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# A comparison of methane emission measurements using eddy covariance and manual and automated chamber-based techniques in Tibetan Plateau alpine wetland

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ABSTRACT

Comparing of different $CH_4$ flux measurement techniques allows for the independent evaluation of the performance and reliability of those techniques. We compared three approaches, the traditional discrete Manual Static Chamber (MSC), Continuous Automated Chamber (CAC) and Eddy Covariance (EC) methods of measuring the $CH_4$ fluxes in an alpine wetland. We found a good agreement among the three methods in the seasonal $CH_4$ flux patterns, but the diurnal patterns from both the CAC and EC methods differed. While the diurnal $CH_4$ flux variation from the CAC method was positively correlated with the soil temperature, the diurnal variation from the EC method was closely correlated with the solar radiation and net $CO_2$ fluxes during the daytime but was correlated with the soil temperature at nighttime. The MSC method showed 25.3% and 7.6% greater $CH_4$ fluxes than the CAC and EC methods when measured between 09:00 h and 12:00 h, respectively.



## 1. Introduction

Methane ($CH_4$) has a global warming potential of 25 in a 100-year time horizon and 72 in a 20-year time horizon (IPCC, 2007). Accurate $CH_4$ flux measurements are crucial to global carbon budgets but are largely constrained by methods that differ in their advantages, disadvantages and susceptibilities to measurement errors. The main $CH_4$ flux measurement techniques are the chamber method and the micrometeorological eddy covariance method. No standard or reference exists to test the accuracies of these methods, and large uncertainties characterize all types of measurements (Lund et al., 1999). Using several independent measurement methods is essential to help identify errors in the measurements and to develop confidence in the $CH_4$ flux measurements.

Traditionally, the manual static chamber methods have been widely applied due to their low costs (Song et al., 2009; Tuittila et al., 2000). During sampling, air samples are collected with a syringe and then analyzed using gas chromatography. The $CH_4$ fluxes are then calculated by measuring the rates of change in the $CH_4$ concentrations inside the chamber. The static chamber measurements cannot be sampled frequently due to the high labor intensity and time consumption of the manual operators. Static chambers usually provide periodic measurements, which are often used to estimate the daily and even annual $CH_4$ fluxes using linear interpolations or regression models (Chen et al., 2011; Song et al., 2009). However, large errors may result from the estimation because the $CH_4$ fluxes are not always predictable and vary temporally (Dinsmore et al., 2009; Long et al., 2010). Therefore, a more frequent sampling method is required to accurately capture the temporal $CH_4$ flux variation.

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The continuous automated chamber method can measure $CH_4$ fluxes at a much higher frequency without personal attention (e.g. once per hour). However, the automated chamber systems are more expensive than the static chamber systems and need complicated maintenance and greater infrastructure. Chamber methods (including the static and automated chambers) are often criticized because of poor spatial representation and the so-called chamber effects (Mosier, 1990). The $CH_4$ fluxes are measured with chamber methods covering small patches of soil. The chambers may cause soil disturbance, modify the temperature and moisture in the soil and air under the chamber, alter the $CH_4$ diffusion gradient within the soil profile, turbulent fluctuations and air flow. Although most chamber effects have been eliminated in recent set-ups, the problem of neglecting the influence of wind remains (Denmead, 2008).

To avoid chamber-related problems, alternative techniques, such as the micrometeorological eddy covariance method, have been applied for continuous $CH_4$ flux measurements (Hendriks et al., 2007; Kroon et al., 2010; Long et al., 2010; Rinne et al., 2007; Schrier-Uijl et al., 2010; Zona et al., 2009). The eddy covariance method measures net vertical turbulent $CH_4$ fluxes between the atmosphere and surface (vegetation and soil); these fluxes represent the integrated net fluxes from the landscape upwind from the measurement point. The eddy covariance method has advantages over the chamber method because the eddy covariance method does not disturb the soil surface microenvironment (Dugas, 1993), and most importantly, it integrates over larger areas and thereby can sample the spatial heterogeneity. Another advantage is that the technique is capable of measuring $CH_4$ fluxes continuously over long time periods. However, the eddy covariance method also has a wide array of limitations, such as it is most applicable over horizontally homogeneous area, in flat terrain and in atmospheric steady-state conditions. It has been suggested that the measured total fluxes can be underestimated during nighttime low turbulence conditions due to the large $CH_4$ concentration buildup in the nocturnal boundary layer (Long et al., 2010).

Even though a wide variety of techniques have been developed, a remaining issue is the difficulty of determining which is more accurate when they disagree. The uncertainties related to both the chamber and eddy covariance flux measurements motivate a comparison of these independent methods. Until recently, many studies have been published where the $CO_2$ fluxes measured using different methods were compared in forest (Janssens et al., 2000, 2001; Liang et al., 2003; Liang et al., 2004; Norman et al., 1997; Savage and Davidson, 2003; Wang et al., 2009), grassland (Myklebust et al., 2008; Schrier-Uijl et al., 2010), and wetland systems (Burrows et al., 2005). However, only a few studies have compared the chamber methods with the eddy covariance method for measuring $CH_4$ fluxes in heterogeneous peat meadows, rice paddy fields and northern peatland (Hendriks et al., 2010; Meijide et al., 2011; Sachs et al., 2010; Schrier-Uijl et al., 2010).

Our current study presents the $CH_4$ emissions measured on a Tibetan Plateau alpine wetland using the manual static chamber, continuous automated chamber and eddy covariance methods. Wetlands are the largest natural source of atmospheric $CH_4$, accounting for 20–39% of the total annual emissions worldwide (Denman et al., 2007; Mitsch and Gosselink, 2007). Wetlands on the Tibetan Plateau are predicted to have lowered water tables due to the permafrost degradation caused by rapid climate warming (Cheng and Wu, 2007), and these changes in the soil hydrological conditions may affect the release of the soil carbon stock as greenhouses gases, such as $CH_4$, further inducing climate change. In this paper, we compare the three approaches to measuring the $CH_4$ emission in a Tibetan Plateau alpine wetland. The objectives of this paper are (1) to compare the performances of the three $CH_4$ flux measurement techniques during the 2011 growing season; and (2) to determine the factors driving $CH_4$ flux variations on diurnal and seasonal scales in the alpine wetland.

## 2. Methods

### 2.1. Site description

The methane emission was measured at the Luanhaizi wetland on the northeastern Tibetan Plateau in China (37°35′ N, 101°20′ E) (Fig. 1a). The average altitude is 3200 m, and the local climate is characterized by strong solar radiation with long, cold winters and short, cool summers. The mean annual air temperature was $-1.5 \pm 10.9$ °C in 2011. The highest daily mean temperature was $14.6 \pm 3.7$ °C in August, while the lowest was $-23.4 \pm 8.6$ °C in January. The annual mean precipitation was 501 mm, and 90% of the precipitation was concentrated in the growing season from May to September. The air pressure was low, approximately 70 kPa, due to the area's high altitude.

The wetland is underlain by high-altitude permafrost. The topsoil (0–20 cm) is nearly full of roots, so we only measured the soil C and N contents, which are 12.25% for C and 0.98% for N, respectively, at depths of 20–100 cm. The wetland is characterized by a unique microtopography, with many hummocks scattered. The water depth was approximately 2.7 cm above the flat field, and dry hummocks (with irregular shapes) were approximately 25 cm high over the standing water level from June to October in 2010 and 2011 at the study site. The wetland plant community is dominated by *Carex pamirensis* Clarke with 63.4% coverage in the flat field. In 2011, the average height of this species is 15.8 cm, and the average biomass is 135.8 g $m^{-2}$. Several other species are also present in the flat field, including *Carex alrofusca* Schkuhr, *Hippuris vulgaris* L., *Triglochin palustre* L. and *Heleocharis* spp. The dry hummocks are mainly dominated by *Cremanthodium pleurocaule*. A wide range of moss species are scattered in the wetland.

### 2.2. Measurement techniques

#### 2.2.1. Manual Static Chamber (MSC) system

Stainless steel chambers (40 cm × 40 cm × 40 cm) were used to collect the $CH_4$ (Fig. 1b). To prevent heating inside the chamber caused by solar radiation, the chambers were covered with polystyrene foam. A small fan was installed in the chamber to homogenize the inside air. When sampling, the chamber was inserted into a water-filled groove on a 6 cm high frame inserted into the soil to prevent leakage. The 60 ml gas samples were extracted with plastic syringes every 10 min over a 30 min total period. The $CH_4$ concentrations were analyzed using gas chromatography (Agilent 7890A, Agilent Technologies, Santa Clara, CA, USA) within 24 h. The $CH_4$ was separated with a 2 m stainless steel column packed with 13XMS (60/80 mesh) and was directly measured using a flame ionization detector. The fluxes were determined from the slope of the concentrations in four samples taken at 0, 10, 20 and 30 min after the chamber closure and were corrected for atmospheric pressure and the chamber air temperature. The sample sets were rejected unless they yielded a linear regression $R^2$ value greater than 0.9. The $CH_4$ was sampled approximately once per week between the hours of 09:00 h and 12:00 h. The air temperature inside the chambers was measured using a thermometer (JM222, Jin Ming, Tianjin, China) during the chamber closure. The atmospheric pressure was measured once per half hour at a nearby meteorological station.

We established five plots in the flat field dominated by *C. pamirensis* within the eddy covariance fetch along the installed wood boardwalk. One chamber was placed on each plot when sampling. The distance between two adjacent plots was approximately 5 m.

#### 2.2.2. Continuous automated chamber (CAC) system

We deployed a multichannel automated chamber system to measure the $CH_4$ fluxes over entire seasons (Fig. 1c). This system has been previously described in detail (Liang et al., 2003, 2004), but a brief summary follows. This system measures the $CH_4$ flux in a flow-through and non-steady-state manner and comprises 20 automated chambers, a 24-channel gas sampler, an IRGA (Li-Cor 840, Li-Cor, Lincoln, NE, USA), a datalogger (CR1000, Campbell Scientific, Utah, USA) and a $CO_2/CH_4/H_2O$ gas analyzer (Picarro G1301, Picarro, Santa Clara, CA, USA). The automated chambers (90 cm × 90 cm × 50 cm) are made of clear PVC glued to a steel pipe frame. The bottom of each chamber is 5 times larger than that of the static chamber to minimize the small-scale spatial variability. Between measurements, the chamber lids are opened to allow precipitation to reach the enclosed soil surface to keep the soil conditions as natural as possible. When a chamber is closed, the chamber air is pumped continuously from the side wall of chamber to the IRGA and $CO_2/CH_4/H_2O$ gas analyzer. Meanwhile, the air is returned from the IRGA and $CO_2/CH_4/H_2O$ gas analyzer to the chamber through a manifold. The flow rate through the system is 0.7 L $min^{-1}$. Each chamber is equipped with two fans to mix the air and three small vents to equilibrate the pressure between the outside and inside of the chamber during measurements. Over the course of an hour, the 20 chambers are closed in sequence by the CR1000 installed in the 24-channel gas sampler. We set the sampling period for each chamber to 180 s to finish a cycle of measurements within 1 h.