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Carbon dioxide and methane production and release from eroding permafrost deposits of northeast Siberia

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Permafrost thaw liberates formerly frozen organic carbon, which is decomposed by microorganisms to carbon dioxide (CO_2) and methane (CH4). The release of these greenhouse gases (GHG) from soils may form a positive feedback to atmospheric CO_2 and CH4 concentrations and accelerate climate change. Quantifying the contribution of CO_2 and CH4 from permafrost, which is thawing at the bottom of the seasonal thaw layer (active layer) is challenging, since GHG fluxes from the surface of permafrost affected soils originate from both the active layer and the thawing permafrost below. Incubation studies with thawed permafrost material are used to quantify the potential formation of CO_2 and CH4 after permafrost thaw. However, it is unclear how far the results from such laboratory studies, that do not consider a wide range of environmental parameters, represent GHG production under in situ conditions and how far the results from laboratory incubations may be related to in situ GHG fluxes. We here present data on CO_2 and CH4 fluxes from non-vegetated thawing ice-rich permafrost deposits (Yedoma) in an active thaw slump at the banks of the Lena River, northeast Siberia. To evaluate how far data from laboratory studies may be used to calculate in situ fluxes, the same thawing permafrost material was incubated at constant temperature. Mean in situ CO_2 fluxes in July ranged between 0.5 and 2.7 g CO_2-C m-2 d-1, which is in the higher range of the very few reports of CO_2 fluxes from Siberian Yedoma deposits. Methane fluxes were substantially lower with mean rates between 6.5 - 23.3 mg CH4-C m-2 d-1. However, while all sites were clear sources for CO_2, three sites were CH4 neutral. The absence of CH4 emissions could be explained by CH4 oxidation in the unsaturated surface soil at one site and by the absence of CH4 production in two other sites, likely due to a lack of an active CH4 producing microbial community in the recently thawed permafrost. Methane represented less than 1% of total GHG fluxes. Based on the mean GHG fluxes, only about 1% of the thawed permafrost carbon was emitted over one thawing season as CH4 and CO_2 into the atmosphere. Aerobic laboratory incubations substantially overestimated in situ CO_2 fluxes by a factor of 1.3 to 6.4 (mean 3.9 $\pm$ 1.9) while potential CO_2 fluxes from anaerobic incubations were only 1.7 $\pm$ 0.5 higher than under in situ conditions. In contrast, in situ CH4 fluxes were generally significantly higher than upscaled laboratory fluxes with a mean ratio between in situ and laboratory fluxes of 0.4 $\pm$ 0.5. The low CH4 production in short term laboratory incubations is explained by a disturbance of the methanogenic community during sample preparation.

The presented data indicate that despite relatively high GHG fluxes only a minor fraction of thawing permafrost carbon is decomposed to CO_2 and CH4 in one thawing season and that data from short term incubations substantially overestimate in situ CO_2 fluxes while underestimating CH4 production.