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Linking Thermo-Hydro-Biogeochemical Modeling with Satellite Measurements Can Constrain Permafrost Greenhouse Gas Emissions Predictions

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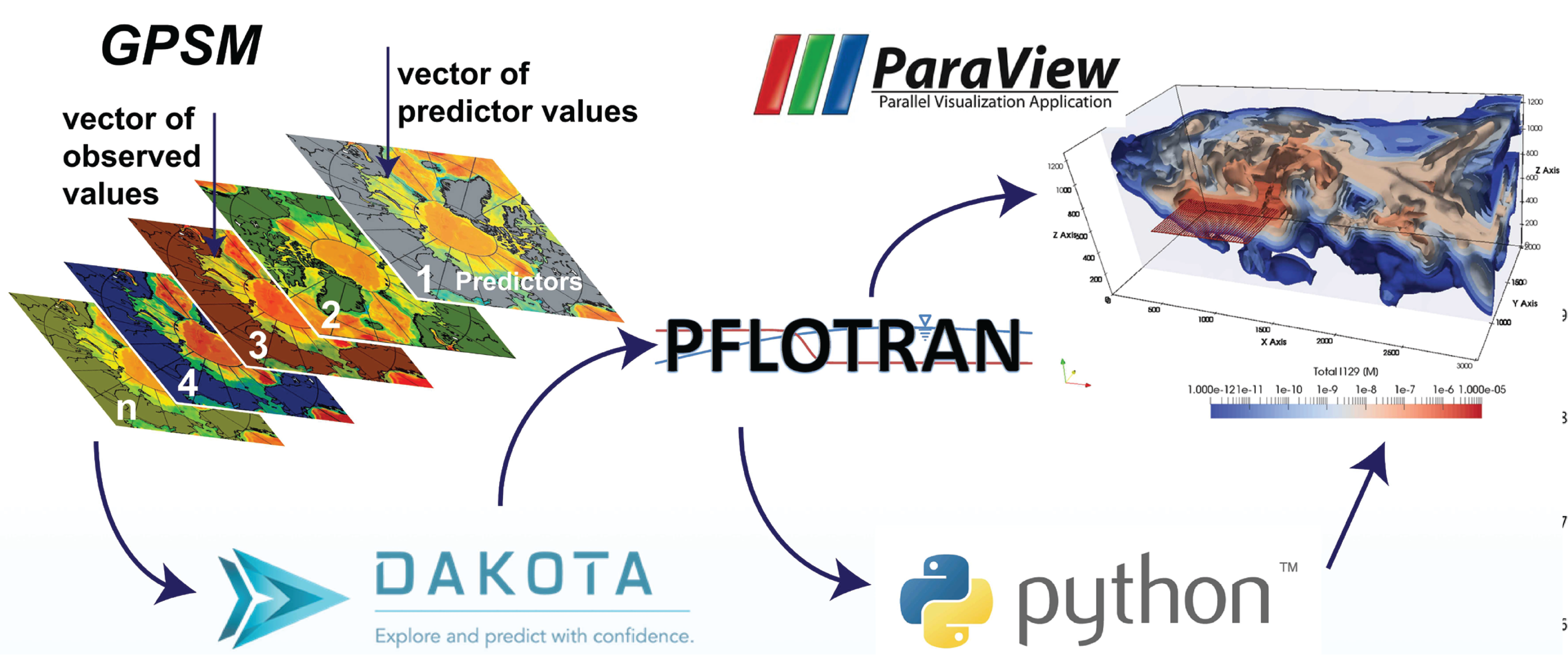
Overview

Global climate models lack sources of methane from permafrost soils, though it is understood that methane is an increasingly important component to global greehouse gas (GHG) emissions, and methane is now a focus of U.S. and international GHG emissions concerns. Current methane measurement upscaling methods do not include transient permafrost modeling to link emissions with thermo-hydrologic evolution, which limits predictive capability especially as permafrost thaw dynamics evolve. In order to adequately predict the future state of emissions from thawing permafrost soils, it is important to be able to mechanistically link large-scale satellite measurements with subsurface biogeochemical GHG production and system thermo-hydrology. We have developed a framework for probabilistic modeling of liquid, gas, gas hydrate, and ice formation in permafrost sediments.



Summary

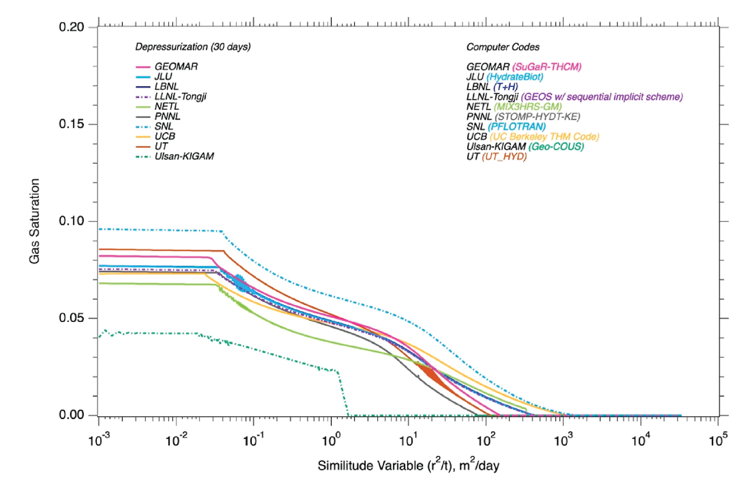
• We have developed a framework for running large-scale, probabilistic simulations by linking machine learned maps of boundary conditions (GPSM) to a statistical analysis and optimization software driver (DAKOTA) to run our high performance multiphase flow and reactive transport simulator, PFLOTRAN.

• We have developed and verified the capability in PFLOTRAN to model gas generation, ice formation, and gas hydrate formation in sediments to capture all possible phases that could be present and contribute to GHG mobility in permafrost sediments.

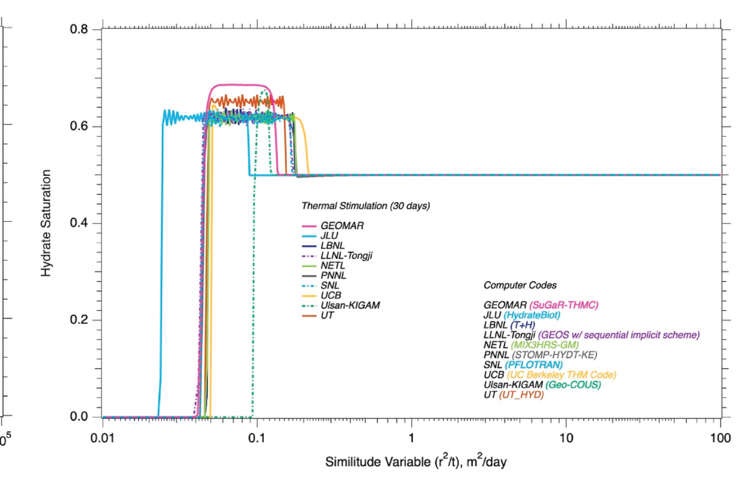
• Next, we hope to couple biogeochemical reactions, run larger-scale permafrost models, and calibrate to space-based observations

Verification

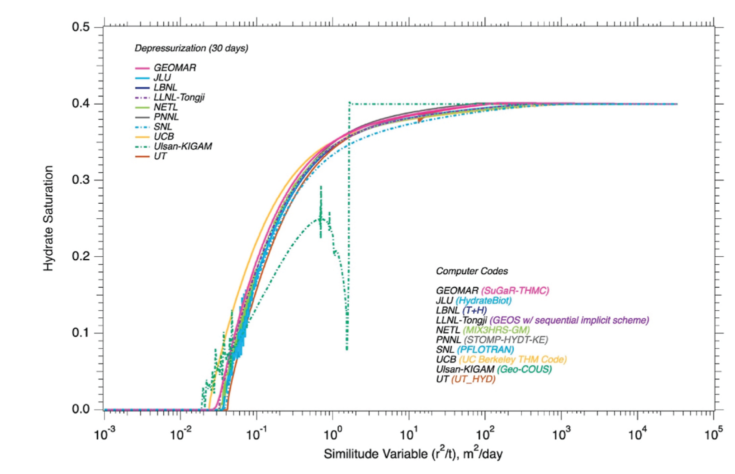
• We have developed a modeling framework for simulating multiphase liquid, gas, gas hydrate, and ice formation in sediments and verified performance in an international code comparison effort (White et al., 2020).



A) Free gas saturation profile during thermal stimulation of a methane hydrate reservoir



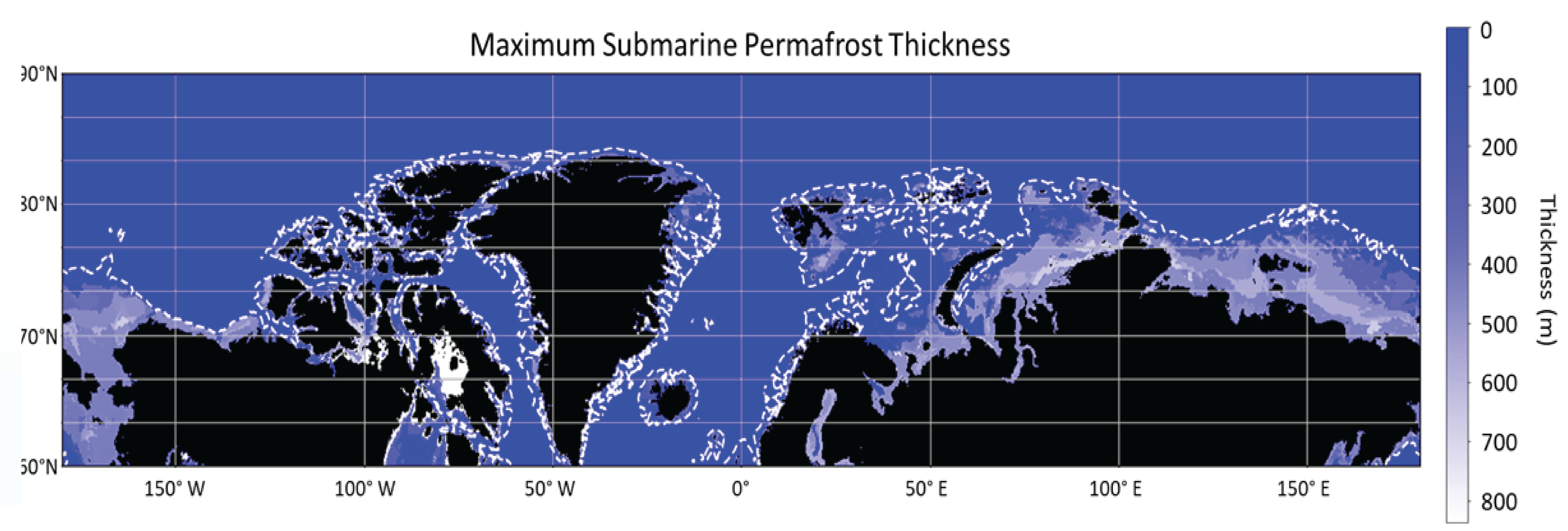
B) Methane hydrate saturation profile during thermal stimulation of a methane hydrate reservoir



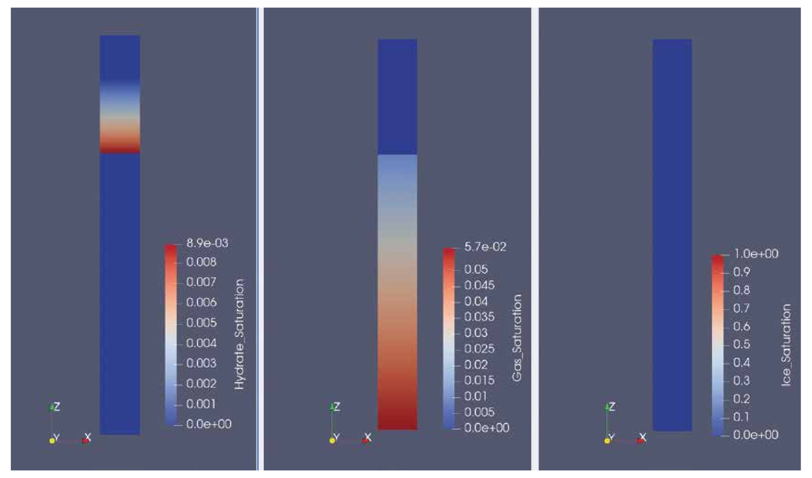
C) Methane hydrate saturation profile during depressurization of a methane hydrate reservoir

Approach

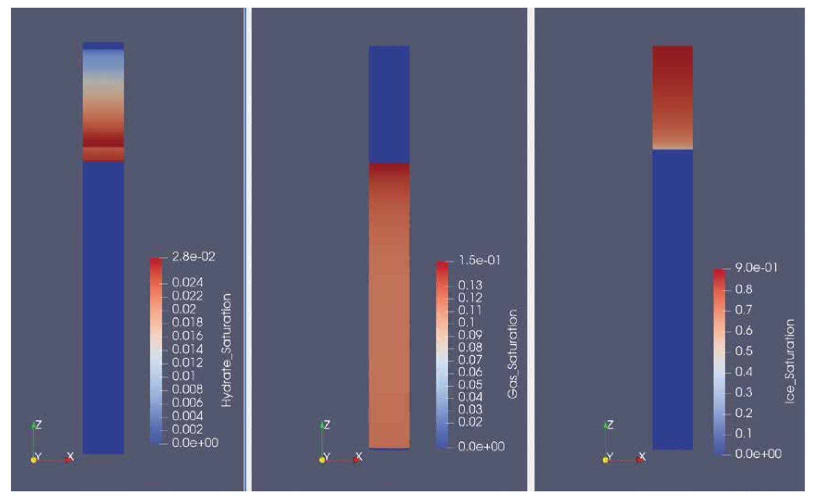
• Using our probabilistic workflow coupling machine learned maps of data inputs with a parameter sampling driver, we are generating maps of submarine permafrost and associated biogeochemical methane production.



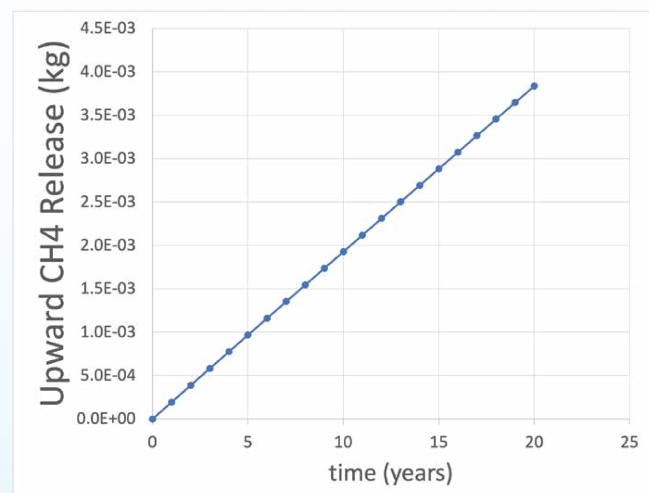
• Simulating a glacial-interglacial cycle at a given location, we model:
A) marine biogeochemical methane production;



B) ice formation when sediments are exposed to air;



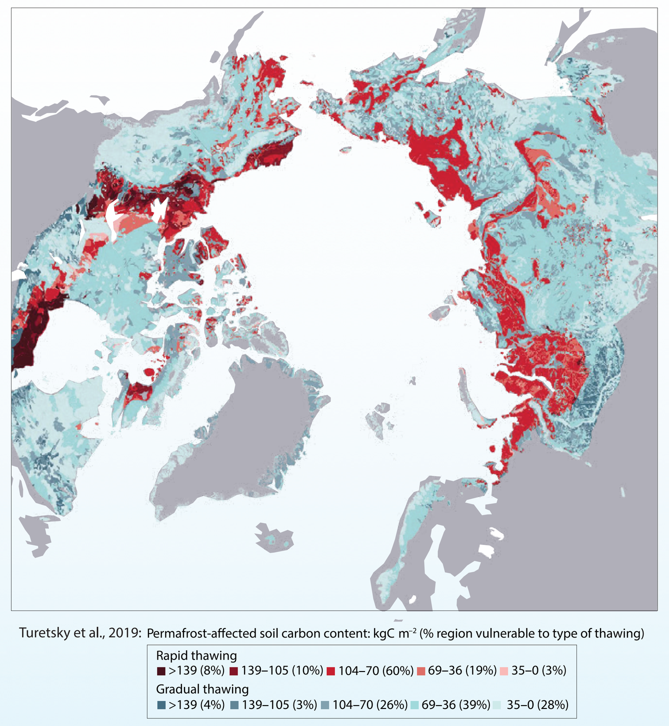
C) cumulative methane released from the column when sediments are exposed to warming surface temperatures

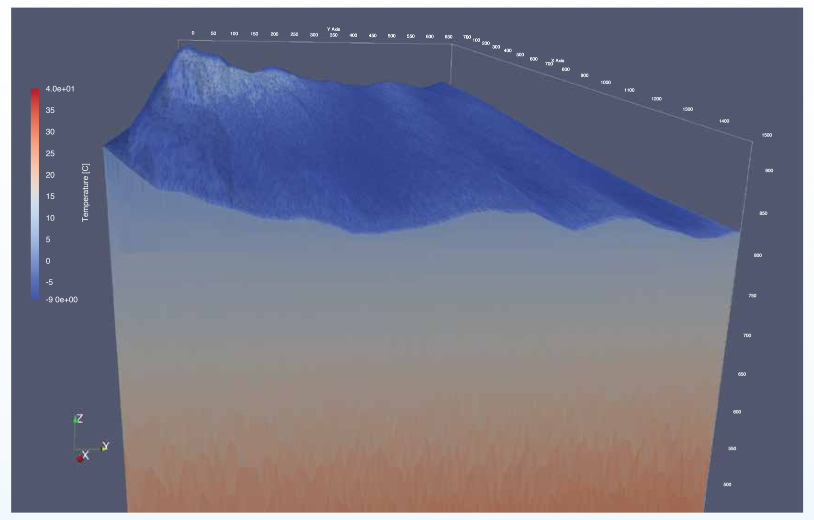


Looking Ahead:

• Terrestrial permafrost is known to contain vast carbon stocks that are vulnerable to various modes of permafrost thaw.

• Permafrost thaw mode (rapid vs. gradual) is understood to exert influence on composition of GHGs released from soils





• We plan to incorporate biogeochemical reactions as a function of permafrost thaw behavior and forward model terrestrial permafrost at a regional scale, constraining models against remote sensing data

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• White, M. D., Kneafsey, T. J., Seol, Y., Waite, W. F., Uchida, S., Lin, J. S., ... & Zyrianova, M. (2020). An international code comparison study on coupled thermal, hydrologic and geomechanical processes of natural gas hydrate-bearing sediments. Marine and Petroleum Geology, 120, 104566.

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