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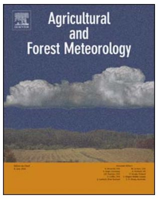

Research Paper

Wetland-atmosphere methane exchange in Northeast China: A comparison of permafrost peatland and freshwater wetlands

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ABSTRACT

Northeast China contains a large concentration of wetlands, primarily in two prominent types, freshwater marshes on the lowlands plains to the northeast and mountain permafrost peatlands in the north. Both wetlands types are threatened by disturbance, the marshes from agricultural conversion and the peatlands due to climate warming and loss of permafrost. Here we compare two seasons of ecosystem-scale CH_4 fluxes measured via eddy covariance for a permafrost peatland in the Da Xing'anling Mountains and a freshwater marsh on the Sanjiang Plain. The objectives were to quantify CH_4 fluxes, compare seasonal trends in the flux and determine the dominant environmental and biophysical drivers of the CH_4 flux for these two distinct wetland types.

CH_4 fluxes at the marsh had a strong seasonal trend peaking in mid-summer, while the pattern for the peatland was muted. Maximum instantaneous fluxes were 1.34 μg CH_4 m^{-2} s^{-1} and 9.5 μg CH_4 m^{-2} s^{-1} at the peatland and marsh, respectively. Total seasonal CH_4 emissions for the peatland, 0.38–1.27 g C-CH_4 m^{-2}, were an order of magnitude smaller than those at the marsh, 19.71–21.8 g C-CH_4 m^{-2}. Differences between years were small for both wetlands. We used path analysis to examine environmental and biophysical drivers of the flux and found that soil temperature (average soil temperature between 10 cm to 60 cm depths for the peatland and 10 cm depth for the marsh) was most strongly correlated with seasonal CH_4 variability for both wetlands. Secondary influences were thaw depth for the peatland and net ecosystem CO_2 exchange for the marsh.

Given the temperature sensitivity of CH_4 flux for both of these wetlands, future climate warming will likely increase CH_4 emissions in northeast China, as well, the continued loss of permafrost in the mountain peatlands will likely further contribute to enhanced CH_4 emissions.

1. Introduction

Wetlands occupy only a small portion of the global terrestrial surface (5–8%), but play an important role in the global carbon cycle (Mitsch and Gosselink, 2007). Wetlands store more than 30% of the world's soil carbon, with the majority contained in northern peatlands (Bridgham et al., 2006; Mitra et al., 2005; Mitsch et al., 2013; Zedler and Kercher, 2005). These diverse ecosystems sequester carbon dioxide (CO_2) from the atmosphere, but are also identified as the largest natural source for atmospheric methane (CH_4) (Forster et al., 2007; Lafleur, 2009; Limpens et al., 2008; Roulet, 2000). Because CH_4 has a global warming potential 28 times of that of CO_2 on a 100 year time horizon and contributes to over 20% of recent global warming (IPCC, 2013) even a modest change in methane sources can change the sign of the greenhouse gas budgets of wetlands. Wetland type (e.g., fen, bog, marsh) greatly influences the relative importance of CH_4 emissions, the magnitude and seasonal pattern of CH_4 exchange varies greatly among wetlands depending upon temperature, vegetation cover and hydrology (Iwata et al., 2015; Koebsch et al., 2015; Nadeau et al., 2013; Sun et al., 2013). In addition, the presence/absence of permafrost in high-latitude wetlands affects CH_4 flux (Olefeldt et al., 2013; Turetsky et al., 2014), suggesting that climate warming could greatly impact emission from these ecosystems. Hence, a better understanding of the dynamics of wetland CH_4 emissions and the mechanistic controls on ecosystem scale CH_4 exchange is urgently needed for improvement and validation of models used for predicting variations in atmospheric CH_4 concentration and for the anticipation of ecosystem feedbacks to global change.

There have been many studies of CH_4 emissions from wetlands, much of this work has been outlined in extensive reviews (see Bartlett and Harriss, 1993; Bridgham et al., 2006, 2013; Lai, 2009; Turetsky

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et al., 2014). While these syntheses tend to focus on the magnitude and variability of the CH_4 flux in time and space and controls on the flux, it is also clear that most of the existing studies have been concentrated in North America and Europe, leaving some regions, such as Asia and the tropics, relatively understudied.

China contains a considerable amount of wetland, $\sim 3.85 \times 10^5$ km^2 representing about 4% of the surface area (Ma et al., 2012). Yet, only a few whole ecosystem studies of wetland methane flux have taken place in China. One of the greatest concentrations of natural wetlands in China is in the far northeast region (Niu et al., 2009). The dominant wetland types (excluding rice paddies) in this region are freshwater herbaceous wetlands (fens and marshes) with little or no peat accumulation and woody-herbaceous-moss peatlands with peat accumulations ranging from 30 cm to 9 m (Zhao, 1999). The fresh water systems are located toward the northeast and east of the region, the most notable concentration being on the Sanjiang Plain (Niu et al., 2009). Nine national wetland nature reserves, six of which are on the list of Ramsar wetlands of international importance, are on the Sanjiang Plain. Mountain peatlands are located toward the north and east and contain about 7% of the national peatland resources. The majority of these located in the mountainous permafrost zone south of the Russian boarder (Liu, 2005; Ma et al., 2013). Both of these wetland types are under threat. In recent decades marshes on the Sanjiang Plain have been reduced dramatically due to agricultural conversions, with total wetland loss of > 75% since the 1950's (Dong et al., 2015; Wang et al., 2011). Meanwhile, regional warming after the 1970s has affected all of northeast China, but has particularly impacted the mountain peatlands where more than 35% of the permafrost area has been lost and temperature increases in the coming decades are projected to reduce permafrost area by an additional 28–50% (Chang et al., 2008; Jin et al., 2009). Therefore, understanding the impact of these types of changes on greenhouse gas emission of wetlands is of critical concern for regional and national assessments.

In this study we compare two growing seasons of whole ecosystem CH_4 fluxes from a permafrost peatland located in the Da Xing'anling Mountains and a freshwater marsh on the Sanjiang Plain. As noted above, these are the two most dominant natural wetland types in northeast China (Niu et al., 2009; Zhao, 1999). Although aspects of the C cycle for both of these wetlands have been studied previously (e.g., Meng et al., 2014; Miao et al., 2012; Song et al., 2009; Sun et al., 2013; Wang et al., 2013), no previous comparison of whole ecosystem methane fluxes from these wetland types has been conducted. The two wetlands differ significantly in their hydrological, soil and vegetation characteristics. Although climatic conditions also differ between the sites, where the more northerly peatland has somewhat cooler temperatures and less precipitation than the marsh, we expected that hydrologic and biophysical differences would be the primary factors regulating differences in wetland-atmosphere CH_4 exchange. The overall objectives of the study are to compare whole ecosystem CH_4 fluxes from these two wetlands as measured via eddy covariance, to clarify differences in CH_4 exchange at diurnal to seasonal time scales, to determine the primary drivers of CH_4 flux at each site and to quantify the total seasonal CH_4 exchange at the two wetlands.

2. Material and methods

2.1. Study sites

The permafrost peatland is located in the Da Xing'anling Mountains of Heilongjiang province (52°56′32.40″ N, 122°51′23.26″ E, 473 m a.s.l.) south of the Russian boarder (see Supplemental Materials, Fig. S1). It is within the Eurasian zone of continuous permafrost. Climate of the region is cold temperate monsoon, with a mean annual temperature of −3.9 °C, mean July temperature of 18.4 °C and mean annual precipitation is 452 mm. The site is pristine, with no disturbance from human activities. Surrounded by shrubs and forests, the peatland extends approximately 1.1 km in east-west direction and 170–650 m in north-south direction (Fig. S2a). Although a branch of the Emuer River runs along the southern border of the peatland, its hydrology is mainly controlled by precipitation and there are no visible streams flowing into or out of the peatland. The peat depths varied from 50 to 100 cm. The surface has a hummock-hollow pattern, with mosses (*Sphagnum* sp., *Aulacomnium androgynum,* and *Polytrichum juniperinum*) covering the surface. The dominant vascular vegetation is shrubs (*Betula fruticosa, Ledum palustre, Chamaedaphne calyculata, Vaccinium uliginosum,* and *Rhododendron parvifolium*) with a sparse cover of sedge (*Eriophorum vaginatum*) and grass (*Deyeuxia angustifolia*). Average shrub height is 60–70 cm. Active layer thickness ranges from 50 to 70 cm in late summer and summer water table depth typically range between −10 and −36 cm.

The freshwater marsh is located near the Sanjiang Experimental Station of Wetland Ecology on the Sanjiang Plain (Figs. S1 and S3a, 47°35′10.66″ N, 133°29′57.06″E, 55 m a.s.l.). Approximately 400 m long in the east-west direction and 300–400 m in north-south direction, the marsh is surrounded by shrubs and forests to the south and east and bordered by cropland to the north. The buildings of the Experimental Station are located about 400 m to the east. The marsh is a protected experimental site and has been preserved in its natural state since 1986. This eutrophic wetland is permanently inundated with a varying water depth (normally between 0 and 50 cm). It is a non-peat forming wetland, with a 20–40 cm root mass layer overlying 5–10 cm of humus and clay soil below. Vegetation at the site is dominated by the sedge *Carex lasiocarpa* and *C. pseudocuraica. C. meyeriana* and *Glyceria spiculosa* are also present. Mean canopy height during the growing season is typically about 0.7 m. The climate is temperate continental monsoon, with mean annual temperature of 2.5 °C and July mean temperature of 22 °C. The mean annual precipitation is 558 mm with approximately 80% occurring from May to September. The topography of the marsh is flat and precipitation is the main water source. There are no identified permanent inflows or outflows.

The vegetation in the marsh begins to leaf-out in early May with the leaf area index (LAI) close to zero. LAI increases gradually and approaches the maximum of about 2.4 near the end of July or early August. The plants show visible signs of senescence in late August. Senescence accelerates in September and almost no green leaves remain by late September. Although not directly monitored, site visit observations suggest that vegetation phenology at the peatland is similar to that of the marsh. Accordingly, we define the growing season for both sites as May to September.

2.2. Measurements

Flux measurement periods were from 1 May to early October in 2012 and 2013 at the marsh and 23 May to early October in 2012 and 8 May to early October in 2013 at the peatland. The closed-path eddy covariance technique was used to measure CH_4, CO_2 and H_2O fluxes at both sites. The system included a three-dimensional ultrasonic anemometer (CSAT-3 Campbell, Scientific, USA), a fast greenhouse gas analyzer (FGGA, Los Gatos Research, Mountain View, CA, USA) and a dry vacuum scroll pump (XDS35i, BOC Edwards, Crawley, UK). Anemometers were installed on the masts at the height of 3.0 m and 2.5 m above the ground at the peatland and marsh, respectively. An inlet tube situated at the same height of the anemometer, with a separation of 15 cm, was used to draw air toward FGGA where CH_4, CO_2 and H_2O concentrations were measured based on off-axis integrated cavity ringdown spectroscopy (Baer et al., 2002). All measurements were taken at a frequency of 10 Hz and the data were stored on dataloggers (CR3000, Campbell, Scientific, USA). The pump used at each site drew the sample air through a 7 m tube (inner diameter 6.4 mm, made of fluorinated ethylene propylene to minimize sorption or desorption) at flow rates about 40 L min^{-1} into the measuring cell at an operating pressure of approximately 19 kPa.