A geospatial data framework for assessing circumarctic-scale permafrost carbon vulnerability based on observations, experiments and modeling

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A large amount of organic carbon stored in permafrost soils across the high latitudes is vulnerable to thaw, decomposition and release to the atmosphere as a result of climate warming. This process is anticipated to be a significant positive feedback on future radiative forcing from terrestrial ecosystems to the Earth's climate system. Here, we describe the development of a geospatial data synthesis and analysis framework designed to characterize permafrost carbon vulnerability across the northern high-latitudes. The broadly-defined regional classification is based on a circumarctic spatial representation of the major environmental controls on a) the rate and extent of permafrost degradation and thaw, b) the quantity and quality of soil organic matter stocks, and c) the form of permafrost carbon emissions as CO_2 and CH_4. The framework was developed by integrating existing spatial data layers describing permafrost and ground ice conditions, bioclimatic zones, and topographic and geographic attributes. The resulting Permafrost Regionalization Map (PeRM) is the foundation for synthesis studies on permafrost carbon vulnerability, including data representativeness, up-scaling and gap analysis along with model-data integration and benchmarking.

The utility of the PeRM framework is demonstrated here through areal density analysis and spatial summaries of existing data collections describing the fundamental components of permafrost carbon vulnerability. We use this framework to describe the spatial representativeness and variability in measurements within and across PeRM regions using observational data sets describing active layer thickness, soil pedons and carbon storage, long-term incubations for carbon turnover rates, and site-level monitoring of CO_2 and CH_4 fluxes from arctic tundra and boreal forest ecosystems. We then use these regional summaries of the observational data to benchmark the results of a process-based biogeochemical model for its skill in representing the magnitudes and spatial variability in these key indicators. Finally, we are using this framework as a basis for higher-resolution mapping of key regions of particular vulnerability to both press (active layer thickening) and pulse (thermokarst development) disturbances, which is guiding on-going research toward characterizing permafrost degradation and associated vegetation changes through multi-scale remote sensing. Overall, this work provides a critical bridge between the abundant but disordered observational and experimental data collections and the development of higher-complexity process representation of the permafrost carbon feedback in geospatial modeling frameworks.