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Carbon trace gas dynamics in three subarctic lakes in winter and spring

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Northern lakes are an important atmospheric source of radiatively active trace gases - methane and carbon dioxide - despite being ice covered for up to 7 months of the year. As much as 56% of annual emissions occur during ice-out in spring. Although important, this flux is currently both poorly understood and constrained. Here we present a detailed annual carbon gas budget for three subarctic lakes in Northern Sweden. We combine year-round continuous eddy covariance measurements from one lake with monthly observations of the dissolved gas content and ice-free season measurements of ebullition and turbulence-driven diffusive fluxes in all three lakes. Dissolved methane begun to accumulate when anoxia set in, approximately two months after ice-on. Dissolved inorganic carbon concentrations increased throughout winter. Total CO_2 accumulation exceeded total O_2 consumption, pointing to an additional carbon source to the under-ice water, presumably the sediment. A total winter accumulation of 0.9-2.8 g/m^2 CH_4 and 55-145 g/m^2 CO_2 was measured: the largest values were from the deepest lakes. We found that while some dissolved gas was released with ice-out, between 65 and 84% disappeared several weeks prior in two of the study lakes, during a period of heavy snowmelt. This suggests that hydrology plays an important part in determining the spring carbon budget by diluting or replacing the under-ice water column. Should this fraction reach the atmosphere, the total ice-covered season flux represents 22-61% of the annual CH_4 flux (three lakes), and reduces the annual CO_2 sink by 70% (one lake). The CH_4 flux during ice-out alone represented 10-55% of the annual flux.