

## **Mechanistic modeling of thermo-hydrological processes and microbial interactions at pore to profile scales resolve methane emission dynamics from permafrost soil**

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The sensitivity of the Earth's polar regions to raising global temperatures is reflected in rapidly changing hydrological processes with pronounced seasonal thawing of permafrost soil and increased biological activity. Of particular concern is the potential release of large amounts of soil carbon and the stimulation of other soil-borne GHG emissions such as methane. Soil methanotrophic and methanogenic microbial communities rapidly adjust their activity and spatial organization in response to permafrost thawing and a host of other environmental factors. Soil structural elements such as aggregates and layering and hydration status affect oxygen and nutrient diffusion processes thereby contributing to methanogenic activity within temporal anoxic niches (hotspots or hot-layers). We developed a mechanistic individual based model to quantify microbial activity dynamics within soil pore networks considering, hydration, temperature, transport processes and enzymatic activity associated with methane production in soil. The model was the upscaled from single aggregates (or hotspots) to quantifying emissions from soil profiles in which freezing/thawing processes provide macroscopic boundary conditions for microbial activity at different soil depths. The model distinguishes microbial activity in aerate bulk soil from aggregates (or submerged parts of the profile) for resolving methane production and oxidation rates. Methane transport pathways through soil by diffusion and ebullition of bubbles vary with hydration dynamics and affect emission patterns. The model links seasonal thermal and hydrologic dynamics with evolution of microbial community composition and function affecting net methane emissions in good agreement with experimental data. The mechanistic model enables systematic evaluation of key controlling factors in thawing permafrost and microbial response (e.g., nutrient availability, enzyme activity, PH) on long term methane emissions and carbon decomposition rates in the rapidly changing polar regions.