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.