MEMO^2: MEthane goes MObile – MEasurements and MOdelling

Report / publication on CH_4 emissions from wetland and lakes in Sweden

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1. Executive Summary

The Artic is exposed to faster temperature changes than most other areas on Earth. Constantly increasing temperature will lead to thawing permafrost and changes in the CH_4 emissions from wetlands. One of the places exposed to those changes is Abisko-Stordalen mire in northern Sweden, where climate and vegetation studies have been conducted from the 1970s.

In our study, we analyzed field-scale methane emissions measured by the eddy covariance method at Abisko-Stordalen mire for three years (2014-2016). The site is a subarctic mire mosaic of palsas, thawing palsas, fully thawed fens, and open water bodies. A bidirectional wind pattern prevalent at the site provides an ideal opportunity to measure mire patches with different permafrost statuses with one flux measurement system. The flux footprint for easterly winds is dominated by elevated palsa plateaus, while the footprint is almost equally distributed between palsas and thawing bog-like areas for westerly winds. As these patches are exposed to the same climatic conditions, we analyzed the differences in the responses of their methane emission for environmental parameters.

The methane fluxes followed a similar annual cycle over the three years, with a gentle rise during spring and decrease during autumn and with no emission burst at either end of ice-free season. Peak season emission from the mire with two permafrost statuses was significantly different, palsa mire emitting 24 mg-CH_4 m^{-2} d^{-1} and thawing wet sector 56 mg-CH_4 m^{-2} d^{-1}.

Factors controlling the methane emission were analyzed using generalized linear models. The main driver for methane fluxes was peat temperature for both wind sectors. Soil water content above the water table emerged as an explanatory variable for the three years for western sectors and the year 2016 in the eastern sector. Water table level showed a significant correlation with methane emission for the year 2016 as well. Gross primary production did not show a significant correlation with methane emissions.

Annual methane emissions were estimated with the use of four different gap-filing methods. The different methods generally resulted in very similar annual emissions. The mean annual emission based on all models was 4.2 ± 0.4 g-CH_4 m^{-2} a^{-1} for western sector and 7.3 ± 0.7 g-CH_4 m^{-2} a^{-1} for the eastern. Winter fluxes were relatively high, contributing 27 - 45 % to the annual emissions.

This deliverable is an extract of a publication which is close to submission. The publication will be available on the MEMO^2 website after acceptation.

2. Introduction

2.1 Background

Methane concentrations in the atmosphere have been rising again from the year 2007, after few years of stabilization (Dlugokencky et al. 2011, Nisbet et al. 2014). The reason for that is not fully clear yet as the mechanisms that control the global CH_4 budget are not completely comprehended (Kirschke et al., 2013, Saunois et al. 2020). The largest natural source of CH_4 is wetlands, based on top-down emission estimates (Saunois et al. 2020), and this source may be becoming stronger in the warming climate. The shift in the isotopic composition of CH_4 towards more negative values also supports the hypothesis of changes in the biological source strength driving the increase in methane concentration, as atmospheric CH_4 is becoming more ^{13}C-depleted (Nisbet et al. 2016).

The high northern latitudes are experiencing the fastest temperature increase due to the ongoing global warming. Temperature changes in the Arctic have been twice as high as the global average (Post et al. 2019). Increasing temperature has shown to speed up the degradation of permafrost which leads to losses in the soil carbon pool, often in the form of carbon dioxide (CO_2) and CH_4 (Malmer et al. 2005).

Ecosystems near the annual 0°C isotherms are vulnerable to permafrost thaw and changes in ecosystem characteristics in a warming climate. These vulnerable ecosystems include palsa mires, such as Stordalen Mire near Abisko, Sweden, where the recent warming has led to annual average temperatures exceeding 0°C for several consecutive years (Callaghan et al. 2010, Post et al. 2019). The warming has led to an acceleration of permafrost thaw processes and a transition from palsa plateaus, underlain by permafrost, to non-permafrost fen systems (Malmer et al. 2005). These deviations are likely to induce changes in biogeochemical processes, including increased CH_4 emissions (Christensen et al. 2003).

We analyzed field-scale CH_4 emission from two areas of Stordalen sub-arctic mire. The first area is dominated by permafrost plateau, while the second one is thawing, wetter areas. Outputs from this analysis are differences in the CH4 emissions from the mire patches with heterogeneous permafrost status. We are expecting, based on the previous studies, that fluxes from the wetter sector will be around 40 mg-CH4 m-2 d-2, while palsa plateau will emit significantly lower fluxes during a peak season. We presume that winter fluxes will be positive but very low.

For estimation of annual CH4 emission we need gap-free datasets. As there now exists no generally accepted gap-filling method for methane fluxes, four different gap-filling methods were compared. All these methods are uncertain and dealing with the gaps differently. Test of the four methods will decrease the uncertainty in an annual balance estimation. It was important to use more than one method in this case of study because datasets were portioning and due to that contained more gaps.

2.2 Scope of the deliverable

This deliverable is an extract of a publication which is close to submission. The publication will be available on the MEMO^2 website after acceptation.

This study described aims to estimate the annual CH_4 emission from two distinct different ecotypes, with heterogeneous permafrost status, exposed to the same environmental factors. Furthermore, the seasonal cycle of CH_4 emission has been analysed to quantify the contribution during different seasons. Moreover, differences in controlling factors for the permafrost area and the thawing area were analysed.

3. Content

The study area is Stordalen Mire, a mire complex underlain by discontinuous permafrost located in northern subarctic Sweden (68º20' N, 19º30' E) near Abisko. The station Abisko-Stordalen (SE-Sto) is a part of the ICOS Sweden research infrastructure and is the only one situated in the sub-arctic region in Sweden. The measurement period that is analyzed here covered three years from 2014 to 2016. The mean annual temperature in this region has been increasing during the last decades and temperatures recorded by Abisko SMHI (Sveriges meteorologiska och hydrologiska institut) at ANS (Abisko Naturvetenskapliga Station) has exceeded the 0 ºC threshold in the late 1980s (Callaghan et al. 2013, Figure S1). During the years 2014-2016, the mean annual air temperature (Ta) was 1.03 °C and 0.27 °C at ANS and the ICOS Sweden station Abisko-Stordalen (SE-Sto), respectively. The annual precipitation, based on ANS data, was around 330 mm yr^{-1}. The acceleration of permafrost loss with increasing temperatures is likely (Callaghan et al. 2013).

The large mountain valley of Lake Torneträsk channels winds at the measurement site, leading to a bidirectional wind distribution (Fig. 1) that allows us to divide our analyses into two distinct sectors. The plant community structure around the tower is determined by the hydrology which in turn is determined by the microtopographic variation in the surface due to the local permafrost dynamics. Different plant communities would have different productivities thus controlling the CO_2 and CH_4 fluxes from those surfaces. The area to the west of the EC mast is dominated by a drier permafrost palsa plateau hereafter referred to as the western sector, whereas the area to the east is a mixture of thawing wet areas and palsas, hereafter referred to as the eastern sector.

Fluxes of CO_2, CH_4, H_2O, and sensible heat were calculated using EddyPro 6.2.1 (LICOR Environment, USA). Fluxes and turbulence statistics were calculated as half-hourly averages. The data quality flagging system and advanced options for EddyPro were set up following Jammet et al. (2017). Options selected and used by Jammet et al. (2017) for CO_2 were applied for all fluxes, for this study.

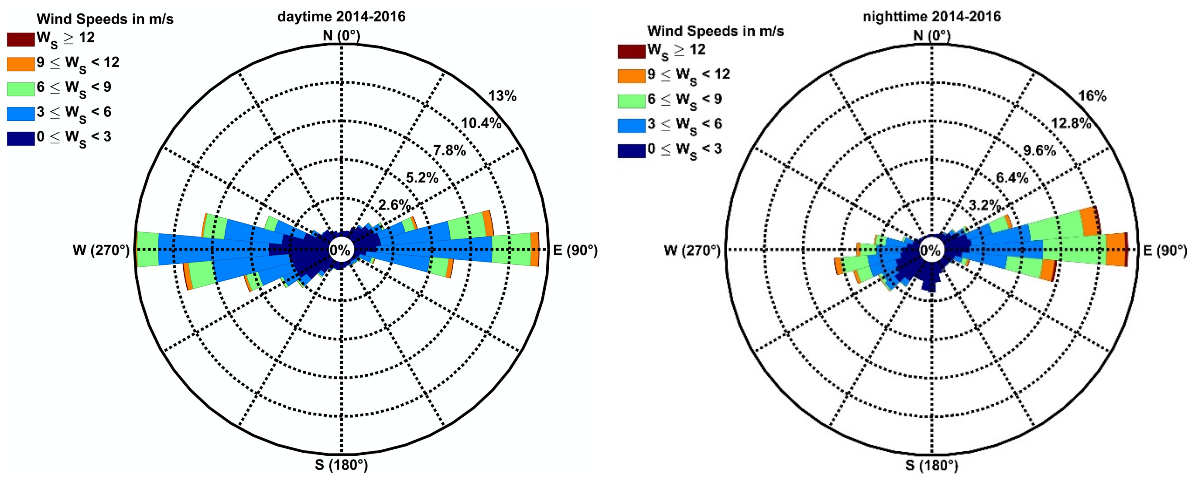

Fig. 1: The wind rose for SE-Sto tower for years 2014-2016 for the daytime (left panel) and nighttime (right panel)

Based on the wind direction, the half-hourly data were divided into western and eastern datasets, similarly to analyses by Jackowicz-Korczyński et al. (2010) and Jammet et al. (2015, 2017). The eastern dataset contained fluxes and other variables recorded when the wind was from 45º - 135º, and the western dataset parameters when wind directions were 225º - 315º. These two datasets were analyzed separately. Fluxes measured with wind from these two sectors are influenced by mire surfaces dominated by differing permafrost status, moisture regimes, and plant community structures. These reflect the thaw stages of a dynamic arctic land surface, responding to the warming climate. These two wind sectors cover more than 80 % of all data during the years 2014 - 2016. Northerly and Southerly wind directions, i.e. winds from outside these sectors occurred mainly in low wind speed conditions. The distribution of wind directions is presented in Fig. 1.

The analysis of relations of CH_4 fluxes to environmental parameters was done using non-gap-filled dataset of daily averages, to avoid the danger of circular reasoning of analyzing the relations to the same factors that were be used for gap-filling.

Footprint calculation has been made with the model described by Kljun et al. (2015) using receptor height, Obukhov length, the standard deviation of lateral velocity fluctuations, friction velocity, and roughness length as input data. The input data were divided into the two sectors mentioned above, before footprint calculation, and footprints were calculated separately for them. We calculated footprints for each half-hourly data point and aggregated these to annual footprint climatology for each sector. A land cover classification was performed over the EC-tower footprint to estimate the flux contribution from the drained palsa and the thawing wet areas. Based on the land cover classification and annual CH_4 fluxes for each sector it was possible to estimate annual emission from different surface type.

The beginning of the unfrozen period was defined as that day when daily averages of peat temperature at 10 cm depth had been above 0 ºC for three consecutive days. The end of the unfrozen period was defined as the day when daily averages of peat temperature at 10 cm depth had been below 0 ºC for three consecutive days.

Table 1: Start, end, and length of unfrozen periods in the footprints of the EC measurements.

	2014 W	***2015 W***	***2016 W***	***2014 E***	***2015 E***	***2016 E***
Beginning of unfrozen period (DoY)	141	136	129	143	142	133
End of unfrozen period (DoY)	289	305	297	292	307	300
Length of unfrozen season	148	169	168	149	165	167

The unfrozen and frozen periods commence in the western sector on average 3 days earlier than in the eastern sector, but differences in the unfrozen season length are not systematical (Table 1). The beginning and the end of the unfrozen season for both sectors were determined independently. The horizontal distance between soil temperature sensors in eastern and western sectors was around 75 m, differed about 2 m elevations, and were roughly 40 m from the flux tower.

CH_4 fluxes, both for the western sector and the eastern sector started increasing after snowmelt up to the maximum in August (Fig. 2). No major springtime emission burst nor autumn freeze-in burst were observed in any of the years.

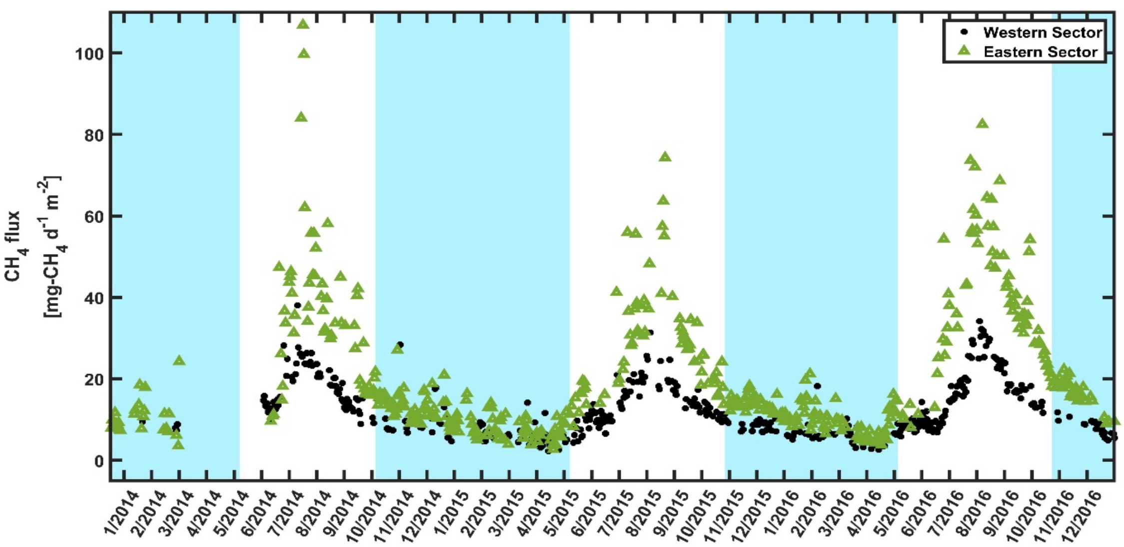

Fig. 2: Time series for non-gap-filled CH_4 daily averaged fluxes for the western sector and the eastern sector, where the shaded light blue area is frozen period.

In the eastern sector, the CH_4 flux correlated best with the peat temperature at 30 cm depth, and in the western sector with the temperature at 10 cm depth. Using temperatures above the level of maximum correlation led to similar hysteresis-like behavior in CH_4 flux - temperature relations as presented by Chang et al., (2020), but using deeper temperatures led to inverse hysteresis compared to shallower temperatures (Fig. 3).

The correlation matrix shows importance of the SWC in the CH_4 emissions, while WTL does not correlate significantly with CH_4 flux.

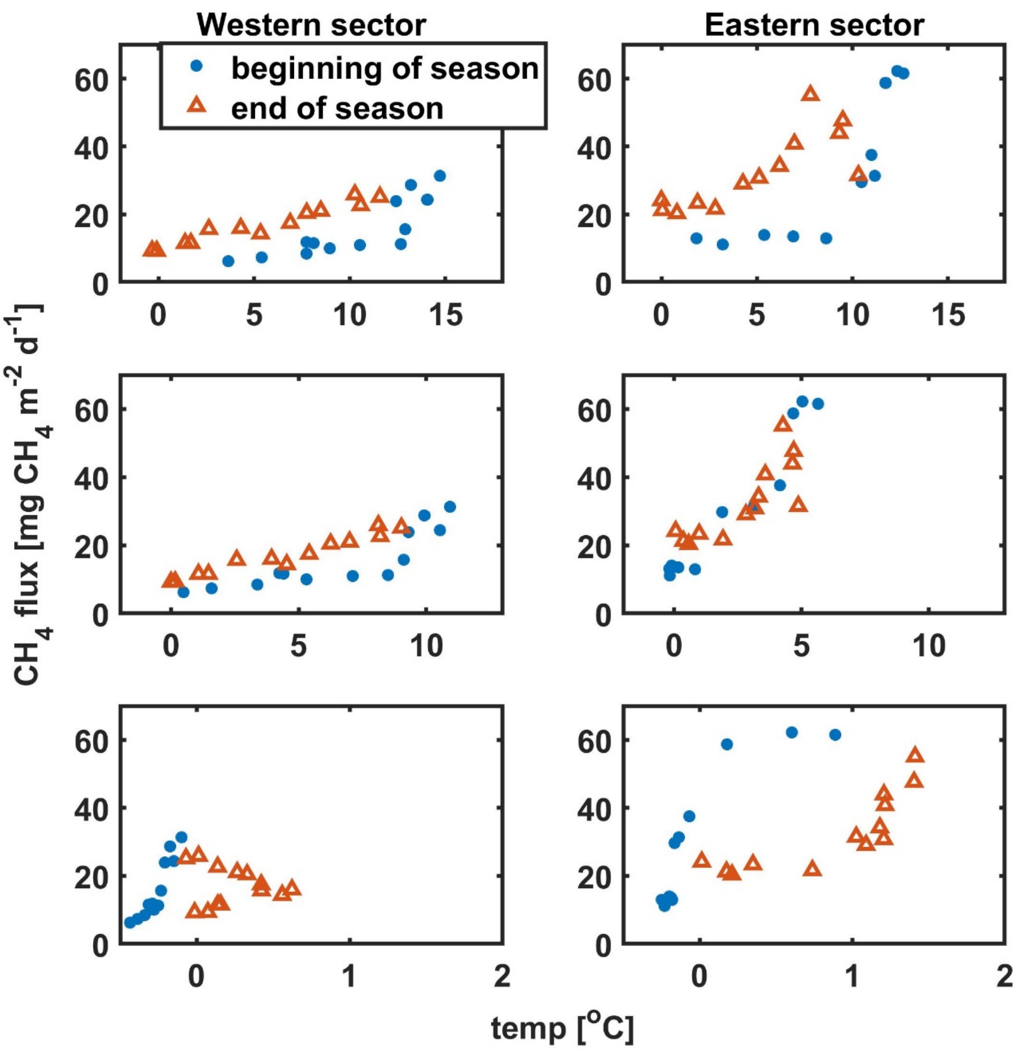

Fig. 3: Weekly averages of CH_4 fluxes vs surface peat temperature (top panels) the best correlated layer (middle panels) and the deeper layer (bottom panel). Data were divided do the beginning of the growing season (blue dots) and end of the growing season (orange triangles), where breakout week was the week with the highest emission.

4. Conclusion and possible impact

The EC measurements showed two different sub-arctic mire areas, one dominated by palsa plateaus and the other a mixture of palsas and thawing wet surfaces, to have clear differences in their annual CH_4 emission, with the area dominated by palsas having lower emission. The annual emission from thawing surface (11 g CH_4 m^{-2} d^{-1}) is nearly three times higher than from palsa surface (3.6 g CH_4 m^{-2} d^{-1}) but only half of the emission previously reported from fully thawed tall graminoid fen. Areas measured in this study had similar seasonal cycles of emission, with maxima appearing in August and lower but significant fluxes in winter. The seasonal cycles were furthermore characterized by a gentle increase in spring and a more rapid decrease in fall, without any obvious burst events during spring thaw or autumn freeze-in. The wintertime period contributed 27 – 45 % to the annual emission.

According to the correlation matrix and the GLM analysis, CH_4 emissions from the western and eastern sectors were controlled partly by different factors. As in most studies on CH_4 emission from wetlands, peat temperature was the most important factor explaining the emission. However, the temperature at different depths seems to control the CH_4 fluxes for the two analyzed mire sectors. The relation of CH_4 flux with peat temperature at shallower depths showed similar hysteresis-like behavior as observed by Chang et al. (2020), but inverse behavior with temperature at deeper peat depths.

The relation of CH_4 emission and WTL in the eastern sector did not show a significant correlation, but in the western sector, the SWC does appear to have control on the emission.

The estimation of annual CH_4 emission was based on gap-filling with four different methods. All methods resulted in rather similar annual fluxes, especially for the two years with just relatively short gaps. The performance of methods was dependent on a gap distribution. The longer gaps were the most problematic to be reconstructed by any of the methods. The average annual emission from the western sector was 4.2 g CH_4 m^{-2} yr^{-1} and from the eastern sector was 7.3 g CH_4 m^{-2} yr^{-1}. Both were substantially lower than those obtained from tall graminoid fen at the same mire system.

Based on the presented results further studies should focus on winter fluxes, which are important in the northern, low emissions wetlands with discontinuous permafrost. The understanding of the process behind those emissions is less comprehended. Also, the origin of wintertime CH_4 emission is somewhat unknown. CH_4 can be produced during the winter period but also CH_4 produced during growing season can remain stored in the peat and be slowly released during the frozen period. It could relate to the hysteresis-like behaviour of the CH_4 emissions.

5. Dissemination & Exploitation

Intermediate results have been presented at scientific conferences (Nordic ICOS Symposium 2019, ICOS Science Conference 2020, EGU 2020) in form of poster presentations. The final study will be submitted for peer-reviewed publication in Biogeosciences (Patryk Łakomiec, Jutta Holst, Thomas Friborg, Patrick Crill, Niklas Rakos, Natascha Kljun, Per-Ola Olsson, Lars Eklundh, Janne Rinne. Field-scale CH_4 emission at a sub-arctic mire with heterogeneous permafrost thaw status).

6. References

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