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Interannual variations in methane emission from an irrigated rice paddy caused by rainfalls during the aeration period

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ABSTRACT

Mid-season drainage (MSD) decreases methane emission from an irrigated rice paddy. For this reason, the 2006 IPCC Guidelines and several methane estimation models consider MSD as a static input factor. However, if rainfall occurs during the MSD period, the reduction effect on methane emission may become small. In this paper, we report the methane emission from an intermittently irrigated rice paddy with MSD for three growing seasons. Methane flux was measured using eddy covariance technique with an open-path methane analyzer. Our objective is to ascertain the seasonal and interannual variations in methane emission caused by rainfalls during the MSD period. The growing season (from June to Oct.) methane emission during the three year study period ranged from 198 to 450 kg CH_4 ha^{-1}, showing significant interannual variability with changes in rainfall during the MSD period. In order to implement the effect of rainfall during the MSD on methane emission (not considered in the IPCC method), we developed a simple method for a scaling factor. The estimated and the observed CH_4 emissions agreed within 40%, and additional consideration of soil pH further improved the agreement within 10%. These results suggest that the rainfall effect should be considered when estimating national or global methane emission from irrigated rice paddies.

1. Introduction

Methane (CH_4) is one of the most influential greenhouse gases; the Global Warming Potential (GWP) per unit mass is 25 times more than that of carbon dioxide (CO_2) (Shindell et al., 2009). Irrigated rice paddies are one of the major sources of CH_4, which emitted 33–40 Tg (CH_4) yr^{-1} worldwide from 2000 to 2009 (Stocker et al., 2014). In addition, CH_4 emission from rice paddies is expected to increase in the future due to growing demand for food, warming effect with increasing temperature, and fertilization effect with increasing CO_2 concentrations (e.g., Smith et al., 2007; Pereira et al., 2013; Van Groenigen et al., 2013). Yet, large uncertainties still remain in their magnitudes and projection, which must be resolved (e.g., Kang et al., 2015a).

The IPCC (2006) Guidelines specify methodologies and emission factors to quantify CH_4 emission from rice paddies and indicate three tiers to reflect the different levels of technical prowess and information gathering capability of countries. Some countries that have not developed country-specific CH_4 emission factors can use these emission factors developed by the IPCC (i.e., Tier 1). Tier 2 utilizes country-specific CH_4 emission factors which are developed at the unit of the state, and applies the same approach as Tier 1. Tier 3 specifies CH_4 emissions to sub-national levels and also considers interannual variations in CH_4 emissions. In sum, the methodologies from Tier 1 to Tier 3 are classified according to spatio-temporal resolution (IPCC, 2006).

The IPCC method (i.e., Tiers 1 and 2) and several CH_4 estimation models consider mid-season drainage (MSD) as an input (e.g., Huang

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et al., 2004; IPCC, 2006; Chun et al., 2015) because the effect of MSD on CH_4 emission is significant. In East Asia, MSD is usually performed to vitalize root physiologically and to prevent rice from nonproductive tillering. MSD causes a decrease in CH_4 emissions because drainage changes the soil condition from anaerobic to aerobic, thereby facilitating methane oxidation (Sass et al., 1992; Wassmann et al., 2000; Nishimura et al., 2004). Especially, MSD can reduce CH_4 emission without decreasing rice grain yields (Kudo et al., 2014).

Changes in spatial and temporal distributions of summer rainfalls can generate significant variations in CH_4 emissions. Especially when rainfall occurs during the MSD period, drainage is terminated earlier than scheduled and methane emission is not curbed but enhanced. Yao et al. (2012) and Zhou et al. (2015) conducted a three year study of CH_4 emissions under various nitrogen fertilization in China. Interestingly, the most influential factor on CH_4 emission in the studies was not the nitrogen fertilization, but the rainfalls during MSD. Also, Yagi et al. (1996) showed that the MSD period and CH_4 emissions have a negative correlation. However, some CH_4 estimation methodologies and models, including the IPCC method, have not considered such an effect of rainfall during MSD (e.g., Huang et al., 2004; IPCC, 2006). Therefore, the estimates of CH_4 emission from irrigated rice paddies reported in the prior studies may have been underestimated, particularly for the Asian regions where summer monsoon coincides with the MSD period. Approximately 90% of rice paddies are located in monsoon countries, and single or multi drainage was conducted in more than 50% of rice fields (Yan et al., 2009).

The objectives of our study are (1) to scrutinize the seasonal and interannual variations in CH_4 emissions from rice paddies associated with the occurrence of rainfall during the MSD period and (2) to suggest a simple method to implement the effects of rainfall and evaluate it against the method recommended in the National Greenhouse Gas Inventory Report. Our results are expected to contribute to reducing uncertainty in quantifying CH_4 emissions from rice paddies.

2. Materials and methods

CH_4 flux and meteorological variables were observed from 2011 to 2014 in South Korea by the eddy covariance technique. In this study, however, we did not use data from 2013 because of flooding inside the instrument and a memory card error. We focused on precipitation, soil water content, CH_4 flux, and the MSD period in 2011, 2012 and 2014. The site and observation system are described in Sections 2.1 and 2.2. Also, information about the KNIR (2014), IPCC (2006), and the new method's framework are described in Sections 2.3 and 2.4.

2.1. Site description and field management

The flux tower was located in Gimje, South Korea (35°44′N, 126°51′E, 4 m above m.s.l.). This site has been a rice (June–October) and barley (November–April) double-cropping field for more than 20 years. A small village is located 400 m southwest of the flux tower, and a small cattle shed is located 200 m northeast of the tower. With the exception of those factors, the rice paddy around the tower is homogeneous (Fig. 1). Cows can affect CH_4 flux when the footprint includes them (Detto et al., 2011), but the cattle shed hardly affected CH_4 flux in this study. A more specific explanation about the effects of the cattle shed is given in Section 2.2.

The rice cultivar was "*Sindongjin*", a medium-late *japonica* rice cultivar. The soil of the rice paddy was silt loam, a rich well-drained soil called *"Jeonbuk Series"* (Kang et al., 2015b). The surface soil contained 32.3 g C kg^{-1} of organic materials and the pH was approximately 5.6 (Min et al., 2013). Transplanting was fulfilled in the middle of June every year. The transplanting was performed by a machine with infant seeding and fresh water. After a stable irrigation period, MSD was executed. The field was intermittently irrigated but kept saturated after MSD. The specific information about field management is summarized in Table 1.

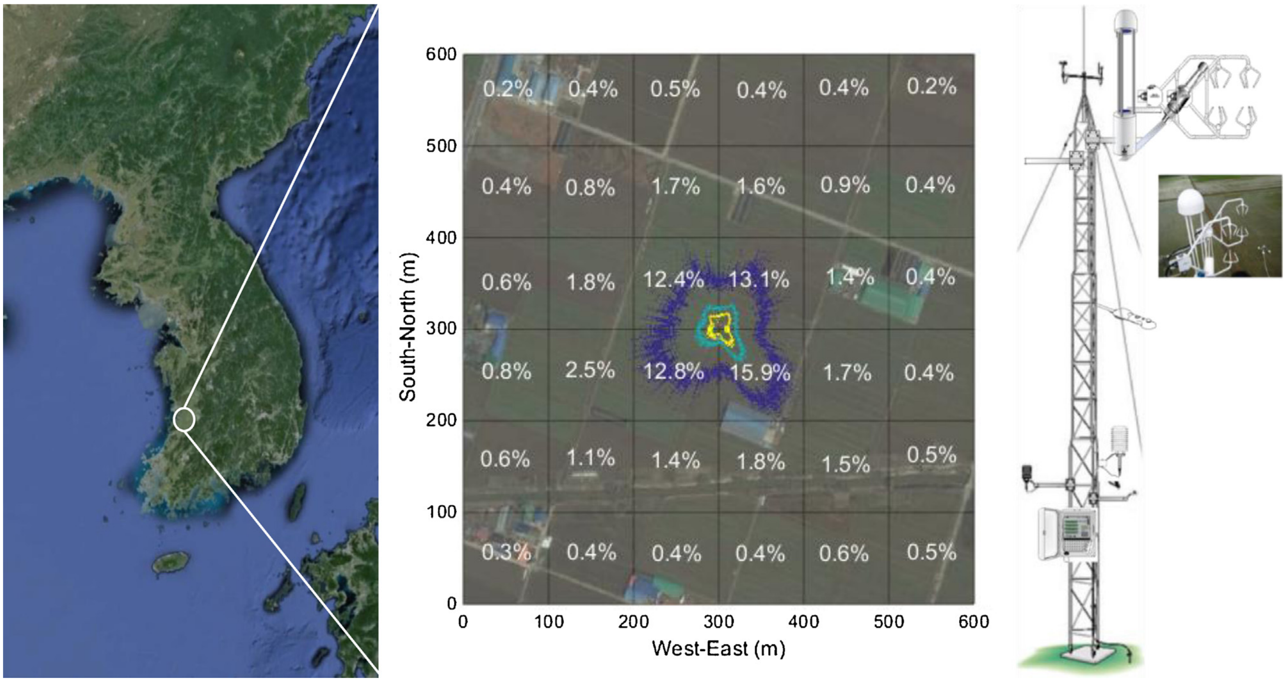

Fig. 1. Location (left), surroundings (center) and diagram of the measurement tower (right). The tower was located in center spot [300,300] on the satellite image; the contributions to flux footprint during the study period (June–October 2011, 2012 and 2014) are reported for each grid cell; three lines from the inside out represent 0.01, 0.005, 0.001 (percent per 1 m × 1 m) isopleth of relative flux footprint, respectively.