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Importance of methane production for the greenhouse gas budget of thawing permafrost on climate relevant time scales

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Permafrost in circum-arctic soils stores as much carbon as the global atmosphere. Permafrost thaw liberates organic matter, which is mineralized by microorganisms to carbon dioxide (CO_2) and methane (CH4). The release of these greenhouse gases (GHGs) may form a positive feedback to atmospheric CO_2 and CH4-concentrations and accelerate climate change. Methane, which has 28 to 45 times the global warming potential (GWP) of CO_2 (100 years time scale), is formed by microorganisms in anoxic, water-saturated soils. Current studies indicate that permafrost thaw at the bottom of well drained (oxic) soils cause a higher formation of GHGs than in water saturated (anoxic) soils since more CO_2 is formed under oxic conditions and only small amounts of CH4 are formed from permafrost organic matter under anoxic conditions. Here we show through 7-year laboratory incubations, molecular analysis and in-situ CH4-flux measurements that low CH4-production from Siberian permafrost organic matter is due to the lack of active methanogens. Equal amounts of organic carbon are mineralized to CO_2 and CH4 under anoxic conditions after an active methanogenic community has established. An organic carbon decomposition model, calibrated with the collected long-term incubation data, predicts that 11.3% of initial permafrost carbon may be released as CO_2 under oxic conditions until 2100 but only 1.7% and 2.2% as CO_2 and CH4 under anoxic conditions, respectively. However, if considering the higher GWP of CH4, the production of CO_2-C equivalents is more than twice as high under anoxic conditions.

Field measurements of CH4-fluxes from recently thawed permafrost deposits in northeast Siberia demonstrated that thawed Pleistocene Yedoma sediments, although water saturated, did not release any CH4. Furthermore, no CH4-production could be observed in anoxic short-term (33 days) laboratory incubations. In contrast, if Pleistocene Yedoma sediments were mixed with surface material by thermo-erosion of Yedoma outcrops, CH4-fluxes of up to 180 mg m-2 d-1 were observed. The latter high CH4-fluxes are likely due to priming of thawing permafrost organic matter with active methanogenic communities from the surface soils.

The presented data indicate that low CH4-production rates in short term incubations and recently thawed Pleistocene Yedoma sediments are due to a low abundance of methanogenic microorganisms that will increase over longer periods or by priming with methanogenic communities from surface soils. On longer, climate relevant time scales, GHG production from thawing permafrost organic matter will be higher under water-saturated conditions if considering the higher GWP of CH4. These findings challenge the current view of a higher permafrost carbon-climate feedback from well drained soils. Improved predictions on GHG fluxes from thawing permafrost require a better understanding of the distribution of water-saturated and well drained soils and on the change of soil hydrology in response to permafrost thaw on a circum-arctic scale.