PhD project: Methane emissions from high latitude peatlands - bridging the abyss between environmental factors and ecosystem scale methane formation and emission

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Aim

This research aims to take advantage of the good existing understanding of the basic biogeochemistry of methane, in order to link direct ecosystem scale Eddy covariance measurements of methane fluxes to the main drivers of methane formation and oxidation.
To achieve this overall goal, the research will encompass the following studies:

I. The Kulbäcksliden research infrastructure: a unique setting for northern peatland complex studies

II. Comparing ecosystem scale Eddy Covariance derived methane fluxes from four adjacent boreal mires

III. Combining footprint analysis and airborne GIS data to understand spatial variability in boreal mire methane emissions

IV. Relating boreal mire ecosystem scale temporal variability in methane emissions to estimated methane production and oxidation

Other studies could originate from the previously mentioned papers, and could lead to developing more accurate mechanistic models. The latter will go beyond only temperature and water table level, which are the commonly used proxies for the activity of methane producing and oxidizing microorganisms.

Background / theoretical reference context

Methane is the second most important biogenic greenhouse gas after carbon dioxide (Boucher et al., 2009; Tiwari et al., 2020), but it is more than 20 times as potent as carbon dioxide on a molecule-to-molecule basis in terms of warming potential (Shindell et al., 2013). A recent study reported a growth rate of 18.2 (17.3-19) Tg CH_4 / yr in atmospheric methane concentrations for the period 2008-2017 (Saunois et al., 2020), which makes methane an attractive target for climate change mitigation policies. Wetlands in general and peatlands in particular are the most important natural source of atmospheric methane. High latitude peatlands are particularly of interest since they are undergoing the most substantial changing climate, which could affect significantly methane emissions from these ecosystems (Tiwari et al., 2020). Thus, it is of paramount importance to understand properly how high latitude peatlands will behave, by linking actual measured emissions, to the fundamental drivers of methane formation and oxidation.

Scientific problems and relevance

Several studies have proven water table depth and temperature to be good proxies for methane production and oxidation (Abdalla et al., 2016; Moore and Knowles, 1989). In fact, the microorganisms responsible for methane production (methanogens) require anoxic conditions made possible by the saturated and wet part of peatlands. At higher temperatures, methanotrophs are not able to compensate for the increased production of methane, leading to higher emissions (van Winden et al., 2012). Although temperature and water table depth alone can explain a good part of methane fluxes, they are not the fundamental drivers, but instead, they act as regulators. Recent studies also showed the importance of substrate availability over environmental drivers on methane production (Mitra et al., 2020). It would be therefore important to consider the main drivers involved in methane production and oxidation, i.e. the ratio of methanogens and methanotrophs, as well as substrate supply (GPP and plant phenology) in the attempt of a more comprehensive description of methane fluxes.

Study sites

The mires, subject of this PhD project are located in the Kulbäcksliden area (near the municipality of Vindeln, county of Västerbotten in northern Sweden), all four within a distance of less than 3 km. They are all more or less nutrient poor, as they do not receive water and nutrients from any major water sources. Coordinates of each site are listed in the Table 1 below.

Table 1: Geographic coordinates and altitudes of the four mires

Site	Latitude	Longitude	Altitude
Degerö	64° 10' 55.2" N	64° 10' 55.2" N	269 m.a.s.l.
Stortjarn	64° 10' 30" N	19° 33' 50.4" E	269 m.a.s.l
Hålmyran	64° 9' 36" N	19° 34' 8.4" E	291 m.a.s.l
Hälsingfors	64° 9' 32.4" N	19° 33' 10.8" E	299 m.a.s.l.

Mean annual precipitation and temperature over 30 years (1961-1990) are 523 mm and +1.2 °C, respectively (Alexandersson et al., 1991).

Methods

Paper 1 – The Kulbäcksliden research infrastructure: a unique setting for northern peatland complex studies

This first paper aims at describing the research infrastructure, including the four sites (Degerö, Stortjärn, Hålmyran and Hälsingfors). Northern peatlands often occur as complexes of several morphologically distinct sites which are however hydrologically connected. They are often studied as a single ecosystem, ignoring the spatial heterogeneity that may exist across the different sites of the peatland complex. The Kulbäcksliden research infrastructure represents a unique setting with similar installations at the four sites of the same peatland complex, which would help investigate the spatial variation of gas emissions across the different sites. This paper aims at presenting the design and history of the infrastructure, ongoing experiments and installed equipments, current and foreseeable research directions of the infrastructure intended to be a long-term research infrastructure, as well as data availability statement.

Paper 2 – Comparing ecosystem scale Eddy Covariance derived methane fluxes from four adjacent boreal mires

Given that the four mires investigated in this research are not very distant from each other, the macroclimate should be very similar. In addition, they are all undisturbed and therefore, any differences in methane fluxes would be interesting to investigate in order to figure out the underlying drivers. This paper will attempt to answer the following question: *What drives the differences between ecosystem scale Eddy Covariance measured methane fluxes in four undisturbed adjacent mires?* To that end, Eddy covariance flux data will be processed for the four sites, focusing mostly on methane fluxes, but also CO_2 fluxes. We anticipate that substrate availability would be an important factor in explaining the differences between methane fluxes across the four sites. To test this hypothesis, we will partition CO_2 fluxes to retrieve gross primary production (GPP) and check how it relates to methane fluxes, and therefore how it explains the observed differences. In addition, microclimate conditions (e.g. water table depth, temperature), vegetation composition and the site average proportion of methanogens and methanotrophs will be checked, to identify the main drivers of the observed differences in methane fluxes.

Paper 3 – Combining footprint analysis and air borne GIS data to understand spatial variability in boreal mire methane emissions

The fluxes measured by an eddy covariance tower represent an overall contribution from a dynamic area called footprint, influenced by wind. The footprint can be defined as the relative contribution of each element of the surface to the measured vertical flux or concentration (Rannik et al., 2012). The paper 3 will therefore attempt to answer the following question: *How do the drivers of methane production and oxidation (water table depth, ratio of methanogens and methanotrophs …) affect the spatial contribution to measured methane fluxes?* To answer to this question, we will conduct dynamic footprint analysis along with eddy covariance data processing. This will allow identifying the spots on each mire that contribute the most to the measured fluxes. The water table depth will be approximated by soil moisture, derived from synthetic aperture radar (SAR) Sentinel 1 images that will allow explaining, along with other drivers (e.g. ratio of methanogens and methanotrophs, vegetation distribution), the estimated footprints.

Paper 4 – Relating boreal mire ecosystem scale temporal variability in methane emissions to estimated methane production and oxidation

Two main processes regulate methane emissions in peatlands, i.e. methane production and oxidation. While the first occurs in the saturated wet peat, the latter takes place above the water table where methanotrophs use oxygen and decompose methane. The non-oxidized methane is potentially released to the atmosphere. In this paper, we will attempt to answer the following question: *Do the measured methane emissions overtime reflect estimated methane production and oxidation?*

Using the data about substrate availability (GPP), phenology, water table depth, temperature and the proportion of methanogens and methanotrophs, we will estimate methane production and oxidation. These estimates will be compared to the measured emissions, to test their agreement. By doing so, we will also try to understand what can possibly explain any observed discrepancies over time. If longer measurements are required to have enough data for this study, we could focus on the Degerö mire, which has eddy covariance methane measurements for a longer time than the other three sites.

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