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Coupled Hydrological and Thermal Modeling of Permafrost Dynamics: Implications to Permafrost Carbon Pool

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Thawing and freezing of Arctic soils is affected by many factors, with air temperature, vegetation, snow accumulation, and soil moisture among the most significant. To investigate how changes in these factors influence permafrost dynamics in the Arctic, we developed a Geophysical Institute Permafrost Lab (GIPL) permafrost dynamics model. This model simulates soil temperature dynamics and depth of seasonal freezing and thawing by solving a non-linear heat equation with phase change numerically.

Although the GIPL model is helpful for understanding the effects of climatic and landscape factors on heat flow and phase change in soil retrospectively and prognostically, it does not simulate soil moisture dynamics and storage across diverse landscapes. Coupling of the GIPL model with a suitably-scaled hydrological model captures thresholds and highly non-linear feedback processes induced by changes in hydrology and the temperature regime over the pan-Arctic. We developed a robust coupling of a GIPL Permafrost Model and modified version of the pan-Arctic Water Balance Model (P/WBM) developed at the University of Alaska Fairbanks and the University of New Hampshire, respectively. Through explicit coupling of the Permafrost Model with the PWBM we are able to simulate the temporal and spatial variability in soil water/ice content, active layer thickness, and associated large-scale hydrology that are driven by contemporary and future climate variability and change.

We assess the changes in permafrost characteristics in Northern regions of Eurasia using a coupled, large scale, grid-based water balance/permafrost model that simulates hydrological budgets, the distribution of soil temperature and active layer dynamics, permafrost thawing and freezing, using a number of projections of future climate for the next century. The model takes into account the geographic distribution of organic soils and peatlands, vegetation cover and soil properties, and is tested against a number of permafrost temperature records for the last century. We report results of simulations for a number of different climate scenarios derived from IPCC climate models outputs. Despite the slower rate of soil warming in peatland areas and a slower degradation of permafrost under peat soils, a considerable volume of peat (approximately 20% of the total volume of peat in Northern Eurasia) could be thawed by the end of the current century. The potential release of carbon and the net effect of this thawing will depend on the balance between increased productivity and respiration, and will be mitigated by peat moisture.

Keywords: Permafrost, Active Layer, Hydrology, Modeling, Peatland