Agricultural and Forest Meteorology 214-215 (2015) 456–472

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Studying the spatial variability of methane flux with five eddy covariance towers of varying height

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ARTICLE INFO

Article history:
Received 27 March 2015
Received in revised form 7 August 2015
Accepted 13 September 2015
Available online 30 September 2015

Keywords:
Eddy covariance
Methane flux
Spatial variability
Peatland
Tall tower
Footprint

ABSTRACT

In this study, the spatial representativeness of eddy covariance (EC) methane (CH_4) measurements was examined by comparing parallel CH_4 fluxes from three short (6 m) towers separated by a few kilometres and from two higher levels (20 m and 60 m) at one location. The measurement campaign was held on an intensively managed grassland on peat soil in the Netherlands. The land use and land cover types are to a large degree homogeneous in the area.

The CH_4 fluxes exhibited significant variability between the sites on 30-min scale. The spatial coefficient of variation (CV_{spa}) between the three short towers was 56% and it was of similar magnitude as the temporal variability, unlike for the other fluxes (friction velocity, sensible heat flux) for which the temporal variability was considerably larger than the spatial variability. The CV_{spa} decreased with temporal averaging, although less than what could be expected for a purely random process ($1/\sqrt{N}$), and it was 14% for 26-day means of CH_4 flux. This reflects the underlying heterogeneity of CH_4 flux in the studied landscape at spatial scales ranging from 1 ha (flux footprint) to 10 km^2 (area bounded by the short towers). This heterogeneity should be taken into account when interpreting and comparing EC measurements. On an annual scale, the flux spatial variability contributed up to 50% of the uncertainty in CH_4 emissions. It was further tested whether EC flux measurements at higher levels could be used to acquire a more accurate estimate of the spatially integrated CH_4 emissions. Contrarily to what was expected, flux intensity was found to both increase and decrease depending on measurement height. Using footprint modelling, 56% of the variation between 6 m and 60 m CH_4 fluxes was attributed to emissions from local anthropogenic hotspots (farms). Furthermore, morning hours proved to be demanding for the tall tower EC where fluxes at 60 m were up to four-fold those at lower heights. These differences were connected with the onset of convective mixing during the morning period.

1. Introduction

Some 14% of European peatlands are used for agricultural purposes; this number can be as high as 85% in countries with high population density, such as the Netherlands (Joosten and Clarke, 2002). CH_4 fluxes show significant spatial variability, especially in agricultural areas on peat soils (Hendriks et al., 2010; Schrier-Uijl et al., 2010a, 2010b; Teh et al., 2011), due to heterogeneous soil moisture conditions, agricultural management practices and vegetation composition. For instance Hendriks et al. (2010) found up to 25-fold differences in CH_4 fluxes between measurement locations in a single abandoned peat meadow, using chamber systems. This variability was explained by differences in soil water level in combination with root depth patterns and presence of aerenchymatous plant species. High spatial variability of the flux complicates upscaling, since it is difficult to assess how representative of the

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http://dx.doi.org/10.1016/j.agrformet.2015.09.007

wider geographic area measurements are. Upscaling is essential if measurements are to be extrapolated to continental and global CH_4 budgets. Upscaled CH_4 emissions tend to have large uncertainties (Kirschke et al., 2013; Schulze et al., 2009) and agreement with other large scale flux estimation methods (e.g. so-called top-down estimates obtained with inverse modelling) is unsatisfactory at continental (Schulze et al., 2009) and global scales (Kirschke et al., 2013). CH_4 flux spatial variability is often found to be related to spatial variability of water table level and plant communities (Hendriks et al., 2010; Lai et al., 2014), whereas the most important driver for seasonal variability is soil temperature (e.g. Rinne et al., 2007; Yvon-Durocher et al., 2014). In addition, temporal and spatial variability can be caused by ebullition (Tokida et al., 2007) and plant-aided transport (Hendriks et al., 2010; Kim et al., 1999). Plant-aided transport may be passive via diffusion (e.g. Henneberg et al., 2012) or active via convective through-flow through the aerenchyma (e.g. Hendriks et al., 2010; Kim et al., 1999). Generally only a fraction of CH_4 produced in the anoxic conditions is released to the atmosphere, since most of the produced CH_4 is oxidised while it is transported through the oxic zone in the soil (e.g. Le Mer and Roger, 2001).

CH_4 flux spatial variability has been studied at the field scale with a combination of chamber and short tower eddy covariance (EC) measurements, providing information on fluxes at different spatial scales, e.g. chambers on plot scale ($\sim$1 m^2) and EC on ecosystem scale ($\sim$1 ha) (e.g. Hendriks et al., 2010; Schrier-Uijl et al., 2010b; Teh et al., 2011). Schrier-Uijl et al. (2010b) and Hendriks et al. (2010) found 13% and 37% differences in long term CH_4 budgets between the fluxes obtained with these techniques, respectively, at two Dutch peat meadow sites. Even though the agreement between the methods was reasonable, it is difficult to assess how well they scale up to larger spatial areas, i.e. how representative the obtained CH_4 flux estimate at the field scale is for the whole landscape (>1 km^2).

The objective of this study was to assess the CH_4 emissions at spatial scales which fall between the regular EC towers (field scale, $\sim$1 ha) and inverse modelling ($\sim$100–500 km^2). At the same time this study assesses the application of installing EC measurements on tall towers established for the concentration monitoring needed for the inverse modelling in order to simultaneously provide information on emissions at the regional and at the landscape scale. Such studies could help bridge the gap between these two methods and may help understand why bottom-up and top-down estimates for large scale CH_4 emissions often disagree. During the measurement campaign the spatial variability of CH_4 emission in an agricultural peatland landscape in the Netherlands was investigated with three short eddy covariance towers, separated by a few kilometres, and one tall tower which integrated CH_4 emissions from a larger area. It was hypothesised that the tall tower averages out the CH_4 flux variability seen with the three short towers, providing the integrated flux from the studied landscape to the atmosphere. Multilevel EC measurements allowed the spatial variability of CH_4 flux to be studied in the surrounding landscape, since the size of the source area of the flux, i.e. flux footprint, increases with measurement height (e.g. Rannik et al., 2012). Footprint modelling (Kljun et al., 2002, 2004) was used for spatial apportionment of observed fluxes and their comparison with known distributions of local sources of CH_4. Differences in spatial scales between tall tower and short towers were also investigated.

2. Materials and methods

The present study was supported by an EU FP7 infrastructure project InGOS (Integrated non-CO_2 Greenhouse gas Observing System) and was held 1–25 July 2012 in the surroundings of the Cabauw Experimental Site for Atmospheric Research (CESAR). It was a follow-up campaign to a CH_4 flux instrument intercomparison campaign which was held during June 2012. Results from the intercomparison experiment have been summarised elsewhere (Peltola et al., 2014); the same instruments were used in this study.

2.1. Site description

2.1.1. Landscape characteristics

The CESAR site (51°58′12.00″ N, 4°55′34.48″ E, −0.7 m a.s.l) is located in the “Groene Hart” (i.e. Green Heart) of the Netherlands. Compared to other parts of the country, this area is relatively sparsely populated and largely used for agriculture, predominantly dairy farming.

The landscape comprises polders separated by dikes. Polder areas consist of large numbers of rectangular fields with drainage ditches running between them (see Fig. 1a). The fields are mostly intensively managed grasslands used as pasture and for growing hay and livestock fodder (e.g. maize (*Zea mays*)). Based on Beljaars and Bosveld (1997) the dominant grass species in the area are *Lolium perenne*, *Poa trivialis*, and *Alopecurus geniculatus*. The area is flat with no apparent slopes or hills and thus it is ideal for micrometeorological measurements. The farms in the area were located close to each other and were lined up between the fields (Fig. 1a). Cattle were the main type of livestock in the area, however sheep, pigs, poultry, rabbits, turkeys and horses were also present. Statistics on the main livestock categories are given in Table 1.

The soil consists mostly of river clay and peat, with peat fraction increasing with distance from the nearby river Lek. All EC measurements in this study were located in an area where the soil was classified as soil profile type Rv01C or ‘Drechtvaaggrond’ in the Dutch soil classification system (Wösten et al., 2001). This soil class is characterised by a few tens of centimetres thick layer of clay which overlays a deep peat layer. Soil profiles measured at the CESAR site by Jager et al. (1976) showed that the top 0.60 m consisted mostly of clay (8–12% organic matter with high root density), 0.60–0.75 m depth was a mixture of clay and peat (1–3% organic matter with low root density) and a peat layer extended from 0.75 m to 7.00 m below the surface. Most of the (grass) roots were confined to the top 0.18 m deep layer.

The water table depth is actively monitored and controlled in several locations within the polder area (Fig. 1). Water is pumped out of the polder and into the river Lek (a tributary of the Rhine river) if the level exceeds a preset threshold. During dry spells in summer, this drainage may be reversed by letting in water from the river. The water level in the ditches is maintained at on average about 0.4 m below the surface (Beljaars and Bosveld, 1997). In previous studies conducted in similar ecosystems during summer time, drainage ditches and ditch edges have been observed to be CH_4 emission hotspots (Hendriks et al., 2010; Schrier-Uijl et al., 2010b), whereas the central parts of the fields were not such significant CH_4 emitters due to the fact that the water level in the soil depends on the distance from the closest drainage ditch.

2.1.2. CESAR site

2.1.2.1. Site description. The vegetation at the CESAR site itself was dominated by grasses (*Lolium perenne* (55%), *Festuca pratense* (15%), and *Phleum pratense* (15%)) (Beljaars and Bosveld, 1997). During the campaign, tussocks of *Juncus effusus* were observed in the fields and especially on edges of the drainage ditches. *J. effusus* may act as a conduit for diffusive transport of CH_4 within its aerenchyma (Henneberg et al., 2012; Schäfer et al., 2012), thereby thus potentially increasing the efflux of CH_4 to the atmosphere. Next to the CESAR 6 m tower, which was located 87 m away from the main mast (213 m high tall tower, see Fig. 1b), maize (*Z. mays*) was grown in two fields in the 180–280° wind sector. This was the prevailing