depressed decomposition in vitro, *Biogeochemistry*, 103, 45–57, 2011.
- Hargreaves, K. J. and Fowler, D.: Quantifying the effects of water table and soil temperature on the emission of methane from peat wetlands at the field scale, *Atmos. Environ.*, 32, 3275–3282, 1998.
- Herbst, M., Friborg, T., Ringgaard, R., and Soegaard, H.: Interpreting the variations in atmospheric methane fluxes observed above a restored wetland, *Agr. Forest Meteorol.*, 151, 841–853, 2011.
- Humphreys, E. R., Lafleur, P. M., Flanagan, L. B., Hedstrom, N. R., Syed, K. H., Glenn, A. J., and Granger, R.: Summer carbon dioxide and water vapor fluxes across a range of northern peatlands, *J. Geophys. Res.*, 111, G04011, doi:10.1029/2005JG000111, 2006.
- IPCC: *Climate Change 2007: the Physical Science Basis*, Cambridge, 2007.

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- Jackowicz-Korczynski, M., Christensen, T. R., Backstrand, K., Crill, P., Friborg, T., Mastepanov, M., and Strom, L.: Annual cycle of methane emission from a subarctic peatland, *J. Geophys. Res.-Biogeo.*, 115, G02009, doi:10.1029/2008JG000913, 2010.
- Joabsson, A. and Christensen, T. R.: Methane emissions from wetlands and their relationship with vascular plants: an Arctic example, *Glob. Change Biol.*, 7, 919–932, 2001.
- Joabsson, A., Christensen, T. R., and Wallen, B.: Vascular plant controls on methane emissions from northern peatforming wetlands, *Trends Ecol. Evol.*, 14, 385–388, 1999.
- Johnson, C. P., Pypker, T. G., Hribljan, J. A., and Chimner, R. A.: Open top chambers and infrared lamps: a comparison of heating efficacy and CO₂/CH₄ dynamics in a northern Michigan peatland, *Ecosystems*, in press, doi:10.1007/s10021-013-9646-3, 2013.
- Kaimal, J. and Finnigan, J.: *Atmospheric Boundary Layer Flows: their Structure and Measurement*, Oxford University Press, New York, 1994.
- Kellner, E., Price, J. S., and Waddington, J. M.: Pressure variations in peat as a result of gas bubble dynamics, *Hydrol. Process*, 18, 2599–2605, 2004.
- Lai, D. Y. F.: Methane dynamics in northern peatlands: a review, *Pedosphere*, 19, 409–421, 2009.
- Lappalainen, E.: General review on world peatland and peat resources, *Global Peat Resources*, International Peat Society and Geological Survey of Finland, 53–56, 1996.
- Liblik, L. K., Moore, T. R., Bubier, J. L., and Robinson, S. D.: Methane emissions from wetlands in the zone of discontinuous permafrost: Fort Simpson, Northwest Territories, Canada, *Global Biogeochem. Cy.*, 11, 485–494, 1997.
- Long, K. D., Flanagan, L. B., and Cai, T.: Diurnal and seasonal variation in methane emissions in a northern Canadian peatland measured by eddy covariance, *Glob. Change Biol.*, 16, 2420–2435, 2010.
- Massman, W. J.: A simple method for estimating frequency response corrections for eddy covariance systems, *Agr. Forest Meteorol.*, 104, 185–198, 2000.
- Moffat, A. M., Papale, D., Reichstein, M., Hollinger, D. Y., Richardson, A. D., Barr, A. G., Beckstein, C., Braswell, B. H., Churkina, G., Desai, A. R., Falge, E., Gove, J. H., Heimann, M., Hui, D., Jarvis, A. J., Kattge, J., Noormets, A., and Stauch, V. J.: Comprehensive comparison of gap-filling techniques for eddy covariance net carbon fluxes, *Agr. Forest Meteorol.*, 147, 209–232, 2007.
- Moore, T. R. and Knowles, R.: The influence of water-table levels on methane and carbon-dioxide emissions from peatland soils. *Can. J. Soil Sci.*, 69, 33–38, 1989.

Shifting environmental controls on CH₄ fluxes

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- Moore, T. R. and Knowles, R.: Methane emissions from fen, bog and swamp peatlands in Quebec, *Biogeochemistry*, 11, 45–61, 1990.
- Moore, T. R., Heyes, A., and Roulet, N. T.: Methane emissions from wetlands, southern Hudson-Bay lowland, *J. Geophys. Res.-Atmos.*, 99, 1455–1467, 1994.
- 5 Moore, T. R., Roulet, N. T., and Waddington, J. M.: Uncertainty in predicting the effect of climatic change on the carbon cycling of Canadian peatlands, *Clim. Change*, 40, 229–245, 1998.
- Pelletier, L., Moore, T. R., Roulet, N. T., Garneau, M., and Beaulieu-Audy, V.: Methane fluxes from three peatlands in the La Grande Riviere watershed, James Bay lowland, Canada, *J. Geophys. Res.-Biogeo.*, 112, G01018, doi:10.1029/2006JG000216, 2007.
- 10 Räsänen, J.: Objective comparison of patterns of CO₂ induced climate change in coupled GCM experiments, *Clim. Dynam.*, 13, 197–211, 1997.
- Rinne, J., Riutta, T., Pihlatie, M., Aurela, M., Haapanala, S., Tuovinen, J. P., Tuittila, E. S., and Vesala, T.: Annual cycle of methane emission from a boreal fen measured by the eddy covariance technique, *Tellus B*, 59, 449–457, 2007.
- 15 Roulet, N. T.: Peatlands, carbon storage, greenhouse gases, and the Kyoto protocol: prospects and significance for Canada, *Wetlands*, 20, 605–615, 2000.
- Roulet, N. T., Ash, R., and Moore, T. R.: Low boreal wetlands as a source of atmospheric methane, *J. Geophys. Res.-Atmos.*, 97, 3739–3749, 1992.
- Segers, R.: Methane production and methane consumption: a review of processes underlying wetland methane fluxes, *Biogeochemistry*, 41, 23–51, 1998.
- 20 Shannon, R. D. and White, J. R.: 3-year study of controls on methane emissions from 2 michigan peatlands, *Biogeochemistry*, 27, 35–60, 1994.
- Silvola, J., Alm, J., Ahlholm, U., Nykanen, H., and Martikainen, P. J.: CO₂ fluxes from peat in boreal mires under varying temperature and moisture conditions, *J. Ecol.*, 84, 219–228, 1996.
- 25 Strack, M., Kellner, E., and Waddington, J. M.: Dynamics of biogenic gas bubbles in peat and their effects on peatland biogeochemistry, *Global Biogeochem. Cy.*, 19, GB1003, doi:10.1029/2004GB002330, 2005.
- Tanner, C. and Thurtell, G.: Anemoclinometer measurements of Reynolds stress and heat transport in the atmospheric surface layer, University of Wisconsin, Madison, Wisconsin, 1969.
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Treat, C. C., Bubier, J. L., Varnier, R. K., and Crill, P. M.: Timescale dependence of environmental and plant-mediated controls on CH₄ flux in a temperate fen, *J. Geophys. Res.-Biogeo.*, 112, G1014, doi:10.1029/2006JG000210, 2007.

Turetsky, M. R., Crow, S. E., Evans, R. J., Vitt, D. H., and Wieder, R. K.: Trade-offs in resource allocation among moss species control decomposition in boreal peatlands, *J. Ecol.*, 96, 1297–1305, 2008a.

Turetsky, M. R., Treat, C. C., Waldrop, M. P., Waddington, J. M., Harden, J. W., and McGuire, A. D.: Short-term response of methane fluxes and methanogen activity to water table and soil warming manipulations in an Alaskan peatland, *J. Geophys. Res.* 113, G00A10, doi:10.1029/2007JG000496, 2008b.

Updegraff, K., Pastor, J., Bridgham, S. D., and Johnston, C. A.: Environmental and substrate controls over carbon and nitrogen mineralization in northern wetlands, *Ecol. Appl.*, 5, 151–163, 1995.

USFWS: Seney National Wildlife Refuge Comprehensive Conservation Plan, Fort Snelling, MN, 2009.

Valentine, D. W., Holland, E. A., and Schimel, D. S.: Ecosystem and physiological controls over methane production in northern wetlands, *J. Geophys. Res.-Atmos.*, 99, 1563–1571, 1994.

van Breemen, N.: How *Sphagnum* bogs down other plants, *Trends Ecol. Evol.*, 10, 270–275, 1995.

Vasander, H. and Kettunen, A.: Carbon in boreal peatlands, in: *Boreal peatland ecosystems, Ecological Studies*, edited by: Wieder, R. K. and Vitt, D. H., Springer-Verlag, Heidelberg, 165–194, 2006.

Vickers, D. and Mahrt, L.: Quality control and flux sampling problems for tower and aircraft data, *J. Atmos. Ocean. Tech.*, 14, 512–526, 1997.

Waddington, J. M., Roulet, N. T., and Swanson, R. V.: Water table control of CH₄ emission enhancement by vascular plants in boreal peatlands, *J. Geophys. Res.-Atmos.*, 101, 22775–22785, 1996.

Webb, E. K., Pearman, G. I., and Leuning, R.: Correction of flux measurements for density effects due to heat and water-vapor transfer, *Q. J. Roy. Meteor. Soc.*, 106, 85–100, 1980.

White, J. R., Shannon, R. D., Weltzin, J. F., Pastor, J., and Bridgham, S. D.: Effects of soil warming and drying on methane cycling in a northern peatland mesocosm study, *J. Geophys. Res.-Biogeo.*, 113, G00A06, doi:10.1029/2007JG000609, 2008.

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Whiting, G. J. and Chanton, J. P.: Primary production control of methane emission from wetlands, *Nature*, 364, 794–795, 1993.

Wilcox, D. A., Sweat, M. J., Carlson, M. L., and Kowalski, K. P.: A water-budget approach to restoring a sedge fen affected by diking and ditching, *J. Hydrol.*, 320, 501–517, 2006.

5 Wilczak, J. M., Oncley, S. P., and Stage, S. A.: Sonic anemometer tilt correction algorithms, *Bound.-Lay. Meteorol.*, 99, 127–150, 2001.

Williams, R. T. and Crawford, R. L.: Methane production in Minnesota peatlands, *Appl. Environ. Microb.*, 47, 1266–1271, 1984.

10 Yavitt, J. B. and Seidmann-Zager, M.: Methanogenic conditions in northern peat soils, *Geomicrobiol. J.*, 23, 119–127, 2006

Zoltai, S. C. and Martikainen, P. J.: The role of forested peatlands in the global carbon cycle, in: *Forested Ecosystems, Forest Management and the Global Carbon Cycle*, edited by: Apps, A. J. and Price, D. T., NATO ASI Series, Series I, 47–58, 1996.

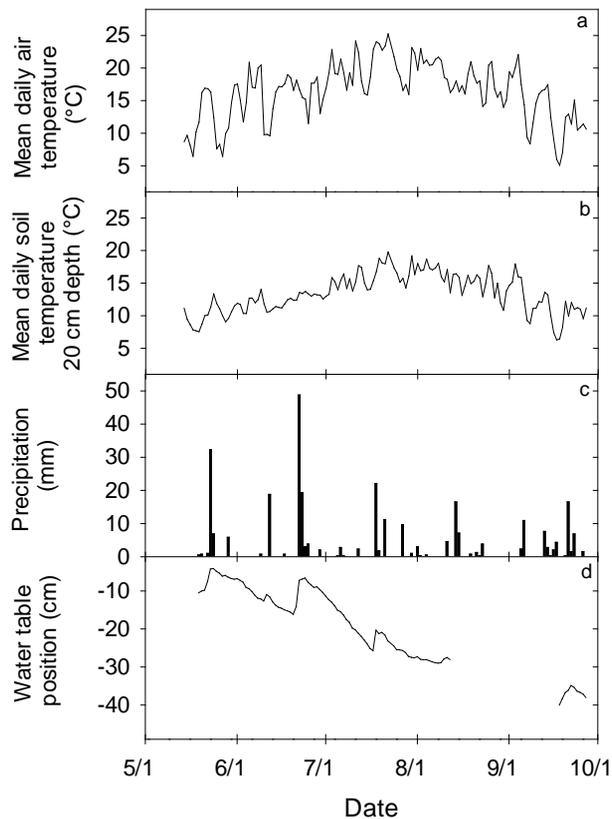


Fig. 1. Changes in Mean daily air temperature **(a)**, mean daily soil temperature **(b)**, precipitation **(c)**, and water table position relative to the surface **(d)** in a poor fen from 19 May to 27 September 2011.

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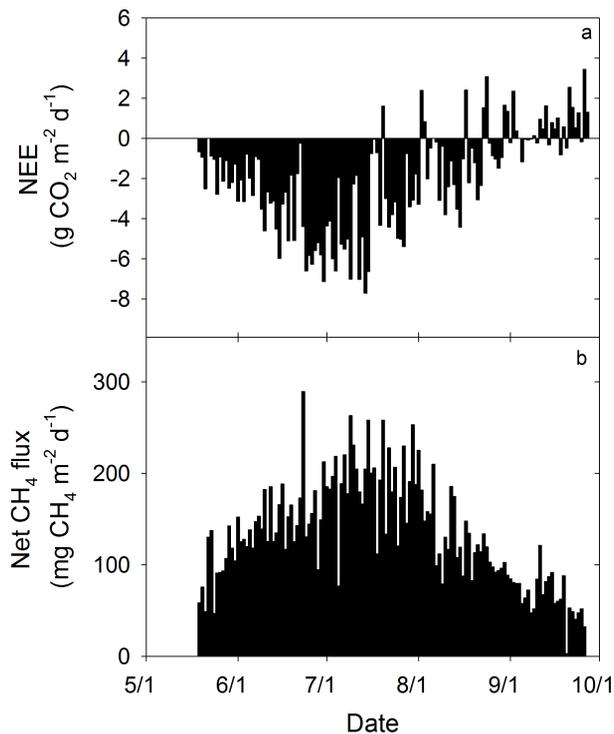


Fig. 2. Changes in daily net ecosystem CO₂ exchange (NEE) **(a)** and net daily CH₄ **(b)** fluxes from a poor fen from 19 May to 27 September 2011. The peatland is located in the Upper Peninsula of Michigan, USA.

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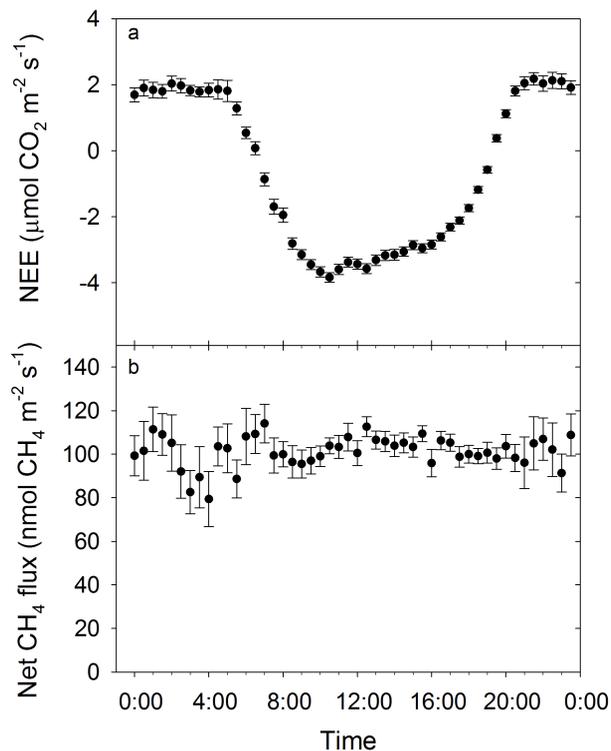


Fig. 3. Mean diurnal changes in net ecosystem CO₂ exchange (NEE) (a) and net CH₄ (b) fluxes for poor fen from 19 May to 27 September 2011. Error bars represent the standard error.

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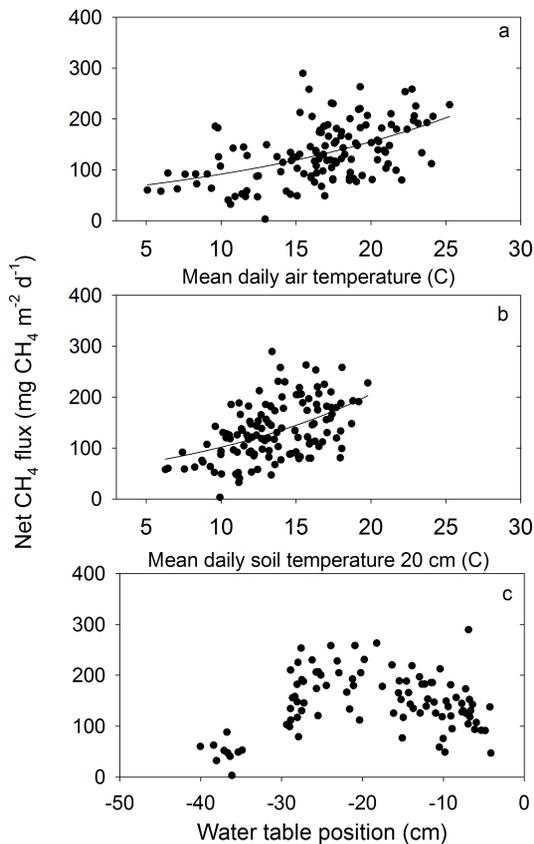


Fig. 4. Relationship between mean daily air temperature, mean daily soil temperature and water table position. There were significant exponential relationships between mean daily soil temperature ($50.3\exp^{0.070x}$, $R^2 = 0.23$, p value < 0.0001) and mean daily air temperature ($53.9\exp^{0.05x}$, $R^2 = 0.25$, p value < 0.0001).

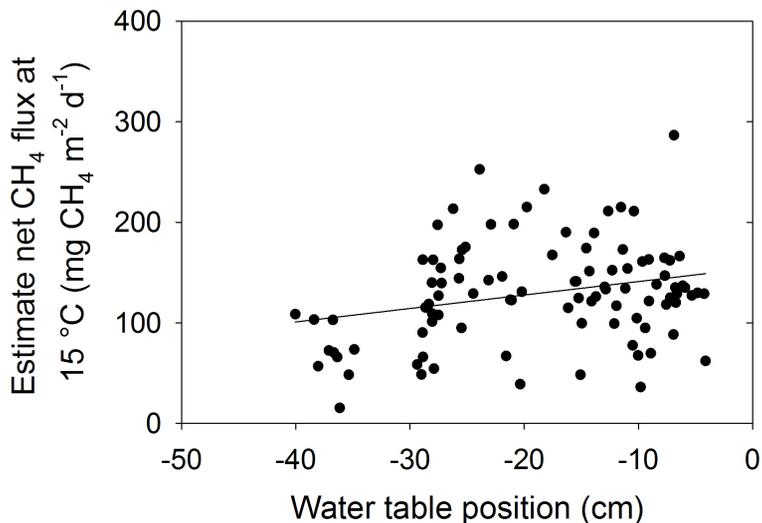


Fig. 5. The relationship between water table position and net CH₄ flux after accounting for mean daily air temperature. The net CH₄ flux at 15 °C was estimated using the exponential equation relating mean daily air temperature to the CH₄ flux (Fig. 4). The difference between the measured and predicted net CH₄ flux was then used in the graph above to determine if water table position had an impact on the net CH₄ flux after mean daily temperature effects were accounted for. The linear regression is significant, but the data explain very little of the variance ($R^2 = 0.06$).

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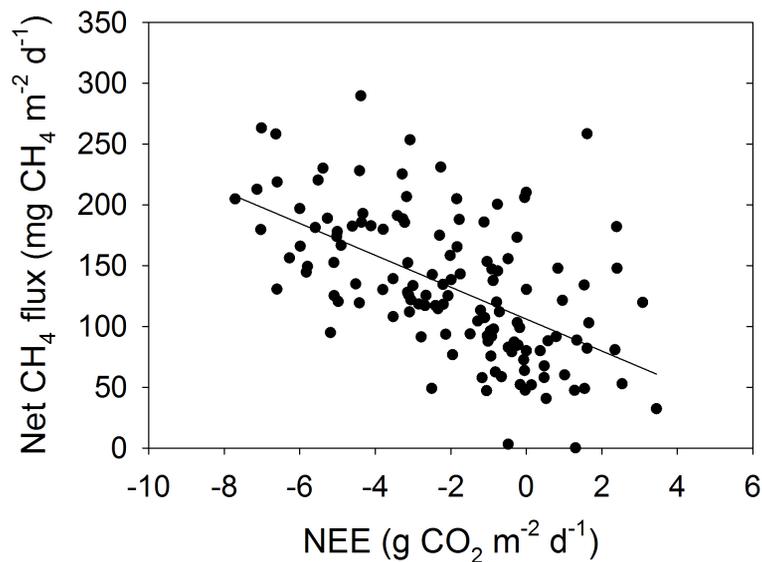


Fig. 6. Relationship between daily net ecosystem CO₂ exchange (NEE) and net daily CH₄ fluxes measured on the same day. Fluxes were measured from 19 May to 27 September 2012. The linear relationship has an R^2 of 0.28 and a p value < 0.0001 .

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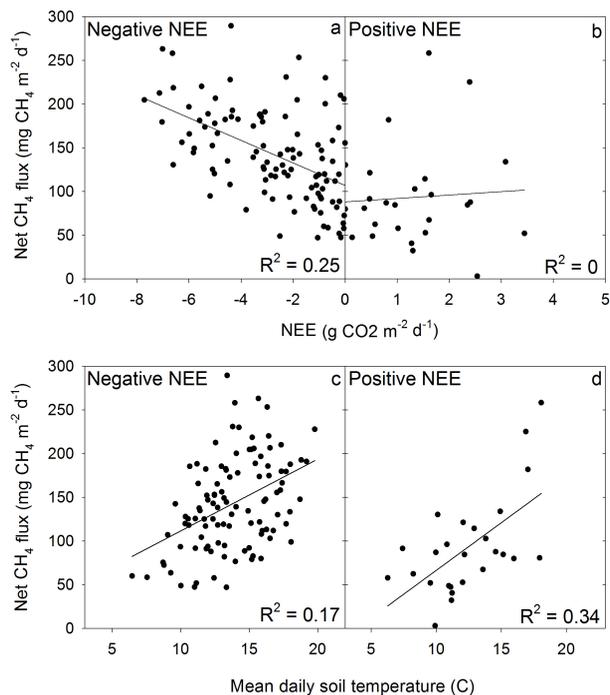


Fig. 7. The relationship between daily net ecosystem CO₂ exchange (NEE) (**a** and **b**) and mean daily air temperature (**c** and **d**) and net daily CH₄ fluxes for periods when daily NEE was negative (**a** and **c**) and positive (**b** and **d**).