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Methane Emission from Siberian arctic polygonal Tundra: Eddy Covariance Measurements and Modeling

INTRODUCTION

Northern wetlands and tundra are major sources of methane. Methane emissions were shown to turn tundra landscapes into effective greenhouse gas (GHG) sources although they were strong sinks of CO_2 [1,2]. However, there is still much uncertainty about the source strength and the driving forces of methane flux of tundra landscapes. Long-term high latitude methane flux data is scarce, and especially the Siberian tundra is under-represented. Furthermore, existing studies are mostly based on the closed-chamber technique, which alone cannot deliver representative results due to the high temporal and spatial variability of methane fluxes.

Here we present the first eddy covariance methane flux data from a Siberian Arctic tundra landscape. The objective of this study was to quantify the methane emission over the full course of the “active” season from early spring to early winter, to analyze the contribution of different parts of the vegetation period, particularly the little studied periods of spring thaw and soil re-freeze, to identify the biological and physical parameters which control the methane fluxes, and to estimate the annual methane emission.

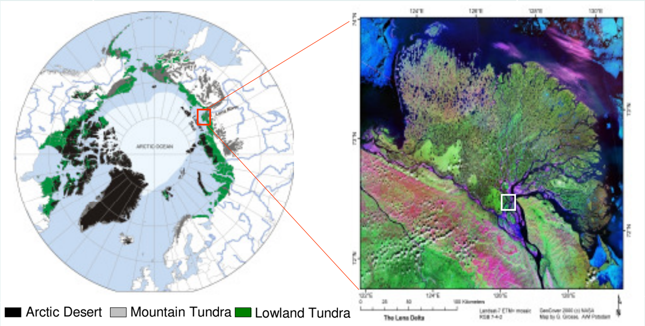

Fig.1. Vegetation zones in the Arctic [3], location of the Lena River Delta and study area

INVESTIGATION AREA

Location
- Central Lena River Delta (Fig. 1)
- 72°22'N 126°30'E

Climate
- True-arctic, continental
- Annual air temperature -15 °C
- Mean summer rainfall 140 mm
- Continuous, cold, deep permafrost

Geomorphology
- Holocene river terrace
- Sandy deposits
- Wet polygonal tundra

Hydrology

Mosaic of
- Moderately moist soils at elevated sites (60% surface coverage)
- Water-saturated soils or ponds in depressed sites and lakes (40% surface coverage)

Soils & Vegetation
- *Typic Historthels* and *Typic/Glacic Aquiturbels*, poor nutrient status
- Subarctic lowland tundra dominated by sedges and mosses

METHODS

Flux measurements
- Observation periods
  July - October 2003 (96 days)
  May - July 2004 (52 days)
- Gill R3 sonic anemometer (Fig. 2)
- Campbell Scientific TGA100 tunable diode laser CH_4 analyzer
- Measurement height 3.65 m
- 80%-fetch distance typically 500 m
- Data analysis using EdiRe
- Flux averaging interval 60 min

Environmental variables
- Air temperature & humidity,
- Soil temperature & moisture,
- Snow height, rainfall, radiation measured all year by Campbell Scientific Met Station
- Soil thaw depth and water level measured manually during observation period

Modeling
- Empirical model based on environmental variables soil temperature and friction velocity

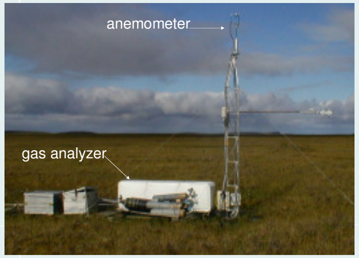

Fig.2. Eddy covariance set-up at the tundra site

RESULTS

Summer time mean daily CH_4 fluxes were typically around 20 mg m^{-2} d^{-1} (Fig. 3). Short term variations of CH_4 fluxes were large and correlated with friction velocity, which is a measure for turbulence in the surface boundary layer and closely correlated to wind speed. The long-term development of fluxes followed the changes of soil temperature in 15 - 20 cm depth.

No marked influence of the freezing of the top soil layer (end of Sept. 2003) on the CH_4 flux was visible. Significant emission of CH_4 of about 10 mg m^{-2} d^{-1} continued until the end of October 2003 when the air temperature was well below -20°C. Large variations of CH4 fluxes were observed during the thaw period (8 - 25 June 2004). A model of mean daily CH_4 flux as function of friction velocity and soil temperature explained about 75% of the observed flux variation. Soil thaw depth and water table position showed only a very weak correlation with CH_4 flux and did not improve the model performance. During both study periods, which together covered one “active” flux season, the cumulative CH_4 emission of the polygonal tundra was -2.4 g m^{-2}.

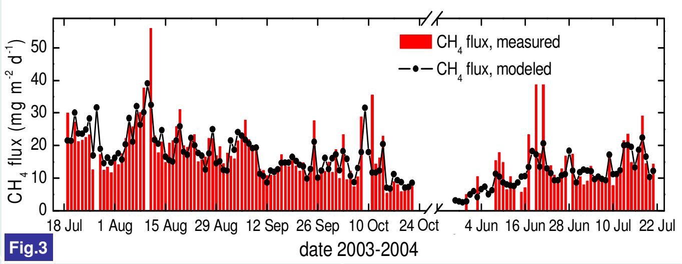

Fig.3

DISCUSSION

Summer methane emission from the polygonal tundra was low compared to values reported by many other flux studies from arctic wetlands [2,4,5]. The main reasons for this are thought to be the very low permafrost temperature in the study region, comparatively large area coverage of non-wet sites, and the low bio-availability of nutrients in the soils.

The main driving forces of CH_4 fluxes were friction velocity (Fig. 4) and soil temperature (Fig. 5). The dependence of CH_4 flux on friction velocity and hence wind speed is very likely due to the high surface coverage of water bodies at the study site. Flux variations not described by the model were attributed to spring thaw and turbulence- and pressure-induced ebullition and were estimated to contribute about 10 % to the measured flux.

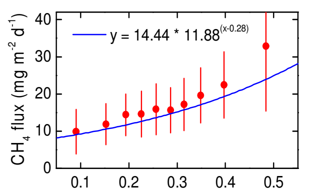

Fig.4

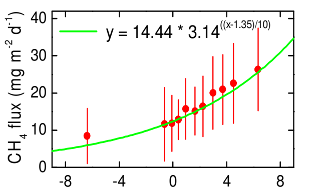

Fig.5

The relationship between methane flux and soil temperature was extrapolated to estimate the methane emission during the winter (Fig. 6). This approach is thought to be applicable because methanogenesis was recently shown to occur at sub-zero temperatures [6,7]. Based on this estimate, the annual methane flux was 3 g m^{-2} and the contribution of the cold season (Oct. - May) to the annual flux was 30 %.

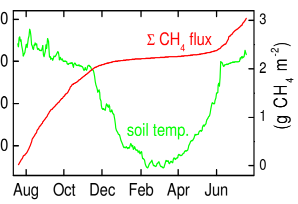

Fig.6

CONCLUSIONS

- The identification of the near surface turbulence as a main flux driver demonstrates the close coupling of the soil and atmosphere systems and the importance of water bodies for the methane budget of tundra ecosystems.
- The large proportion of the estimated winter fluxes compared to the annual fluxes highlights the importance of the cold season to the annual GHG budget of the tundra and the necessity to adequately study and quantify the fluxes during these periods.
- Including CO_2 flux data [8], the overall carbon balance of the tundra during the period July 2003 - July 2004 was -17.4 g C m^{-2}. Considering the global warming potential of methane compared to carbon dioxide, the GHG balance of the tundra in units of CO2-C equivalents was +32 g C_{equiv} m^{-2}. Thus, although the methane emission had only a small influence on the tundra’s capacity as a carbon sink, it turned the tundra into an effective source of greenhouse gases.

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