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Summertime N_2O, CH_4 and CO_2 exchanges from a tundra marsh and an upland tundra in maritime Antarctica

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HIGHLIGHTS

- Spatial variability in N_2O and CH_4 fluxes depended on tundra hydrological regimes.
- N_2O sinks generally occurred at waterlogged marsh sites.
- Water table lowering increased N_2O emissions and CH_4 consumption, decreased C loss.
- Tundra ER was limited by low soil temperature in maritime Antarctica.

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ABSTRACT

This study provides the first concurrent measurements of nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) fluxes from a tundra marsh and an upland tundra in maritime Antarctica over the summers of 2007/2008 and 2011/2012. Tundra N_2O and CH_4 fluxes showed large spatial variations depending on local hydrological regimes. N_2O sinks generally occurred at waterlogged marsh sites (−3.0 to 27.5 μg N_2O m^{-2} h^{-1}) whereas relatively dry and mesic sites presented weak or strong N_2O sources (2.2–41.6 μg N_2O m^{-2} h^{-1}). Upland tundra sites showed negligible N_2O emissions due to low soil TN and NH_4^+–N contents. Dry/upland tundra sites showed weak to strong CH_4 uptake (−4.5 to −85.8 μg CH_4 m^{-2} h^{-1}). The waterlogged sites showed weak to strong CH_4 emissions (29.8 μg CH_4 m^{-2} h^{-1}–2.4 mg CH_4 m^{-2} h^{-1}). Both tundra marsh and upland tundra experienced a large net CO_2 uptake with the greatest mean CO_2 uptake rate (−92.1 mg CO_2 m^{-2} h^{-1}) at dry marsh sites. Mean ecosystem respiration (ER) ranged between 82.5 ± 13.2 and 174.9 ± 25.7 mg CO_2 m^{-2} h^{-1} at all the sites, and showed a strong exponential correlation ($P < 0.001$) with 0–10 cm soil temperature. Gross photosynthesis (P_g) was more than two times higher in tundra marsh than in upland tundra due to the difference of vegetation coverage. N_2O flux showed a strong negative correlation ($P < 0.01$) with 0–10 cm soil temperature at the marsh sites, and significant or weak positive correlations with total daily radiation (TDR) and sunlight time (ST). No significant correlation was obtained between CH_4 fluxes and environmental variables at tundra marsh and upland tundra sites. There was a significant negative correlation ($P < 0.01$) between NEE and 0–10 cm mean soil temperature, total daily radiation. Our results indicated that the lowering of water table significantly increased N_2O emissions and CH_4 consumption, but decreased C loss from the tundra marsh. In the future, the combination of climate warming and frequent precipitation will alter tundra hydrological conditions, and thus decrease N_2O emission and CH_4 consumption from maritime Antarctic tundra.

1. Introduction

Atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are key radiatively active greenhouse gases (GHGs) (IPCC, 2007). N_2O also takes part in the destruction of stratospheric ozone (Ravishankara et al., 2009). Increase in concentrations of GHGs and their contributions to global warming have been becoming a serious concern. Soils are important sources or sinks for GHGs in terrestrial ecosystems (IPCC, 2007). At present, GHG fluxes have been extensively studied from temperate, subtropical and tropical terrestrial ecosystems (Jungkunst and Fiedler, 2007;

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Takakai et al., 2008; Song et al., 2009; Ullah and Moore, 2011). Many studies on CO_2 and CH_4 fluxes have also been conducted from boreal tundra in the Northern Hemisphere (Oechel et al., 2000; Christensen et al., 2004; Corradi et al., 2005). Recent findings of high N_2O emissions from subarctic peatlands and high N_2O production potential in arctic thawing permafrost (Repo et al., 2009; Elberling et al., 2010; Marushchak et al., 2011), have given rise to an extensive concern about N_2O emissions from permafrost soils. The research about GHG sources and sinks from Antarctic soils mainly concentrated on the McMurdo Dry Valleys of continental Antarctica (e.g. Burkins et al., 2001; Gregorich et al., 2006; Barret et al., 2006; Ball et al., 2009). However, little attention is given to maritime Antarctica.

In maritime Antarctica, the tundra covered with mosses, lichens and algae constitutes part of an area free of permanent snow cover. Maritime Antarctica has experienced the highest temperature increase in the past decades (Steig et al., 2009), accompanied by regional changes in precipitation (Turner et al., 1997). Tundra ecosystems in maritime Antarctica might be unique in response to changing climate, because of warmer temperature and frequent precipitation (Convey and Smith, 2006). A marked expansion of higher plant population (*Deschampsia antarctica Desv*) has recently been observed at some sites of maritime Antarctica (Parnikoza et al., 2009) with similar changes for moss vegetation (Convey and Smith, 2006). These changes are expected to affect GHG emissions from the tundra as soil temperature and moisture are related to microbial activity, and soil C, N mineralization (Bokhorst et al., 2007; Carvalho et al., 2010). Therefore measurements of soil GHG fluxes are essential to understand the C and N cycles in the maritime Antarctic tundra, and how they respond to climate changes. Recently, soil development and nutrient cycles have been studied in some areas, particularly on outlying islands of Antarctic Peninsula (Huiskes et al., 2006; Park et al., 2007; Park and Day, 2007). Summertime CH_4 and N_2O fluxes from tundra soils have been observed in maritime Antarctica (Sun et al., 2002; Zhu and Sun, 2005; Zhu et al., 2005, 2008; Vieira et al., 2013). Nevertheless, such data are available only from limited tundra site-level observations, and the observations simultaneously covering multiple gases (N_2O, CH_4 and CO_2) are still lacking in maritime Antarctic tundra.

During the austral summers of 2007/2008 and 2011/2012, net N_2O, CH_4 and CO_2 fluxes and ecosystem respiration (ER) were investigated in a tundra marsh, and an upland tundra in maritime Antarctica. The objectives of this study were (1) to study temporal and spatial variability in net GHG fluxes and ER from the maritime Antarctic tundra; (2) to investigate the effects of environmental parameters on net GHG fluxes and ER; (3) to compare the differences of GHG fluxes and ER between tundra marsh and upland tundra.

2. Materials and methods

2.1. Study areas and investigation sites

One study area was on Ardley Island (62°13′S, 58°56′W; 2.0 km length and 1.5 km width) (Fig. 1). This island has been defined as an area of special scientific interest by the Scientific Committee of Antarctic Research (SCAR). This area is characterized by oceanic climate and the predominant wind directions are from the west or northwest. The west of this island is a Late-Holocene coastal terrace with elevations from 10 to 14 m a.s.l. The middle of this island is elevated, hilly and relatively dry upland. Active penguin colonies only concentrate in the east of this island. Ornithogenic Cryosols are well developed due to chemical weathering favored by penguin guano deposition and mineralization (Simas et al., 2007). A well-developed tundra marsh (TM) is located in the western terrace

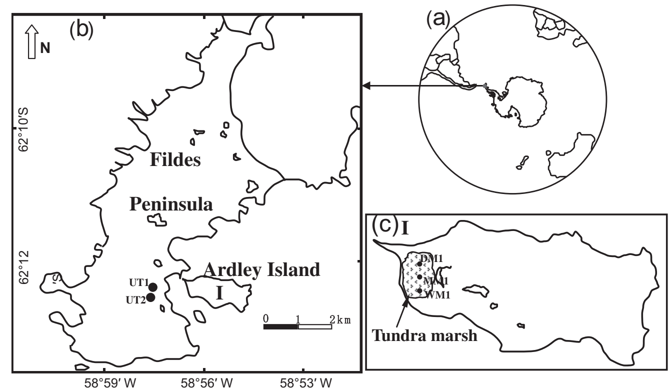

Fig. 1. (a) The circle dot indicates location of the investigation area in maritime Antarctica. (b) Location of the investigation sites on Fildes Peninsula and Ardley Island, King George Island. Two upland tundra sites (UT1 and UT2) were shown in the figure. (c) The investigation sites in tundra marsh of *Ardley* Island. Three regular sites DM1, MM1 and WM1 were located in dry, mesic and wet tundra areas, respectively. Other eight sites included dry marsh sites DM2, DM3 and DM4, mesic marsh sites MM2 and MM3, and wet marsh sites WM2, WM3 and WM4. These eight sites were not shown in the figure.

with an area of about 0.25 km^2. The area around TM was occupied by penguin population during the historical period dating to 3000 years ago (Sun et al., 2000) although at present penguins have not colonized this area. Mosses and algae dominate the vegetation in the poorly drained tundra areas. The drier but still moist rims are dominated by mosses and lichens. Under the vegetation cover is an organic clay layer of about 15–20 cm. The dry tundra area around the marsh is distributed with a thick layer of lichens with the predominance of *Usnea aurantiacoatra* and *Usnea antarctica*. During summer 2007/2008, three regular sites (relatively dry site DM1, mesic site MM1 and waterlogged site WM1) were set up and equipped with three chamber collars each to study the temporal variability in GHG fluxes. Other eight irregular sites (DM2, DM3 and DM4 for relatively dry sites; MM2 and MM3 for mesic sites, WM2, WM3 and WM4 for waterlogged sites) were randomly selected, and equipped with two collars each to study the spatial variability in GHG fluxes. During summer 2011/2012, N_2O and CO_2 fluxes and ER were measured only at two waterlogged sites WM1 and WM2 in the marsh due to the limit of manpower. These observation sites were characteristic of the prevalent surface and vegetation within the marsh (Fig. 1c).

Another study area was on Fildes Peninsula (61°51′–62°15′S, 57°30′–59°00′W), which is situated in the southwestern part of King George Island with an area of about 30 km^2 (Fig. 1). The communities formed of lichens and mosses dominate over the vegetation in the peninsula. An upland tundra (UT) was located in the northwest of Chinese Great Wall Station located on the peninsula, about 500 m apart from this scientific station. The upland tundra was almost dry with the elevation of about 40 m a.s.l. The sampling grounds were covered completely with mosses (*Bryum Pseudotriquetrum* and *Bryum muelthenbeckii*) and lichens (*Usnea* sp.), and the depth of vegetation layer is about 5–10 cm. Under the vegetation cover is an organic clay layer of about 10–15 cm (Fig. 1b). Within the upland tundra community, two observation sites (UT1 and UT2) for GHG fluxes were established at an interval of approximately 10 m along a gentle slope during the summers of 2007/2008 and 2011/2012.

2.2. In-situ GHG flux measurement

The fluxes of GHGs from tundra sites were determined using a static chamber technique (Hutchinson and Mosier, 1981; Sun et al.,