Shoulder season controls on methane emissions from a boreal peatland

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Introduction

Cold-season methane (CH_4) emissions account for 45 % of the annual total of methane emissions from northern (> 60 °N) peatlands (Ito et al., 2023). However, cold-season processes are poorly captured by CH_4 models showing in a high variability in shoulder season estimates and in a general underestimation of cold-season emissions (27 ± 9 % compared to 45 % of annual emissions in observations). Peatland CH_4 emissions results from the balance between CH_4 production in the anaerobic zone below the water table and CH_4 oxidation in the upper aerobic part of the peat column (Hanson and Hanson, 1996). The fraction of CH_4 oxidized further depends on the pathway of CH_4 transport to the atmosphere (Lai, 2009). CH_4 following the concentration gradient to the atmosphere via diffusion through the peat is most prone to oxidation while CH_4 emitted through aerenchyma of wetland sedges or in the form of gas bubbles (ebullition) passes by the aerobic oxidation layer. Our aim with this study was to identify the environmental controls on the components of CH_4 fluxes (production, oxidation, and transport), with a focus on shoulder season processes.

Methods

We partitioned net CH_4 fluxes into their components by combining manual chamber flux measurements on vegetation removal treatments with pore water sampling for concentrations and stable carbon isotope ratios of dissolved CH_4 in the wet hollows of Siikaneva bog in Southern Finland during seasonal field campaigns in 2022. We related seasonal variations in the flux components to changes in environmental and ecological conditions using linear mixed effects models.

Results and Discussion

Rates of CH_4 production were higher than oxidation rates throughout our study period, resulting in net CH_4 emissions of 34 $mgCH_4m^{-2}d^{-1}$ to 1025 $mgCH_4m^{-2}d^{-1}$. As expected, CH_4 production generally decreased with decreasing peat temperatures in the anaerobic peat zone after summer (Dunfield et al., 1993). This decrease was however modified by slightly higher production rates in late fall, probably related to additional input of organic material by decaying vascular plants at the end of the growing season (Joabsson et al., 1999). Despite the leaf senescence, plant-mediated CH_4 transport continued at lower rates also outside of the growing season (55 ± 31 % of emissions in the spring compared to 94 ± 3 % in summer). With decreasing plant transport and with lower peat temperatures making CH_4 more soluble in water, CH_4 accumulated in the pore water during fall. The resulting higher pore water concentrations increased the diffusive flux of CH_4 to the atmosphere. However, we found CH_4 oxidation to be strongly limited by the availability of CH_4 in the pore water. Strong oxidation in late fall (98 ± 1 %) therefore largely compensated for the higher diffusion rates related to accumulation of CH_4 in the pore water. In winter, however, below-zero temperatures in the surface peat are likely to largely inhibit CH_4 oxidation while CH_4 production continues in the deeper, warmer peat layers. High pore water concentrations in spring indicate that the frozen surface layer might furthermore act as a physical barrier to methane transport, delaying the emission of the CH_4 produced over the winter to a pulse release upon spring thaw (Alm et al., 1999; Friborg et al., 1997; Tokida et al., 2007; Zona et al., 2016).
To summarize, shoulder season CH_4 emissions were be higher than expected from a simple temperature relationship because 1) decaying plants supported CH_4 production in fall, 2) plant-mediated CH_4 transport continued through completely senesced leaves outside of the growing season, 3) the emission of CH_4 produced in summer was partly delayed to fall, 4) CH_4 oxidation was probably more strongly inhibited than CH_4 production at below-zero air temperatures. The emission of CH_4 stored in the pore water in fall was largely compensated by substrate-limited CH_4 oxidation.

Conclusion

Our study points towards the high need to refine the current model parameterizations of the processes controlling peatland CH_4 emissions during the shoulder seasons. Accounting for the identified processes specific to the shoulder seasons through replacing simple temperature dependencies of CH_4 emissions by the interaction of separately modeled components of CH_4 fluxes (CH_4 production, oxidation, and transport) will likely work against the underestimation of cold-season CH_4 emissions from northern peatlands.

References

Alm, J., Saarnio, S., Nykänen, H., Silvola, J., Martikainen, P., 1999. Winter CO2, CH4 and N2O fluxes on some natural and drained boreal peatlands. Biogeochemistry 44, 163–186. https://doi.org/10.1007/BF00992977

Dunfield, P., Knowles, R., Dumont, R., Moore, T., 1993. Methane production and consumption in temperate and subarctic peat soils: Response to temperature and pH. Soil Biology and Biochemistry 25, 321–326. https://doi.org/10.1016/0038-0717(93)90130-4

Friborg, T., Christensen, T.R., Søgaard, H., 1997. Rapid response of greenhouse gas emission to early spring thaw in a subarctic mire as shown by micrometeorological techniques. Geophys. Res. Lett. 24, 3061–3064. https://doi.org/10.1029/97GL03024

Hanson, R.S., Hanson, T.E., 1996. Methanotrophic bacteria. Microbiol Rev 60, 439–471. https://doi.org/10.1128/mr.60.2.439-471.1996

Ito, A., Li, T., Qin, Z., Melton, J.R., Tian, H., Kleinen, T., Zhang, W., Zhang, Z., Joos, F., Ciais, P., Hopcroft, P.O., Beerling, D.J., Liu, X., Zhuang, Q., Zhu, Q., Peng, C., Chang, K. -Y., Fluet-Chouinard, E., McNicol, G., Patra, P., Poulter, B., Sitch, S., Riley, W., Zhu, Q., 2023. Cold-Season Methane Fluxes Simulated by GCP-CH_4 Models. Geophysical Research Letters 50, e2023GL103037. https://doi.org/10.1029/2023GL103037

Joabsson, A., Christensen, T.R., Wallén, B., 1999. Vascular plant controls on methane emissions from northern peatforming wetlands. Trends in Ecology & Evolution 14, 385–388. https://doi.org/10.1016/S0169-5347(99)01649-3

Lai, D.Y.F., 2009. Methane Dynamics in Northern Peatlands: A Review. Pedosphere 19, 409–421. https://doi.org/10.1016/S1002-0160(09)00003-4

Tokida, T., Mizoguchi, M., Miyazaki, T., Kagemoto, A., Nagata, O., Hatano, R., 2007. Episodic release of methane bubbles from peatland during spring thaw. Chemosphere 70, 165–171. https://doi.org/10.1016/j.chemosphere.2007.06.042

Zona, D., Gioli, B., Commane, R., Lindaas, J., Wofsy, S.C., Miller, C.E., Dinardo, S.J., Dengel, S., Sweeney, C., Karion, A., Chang, R.Y.-W., Henderson, J.M., Murphy, P.C., Goodrich, J.P., Moreaux, V., Liljedahl, A., Watts, J.D., Kimball, J.S., Lipson, D.A., Oechel, W.C., 2016. Cold season emissions dominate the Arctic tundra methane budget. Proc. Natl. Acad. Sci. U.S.A. 113, 40–45. https://doi.org/10.1073/pnas.1516017113

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