

EGU21-176, updated on 16 Sep 2021

<https://doi.org/10.5194/egusphere-egu21-176>

EGU General Assembly 2021

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Modeling methane production and emission from thawing sub-sea permafrost on the warming Arctic Shelf

Emilia Ridolfi¹, Stig Wilkenskjeld², Frederieke Miesner³, Victor Brovkin^{2,4}, Paul Overduin³, and Sandra Arndt¹

¹Universite Libre de Bruxelles, Bruxelles, Belgium (emilia.ridolfi@ulb.ac.be)

²Max-Planck Institute for Meteorology, Hamburg, Germany

³Alfred Wegener Institut, Potsdam, Germany

⁴Center for Earth System Research and Sustainability, University of Hamburg, Germany

The Arctic shelf hosts a large, yet poorly quantified reservoir of relic permafrost. It has been suggested that global warming, which is amplified in polar regions, will accelerate the thawing of this subsea permafrost, thus potentially unlocking large stocks of comparably reactive organic matter (OM). The microbial degradation of OM in the thawing and generally anoxic permafrost layer has the potential of producing and, ultimately, releasing important fluxes of CH₄ to the atmosphere. Because CH₄ is a potent greenhouse gas, such a release would further intensify global warming. However, the potential role of subsea permafrost thaw on microbial CH₄ production and CH₄ emissions from Arctic sediments currently remains unconstrained.

Here, we use a nested model approach to address this critical knowledge gap. We developed a pseudo-three-dimensional reaction-transport model for permafrost bearing sediments on the Arctic shelf to estimate the production, consumption, and, efflux of CH₄ on the Arctic shelf in response to projected subsea permafrost thaw. The model accounts for the most pertinent biogeochemical processes affecting methane and sulfur cycling in permafrost bearing marine sediments.

It is initialized based on a published submarine permafrost map (SuPerMap, [1]) and forced by a range of projected thawing rate scenarios derived from the Max Planck Institute Earth System Model (MPI-ESM) simulation results for the period 1850-2100. Critical model parameters, such as permafrost OM content and its apparent reactivity are chosen based on a comprehensive analysis of published experimental data. Here, we present the output of this environmental scenario ensemble.

Simulation results reveal that CH₄ production rates are highly sensitive to changes in the apparent reactivity of permafrost OM. Although simulated CH₄ production rates vary over a large range (0.001-130 PgC produced over 250 years), they generally highlight the potential for producing and, thus releasing large amounts of methane from thawing subsea permafrost on the warming Arctic Shelf.

[1] Overduin, P. P., Schneider von Deimling, T., Miesner, F., Grigoriev, M. N., Ruppel, C. D., Vasiliev, A., et al. (2019).

Submarine permafrost map in the Arctic modeled using 1D transient heat flux (SuPerMAP).
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