Abstract. Methane emission from a wetland was measured with the eddy covariance system. The location of the system allowed observation of methane efflux from areas that were covered by different vegetation types. The data presented in this paper were collected in the period between the 13th of June and the 31st of August 2012. During the warmest months of the summer, there was no strong correlation between methane emissions and either the water table depth or peat temperature. The presence of reed and cattail contributed to a pronounced diurnal pattern of the flux and lower methane emission, while areas covered by sedges emitted higher amounts more with no clear diurnal pattern.

Keywords: eddy covariance, methane emission, wetland

INTRODUCTION

There is agreement among most scientists that the temperature increase observed recently in the atmosphere is related to the rise in the concentration of greenhouse gases (IPCC 2007), but simultaneously this statement is questioned by others (Kutilek, 2011). Methane from wetlands is one of the major sources of this gas in the atmosphere. After water vapour and carbon dioxide, methane is the third most important greenhouse gas, although its concentration in the atmosphere is two hundred times lower than that of CO2. Taking into account the atmospheric lifetime of methane (12 years) and its radiative properties, we arrive at the Global Warming Potential (GWP) of methane being 25 times that of carbon dioxide (emission of 1 g of CH4 is equal to 25 g of CO2) for 100-year time horizon. Both CH4 and CO2 are the major components of the wetland carbon budget regarding the exchange with the atmosphere (Rinne et al., 2007). An undisturbed wetland is typically a sink of CO2 and source of CH4 in the atmosphere on an annual scale (Aurela et al., 2001; Rinne et al., 2007). The emission of CH4 is strongly related to the anaerobic conditions, which are the result of the high water table in this type of environment.

The emission of CH4 intensity is also related to the type of vegetation. This is due to convective flow through shoots and rhizomes, which is a mechanism for below-ground aeration of wetland plants. A convective flow of gases is caused by internal gas movement in plants by pressurization of shoot aerenchyma (Sorrel et al., 2010). This mechanism can be explained by pressurization caused by diffusion of gases from the air into the roots. Gases that enter the plant through diffusion pass through the submerged parts of the plant, as their escape into the atmosphere takes place in different parts of plants. In Phragmites australis, the flow convection is substantial and often greater than diffusion (Armstrong et al., 1991). In this study, a relationship between methane emission and the type of vegetation was found.

The gas exchange between wetlands and atmosphere has traditionally been measured in chambers (Christiansen et al., 2011; Juszczak et al., 2012a; Juszczak, 2013; Lund et al., 2010; Rask et al., 2002; Schrier-Uijl et al., 2009), but recently the eddy covariance technique has become a common tool for ecosystem-scale mass and energy exchange (Baldocchi, 2003). However, even though the eddy covariance method has been used for studies of the ecosystem-scale CO2 exchange for over a decade (Launiainen et al., 2013).
2005; Lee et al., 2004), ecosystem-scale methane emission remains much more poorly studied due to the instrumental limitations until very recently (Hendriks et al., 2008; Kroon et al., 2007, 2009). So far, the wetland ecosystems on which the eddy covariance method has been used to obtain methane emissions include eg boreal fens, rewetted systems. There have been no measurements in Eurasian temperate natural wetlands.

Thus, the main goal of this paper is to present and discuss preliminary results of CH$_4$ efflux values that were measured with the eddy covariance technique.

MATERIAL AND METHODS

The data set presented in this paper was obtained during the period between the 13th of June and the 31st of August 2012. The area studied (140 ha) is located about 70 km NW of Poznań (Chojnicki et al., 2007, 2012). The wetland is a georgenous mire, where the most common are moss (Sphagnum spp.), moss (Dicranum spp.), sedge (Carex spp.), reed (Phragmites australis), cattail (Typha latifolia), cranberry (Vaccinium oxycoccus), round-leaved sundew (Drosera rotundifolia), purple marshlocks (Potentilla palustris), meadow buttercup (Ranunculus acris) and bog-bean (Menyanthes trifoliata). The average annual air temperature is 8.5°C, the sum of precipitation is 526 mm, and westerly winds prevail (Farat et al., 2004). The measurements were carried out on a platform located in the centre of the wetland surveyed (Fig. 1). To the north of the measurement platform, the vegetation consisted of Phragmites spp., whereas to the south it consisted of Carex spp., Sphagnum spp., Menyanthes trifoliata, and Potentilla palustris.

The net CH$_4$ exchange ($F_{CH_4}$) was measured with the eddy covariance technique. The eddy covariance technique is the most widely used accurate and direct method presently available for quantifying exchanges of carbon dioxide, water vapour, methane, various other gases and energy between the surface of earth and the atmosphere. Eddy covariance provides an accurate way to measure surface-to-atmosphere fluxes, gas exchange budgets and emissions from a variety of ecosystems, including agricultural and urban plots, landfills, and various water surfaces. Emissions and fluxes can be measured by instrumentation on either a stationary or mobile tower, floating vessel (such as ship or buoy), or aircraft. The undertaken research provides knowledge about methane emission from wetlands depending on the type of plants.

The system consisted of two basic elements: a sonic anemometer (R3-100, Gill Instruments Ltd., Lymington, UK) and a closed-path gas analyzer (DLT-100 Los Gatos Research Inc., Mountain View, CA, USA) (Fig. 2). Suitability of the DLT-100 for eddy covariance measurements was described by Hendriks et al. (2008).

Fig. 1. Airborne image of Rzecin wetland. The black cross indicates the location of the measuring platform, with a white line drawn around the reed (Phragmites australis) dominated area; Roman numerals indicate wind direction sectors.

Fig. 2. Scheme of the eddy covariance system for measuring methane. The arrows indicate the direction of the intake air.
The 4 m long heated teflon tube (inner diameter 8 mm) was applied to carry on the air to the gas analyzer. A flow rate of 60 l min\(^{-1}\) was achieved by an oil recirculating vane pump (R5 0021B, Busch, USA). A funnel was mounted at the inlet to protect it from rain, and a 0.2 µm PTFE (Polytetrafluoroethylene) membrane (AcroPak 300, Pall, Port Washington, NY, USA) was installed on the tube 10 cm before the inlet to the gas analyzer. The teflon tube was heated with resistance wire (JLC Electromet Pvt. Ltd., Jaipur, Rajasthan, India) with total heating power of 32W in order to prevent condensation of water vapour.

The anemometer was installed 4.5 m above the peat surface, whereas the tube inlet was 40 cm below. The gas analyzer and pump were placed in separate metal boxes 1m above the surface. This device was installed beside of anemometer. The net CO\(_2\) exchange (F\(_{CO_2}\)) was measured in parallel to F\(_{CH_4}\) with an open path infrared H\(_2\)O/CO\(_2\) analyzer LI-7500 (LI-COR Inc., Lincoln, NE, USA).

Methane, carbon dioxide and water vapour concentrations were measured with a frequency of 10 Hz and the data obtained were recorded by a field computer installed in the gas analyzer. The pump box was also equipped with a telemetry module that allows remote monitoring of power supply and the pump temperature.

The temperature of substrate was measured with a temperature probe (T107, Campbell Scientific Ltd.) at 2 cm depth.

The EddyPro software, version 4.0.0 (LI-COR Inc., USA) was used to calculate 30 min average values, such as methane flux (F\(_{CH_4}\)), carbon dioxide flux F\(_{CO_2}\), and friction velocity (u*).

The use of the eddy covariance method requires well developed atmospheric turbulence. Friction velocity (u\(_m^*\)) is regarded as a measure of turbulence intensity. Normally, the u* threshold value, below which the turbulent mixing is assumed to be insufficient for the eddy covariance method, is used to filter the data (Foken and Wichura, 1996).

According to Baldocchi (2003), the u* threshold values (u\(_m^*\)) are normally in the range from 0.1 to 0.6 m s\(^{-1}\). However, exact estimation of u\(_m^*\) needs to be always done locally on the basis of obtained data. The u\(_m^*\) was estimated within the analysis of methane flux values obtained. The median values of F\(_{CH_4}\) become independent of friction velocity, and flux standard deviation is substantially reduced for u* values higher than 0.15 m s\(^{-1}\) (Fig. 3). Thus, further analysis in this paper was performed on data where u* >=0.15 m s\(^{-1}\). The application of this threshold value removed about 26% of data (Fig. 4).

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**Fig. 3.** Methane efflux density (F\(_{CH_4}\)) versus friction velocity (u*). The triangles indicate the median values, black diamonds indicate the mean values, and bars indicate standard deviations.

**Fig. 4.** Friction velocity (u*) distribution.
RESULTS

The eddy covariance technique applied at the wetland studied allows estimation of the net gas exchange averaged over the so-called footprint area downwind of the measurement system. Since the eddy covariance tower was located on the border between different vegetation types, the dependence between $F_{CH_4}$ and the vegetation type was studied by selecting the data by the wind direction.

The data were divided into four wind direction sectors (WDS) selected after initial analysis of methane effluxes against wind direction and by dominant vegetation in the different sectors (Figs 1 and 5). The following sectors were chosen: I – 330-30, II – 30-190, III – 190-270, and IV – 270-330°. The average effluxes in these sectors were 0.20, 0.22, 0.27, and 0.22 µmol m⁻² s⁻¹, respectively (Table 1). The lowest mean methane efflux value (0.20 µmol m⁻² s⁻¹) was observed for wind sector I, where the vegetation was dominated by a mixture of reed (*Phragmites australis*) and cattail (*Typha latifolia*). The area was covered mostly by different species of sedges (*Carex* spp.) (wind sector III) was found to be the strongest emitter of CH₄ (0.27 µmol m⁻² s⁻¹). The efflux variability expressed by standard deviation (STD) values was the highest within sector III as well (0.67 µmol m⁻² s⁻¹), while the lowest one was observed for sector IV (0.05 µmol m⁻² s⁻¹) (Table 1).

A pronounced diurnal pattern of $F_{CH_4}$ was found only for sectors I and IV (Fig. 6I, 6IV). The reed and cattail were the dominating species in those two sectors. The average $F_{CH_4}$ values were the lowest during the night with a clear decrease in the late afternoon, while the highest $F_{CH_4}$ were observed during the day and the strongest increase in the methane efflux values was observed about 6AM LT.

Sector II had a high variability of the flux, but no clear diurnal cycle. Both the daily minimum (-0.05 µmolCH₄ m⁻² s⁻¹) and maximum (0.70 µmolCH₄ m⁻² s⁻¹) values of $F_{CH_4}$ were the lowest for wind direction sector II in average daily run.

The variability of $F_{CO_2}$ in average daily run from WDS III was the highest, and the maximum and minimum values were equal to 27.00 µmol CO₂ m⁻² s⁻¹ and -21.36 µmol CO₂ m⁻² s⁻¹, respectively (Table 2).

![Fig. 5. Methane efflux ($F_{CH_4}$) versus wind direction (WD), the black diamonds indicate the average values, bars indicate standard deviation, dotted lines indicate selected wind direction sectors.](image)

**Table 1.** The mean (AVG), standard deviation (STD), and median values of methane efflux for four selected wind sectors

<table>
<thead>
<tr>
<th>Wind sector</th>
<th>Degrees (°)</th>
<th>AVG (µmol m⁻² s⁻¹)</th>
<th>STD (µmol m⁻² s⁻¹)</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>330-30</td>
<td>0.20</td>
<td>0.64</td>
<td>0.13</td>
</tr>
<tr>
<td>II</td>
<td>30-190</td>
<td>0.22</td>
<td>0.10</td>
<td>0.18</td>
</tr>
<tr>
<td>III</td>
<td>190-270</td>
<td>0.27</td>
<td>0.11</td>
<td>0.26</td>
</tr>
<tr>
<td>IV</td>
<td>270-330</td>
<td>0.22</td>
<td>0.05</td>
<td>0.21</td>
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</table>
The 30 min average substrate temperature measured at 5 cm depth (Ts) ranged from 14.7 to 20.3°C during the measurement period. The correlation between the 30 min average values of methane efflux (FCH4) and Ts was found to be very low (R²=0.0049), even though FCH4 was slightly increasing with increasing Ts (Fig. 7).

There was a negative correlation between FCH4 and FCO2 in all four wind sectors. This is the consequence of the inverse diurnal cycles of FCH4 and FCO2, especially in sectors I and IV with the clear diurnal pattern in FCH4. The lowest highest coefficient value was found for WDS I (-23.77), while the highest one was found for WDS IV (-7.48).
DISCUSSION

The wetland studied has a complex structure of vegetation with different dominant vegetation types in the different parts of the area (Chojnicki, 2007). Thus, the values of both $F_{\text{CH}_4}$ and $F_{\text{CO}_2}$ observed and their diurnal cycles obtained by application of the eddy covariance technique vary depending on the vegetation type, and wind direction was used to determine above which area the air comes.

The highest averaged methane efflux during the study period was reported from the area covered by vegetation dominated by sedges (wind sector III), while the lowest emission was found from the reed/cattail habitat (wind sector I) (Fig. 5). The highest emission rate from WDS III and the lowest from WDS I suggests that presence of reed and cattail plants reduces $F_{\text{CH}_4}$. These results are similar to flux values observed in North East Siberia (Parmentier, 2011).

Methane production is a result of organic matter decomposition in anoxic conditions. Organic matter is a product of photosynthesis; therefore, long-term CH$_4$ production depends on $F_{\text{CO}_2}$. There is a clear daily pattern in $F_{\text{CH}_4}$ from sectors WDS I and WDS IV, which is inverse to that of $F_{\text{CO}_2}$. The diurnal pattern of CH$_4$ emission can be explained by the convective gas flow in reed, which is absent in sedges (Riutta et al., 2007). The pronounced diurnal pattern of $F_{\text{CH}_4}$ from reed/cattail sector indicates that these plants influence the $F_{\text{CH}_4}$ daily dynamics via convective gas transport in their bodies. The relatively low emission from this area supports this hypothesis, since the convective flow would also aerate the root zone reducing the emission rate from this area. The presence of cattail and sparse reed within WDS IV can also explain the daily pattern of $F_{\text{CH}_4}$ and averaged low emission (Kim et al., 1998).

The lack of reed and cattail plants in the areas within sectors II and III lead to absence of the diurnal pattern in $F_{\text{CH}_4}$ from these sectors (Fig. 6II and 6III). Even though the aerenchyma of sedges does serve as a conduit for gas transport from the root zone to the atmosphere, this transport proceeds through diffusion and does not create a diurnal pattern. It has been well established that the impact of plant processes on the net CH$_4$ emission is important. Plants can influence the methane emission through different ways (King et al., 1998). Many studies show that plants play a significant role in determining net CH$_4$ emissions through transport (Shannon et al., 1996; Yavitt and Knapp, 1995). In one study, the CH$_4$ emission from a measurement site overgrown by sedge was higher than the emission from sites without sedge coverage. The influence of sedges on methane emission was observed also in other studies (Thomas et al., 1996).

Methane production in a substrate is dependent on its temperature (Juszczak et al., 2012b). However, we did not observe a strong dependence of CH$_4$ net emission on temperature (Fig. 7). For comparison, the correlation between methane flux and soil temperature (measured at 20 cm depth) in arctic polygonal tundra was very strong, and $R^2 = 0.67$ (Wille et al., 2008). The strongest dependence is supposed to be found in long term $Ts$ versus $F_{\text{CH}_4}$ dependence.

The dependence between the methane efflux and net carbon dioxide exchange in an hourly-time scale is not strong and only a weak correlation between those two fluxes was observed (Fig. 8I, 8II, 8III, 8IV).

The observations presented in this paper support the hypothesis about varying influences of different vascular plants to the methane transport from the root zone to the atmosphere. The different diurnal patterns of methane emission observed from the different vegetation types indicate differences in transport mechanisms in Phragmites and in Carex. The more effective aeration of the root zone by Phragmites can also reduce methane emission from this vegetation type.

![Fig. 7. Methane efflux ($F_{\text{CH}_4}$) versus substrate temperature ($Ts$) measured at 5 cm depth.](image-url)
CONCLUSIONS

1. There was no clear dependence between methane efflux and either soil water depth or substrate temperature due to the shortness of the study period during the warmest months of the summer.

2. The highest methane efflux was observed from the sedge covered area, while the presence of reed and cattail plants caused the lowest emission from the northern part of the site studied.

3. There was a distinct daily dynamics of methane emission from the reed covered areas, which was absent in the sedge covered areas. This can be explained by convective gas transport in reed, which does not occur in sedges. Both low emission and daily runs of methane efflux is an effect of reed and cattail aerating properties.

REFERENCES


