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Greenhouse gas emissions from different wetlands during the snow-covered season in Northeast China

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HIGHLIGHTS

► The natural wetlands in the middle latitude are source for CO_2 and CH_4 in the snow-covered season.
► During the snow-covered season, peatland acts as N_2O sink and marshland acts as a N_2O source.
► Soil temperature is the primary factor controlling marshland greenhouse gas fluxes in the snow-covered season.

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ABSTRACT

Emission of CO_2, CH_4 and N_2O from the snowpack is an important component of annual C and N budgets in wetland ecosystems in mid- and high-latitude. However, there is little information about greenhouse gas fluxes during the snow-covered season in wetlands in Northeast China. In the present study, we investigated the trace gas fluxes from a peatland and a marsh using the methods of concentration gradient and diffusion model during the snow-covered season of 2010/2011 in this region. Estimates of CO_2 efflux from a peatland and a marsh during this period were 4.179 and 5.026 g C m^{-2} $season^{-1}$, respectively. The seasonal release of CH_4 from the peatland (0.009 g C m^{-2} $season^{-1}$) was much lower than that from the marsh (0.818 g C m^{-2} $season^{-1}$). Intriguingly, we observed that the peatland acted as sink for N_2O, and the marsh as a source for N_2O during the snow-covered season. For the peatland, snowpack such as snow density is important for CO_2 and CH_4 fluxes, while N_2O flux was controlled by soil–snow interface temperature. In the marsh, however, soil temperature was the primary parameter regulating greenhouse gas fluxes. Our results suggest that in mid- and high-latitude regions, greenhouse gas fluxes during the snow-covered season is an important part of C and N cycles in seasonally snow-covered wetland ecosystems. The difference in greenhouse gas emission from both peatland and marsh suggests that wetland types should be considered when evaluating regional gas budgets.

1. Introduction

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are three major greenhouse gases which trap outgoing heat from Earth's surface. In the last hundred years, the amount of greenhouse gas in the atmosphere has increased because of human activities, thus enhanced the natural greenhouse effect. Solomon et al. (2007) reported that atmospheric greenhouse gas increased from 280 ppm in 1750s to 379 ppm for CO_2, 715 to 1732 ppb for CH_4 and 270 to 319 ppb for N_2O in 2005, respectively. As one of the primary ecosystems in the world, wetland plays a significant role in estimating global greenhouse gas fluxes. Northern peatlands, act as carbon sink owing to its water-saturated condition which restricts organic matter decomposition, accumulate organic carbon for millennia and store nearly one thirds of soil organic carbon (Gorham, 1991; Smith et al., 2004). Meanwhile, methane can be produced via anaerobic decomposition in the form of organic matter breakdown in the absence of oxygen. According to Anderson et al. (2010), natural wetlands contribute 170 Tg CH_4 every year, which account for 37% of the total CH_4 flux into the atmosphere. Nitrous oxide is produced by two key microbial processes such as nitrification under aerobic conditions and denitrification under anoxic conditions (Firestone and Davidson, 1989). Therefore, N_2O flux from wetlands was commonly depended on soil aerobic and/or anoxic conditions.

Some previous studies suggest that greenhouse gas can be produced or consumed in soils even at temperatures below 0 °C

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(Groffman et al., 2006; Oquist et al., 2004). Greenhouse gas fluxes through snowpack are significant part of the global carbon and nitrogen budget and also to be the important component of the annual flux in mid- and high-latitude regions due to their large snow-covered land surface and long snow-covered season and possible biological production or released of gas trapped by frozen soils (Panikov and Dedysh, 2000; Schimel et al., 2006; Zhang et al., 2005; Zimov et al., 1993). It has been reported that winter emission of greenhouse gas accounted for 12–30% of CO_2 (Fahnestock et al., 1999; Kim et al., 2007), 3.5–50% of CH_4 (Heikkinen et al., 2002; Melloh and Crill, 1996; Panikov and Dedysh, 2000), 19–28% of N_2O from mid- and high-latitude ecosystems through a year (Alm et al., 1999). To understand global terrestrial biosphere–atmosphere C/N interactions and construct C and N budgets within these ecosystems, greenhouse gas emission from these snow-covered areas deserves more attention.

However, most measurements were mainly conducted in arctic and subarctic regions (Aurela et al., 2002; Fahnestock et al., 1999; Heikkinen et al., 2002; Welker et al., 2000). Little attention is given to wetlands in mid-latitude and mountain permafrost regions, where experience long cold winter covered by snowpack. In Northeast China, the area of natural wetlands which dominated by freshwater marshes and mountain permafrost peatlands is 1.017×10^{10} m^2, accounting for 26.5% of total national natural wetlands (Liu, 2005) and 0.2% of global natural wetlands (Cao et al., 1998). These wetlands are generally covered by snowpack lasting four to six months throughout a year. However, only Zhang et al. (2005) reported greenhouse gas emission from wetlands located in Sanjiang Plain in Northeast China during cold seasons. Field measurements of greenhouse gas emission are limited in this region, especially during snowpack period. So far, no investigation has ever been carried out on mountain permafrost peatlands in China. Hence, precise estimation of greenhouse gas budgets in regional and national level needs more observations in field. The aim of the present study is to evaluate greenhouse gas fluxes through snowpack in freshwater marsh and mountain permafrost peatland in Northeast China.

2. Site description and methods

2.1. Site description

The measurements were conducted in a minerotrophic peatland at Great Xing'an mountain (52.94°N, 122.86°E), and in a freshwater marsh at Sanjiang Experimental Station of Wetland Ecology (47.58°N, 133.51°E) in the Sanjiang Plain. These sites are located in mid- and high-latitude zones in Northeast China. The peatland is situated in the continuous permafrost zone, and the marsh is located in the region where underlain by seasonal frozen soil which would entirely melt during summer. The climate of the peatland is cool continental, with a 30-year (1971–2000) mean annual temperature of −4.3 °C and mean annual precipitation of 435 mm. At Sanjiang Plain, it belongs to temperature monsoon climate. The mean annual temperature and precipitation of this study area are approximately 2.52 °C and 558 mm (2002–2006) (Song et al., 2009).

The main microtopographies in the peatland surface are characterized as hummock, tussock and hollow, which are dominated by dwarf shrubs such as *Chamaedaphne calyculata*, *Leduim palustre*, *Vaccinium vitis-idaea* and *Betula fruticosa*, sedges and mosses. *Eriophorum vaginatum* comprise a sparse cover and a few previous-mentioned shrubs are present on tussocks. Hummocks and hollows are covered by *Sphagnum* mosses (*Sphagnum capillifolium*, *Sphagnum magellanicum*) and *Polytrichum commune*. At Sanjiang Plain, the marsh site with a flat topography is covered with homogeneous herbaceous vegetation dominated by *Carex lasiocarpa*. Other species in the marsh are *Carex pseudocuraica*, *Glyceria spiculosa* and *Carex meyeriama*. More data on physical-chemical characteristics of soil are given in Table 1.

2.2. Flux measurement and calculation

All measurements were carried out during the snow-covered season when lasted from October 2010 to April 2011 at the peatland and the marsh. Gas fluxes were estimated using snowpack properties and concentration gradient of CO_2, CH_4 and N_2O in the snowpack. Gases in snowpack were sampled through permanent samplers that installed before significant snow accumulation had occurred. The snowpack surrounding the samplers was not disturbed when sampling throughout the snow-covered season. The sampler was constructed of stainless steel (2 mm ID, 3 mm OD) tubings with 50 cm long fitted on a rod at heights of 0, 10, 20, 40, and 60 cm above the ground. Each of the five stainless steel tubes supported a pair of inlets, which one was connected with platinum silicone tubing (2 mm ID, 4 mm OD; 150 cm length; Shenzhen Rubber & Plastic Co., China), and the end of the tubing was attached to a three-way stopcock. The other inlet was fitted with 80 mesh gauze to prevent debris from entering the sampling line. In the peatland, we randomly installed five samplers. Gas samples collection began in late October, just after a few days of the snow and the snowpack was approximately 18 cm thick, and ended in March. In the marsh, the standard stainless steel tubings in the sampler were fitted on a rod at heights of 0, 20, 40 and 60 cm above the ground. Three samplers were established in the homogeneous terrain. We sampled snowpack gases from December to March at the marsh. The snowpack gases were collected two or three consecutive dates at both sites in each month.

Snow and atmospheric air samples for greenhouse gas analyses were taken with plastic syringes (60 mL) and the sample size was 50 mL. Approximately 10 mL were drawn and discarded to completely purge the tubing, whose internal volume was approximately 6.5 mL. Assuming a sphere volume of gas flow was sampled, the 50 mL of air withdrawn at inlet would yield an effective radius of ~2.7 cm. The sampling ports were 10 and 20 cm apart in the vertical, so there might be little influence on gas leakage from above/below layers. Samples were withdrawn from the syringes by injecting into previously evacuated Tedlar® air bags (100 mL, Delin Ltd, Liaoning, China). The sealed air bags were then transported to the laboratory and greenhouse gas concentrations were analyzed by the use of a gas chromatograph (Agilent 4890D, Agilent Co., Santa Clara, USA). The modified gas chromatograph equipped with a flame ionization detector (FID) and an electron capture detector (ECD) (Wang and Wang, 2003). N_2 was used as the carrier gas with a flow rate of 30 mL min^{-1}. CH_4 was directly measured by FID. CO_2 was firstly reduced to CH_4 and then detected by FID. N_2O was measured by ECD. To avoid the interference of CO_2 upon the N_2O signals described by Zheng et al. (2008), a buffer gas (CO_2:N_2 = 10:90) was applied to flow through the ECD cell at a rate of 1–3 mL min^{-1}. More details about gas analysis can be found in Wang and Wang (2003).

Table 1
Characteristics of wetland soils in Northeast China.

Site	SOC, g kg^{-1}	TN, g kg^{-1}	C/N	pH
Marsh	53.7 ± 0.3	4.4 ± 0.7	12.2	5.0 ± 0.04
peatland	371.7 ± 1.3	19.8 ± 0.1	18.8	4.9 ± 0.1

SOC indicates soil organic carbon; TN represents total nitrogen, the value behind plus and minus represents standard error.