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Impacts of Permafrost Dynamics and Nitrogen Deposition on High Affinity Methanotrophy and Net Methane Fluxes in the Pan-Arctic Terrestrial Ecosystems

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Arctic soils constitute an important methane (CH_4) source to the atmosphere. Mechanistic CH_4 models indicate that CH_4 emissions from the Arctic may be doubled by 2100, as temperature increases and permafrost thaws. However, recent field studies have documented a surprisingly strong and consistent CH_4 sink in Arctic mineral soils. This overlooked CH_4 sink is likely due to the activity of novel CH_4-oxidizing bacteria, or high-affinity methanotroph (HAM), that can survive and oxidize CH_4 at atmospheric CH_4 concentrations. Our early study further shows that nitrogen deposition and permafrost thaws affect the CH_4 sink. However, the distinctive physiology of HAM has not been represented in existing regional methane simulations. Also, the mechanistic CH_4 models consistently overestimate methane emissions relative to observation-based atmospheric inversions in the Arctic.

We recently developed a site-level mechanistic CH_4 model, eXplicit High Affinity Methanotroph model (XHAM) that includes HAM-specific physiology and microbial biomass change. The model was tested against soil core-thawing experiments and field-based measurements of methane fluxes and was compared to conventional mechanistic methane models. Our simulations show that high-affinity methanotrophy can be important in affecting net methane fluxes. Simulations without this process overestimate methane emissions. The model accurately simulated CH_4 uptake for four arctic sites, but has not considered the effects of labile carbon, nitrogen deposition, and permafrost thaw.

Thus, we incorporate XHAM model into a methane biogeochemistry model, the Terrestrial Ecosystem Model (TEM), to quantify the role of this mineral CH_4 sink in the regional methane budget. TEM couples carbon, nitrogen, water, and heat processes in terrestrial ecosystems to simulate CO_2 and CH_4 cycles. Using the XHAM-TEM, we tend to: 1) reconcile the discrepancy in the overall CH_4 emission quantification by current mechanistic CH_4 models and atmospheric inversions; 2) examine how the mineral CH_4 sink will change due to soil temperature and moisture as well as CH_4 production associated with thawing permafrost; and 3) quantify the reduction of the CH_4 sink due to nitrogen deposition effects. Our preliminary results show that sparsely- vegetated mineral soils of tundra ecosystems explain 60% of the discrepancy of the methane budget estimates between mechanistic methane models and atmospheric inversions. We also find that the mineral CH_4 sink strongly depends on atmospheric CH_4 concentrations and soil moisture while nitrogen deposition has a moderate effect.