Investigating Soil Organic Matter Composition and Degradation State Across Hillslope Positions in the Arctic Foothills of Alaska

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Project Abstract: In the permafrost region, the soil organic carbon (SOC) stocks of hilly terrains are highly uncertain. In particular, frozen hill-toe soil deposits are one of the highest uncertainties at the circumpolar scale. The vulnerability of SOC stocks to warming depends on ice contents and the amount and composition of soil organic matter (SOM) occurring at different depths across the landscape. In addition to erosion and other processes, hillslopes in the Arctic are impacted by permafrost-affected solifluction and other lateral mass movements, cryoturbation, and patterned-ground formation. These processes might differently affect the accumulation, distribution, and decomposition of SOM across hillslope toposequences. We investigated the composition and degradation state of SOM at different landscape positions across two toposequences formed on differing land surface ages in the Arctic Foothills of Alaska. The soil profiles of seven hillslope positions (summit, shoulder, upper and lower backslope, upper and lower footslope, and basin) were sampled by soil layers to depths of 1-3 m. We determined SOC stocks and water/ice contents at comparable hillslope positions for each toposequence. We also evaluated profile variations in SOM composition (organic functional groups and minerals) and indicators of SOM degradation state by analyzing the mid-infrared spectra of the soil. Both hillslopes contained large SOC stocks to 1-m depth across the toposequence. Volumetric ice content was high at all hillslope positions with pore ice and ice lenses forming a range of soil cryostructures. Ice-wedges were observed at summit, shoulder, lower footslope, and basin positions. A principal component analysis indicated similar SOM composition occurred across all slope positions with the exception of the basin areas, where greater accumulation of non-polar methyl group compounds dominated over other organic functional groups. Indicators of SOM degradation state, such as high ratios of carboxylates to polysaccharides, were negatively correlated with SOC content suggesting that SOM associated with mineral soil layers were more degraded than organic or mixed organic/mineral layers. Next steps will focus on understanding how SOM degradation state varies with the depth distribution of different soil layers across each toposequence — with the aim of generating spatially explicit local and regional estimates of SOM degradation state and potential decomposability for hillslope-dominated arctic landscapes.

Improving Long-Term Modeling of Soil Carbon and Permafrost Response to Wildfire through Observational Evidence in the Southernmost Permafrost Region of Alaska

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Project Abstract: The permafrost-affected soils and ecosystems of the Copper River Basin (CRB) represent the southernmost area of extensive, discontinuous permafrost in Alaska. These soils are considered ecosystem-protected because prevailing ecological conditions, rather than climate alone, are the major influence on permafrost stability. In subarctic and boreal regions, soil carbon and permafrost depth are strongly dependent on the thickness of the surface organic layer, which stores large amounts of carbon at a landscape scale and acts as an insulator to protect permafrost from degradation. Nevertheless, the surface organic layer is extremely sensitive to disturbances such as wildfire. Depending on severity, wildfires can remove or severely reduce the thickness of the organic layer, reduce insulation, and lead to soil carbon loss and permafrost degradation. Many observational and modeling efforts have examined fire-induced changes in organic layer thickness, soil carbon, and permafrost in Interior Alaska over decadal scales. However, the soils, permafrost, and landscapes of the CRB are dominated by clayey, fine-textured soils on flatter terrain with longer fire-return intervals compared to Interior Alaska. Preliminary work has shown that the fire responses of permafrost-affected soils and their carbon stocks in the CRB differ in critical ways from those observed for the generally silty textured, better drained soils of Interior Alaska. Unlike many sites in other permafrost-affected landscapes where soils can become drier following permafrost degradation due to increased drainage, our work has shown that soils in the CRB are more likely to become wetter post-fire. The restrictive permeability of CRB soils, fire-induced loss of transpiration, and low gradient landscapes combine to profoundly influence the long-term trajectory of CRB soils and ecosystems. These factors may lead to dramatically different outcomes with respect to soil carbon balance compared to Interior Alaska, with potentially increased rates of post-fire carbon accumulation due to wetter conditions. Yet, because of relatively warm ambient and permafrost temperatures in the CRB, it is unlikely that permafrost aggradation occurs post-fire by upward freezing from the permafrost table. Rather, the formation of new near-surface permafrost following the recovery of the organic layer may occur simultaneously with the development of taliks. These interacting factors could make CRB soil carbon stocks and permafrost either more or less susceptible to disturbances caused by wildfires and rising annual temperatures.

Quantifying Variations in Soil C:N Relationships for the Permafrost Region

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Project Abstract: Recent worldwide efforts have improved estimates of soil organic carbon (SOC) stocks and their spatial and vertical distributions for the permafrost region. However, predicting the fate of these SOC stocks in response to changing climatic conditions and projecting their impact on carbon-climate feedbacks require better information on additional soil properties. For example, understanding the nitrogen (N) reserves currently held by permafrost-region soils, their relationships with SOC stocks, and their susceptibility to release under changing climatic conditions will be important for efforts to model future ecosystem and regional responses and feedbacks. Soil C:N ratio can be an indicator of decomposability as it can influence microbial decomposition processes—with related effects on N availability, nitrous oxide emissions, and vegetative responses to climatic and hydrologic changes. Yet, efforts to map the patterns of soil N stocks and C:N relationships for the permafrost region currently lag behind those for SOC stocks. The first study to estimate the distribution of soil N stocks across the northern circumpolar region (Palmtag et al., https://doi.org/10.5194/essd-2022-8, in review) used a thematic mapping approach based on land cover classes spatially available at 300-m resolution to upscale a newly available observational dataset. As an important soil forming factor, land cover affects the form and composition (including C:N) of recent organic inputs to soil and also generally reflects the integrated effects of climate and edaphic factors—making it a useful predictor for upscaling studies. In the permafrost region, however, unique cryo-pedogenic processes (such as cryoturbation) and the preservation of poorly degraded soil organic matter at depth suggests the need to investigate soil C:N relationships in the context of other soil forming factors at higher spatial resolutions. However, mapping and interpretation of soil property ratios (including C:N) is challenging, with no set standard, particularly for the heterogeneous profiles of permafrost-affected soils. The drawback to direct mapping of soil C:N is the assumption that similar environmental factors influence the spatial and vertical variability of both SOC and N, which might not be true. Another approach would be to map SOC and N stocks independently, to capture how different environmental factors affect each soil property, and then determine soil C:N distributions from the two digital soil mapping products. In this study, we compare these two approaches at high spatial resolution in Alaska to evaluate which can best capture and explain spatial and vertical variations in soil C:N relationships.