

Multi-scale modeling of permafrost freeze-thaw dynamics in polygonal tundra

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Abstract

Organic carbon rich Arctic ecosystem is highly sensitive to the climate change induced warming which may lead to release of carbon in form of CO_2 and CH_4 from previously frozen soils. Arctic ecosystem consist of complex and interconnected hydrologic, thermal, biogeochemical, geomorphic and vegetation processes. Local to regional scale eco-hydrologic processes are often influenced by micro-topographic variations in the topographically and geomorphologically complex landscape.

Increasing temperatures trigger disturbance in the thermal balance of permafrost freeze-thaw dynamics which propagates through the system via complex process interactions and feedbacks. Modeling of the permafrost freeze-thaw dynamics is key to understand the fate and evolution of the landscape in the warming climate. The Department of Energy's Next Generation Ecosystem Experiments (NGEE-Arctic) project is developing a multi-scale modeling framework to model eco-hydrologic processes in the Arctic ecosystems.

We have developed a finite volume method based model for coupled surface-subsurface mass and energy balance within PFLOTRAN—an open source, state-of-the-art massively parallel subsurface flow and reactive transport code. High resolution 3-D multi-phase thermal model captures the the microtopography and parameterized using field based observations data sets to understand the controls of polygonal tundra microtopography (centers/troughs/ridges) in high-centered/low-centered/transitional polygon landscapes.

Model was applied at NGEE-Arctic field sites at Barrow Environmental Observatory in Alaska. Sub-meter resolution LiDAR based Digital Elevation Model was used to capture the microtopography in high resolution model. Soil hydraulic and thermal properties were parameterized using observations from spatially distributed soil cores. Long term meteorological observations at the sites were used to force the simulations and spatially distributed records of active layer thickness employed to validate and calibrate the model.

Complex non-linear thermal hydrologic processes in heterogeneous Arctic landscape pose numerical and computational challenges. Robust numerical schemes has been developed in scalable parallel PFLOTRAN model for large scale realistic simulations of NGEE-Arctic field sites informed by field and laboratory observations.

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