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Title: Ecosystem level methane fluxes: disentangling sources and sinks from transport using true eddy accumulation, eddy covariance, gradient and chamber flux methods

METHANE-FLUX

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Introduction and motivation

Methane, CH_4, is the third most important greenhouse gas after water vapour and CO_2. Rising atmospheric methane concentrations contribute increasingly to climate change. While principal natural and anthropogenic methane sources and sinks are known, their magnitude remains uncertain. There is a significant gap between bottom-up methane flux estimates and top-down inverse modelling, leaving a "missing methane source" unexplained. Recent experimental evidence suggests that forests might account for a formerly underestimated source of methane, which might close the gap between measurements and models. Closing this gap requires interdisciplinary process studies of the biological/physiological methane production/consumption of forests and the turbulent atmospheric exchange. The net ecosystem exchange of methane above the forest canopy integrates production, consumption, and diffusive (soils), conductive (trees) and turbulent (atmosphere) transport processes. We hypothesize that there is partial recycling of suspected methane emissions from trees to the upper soil horizons, fed by in-canopy turbulence, the magnitude of which is modulated by micrometeorological conditions and the coupling of the canopy with the atmosphere.

Previous studies showed that net methane fluxes above forests were often close to the detection limit of conventional micrometeorological methods and instruments. Improved methods are required. We propose to test true eddy accumulation (TEA).

The northern forest at Hyytiälä is an ideal site for this interdisciplinary study to close the gap in scientific knowledge and flux methods because of potential methane emissions from trees, the rich availability of auxiliary data, and it is an ideal platform for validating novel instrumentation.

Multidisciplinary approach

This work synthesizes multidisciplinary approaches. At the core of this project is the quantification of CH4 and CO2 fluxes using micrometeorological methods. Interpreting observed net CH4 rand CO2 fluxes requires distinguishing between the biological source and

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sink processes and physical atmospheric transport phenomena, i.e. the degree of mixing of the air close to the soil and in the canopy with the atmosphere above.

This work is further part of a collaboration, bringing together micrometeorological methane flux measurements with flux estimates from soil-, trunk-, and leaf chamber based enclosure techniques as well as biophysiological process modeling of methane sources and sinks.

Scientific objectives

1) Assess drivers and quantify magnitudes of ecosystem-scale methane fluxes by micrometeorological methods (true eddy accumulation, eddy covariance),
2) Partition methane fluxes into components from soil, stems and shoots using enclosure methods,
3) Operate for the first time a novel true eddy accumulation system side-by-side to both conventional eddy covariance and gradient techniques for CH_4, CO_2 and H_2O fluxes and assess method specific differences,
4) Develop and promote high performance true eddy accumulation.

Methodology and experimental set-up

Fluxes of CH_4, CO_2 and H_2O were measured at above the forest canopy at the SMEARII/Hyytiälä site at a height of 20 m above ground in the period from 7th to 31st July 2017. We used the eddy covariance (EC) and true eddy accumulation (TEA) methods. The two setups operated side-by-side, using the same sonic anemometer.

The following instruments were used for eddy covariance flux measurements:

Sonic anemometer uSonic-3 (Metek GmbH) and open-path infrared gas analyzer LI-7500 (Licor Inc.).

The following instruments were used for eddy accumulation flux measurements:

Sonic anemometer uSonic-3 (Metek GmbH) and closed-path cavity-ringdown laser spectrometer gas analyzer G2401 (Picarro Inc.).

The uSonic-3 sonic anemometer and the LI-7500 gas analyzer both measured at a frequency of 20 Hz. The G2401 gas analyzer sampled at a frequency of 0.2 Hz.

Fluxes were computed for flux integration intervals of 30 minutes for both methods.

The true eddy accumulation instrument sampled air conditionally into updraft and downdraft reservoirs as a function of the sign of vertical wind velocity with the flow rate being proportional to the magnitude of the vertical wind velocity. The TEA sampling approach followed a principle proposed by Desjardins (1972). The flux of the scalars CH_4, CO_2 and H_2O were then calculated as:

$$\overline{wc} = \frac{1}{T_{avg}} \int_0^{T_{avg}} (\delta^+ cw + \delta^- cw)dt = \overline{wc} + \overline{w'c'}$$

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For a comparative performance evaluation, we will correlate fluxes from the TEA instrument with fluxes from three eddy covariance setups: the side-by-side EC setup described above using an open-path gasanalyzer for CO2 and water vapour fluxes, a closed-path cavity ringdown laser spectrometer EC setup for methane at the same tower, and a closed-path infrared gasanalyzer EC setup installed at another tower at a height of 32 m above ground and at a distance of about 100 m from the tower with the TEA instrument.

Preliminary results and conclusions

The intercomparison of the true eddy accumulation method and the eddy covariance method showed a high correlation of CO2 fluxes from the two methods (Fig.1). We interpret remaining differences as a result of the spatial separation of the measurements on two separate tower (horizontal distance of about 100 m) and method and instrument specific differences. However, the differences are small in relation to the flux itself. The high level of agreement of the two methods for CO2 fluxes provides confidence that the new TEA instrument and method is similarly able to produce correct CH4 fluxes. This is based on the assumption that the TEA air sampling is not gas species specific and should therefore perform in a similar way for non-reactive, non-sticky scalars.

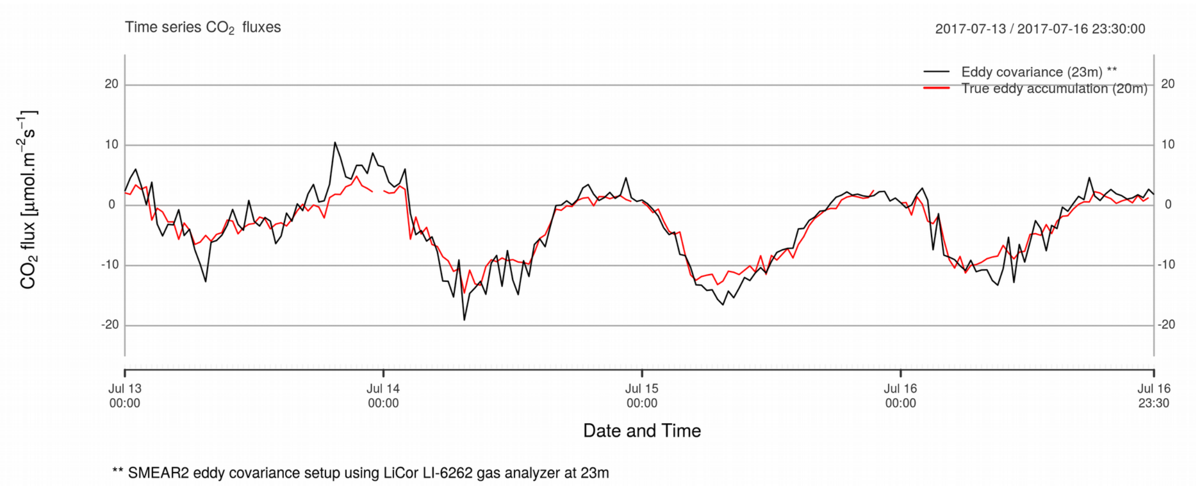

Figure 1: Time series of CO2 fluxes at a 30-min time resolution measured by true eddy accumulation (TEA) and eddy covariance (EC) at two different towers separated by a distance of ca. 100 m.

CH4 flux timeseries obtained from true eddy accumulation are presented for a period of 10 days (Fig. 2). CH4 fluxes show individual flux values in the range of typically -0.01 ymol m-2 s-1 to +0.01 ymol m-2 s-1. The fluxes are highly variable and change their sign during the course of the day. The majority of the 30-min flux values are negative, indicating that the forest system during this period most frequently acted as a sink of methane. However, also positive values are observed, suggesting methane emissions. The duration of net emissions ranges from less than an hour to almost entire days.

Aggregation of 30-min values to a mean diurnal cycle suggests that net methane emissions are more likely during the day and early evening whereas net methane uptake was observed during the early morning (Fig. 3). The mean diurnal cylce (Fig. 3) further shows higher variability of fluxes during the day than at night. We interpret the wide confidence intervals in Fig. 3 and the presence of both negative and positive fluxes during the day as the result of various drivers, the impact of which has to be further investigated. However, the width of the confidence intervals scales with the development of turbulence, as shown by the mean diurnal cycle of friction velocity (Fig. 4), with high flux variability and fluxes during when turbulence is well developed (large ustar) versus relatively narrow confidence intervals during early evening and the night, when turbulent mixing is low (small ustar, see Fig. 4), promoting the decoupling of the soil and the canopy from the atmosphere above and from the point of flux observation. This would explain why observed fluxes are smaller during times of low turbulence.

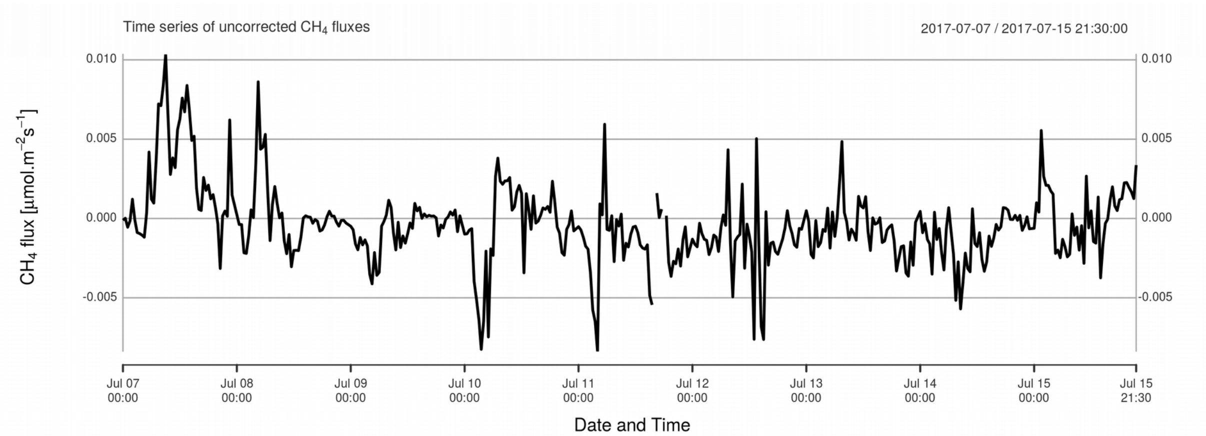

Figure 2: Time series of CH4 fluxes at a 30-min time resolution measured by true eddy accumulation (TEA).

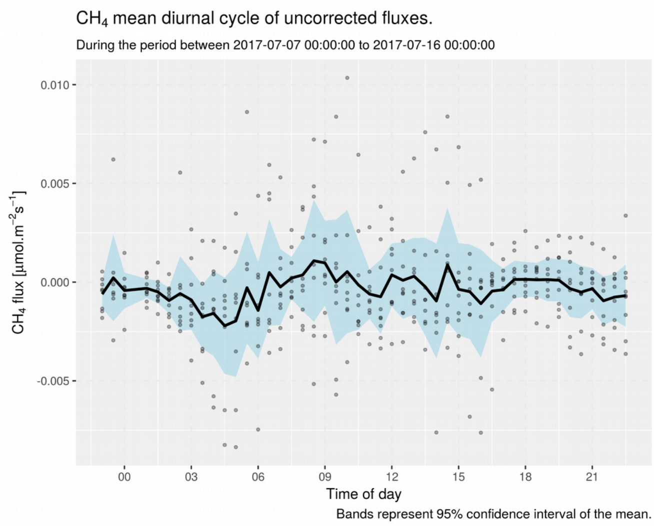

Figure 3: Mean diurnal cycle of CH4 fluxes (over 10 days at a 30-min time resolution) measured by true eddy accumulation (TEA) (black line), the 95% confidence intervals (blue shaded area) and individual flux measurements at a 30-min resolution (points).

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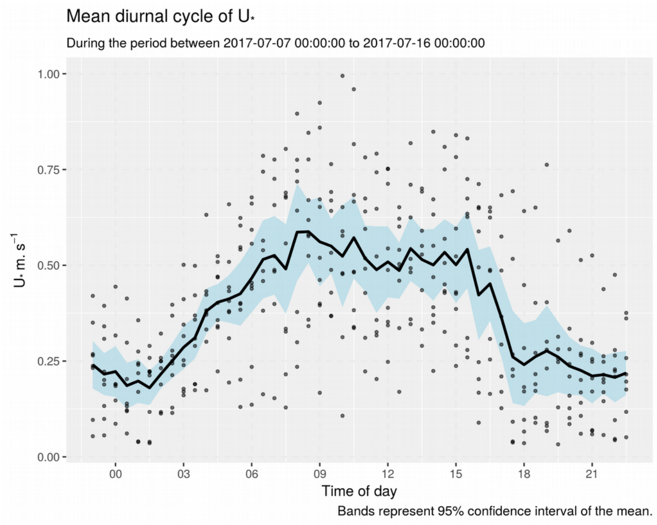

Figure 4: Mean diurnal cycle of friction velocity (over 10 days at a 30-min time resolution) measured by true eddy accumulation (TEA) (black line), the 95% confidence intervals (blue shaded area) and individual measurements at a 30-min resolution (points).

Outcome and future studies

This project successfully performed proposed flux measurements using both eddy covariance and eddy accumulation approaches. The project outcome comprises a data set of measurements of methane and CO2 fluxes from above specified methods and instruments. Further studies are required to analyze this data set with regards to comparing the performance of the different methods, investigating drivers of methane fluxes and to relate micrometeorological observations of net ecosystem exchange of methane with local chamber based methane flux estimates of soil and vegetation components and methane flux models upscaling the local chamber measurements.

References

Desjardins, R. Description and evaluation of a sensible heat flux detector. *Boundary-Layer Meteorology, Springer Netherlands,* 1977*, 11*, 147-154

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