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Large springtime emissions of CH_4 from northern lakes facilitated by winter redox regime

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Northern lakes are an important source to the atmosphere of the climate forcing trace gases methane (CH_4) and carbon dioxide (CO_2). A significant portion of the annual emissions from northern lakes takes place in spring, after prolonged ice cover. This flux is currently neither well constrained nor fully understood: flux-temperature relationships based on summer observations predict negligible productivity in winter. Here we present a detailed, multi-year carbon gas budget for three subarctic lakes in northern Sweden that includes CO_2 and CH_4 stable isotopologues (δ^{13}C and δ^2H of the gases) collected during the open water (154 $\pm$ 15 days) and ice-covered (211 $\pm$ 15 days) seasons. We use an open system isotope fractionation model to estimate the fraction of CH_4 consumed by methanotrophs. We find that the accumulation rate of dissolved CH_4 under the ice (32 $\pm$ 4 mg/m^2/d) is remarkably similar to the open water season net emission rate (25 $\pm$ 7 mg/m^2/d). Our isotope model indicates that the lower CH_4 production rate during winter is accompanied by a dramatic reduction of aerobic oxidation, which removes 20–80% of dissolved CH_4 during summer. As a result, our study lakes emit 31–75% of the annual methane flux, and 16–49% of the annual carbon dioxide flux in spring. While energy input remains a useful proxy for lake trace gas emissions, upscaling efforts need to take into account seasonal changes in the redox regime that allow for cold season emissions.