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# Snow and ice properties and melt water dynamics control the methane fluxes during early spring in two boreal mires in north Eastern Europe

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High-latitude peatlands are globally important sources of the atmospheric trace gas methane ($CH_4$). $CH_4$ emissions from boreal peatlands are characterised by a pronounced small-scale spatial heterogeneity and a high seasonal variability due to extreme climatic contrasts between seasons. Although winter is the predominant season in boreal climates, most $CH_4$ studies were conducted during the vegetation period whereas wintertime data are sparse.

Here, we present the results of two intense field campaigns in two boreal peatlands starting close to the end of winter until the start of the vegetation period, focussing on $CH_4$ fluxes during the very dynamic spring thaw periods. The mire complex Salmisuo in North Karelia (Finland, 62.46˚ N, 30.58˚ E) was investigated during spring 2006, and the mire complex Ust Pojeg in the Komi Republic (Northwest Russia, 61.56˚N, 50.13˚E) was studied during spring 2008. Both peatlands represent transition mire complexes in which both fen and bog types of vegetation can be found with three typical micro-site types: hummocks (dry), lawns (intermediate) and flarks (wet). $CH_4$ fluxes were measured by the snow gradient approach (according to Fick's first law) until the snow was nearly completely melted, followed by closed dark chamber measurements. Fluxes were measured every second or third day.

During the spring thaw period, $CH_4$ fluxes were highly dynamic due to rapidly changing snow and ice properties, hydrological characteristics and temperature variations. Due to melting and refreezing of snow-melt water and surface water, ice layers were created which acted as efficient barriers for $CH_4$ efflux from the peatlands. In both peatlands, an 8 to 15 cm massive ice layer developed during winter in or above the peat soil depending on microtopography and water level. The surface was covered by snow with an average height of 50 cm (Salmisuo) and 65 cm (Ust Pojeg). During the ongoing snowmelt, the $CH_4$ fluxes decreased from highest values (up to 0.5 mg $m^{-2}$ $h^{-1}$) to lowest fluxes ($<$ 0.05 mg $m^{-2}$ $h^{-1}$) when a layer of fresh melt water at the bottom of the snow cover was blocking the diffusive pathways for $CH_4$ emission from the superficially frozen peatlands. After the snow ablation, the massive ice layer melted; however, the $CH_4$ fluxes were then limited by the high surface water levels resulting from the snow melt and small rain events. Only after the water level started to decrease due to outflow and evaporation during the transition period between snowmelt and start of the vegetation period, $CH_4$ emission was gradually increasing. In general, closed chamber $CH_4$ fluxes during the transition period were lower in Salmisuo (hummocks: 0.01 $\pm$ 0.007 to 2.0 $\pm$ 0.14 mg $m^{-2}$ $h^{-1}$, lawns: 0.08 $\pm$ 0.01 to 4.2 $\pm$ 0.3 mg $m^{-2}$ $h^{-1}$, flarks: 0.05 $\pm$ 0.03 to 5.7 $\pm$ 0.4 mg $m^{-2}$ $h^{-1}$) than in Ust Pojeg (hummocks: 0.09 $\pm$ 0.02 to 2.8 $\pm$ 0.6 mg $m^{-2}$ $h^{-1}$, lawns: 0.1 $\pm$ 0.03 to 7.01 $\pm$ 1.7 mg $m^{-2}$ $h^{-1}$, flarks: 0.05 $\pm$ 0.01to 3.7 $\pm$ 0.8 mg $m^{-2}$ $h^{-1}$).

Interestingly, the contribution of the micro-sites to the $CH_4$ emission from the peatlands differed substantially between the cold seasons and the vegetation period when the flarks are known to be hot spots of $CH_4$ emission. In winter and early spring, the $CH_4$ fluxes from the wet flarks were strongly limited by ice and melt water layers which were acting as diffusion barriers. During the early spring, the control of $CH_4$ fluxes from peatlands has to be considered highly heterogeneous in space and time. During this period, the $CH_4$ flux dynamics are mainly controlled by physical factors influencing the gas transport processes whereas biological processes dominate the $CH_4$ flux control later during the vegetation period. Since climate change in high-latitudes is expected to be most extreme during winter, the influence of cryospheric processes on the carbon cycle will be particularly important for future carbon balance changes.