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Temporal and spatial variability of methane emissions in a northern temperate marsh

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HIGHLIGHTS

- We investigated the variability of methane emissions from a cool temperate marsh.
- Surface soil temperature exerted dominant control on the seasonal variability.
- The spatial variability was mainly controlled by the changes of water table level.
- The upscaled chamber based model overestimated methane emission by 28%.

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ABSTRACT

Although methane (CH_4) fluxes from northern wetlands in Asia have been described in previous research at different temporal and spatial scales, integrated studies at the ecosystem scale were scarce. In this study, CH_4 fluxes were measured using eddy covariance (EC) technique and the chamber method in a cool temperate marsh in northeast China during the growing season (May–September) of 2011. CH_4 emissions were highly variable, both temporally and spatially during the measurement period. According to the EC observation data, CH_4 fluxes showed a significant diurnal cycle during the mid-growing season with nighttime average flux about 67% of the average daytime values. Daily cumulative CH_4 fluxes varied from 54 to 250 mg CH_4 m^{-2} d^{-1} with an average flux of 136.2 mg CH_4 m^{-2} d^{-1}. The observations of chamber method showed that CH_4 emissions differed markedly among the three main plant communities. Average flux at the *Carex lasiocarpa* site was about 4 times and 13.5 times of that at the *Glyceria spiculosa* site and *Deyeuxia angustifolia* site, respectively. The spatial variability of CH_4 flux was mainly controlled by the varying water table level as well as the spatial distribution of different vascular plants, while the seasonal dynamic of CH_4 emission could be best explained by the change of surface soil temperature and air pressure. A comparison was made between EC measurements and the upscaled chamber based model. The results from the model overestimated CH_4 emission by 28% compared to the EC data. Considering the large variability of methane emission, it is necessary to conduct continuous observations on CH_4 emission from northern wetlands at different temporal and spatial scales to comprehend the variability and also to predict responses to climate change.

1. Introduction

Northern wetlands are the primary natural source of methane (CH_4) into the atmosphere and they contribute between 6 and 40 Tg CH_4 yr^{-1} with a wide variation in rates (Worthy et al., 2000; Houghton et al., 2001; Zhuang et al., 2006; Roulet et al., 2007). Because CH_4 gas emitted is 25 times more effective in absorbing heat in the atmosphere than CO_2 on a 100-year time scale and contributes to over 20% of global warming (IPCC, 2007), even a modest change in methane sources can change the sign of the greenhouse gas budgets of northern wetlands. A wetland can be a carbon sink and greenhouse gas source at the same time (Whiting and Chanton, 2001; Friborg et al., 2003; Rinne et al., 2007). Because of the high temperature sensitivity of the biogeochemical processes of northern wetlands, CH_4 emission from these ecosystems should be given sustained attention considering the spatial pattern and magnitude of current and anticipated changes in climate (Schlesinger, 1997; IPCC, 2007).

For natural wetlands, CH_4 is produced by microbes in anaerobic sediments and transported to the atmosphere by both physical

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(diffusion and ebullition) and biological (plant-mediated) processes (Lai, 2009). Measuring CH_4 flux which is produced solely by microbes is much more complicated than measuring CO_2 flux which is mainly routed through plants. Microbes produce hot and cold sources across a landscape that may vary by two to three orders of magnitude within a few meters (Baldocchi, 2003, 2012). Therefore both temporal and spatial variability in CH_4 emission should be concerned when investigating ecosystem scale CH_4 dynamics within a wetland site.

The chamber method and the micrometeorological eddy covariance (EC) technique are the main two techniques for CH_4 measurements. Existing studies of CH_4 fluxes from wetlands were mostly based on the chamber method. Although the labor intensive chamber technique provides discontinuous measurements representative on the very small scale (≤ 1 m^2), it is still quite useful when conducting some process-based research. The applications of EC technique for CH_4 flux observation before 2000 were relatively few (Verma et al., 1992; Suyker et al., 1996; Hargreaves and Fowler, 1998; Kim et al., 1998). In recent years, the number of CH_4 measurements using eddy covariance technique is increasing (Rinne et al., 2007; Riutta et al., 2007; Hendriks et al., 2008, 2010; Jackowicz-Korczyński et al., 2010; Schrier-Uijl et al., 2010; Herbst et al., 2011; Parmentier et al., 2011). The EC technique can provide continuous and area-integrated flux at the ecosystem scale (10^2–10^4 m^2). Compared with the chamber method, the use of EC technique for CH_4 emission from natural ecosystems is quite limited at present due to the high cost, the difficulty of maintenance in the harsh field environment and, in some cases, the infeasibility of power supply.

CH_4 fluxes from natural wetlands in Asia have been described in previous research at varying temporal and spatial scales (Ding et al., 2004; Ding and Cai, 2007; Song et al., 2009, 2011; Miao et al., 2012), however, integrated studies at the ecosystem scale has not yet been reported. In this research, based on micrometeorological EC technique and closed-chamber method, the growing season CH_4 emission was measured from a permanently inundated freshwater marsh in northeast China. The three aims of this study were (1) to elucidate the temporal and spatial variability of CH_4 flux at the ecosystem scale; (2) to identify the most relevant factors that influence CH_4 emission from this wetland type; and (3) to make a preliminary comparison between CH_4 emissions derived from EC technique and those from the upscaled chamber measurements.

2. Material and methods

2.1. Site description

The study site is a permanently inundated and eutrophic marsh in the Sanjiang Plain, northeast China (47°53′ N, 133°30′ E) at a latitude representative of the natural freshwater wetlands in this area (55 m a.s.l.). The Sanjiang Plain inhibits approximately 10,400 km^2 freshwater wetland area in China and is at present divided into many zones by cultivated lands (Zhao, 1999; Song et al., 2011).

Although the marsh is a dish-like depression, its slope grade is quite low (about 1:5000) and the topography is flat with *Carex lasiocarpa* as the dominant vegetation. Other plants in the marsh include *Carex pseudo-curaica*, *Glyceria spiculosa*, *Carex limosa*, *Deyeuxia angustifolia and Carex meyeriana*. The morphological appearance of the herbaceous vegetation in the marsh looks quite similar. The three main types of vegetation community dominated by *C. lasiocarpa*, *G. spiculosa* and *D. angustifolia*, respectively, successively show a concentric distribution pattern with the gradual decrease of water table level along the center to the edge of the marsh.

The climate is a temperate continental monsoon type with annual mean temperature 2.5 °C. The mean temperature in July and January is 22 and −21 °C, respectively. The mean annual precipitation is approximately 558 mm with approximately 80% occurring during the growing season from May to September. Precipitation is the main water source in freshwater marshes in normal years. Water and soil in marshes are completely frozen from late October to next April and begin to melt from late April till July.

2.2. Eddy covariance measurements

An instrument mast was erected in the marsh at the beginning of May 2011. To measure wind speed and sonic temperature, a three-dimensional ultrasonic anemometer (CSAT-3 Campbell, Scientific, USA) was installed on the mast at a height of 2.5 m above the ground. At the same height, with a separation of 15 cm, an inlet was situated where air was drawn down toward the fast greenhouse gas analyzer (FGGA, Los Gatos Research, Mountain View, CA, USA). CH_4, CO_2 and H_2O concentrations were measured by FGGA based on off-axis integrated cavity ringdown spectroscopy (Baer et al., 2002). All measurements were taken at a nominal frequency of 10 Hz and the data were stored on a datalogger (CR3000, Campbell, scientific, USA).

For the closed-path gas analyzer, a dry vacuum scroll pump (XDS35i, BOC Edwards, Crawley, UK) was adopted to draw the sampling air through a 7 m tube (inner diameter 6.4 mm, made of fluorinated ethylene propylene to minimize sorption or desorption) into the measuring cell at the operating pressure of approximately 19 kPa. The air was filtered through a filter with a pore size of 10 μm to prevent dust and insects from entering the system and through two 2 μm Swagelok filters (one internal and one external) before entering the measuring cell. Because the pump and the gas analyzer had a high power requirement, the EC system ran on AC power supply during the measurement period.

The average height of marsh plants changed from about 0.0 m to about 0.5 m. The terrain around the instrument mast was flat and uniform with a fetch of at least 280 m in the prevailing southeast wind direction and at least 200 m in all other directions.

Processing of high-frequency EC data was performed with EddyPro 4.1 (www.licor.com/eddypro). Raw data were filtered for spikes and linear detrending was used. Double coordinate rotations were performed to align the mean vertical velocity measurements normal to the mean wind streamlines before scalar flux calculations. Using the maximum cross-correlation method (relative to the vertical velocity or temperature), time lags were determined for each half-hourly period. Half-hourly fluxes of CH_4, CO_2 and H_2O were calculated as the mean covariance of vertical wind velocity and scalar fluctuations. The WPL correction for density fluctuations arising from variations in water vapor was applied according to Ibrom et al. (2007b) by using the uncorrected covariances of water vapor mass density with the vertical wind velocity when correcting the dilution effect. The low-pass filtering effects were assessed and corrected using the method of Ibrom et al. (2007a) based on in site determination of water vapor attenuation and on a model for the corresponding spectral correction factor. Quality control criteria according to Mauder and Foken (2004) were used to reject bad data. Additionally, data were excluded when the pump stopped working due to maintenance or high temperature in summer and when the transmission of sound on the sonic anemometer was blocked by heavy rain. CH_4 flux was calculated by adding the rate of CH_4 storage change (S) to the turbulent flux. S was estimated from the changes in the average CH_4 concentrations at the sensor height over the 30-min intervals