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From Freeze to Flow: Moisture and Thermal Dynamics in Thawing Permafrost Soils

AMANDA J BARKER[1], ROBYN A BARBATO[1], WILLIAM B BAXTER[1], DAVID BRODYLO[1], JACK A CADIGAN[2], THOMAS A DOUGLAS[1], BRIAN D HARRIS[2], RUBEN P KEANE[3], JON B MAAKESTAD[1] AND DRAGOS A VAS[1]

[1]U.S. Army Cold Regions Research and Engineering Laboratory
[2]U.S. Army Coastal and Hydraulics Laboratory
[3]Oak Ridge Institute for Science and Education

Across Arctic regions, permafrost degradation continues to reshape terrestrial and aquatic ecosystems by altering hydrology. As such, soil moisture remains a key variable for understanding surface energy balance and assessing how permafrost degradation impacts biogeochemical processes. Terrain heterogeneity, soil temperature, precipitation, vegetation, soil type, and seasonality drive soil moisture conditions and assessing any long-term trends requires detailed and continuous monitoring of distinct soil systems. While significant research has targeted soil moisture dynamics and permafrost degradation using remote-sensing data and spot observations, many studies overlook spatial heterogeneity and seasonal variability in the subsurface. To address these limitations, we integrated continuous in-situ soil moisture data, soil texture, electrical resistivity tomography, soil strength, matric potential, and soil respiration collected throughout the seasonally frozen and thawed soil of the active layer from seven field sites across Interior and Northern Alaska, encompassing the boreal forest and Arctic tundra. We found that moss and peat soil horizons exhibit high variability in volumetric water content near the surface, while mineral and disturbed silt soils retain moisture content at depth for longer periods of time. Wetness spikes occur at shallow soil depths associated with horizon changes and dissipate quickly after rain events, but saturation plateaus dominate in deeper soil profiles, particularly for mineral and peat layers. For instance, during the 2024 thaw season on the North Slope of Alaska an entire thaw season (2 months) exhibited approximately 50-60% volumetric water content at 40 cm soil depth. Our approach aims to better constrain temporal moisture dependencies on soil type, thermal regime, and depth within thawing permafrost environments as this information will enable more robust modeling of permafrost vulnerability.