The Permafrost Regionalization Map (PeRM): How well do observations, models and experiments represent the circumarctic-scale spatial variability in permafrost carbon vulnerability?

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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. Findings from observational, experimental and modeling studies all suggest that this process could lead to a significant positive feedback on future radiative forcing from terrestrial ecosystems to the Earth's climate system. With respect to the magnitude and timing of this feedback, however, observational data show large variability across sites, experimental studies are few, and different models result in a wide range of responses. These issues represent fundamental limitations on improving our confidence in projecting future permafrost carbon release and associated climate feedbacks. Recent studies have brought new insight into – and even quantitative estimates for – these issues through broader data synthesis and model-data integration approaches. But, how representative of the circumarctic-scale variability in permafrost carbon vulnerability are the data and models from these studies? To address this question, we developed a geospatial data synthesis and analysis framework designed to represent and characterize the variability in permafrost carbon vulnerability across the northern high latitudes. Here, we describe the rationale and methods used to develop the regionalization scheme, and then use the framework to assess the spatial representativeness of, and the variability described by, existing data sets defining the fundamental components and environmental drivers of permafrost carbon vulnerability.
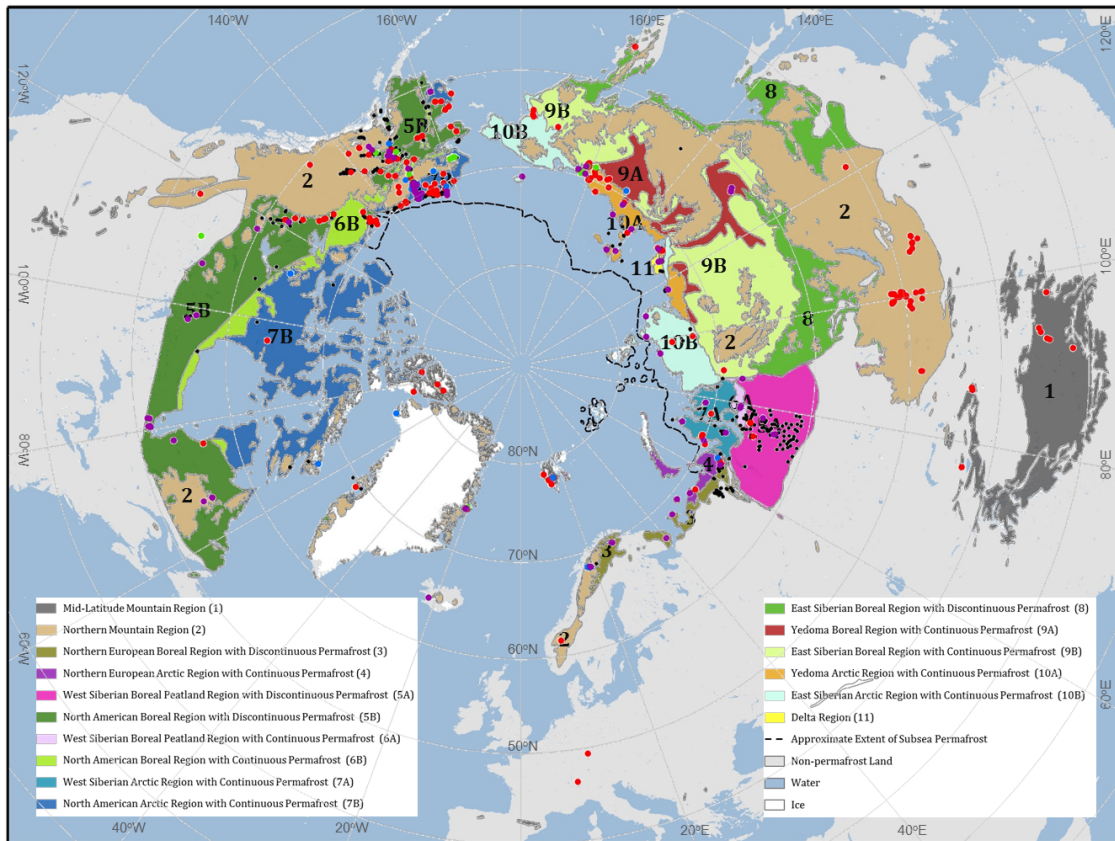
The Permafrost Regionalization Map (PeRM, Fig 1) considers the regional-scale environmental factors that generally determine the spatial variability in permafrost carbon vulnerability across the Arctic. The broadly-defined regional classification is based on a circumarctic spatial representation of the 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. We chose a generalized, pragmatic approach that resulted in a feasible number of regional subdivisions (i.e.,'reporting units') based on an intersection of spatial data layers according to permafrost extent, permafrost distribution, climate regime, biome and terrain.

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 discuss the on-going use of 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. This work is guiding on-going research toward characterizing permafrost degradation and associated ve-

getation changes through multi-scale remote sensing. Overall, this spatial data synthesis framework 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.

Figure 1: The Permafrost Regionalization Map (PeRM) showing the spatial intersection of a set of broadly-defined environmental controls on the circumarctic-scale variability in permafrost carbon vulnerability. Point locations are shown on the map represen