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Micrometeorological measurement of methane flux above a tropical peat swamp forest

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ABSTRACT

Tropical peat swamp forest is a unique ecosystem, in which both swamp forest and peat soil have coexisted over millennia and accumulated a significant amount of soil carbon as peat. Owing to the huge soil carbon stock and high groundwater level (GWL), tropical peatlands potentially represent a significant source of methane (CH_4) to the atmosphere. However, a few studies of CH_4 flux by the soil chamber technique have reported that annual CH_4 emissions from tropical peat swamp forest were very low as compared to mid- and high-latitude peatlands. Recently, it has been reported that some tree species growing in peat swamp forest emit CH_4 from their stems. It is impossible to continuously measure ecosystem-scale CH_4 flux including both soil and plant-mediated CH_4 emissions by the chamber technique. Thus, we have measured net ecosystem CH_4 exchange (FCH_4) above a tropical peat swamp forest in Sarawak, Malaysia using the eddy covariance technique from February 2014 to July 2015 (18 months). The mean (±1 standard deviation) of half-hourly measured FCH_4 was $24.0 \pm 42.2\,\text{nmol m}^{-2}\,\text{s}^{-1}$. Monthly mean FCH_4 was always positive during the 18 months, even in the driest month with mean GWL of −30 cm. FCH_4 was positively associated with GWL or soil moisture in a quadratic form. Annual FCH_4 from March 2014 through February 2015 was 7.5–10.8 $\text{g C m}^{-2}\,\text{yr}^{-1}$. The annual FCH_4 was much higher than annual soil CH_4 emissions from tropical peatlands, because the FCH_4 included aboveground CH_4 emissions mainly from tree stems. However, the annual FCH_4 was relatively low in comparison with those measured by the eddy covariance technique in mid- and high-latitude peatlands.

1. Introduction

Peatlands constitute about 3% of the global land area, yet they represent the largest long-term carbon pool in the terrestrial biosphere (Maltby and Immirzi, 1993; Yu et al., 2014). In the tropics, large areas of peatland exist in the coastal lowlands of Southeast Asia, with about 20.7 Mha in Indonesia and 2.6 Mha in Malaysia (Page et al., 2011). Recently, a large peatland area of about 14.6 Mha was found in the Congo Basin (Dargie et al., 2017). Both peat swamp forest vegetation and underlying peat have coexisted over millennia and formed a highly-concentrated carbon store (Dommain et al., 2011). Owing to the huge carbon stock in the soils and high groundwater level (GWL), tropical peatlands could be a significant source of methane (CH_4).

Tropical peatlands generally have a dome-shaped surface with greater peat depth towards the centre of the peatland (Melling and Hatano, 2004). Tropical peat mainly originates from slightly- or partially-decayed trunks, branches and roots of trees (Melling and Hatano, 2004). Different species composition and vegetation structures can be seen in different zones of peat domes in Borneo (Anderson, 1961). In Sarawak, Malaysia, six zonal communities of forest vegetation are distributed from the edge to the center of a peat dome (Anderson, 1961). These zonal communities are called as follows: mixed peat swamp, Alan Batu, Alan Bunga, Padang Alan, Padang Selunsor and Padang Keruntum forests from the edge (Anderson, 1961; Phillips, 1998). This sequence is different from that of tropical peat swamp forest in Central Kalimantan, Indonesia (Page et al., 1999). The peat depth, hydrology, decomposition level, soil pH and vegetation composition are different among the zonal communities. Thus, carbon dynamics could be heterogeneous according to the zonal communities.

CH_4 is the second most important greenhouse gas (GHG), with a global warming potential 28 times greater than carbon dioxide (CO_2) over a century (Milich, 1999; IPCC, 2013). The atmospheric concentration of CH_4 has increased by 150% since the pre-industrial era, rising from 722 ppb in 1750 to 1803 ppb in 2011 (IPCC, 2013). The

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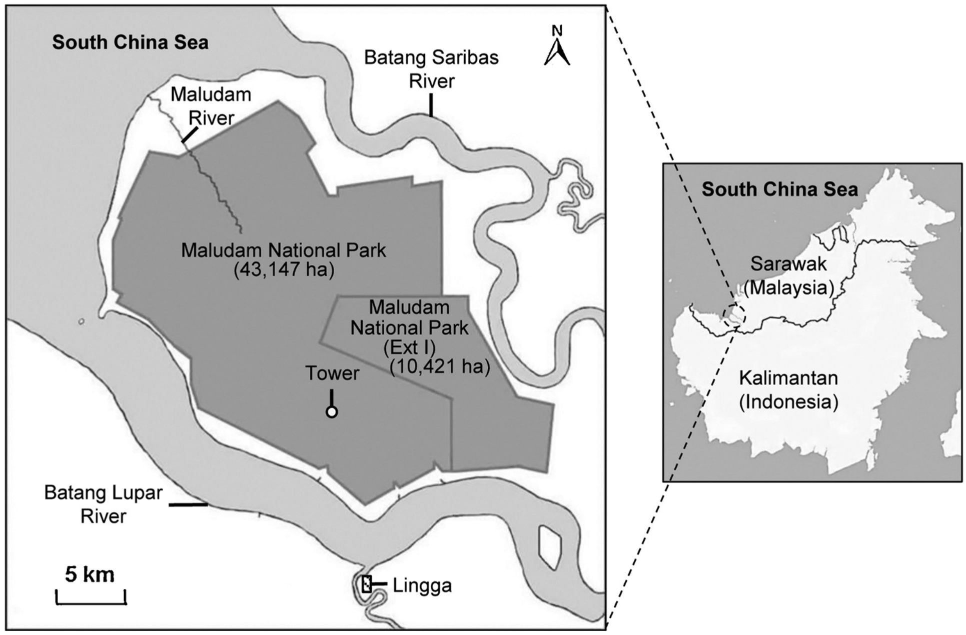

Fig. 1. Map of the study area.

growth rate of CH_4 has declined to near zero during 1999–2006 and increased again in 2007 with two anomalous annual CH_4 emissions estimated by inversions for 2007–2008 (Bousquet et al., 2011; IPCC, 2013). Tropical CH_4 emissions were found to be the main contributor of these emission anomalies (Bousquet et al., 2011). To date, however, there is no evidence that tropical peatland is attributable to the large emissions; this can partly be attributed to a lack of observational data from peat swamp forests. In tropical peat swamp forest, CH_4 flux showed a large spatial variation in horizontal and vertical directions. Microtopography on the forest floor consisting of hummocks and hollows causes the horizontal variation, because soil CH_4 efflux is higher on hollows (Pangala et al., 2013). Also, Pangala et al. (2013) reported that dominant trees in tropical peat swamp forest in Indonesia emitted a considerable amount of CH_4 from their stems. Furthermore, there are CH_4-emitting termites nesting above the ground of tropical peat swamp forests (Fraser et al., 1986; Martius et al., 1993; Jeeva et al., 1999; Vaessen et al., 2011). Thus, the CH_4 is not emitted only from the soil surface but also from tree stems and termites, which causes a vertical variation in CH_4 flux.

Measurement of CH_4 emissions to the atmosphere has largely relied on the static chamber technique and the eddy covariance technique (McDermitt et al., 2011). The chamber technique provides advantages, such as portability, low-cost and detectability of small-scale CH_4 ebullition events in a small sampling area (Nadeau et al., 2013). However, the method is very labour intensive, and is subject to uncertainties due to soil disturbance and insufficient gas mixing (Christiansen et al., 2011). In addition, the chamber technique usually excludes trees. Alternatively, the tower-based micrometeorological approaches, such as the eddy covariance technique, has now been widely used to measure ecosystem-scale CH4 flux over a larger area ($\sim 10^3$–$10^5\,m^2$) (e.g. Nadeau et al., 2013; Song et al., 2015). The eddy covariance technique enables continuous flux measurement with minimal disturbance and allows us to quantify CH_4 flux on multiple time scales (Rinne et al., 2007). In middle- and high-latitude peat ecosystems, many studies on CH_4 flux have been conducted by the eddy covariance technique (e.g. Rinne et al., 2007; Jackowicz- Korczyński et al., 2010; Nadeau et al., 2013; Olson et al., 2013; Song et al., 2015). In tropical peat swamp forest, however, there are only a few soil chamber studies (Melling et al., 2005; Jauhiainen et al., 2005, 2008; Hirano et al., 2009), which reported that CH_4 emissions from tropical peat were lower than those of boreal Sphagnum-dominated bogs.

To our knowledge, there is still no study reporting the CH_4 balance of tropical peat swamp forest using the eddy covariance technique. It is essential to quantify the CH_4 balance of tropical peat swamp forest from field measurement to know its contribution to the tropical CH_4 budget. Therefore, we have measured CH_4 flux above a tropical peat swamp forest using the eddy covariance technique during the period from February 2014 to July 2015 (18 months). The objectives of this study were to: (1) quantify the net ecosystem exchange of CH_4 (FCH_4); (2) examine both the diurnal and seasonal variations of FCH_4; and (3) determine the environmental factors that influence the FCH_4. The outcomes from this study will contribute to a better assessment of FCH_4 for tropical peat swamp forest.

2. Material and methods

2.1. Site description

The study was conducted in Maludam National Park, about 45 km northwest from Betong Division of Sarawak, Malaysia. Maludam National Park is a tropical peat swamp forest located in Maludam Peninsula and covers an area of 43,147 ha (Fig. 1). The Maludam Peninsula is bordered by the Batang Lupar and Batang Saribas Rivers, which flow into the South China Sea. The national park had been subjected to selective logging before it was gazetted as a totally protected area in 2000 (Chai, 2005). Currently, it remains as the largest peat swamp forest in Sarawak. In 2015, the national park was expanded by taking the neighbouring area (Ext I) covering another 10,421 ha. There are four zonal communities in the national park, namely Mixed peat swamp, Alan Batu, Alan Bunga and Padang Alan forests with different tree compositions, heights, densities and peat types (Anderson, 1961; Melling, 2016). In 2010, a 40 m tower was established in the southern part of the national park (1° 27′ 12.87″ N, 111° 8′ 58.17″ E) to measure eddy flux and environmental variables. The tower is located in an ombrotrophic Alan Batu forest, about 4.5 km away from the Batang Lupar River. Alan Batu forest is characterized by its extensive root system which commonly creates a vacant zone of 20–30 cm thickness within the top 100 cm of the peat profile (Melling, 2016).

Around the tower, the terrain is generally flat with an elevation of about 8–9 m above mean sea level with an average peat depth of 10 m. The forest structure is mixed, and the canopy is uneven with a height of 30–35 m. Most of the tree diameters at breast height (DBH, 1.3 m) were