Understanding Active Layer Thickness Variability Under Changing Climatic Conditions Across the North American Taiga-Tundra Ecotone

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Abstract

In Alaska, pervasive irregularities of permafrost coverage and associated boreal forest heterogeneity within the North American Taiga-Tundra Ecological Transition Zone (TTE) are becoming more apparent as the climate warms. These anomalies correspond to extensive shifts in active layer thickness (ALT), carbon cycle disruption, and ecosystem response patterns. The feedback complexities associated with these climate-induced disturbances are evaluated with the integration of remote sensing, modeling, field observations, data assimilation and harmonization techniques, and artificial intelligence technology. In this study, to improve our understanding of shifting belowground dynamics and how they associate with aboveground vegetation patterns, we used the SIBBORK-TTE model to derive permafrost degradation and ecosystem transiency at high-resolution in this study. The intercomparison of model version output was first examined; then, multiple verification and validation methodologies revealed distinct historical and future implications resulting from ALT variability within four regions of the Alaska TTE domain (North Slope, Yukon Delta, Seward Peninsula, Interior). To quantify historical thaw variability and identify seasonality patterns across these regions of interest, in situ ALT point measurements were collected from two campaigns (CALM, SMALT) to cross-validate ALT-derived SAR data (AirMOSS, UAVSAR) and below-ground SIBBORK-TTE simulations between 1990-2020. Future conditions were then projected with a warming climate function and CMIP6 data from CNRM-CERFACS SSP126/585 scenarios. Initial results for derived and measured annual maximum ALT yield a mean-error performance metric of 0.2294. Paradoxically, future climate conditions advance the ubiquity of permafrost thaw and seasonality widening across the TTE. With this investigative approach, spatiotemporal variability in ALT provides a unique signal to enhance model precision and lower uncertainty through fine-tuning driver forcing and modular parameterization, forecast permafrost distribution, and identify the climatic and topographic mechanisms of earth system feedbacks and land cover change.

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