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Methane and carbon dioxide fluxes of a temperate mire in Central Europe

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ABSTRACT

Observational data on greenhouse gases exchange between ecosystems and the atmosphere are crucial in understanding the global climate mechanisms. Among different methods of estimation of this exchange, the eddy-covariance (EC) technique provides a direct measure of the net flux density across the atmosphere-ecosystem interface. Still, such data are highly scarce for Central European wetlands. In this work, we present the results of two years (2013–2014) of continuous open-path EC measurements of methane (CH_4) and carbon dioxide (CO_2) fluxes at the wetlands of the Biebrza National Park in northeastern Poland – one of the biggest coherent lowland wetland area in Central Europe. The measurement site (53°35′30.8″N, 22°53′32.4″E) was located near the Kopytkówka river in a fen peatland, whose soils are slightly decomposed due to dehydration. The mean annual sum of CH_4 release equaled 29 ± 4 g CH_4 m^{-2} yr^{-1} in wetter year 2013 and 20 ± 1 g CH_4 m^{-2} yr^{-1} in drier year 2014. The mean annual uptake of CO_2 reached 980 ± 150 g CO_2 m^{-2} yr^{-1} and 560 ± 130 g CO_2 m^{-2} yr^{-1} in 2013 and 2014, respectively. Both fluxes show a clear annual pattern with maximum CH_4 release in June and July (at a level of 130 nmol m^{-2} s^{-1}) and maximum CO_2 uptake in June (at a level of 4.2 μmol m^{-2} s^{-1}). The considerable C–CO_2 uptake in comparison to C–CH_4 emissions suggests that the Biebrza river wetlands are a significant carbon sink, but the net contribution of the Biebrza mires to the climate forcing is unclear because of different metrics which can be used to specify the relative weights of CO_2 and CH_4.

1. Introduction

Wetlands play an important role in the global cycle of greenhouse gases. Although these ecosystems cover only a few percent of the globe's total land area (approximately between 2% and 6%, depending on definitions), they accumulate in their soils a significant portion of organic carbon (Gorham, 1991; Yu, 2012) which has been consistently sequestered for millennia (Frolking and Roulet, 2007). Surface–atmosphere carbon exchange in wetlands has been given a considerable amount of attention in recent years, which has led to a growing number of publications (see e.g. Lafleur, 2009; Lai, 2009; Kayranli et al., 2010; Lund et al., 2010; Yu, 2012; Bridgham et al., 2013; Nicolini et al., 2013; Baldocchi, 2014; Turetsky et al., 2014 for recent synthesis). Moreover, wetlands affect climate on a local and global scale, characterized by an energy balance with a high portion of latent heat (Lafleur, 2008).

The methane gas emissions and the exchange of carbon dioxide are key processes in understanding the role of mires in the climatic system. A high water table creates the anaerobic conditions where methanogenesis occurs as a result of microbial decomposition of organic matter (Rydin and Jeglum, 2006). In consequence, wetlands are most likely the largest natural source of methane to the atmosphere accounting for ~20–50% of its emissions on a global scale (Matthews, 2000; Denman et al., 2007; Ciais et al., 2013). According to the recent IPCC report (Ciais et al., 2013), global CH_4 emissions from wetlands range from 177 to 284 Tg CH_4 yr^{-1},

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[1] http://meteo.geo.uni.lodz.pl/kf/kf_ang.html.

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whereas Turetsky et al. (2014) suggest a range from 55 to 231 Tg CH_4 yr^{-1}. As it is stressed by the IPCC, the uncertainty of the global CH_4 budget estimates is, notably, a consequence of limited empirical data on exchange on the whole ecosystem scale which can be used for global model calibration and evaluation. An empirical estimation of the peatland-scale budget of CH_4 is complicated due to the complexity of the processes of CH_4 emissions, which results in a high spatial and temporal variation in net methane flux. It is one of the serious limitation of the chamber method. More consistent estimations can be derived from the eddy-covariance (EC) method, which integrates fluxes at the ecosystem level over a source area of the order of tens or hundreds squared meters (Rinne et al., 2007; Herbst et al., 2011; Baldocchi et al., 2012; Hatala et al., 2012; Olson et al., 2013). However, long-term EC measurements of CH_4 fluxes are rare. Notably, such data are lacking for the temperate climate wetlands of Central Europe.

More eddy-covariance data are available for CO_2 fluxes (Arneth et al., 2002; Friborg et al., 2003; Aurela et al., 2004, 2007; Lund et al., 2007, 2010; Roulet et al., 2007; Sottocornola and Kiely, 2010; McVeigh et al., 2014; Peichl et al., 2014), but only a few have been continuously studied for multi-year periods (Aurela et al., 2004; Lund et al., 2010; Sottocornola and Kiely, 2010; McVeigh et al., 2014). These researches have shown that peatland ecosystems are generally a sink of CO_2, but the net CO_2 fluxes vary considerably inter-annually (Aurela et al., 2004; Roulet et al., 2007; Sagerfors et al., 2008) as well as between sites (Moore et al., 2002; Lindroth et al., 2007; Lund et al., 2010). The wetland vegetation plays a key role in CO_2 capture. It assimilates CO_2 in the process of photosynthesis (*GPP* – gross primary productivity), which results in short-term carbon storage in plants, and next its long-term accumulation in organic material, i.e. peat. CO_2 is released through autotrophic and heterotrophic respiration, collectively called ecosystem respiration (R_{eco}). The difference between R_{eco} and *GPP* represents the net ecosystem exchange (*NEE*). Similarly to CH_4, there is very little EC data for the net CO_2 flux in the wetlands of Central Europe.

The main goal of the present work is to provide the first empirical assessment of CH_4 and CO_2 atmosphere-ecosystem exchange on the mires of Central Europe based on the two-year (2013–2014) eddy-covariance measurements at the wetlands of the Biebrza National Park. Because of its importance for the understanding of global carbon exchange, we mainly focused on the estimation of the annual totals of CH_4 and CO_2 fluxes, their annual and diurnal variability and the total carbon balance.

The investigations were carried out in one of the biggest coherent lowland wetland area in Central Europe – the Biebrza river valley, Poland, where wetlands cover an area of over 250 km^2. The Biebrza Valley could be regarded as a reference area in the international wetland research (Wassen et al., 2002) due to its priceless ecological values resulting from the combination of the relatively extensive use of the area, the occurrence of large peat deposits, and near-natural hydrological conditions that influence the natural development of the wetlands. Like many other European wetlands, the Biebrza valley suffered from some drainage works carried out in the area in the 19th and 20th centuries (Okruszko and Byczkowski, 1996). In consequence, both the well preserved peatlands and soils degraded by dehydration are present in the Biebrza Valley. In spite of this process, the Biebrza river valley remains one of the last largely undrained valley mires in Central Europe (Wassen et al., 1992) which can be regarded as a wetland typical of the region. As the measurement area is located close to the eastern Polish border, the results probably can also be representative of part of temperate Eastern Europe, including large wetlands of western Belarus and northwestern Ukraine.

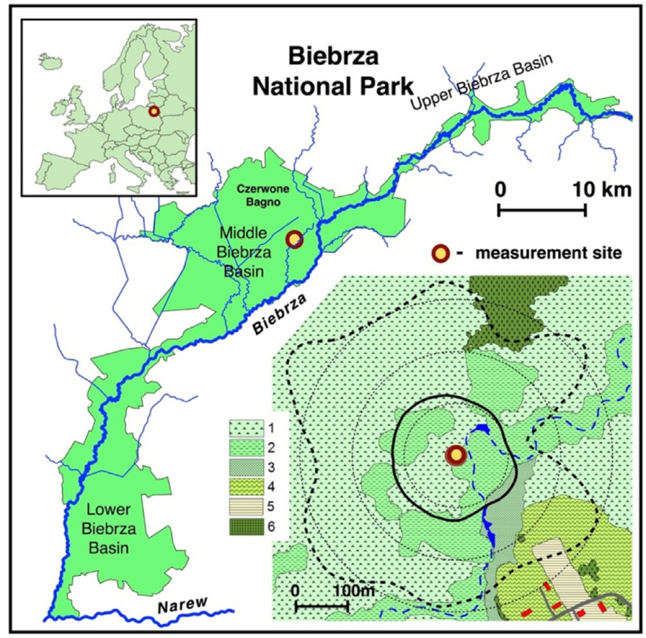

Fig. 1. Location of the measurement site in Biebrza National Park and the nearest neighborhood of the site. The source area at p = 90% calculated for May–August, years 2013–2014, for unstable ($\zeta < -0.5$ – bold full line) and stable ($\zeta > 0.1$ – bold dashed line) conditions. Legend: 1 – area dominated by medium high sedges (association *Caricetum rostratae*), 2 – area dominated by American Reed and ferns (association *Thelypteridi-Phragmitetum*), 3 – area dominated by calamus (association *Acoretum calami*), 4 – grassland, 5 – agriculture, 6 – forest.

2. Materials and methods

2.1. Measurement site and study area

The Biebrza river valley is situated in northeastern Poland (Fig. 1). It is a broad land depression which acts as a sink for groundwater and surface waters originating from the Biebrza catchment (ca 7100 km^2). The valley is subdivided by morphological features into three parts: the Upper, Middle and Lower Basin (Okruszko, 1973). The measurement site is located close to the village Kopytkowo (53°35′30.8″N, 22°53′32.4″E, 109 m a.s.l.), in the Middle Basin, south of the famous mire called "Czerwone Bagno" (the Red Bog). The Middle Basin is about 33 km long and 23 km wide. The flat, peat-cover valley bottom slopes down downstream from about 115–107 m. a.s.l. To the north and the west, the valley passes into slightly higher (1–4 m) outwash levels which are bordered by the Ełk Lakeland and the postglacial Kolneńiska Plateau. In the east and the south-east the flat valley is delimited by the 10–15 m high edge of the Białostocka (Goniądzka) Plateau.

Within 2 km around the measurement site, the area is very flat with elevation differences of up to 2 m. The flat area stretches over 10 km southwest in a wide belt along the Biebrza river and about 8 km in the sector from the north to the east. The mineral island of Polkowo, elevated about 10 m above the peatland and with a diameter of less than 1 km, is located in a distance of ca 2.5 km in the NNE direction. 2–4 km west and north-west of the measurement site, the Grzędy Dunes are locally elevated more than 10 m above the surface of the peatland. To the south-east (in a distance of 4.5 km) and the south (5.5 km), the edge of the Białostocka (Goniądzka) Plateau rises 10–15 m above the valley floor.

The Biebrza Valley is situated within the temperate climate zone, with continental influences. The mean annual air temperature in the region is 6.6 °C and varied over the period 1951–2000 in the range of 4.4–8.2 °C (Banaszuk, 2004). The mean annual precipitation in the Biebrza Valley amounts to 583 mm (Kossowska-Cezak,