The Distribution of Dwarf Shrubs and Drought Resistant Plants Varies With Soil Temperature and Position on Periglacial Patterned Ground at the Goat Flat Alpine Tundra, Montana, USA

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Abstract: The distribution of N-fixing dwarf shrubs, coniferous tree seedlings, and drought resistant herbaceous plants differed with soil temperature and position on polygonal and striped periglacial patterned ground of the Goat Flat alpine tundra (2837 m; 46° 3’ 17” N, 113° 16’ 43” W) in the Pintler Mountains of Montana, USA. We determined the relative percent cover (RPC) of vascular plant species along with a suite of their qualitative functional traits on polygons and stripes, gathered thermographic images with a forward looking infrared (FLIR) camera, and recorded soil temperatures with in-situ Hobo-Onset sensors, hourly from 2018-21. Polygon centers and brown stripes were discernable by their low vascular plant cover (< 20 %) while polygon edges and green stripes were visible because of their high vascular plant cover (> 70 %). Thermographic images demonstrated significantly higher surface temperatures on polygon centers than edges. Maximum soil temperatures and ranges were significantly higher on the polygon centers and brown stripes than on the edges and green stripes, and temperature curves suggest later lasting snow on the polygon edges, where dwarf shrubs had significantly higher RPCs. The RPC of the dominant evergreen dwarf shrub, Dryas octopetala (Mountain Avens, Rosaceae), was significantly higher on polygon edges and green stripes than on polygon centers and brown stripes. D. octopetala is symbiotic with N-fixing Frankia soil bacteria, so the presence of D. octopetala likely influences nitrogen dynamics of the periglacial patterned ground. Seedlings of coniferous evergreen gymnosperms were found only on polygon edges and green stripes, indicative of tree establishment. The polygon centers had a significantly higher RPC for the xeromorphic trait of crassulacean acid metabolism (CAM), which confers drought resistance. Patterns of species and functional traits are likely influenced by temperature variations on the patterned ground.

Machine learning analyses of remote sensing measurements establish strong relationships between vegetation and snow depth in the boreal forest of Interior Alaska

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In the diverse vegetative cover of the Interior Alaska boreal forest in Interior Alaska a warming climate has shortened the winter season by 5 weeks. Since the seasonal snowpack plays a critical role in regulating wintertime soil thermal conditions there are major ramifications for near surface permafrost. Snow depth can be markedly different from one season to another but there are strong relationships between ecotype and snowpack depth. This can be used to identify how present and projected future changes in winter season processes or land cover will affect permafrost. Though vegetation and snow cover can be assessed rapidly over large spatial scales with remote sensing methods remotely measuring snow depth has proven difficult. As a consequence, vegetation-snow depth relationships provide a means of assessing snowpack characteristics. We combined airborne hyperspectral and LiDAR measurements with machine learning methods to characterize relationships between ecotype and more than 26,000 snow end of winter snowpack measurements. We focused from 2014-2019 at three field sites representing common boreal ecoregion land cover types. These winters represent typical mean snowpacks as well as anomalously low (2016) and high (2018) snowpacks. Hyperspectral measurements account for two thirds or more of the variance in the relationship between ecotype and snow depth. Among three modeling approaches, support vector machine yields the strongest statistical correlations between snowpack depth and ecotype for most winters. The strongest relationships between ecotype and snow depth come from an ensemble analysis of model outputs using hyperspectral and LiDAR measurements. Methods used in this study can be applied across the boreal biome to model the coupling effects between vegetation and snowpack depth and to develop more robust means of making standoff measurements of snowpack properties.

Affect of the slope topography on the ground temperature, hydrology and soil formation: a case study at the Seward Peninsula.

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Slope terraces 50-200 meters in width with the reasers at 2 meters high is a widespread feature at the Seward Peninsula. These landforms affect the redistribution of snow during winter seasons and, thus controls soil temperature and moisture regime. It affects the vegetation and the processes of soil development. We conducted our research at one of such terraces at milepost 28 of the Teller road. Studies included soil, vegetation, and snow surveys along the 70 meters long transect, biomass productivity assessment, decomposition experiment, and continuous measurements of the ground temperature and soil moisture at three points located in the rear, middle and front parts of the terrace. According to our results mean annual ground temperature at the depth of 1.2 meters in 2019 gradually decreases from 4.2°C at the rear part to 0.5°C at the terrace's edge. Such a pattern in the ground thermal regime is mostly caused by the difference in winter temperature due to snow redistribution. The soil moisture regime might be identified as Ustic at the rear and middle parts and Udic at the front of the terrace. Across the tread of the terrace vegetation changes from the grassland in the rear part to ericaceous tundra in the middle and lichen tundra at the front. Aboveground bioproductivity increases from the rear (449.6 g/m2) to the front part (1099.76 g/m2) of the terrace. But it is necessary to notice that 87% of production in the frontal part is represented by lichens. A significant portion (66.8%) of the total biomass of the ericaceous tundra is composed of woody species, so only about one-third (816.6 g/m2) of it can be involved in the process of annual carbon turnover as a litter. The rear part is only a section of the terrace where the whole annual harvest of biomass turns into litter. Thus, the amount of annual litter biomass decreases from the rear to the frontal part. The highest rate of litter decomposition during the summer season was recorded at the middle section of the terrace and the lowest – at the front. Processes of the organic stabilization were the lowest at the rear part of the terrace. A combination of all about mentioned factors and processes explain the pattern in soil sequence. The most developed soil profile (Ustic Haplocryols) can be found at the rear part of the terrace replacing with the Typic Humicryepts at the middle and Typic Dystrogelepts/Haplogelepts at the front.

Snow, vegetation, and permafrost interactions and advancements in sensing/monitoring technologies

Active Layer Thickness as a Function of Soil Water Content in Alaska and Canada

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Active layer thickness (ALT) is a critical metric for monitoring permafrost. The influence of soil moisture on ALT is subject to two competing hypotheses: (a) increased soil moisture increases the latent heat of fusion for thaw, resulting in shallower active layers, and (b) increased soil moisture increases soil thermal conductivity, resulting in deeper active layers. To investigate the relative influence of each factor on thaw depth, we analyzed thousands of in-situ soil moisture and thaw depth measurements from the Soil Moisture and Active Layer Thickness (SMALT) dataset, collected at hundreds of sites across Alaska and Canada as part of NASA's Arctic Boreal Vulnerability Experiment (ABoVE). As bulk volumetric water content (VWC) integrated over the entire active layer increases, ALT decreases, supporting the latent heat hypothesis. However, as VWC in the top 12 cm of soil increases, ALT increases, supporting the thermal conductivity hypothesis. Regional temperature variations determine the baseline thaw depth while precipitation may influence the sensitivity of ALT to changes in VWC. Soil latent heat dominates over thermal conductivity in determining ALT, and the effect of bulk VWC on ALT appears consistent across sites.

Explicitly modelling microtopography in permafrost landscapes in the JULES land-surface model

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Microtopography can be a key driver of heterogeneity in the ground thermal and hydrological regime of permafrost landscapes. In turn, this heterogeneity can influence plant communities, methane fluxes and the initiation of abrupt thaw processes. Here we have implemented a two-tile representation of microtopography in JULES (the Joint UK Land Environment Simulator), where tiles are representative of repeating patterns of elevation difference. Tiles are coupled by lateral flows of water, heat and redistribution of snow. A surface water store is added to represent ponding. Simulations are performed of two Siberian polygon sites, Samoylov and Kytalyk, and two Scandinavian palsa sites, Stordalen and Iškoras. Tiling tends to result in a warmer lower tile and a colder raised tile. When comparing the modelled soil temperatures for July at 20 cm depth with observations, the difference in temperature between tiles is smaller than observed for Palsa sites (3.2 vs 5.5°C), while polygons display small (0.2°C) to zero temperature splitting, in agreement with observations. Consequently, methane fluxes are near identical (+0 to 9%) to those for standard JULES for polygons, though can be greater than standard JULES for palsa sites (+10 to 49%). The relative importance of model processes in driving soil temperature and moisture heterogeneity, and their sensitivity to the introduced parameters are tested. We also identify which parameters result in the greatest uncertainty in modelled temperature. Varying the modelled palsa elevation between 0.5 and 3 m has little effect on modelled soil temperatures, showing that having only two tiles can still be a valid representation of sites with a large variability of palsa elevations. Lateral conductive fluxes, while small, reduce the temperature splitting by ~1°C, and correspond to the order of observed lateral degradation rates in peat plateau regions, indicating possible application in an area-based thaw model.

Snow, vegetation, and permafrost interactions and advancements in sensing/monitoring technologies

Extrapolating snowpack properties from small temperature sensors in two watersheds on the Seward Peninsula, Alaska, USA

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Understanding changes in snow cover distribution in Tundra ecosystems is critical to predicting the future of Arctic climates. Snow acts as an insulating layer in permafrost landscapes during the coldest time of the year. Shrub expansion in Tundra ecosystems traps snow—leading to deeper snowpack and increased insulation of frozen soils. Small temperature sensors were deployed at two intensively studied watersheds on the Seward Peninsula of Alaska, USA, as part of the Next Generation Ecosystem Experiments (NGEE) Arctic project. Using small temperature sensors to monitor snowpack conditions provides a cost-effective way to measure a larger spatial and temporal extent than can be measured during a traditional snow survey. The snowpack and air temperature measurements from the sensors were used to extrapolate properties such as snow depth and the insulation effect of snow over the 2020 winter. Spatial and statistical analysis showed that ecosystem types with taller, thicker shrubs had deeper snow for longer during the winter.

Cumulative impacts of fire and climate on permafrost at local and regional scales, southern Northwest Territories, Canada

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Abstract: Climate warming and the growing frequency, severity, and extent of fires in the northern hemisphere are altering post-fire permafrost response. This study examined the impacts of fires from the extreme fire year of 2014 and the more historically typical 2015, at 19 sites along a transect (60.9-63.1° N) within the sporadic and extensive discontinuous permafrost zones in the Northwest Territories, Canada. Annual field measurements from 2015 to 2019 included ground and air temperatures, snow depths, frost table depths, and repeated direct current electrical resistivity tomography (ERT) surveys. Impacts were evaluated by comparing 16 burned sites to three unburned control sites and by intra-site differences at six sites where burned and unburned areas were contiguous. Permafrost changes occurred in the near surface (<5 m depth) at all sites over the monitoring period, but with clear differences between burned sites and controls. Locally, burned sites had greater increases in frost table depths and ground temperatures, and reductions in electrical resistivity, especially at sites with coarse-textured soils, low gravimetric moisture contents, and thin organic layers (<40 cm). Maximum snow depths were generally greater at burned sites than at controls, but there was no substantial difference in snow-depth days or nival offsets. At a regional scale, permafrost appears resilient to fire disturbance at the northern end of the study transect where ground temperatures are lower. At the southern end of the transect, permafrost appears resilient at sites with a thick (>40 cm) residual soil organic layer, but vulnerable to thaw at sites with thin organic layers and coarse-textured soils. These findings indicate that permafrost can persist after fire in certain settings, even near its southerly margin, under climate warming to date. This demonstrates the importance of considering the full range of environmental conditions when forecasting permafrost responses to climate warming.

Distributed Temperature Profiling Networks for Quantifying Soil Thermal Regimes and their Controls across Discontinuous Permafrost Environments

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Insight into subsurface storage and fluxes of water, heat, and nutrients in permafrost environments is essential to understand and predict how Arctic ecosystems will change under warming temperatures. While the characterization and monitoring of snowpack dynamics and soil thermal regimes and properties is critical for improving the predictive understanding of heat and water fluxes across the landscape, conventional measurement approaches do not deliver sufficient spatiotemporal resolution and coverage. Our research focuses on the design, development, deployment and use of an innovative Distributed Temperature Profiling (DTP) network, leveraging technological advancements in the field of ultra-low power integrated circuits, sensors and wireless communication systems. The system consists of a large number of wireless and AA battery powered temperature probes with each probe synchronously recording the temperature at 15 min intervals by sensors distributed vertically with 5 or 10 cm spacing along ~1 m depth. The probes have been deployed at about 100 locations to measure the vertically-resolved temperature of soil, as well as snow at some locations, across a ~1.5 × 2 km watershed near Nome, Alaska, which is characterized by discontinuous permafrost and high spatial variability of soil thermal and physical properties. Snow thickness, soil freeze/thaw dynamics, thermal parameters, and other metrics were determined from the temperature time-series over more than one year. We found that the variability in the soil freeze-thaw durations and thickness was strongly impacted by the snow cover dynamics and the soil water content that were both partly associated with topography and vegetation cover. The study highlights the potentials of the DTP system to monitor the thermal dynamics for improving the predictions of soil hydro-biogeochemical dynamics.

Field Validation of Simulated Permafrost Thaw Depth Across the Vegetation Gradient in Alaska from SIBBORK-TTE Modeling Infrastructure

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In the Arctic, the spatial distribution of boreal forest cover and soil profile sequences characterizing the North American Taiga-Tundra Ecological Transition Zone (TTE) are experiencing rapid transformations; namely, alarming and extensive shifts in permafrost thaw and distribution, carbon cycle mobilization, and ecosystem function and composition as a consequence of rising air temperatures and climate change. The complexities and feedback drivers associated with these ecosystem response patterns may be examined with the integration of remote sensing, earth system modeling, and field observations in addition to extensive data assimilation and harmonization techniques, machine learning approaches, and artificial intelligence technology. More specifically, the SIBBORK-TTE model provides a unique opportunity to predict the spatiotemporal distribution patterns of vegetation heterogeneity and forest structure variability, arctic-boreal forest interactions and ecosystem transition zone transiency, and permafrost degradation with high-resolution scaling across broad domains. Within the TTE, evolving climatological and biogeochemical dynamics such as permafrost thaw and soil turnover facilitate distinct moisture signaling and terrestrial nutrient cycle disruption, thereby catalyzing land cover change and ecosystem instability patterns. This study is an overview of scientifically-supported verification and validation metrics of permafrost dynamics throughout Alaska, efforts which reveal distinct historical and future implications within the Alaska boreal and tundra domains (i.e. SMALT and CALM sites within the North Slope, Brooks Range, Yukon Delta, Seward Peninsula, and Interior). To quantify these trends in permafrost thaw variability, in situ ground measurements for active layer depth (ALD) were collected to evaluate and cross-validate below-ground model simulations between 1996-2018. Shifting trends in derived permafrost thaw variability from these modeling results indicate seasonality biases and were compared statistically to the in situ data collection. Thereafter, the SIBBORK-TTE model was used to project future below-ground conditions utilizing a CMIP6-integrated climate change warming function generated from four CNRM-CERFACS scenarios. Upon visualization and curve-integrated analysis of the simulated freeze-thaw dynamics, the calculated performance metric from derived annual maximum thaw depth and measured active layer depth yielded a mean error of 0.321. With this novel approach, spatiotemporal variability in active layer depth provides an opportunity for tuning model parameterization for increased simulation accuracy, forecasting permafrost distribution and thaw depth variability, and identifying climate and topographic drivers of earth system feedback mechanisms.

Quantifying Permafrost Soil Micro-Structure with Micro X-ray Computed Tomography

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In permafrost systems soil micro-structure is largely uncharacterized, and it is unclear what structural elements are prevalent, be it pore structure, soil aggregation, or cryostructure and how they affect microbial ecology and ecosystem function. X-ray Computed Tomography (micro-CT scanning) is often associated with the health industry but has a wide range of environmental applications. Micro-CT scanning is a powerful technique for analyzing soil physical environments, including pore and aggregate structure which play a role in shaping soil microbial ecology and biogeochemical processes. However, this knowledge is mostly limited to temperate soils. Here we demonstrate a pipeline for acquiring, processing, and analyzing permafrost micro-CT scanning data. We collected four permafrost cores from above the Cold Regions Research and Engineering Lab (CRREL) permafrost Tunnel in Fox, Alaska and subsampled as triplicate pucks (~1 cm in height and ~2.5 cm in diameter) 5 cm below the active layer. Pucks were scanned at 20 µm resolution using a Bruker Skyscan 1173 micro-CT at CRREL (Hanover, NH). Slices were reconstructed and corrected for hard beaming and ring artifacts in CTAn image processing software. Then, image stacks were imported into Dragonfly image processing software, filtered for speckle noise, and segmented to regions of interests (ROI). Finally, relevant morphological operations were applied to ROIs to eliminate remaining scanning artifacts and account for resolution limitations. We calculated volumetric composition of air, ice, and soil. Additionally, ice and pore structure were quantified by calculating ice-soil interface surface area, ice and pore connectivity, and size distribution. Characterizing patterns in permafrost micro-structure will give insight into how the physical soil environment influences microbial distribution, abundance, and diversity in permafrost soils.

Modelled Soil Temperature Sensitivity to Variable Snow and Vegetation Conditions in Low-Relief Coastal Mountains, Nunatsiavut and NunatuKavut, Labrador

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Understanding permafrost vulnerability and resilience to climate warming is critical for predicting impacts on northern communities and ecosystems. The thermal characteristics of near-surface permafrost are largely influenced by effects from overlying vegetation and snow cover, both of which are changing in northern environments. Associations between vegetation and snow cover are particularly important in the coastal mountains of Labrador, northeast Canada because of high annual snowfall totals and greening tundra biomes. Due to a lack of field studies in the region, relatively little is known about contemporary permafrost and the impacts permafrost thaw may have on infrastructure and culturally significant ecosystems. In this study, we present a series of one-dimensional simulations using the Northern Ecosystem Soil Temperature (NEST) model to characterize ground thermal conditions at two field sites (one northern; one southern) in low-relief mountains along the Labrador coast. NEST simulations were run for the period 1979-2018 using climate data derived from ERA5 atmospheric reanalysis. The NEST simulations were prepared for three ecotypes (tundra, shrub, treed) with three different snow accumulation regimes (wind-exposed, flat, topographic hollow) to provide a range of ground thermal conditions at both sites. At the northern field site (near Nain, Nunatsiavut), the perennially-frozen ground was present for all ecotypes when simulated with extensive snow drifting but largely absent for all ecotypes with high snow accumulation. At the southern field site (near Pinware, NunatuKavut), near-surface permafrost was largely absent from simulations for all ecotypes. Scenarios with extensive wind drifting away from the site allowed thin perennially frozen bodies (<15 m) to persist in tundra and shrub ecotypes in most years and under treed ecotypes in cooler years. These results highlight the importance of spatial and temporal variability in snow cover for simulating ground thermal regimes in coastal Labrador.

Comparison of Satellite-Derived Snow Data Benchmarks with Historic Snow Survey Data from the North Slope of Alaska using ILAMB Software.

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Understanding and modeling the permafrost system, hydrologic cycle, energy balance, and biologic systems along the North Slope of Alaska is dependent, in part, on snow depth and snow distribution. Point-source snow measurements provide ground-truthed observations of snow depth and snow density, although these measurements may be limited in spatial and temporal distribution. Satellite-derived remote sensing products provide spatial coverage of snow cover, but the applicability is affected by the balance of resolution, computational speed, and confidence in the remotely sensed data products. The goal of this research is to assess the suitability of specific satellite-derived snow data products for fine scale modeling in the North Slope of Alaska by using International Benchmarking Project (ILAMB) software. ILAMB works to provide software for modelers to compare model results to internationally accepted benchmarks, such as the Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) radiation dataset and Global Fire Emissions Database (EFED4). The benchmark for North America snow water equivalent encouraged for use by ILAMB is the Canadian Sea Ice and Snow Evolution Network (CanSISE) Observation-Based Ensemble of Northern Hemisphere Terrestrial Snow Water Equivalent, Version 2 data product. Historic snow survey data from the North Slope of Alaska dates from 1901 to present day. This historical snow data, collected by agencies, academia, and industry, was curated to create a digital catalog of over 2000 observed snow data points from locations across the North Slope of Alaska. The curated snow data is being ingested into the ILAMB software for comparison to established benchmarks and to earth system model simulations of snow water equivalent . In this study, we will present the curated snow survey data as well as initial results in the assessment of the CanSISE benchmark in reference to the curated data.

Snow, vegetation, and permafrost interactions and advancements in sensing/monitoring technologies

Boreal shrub water use in permafrost and permafrost-free systems

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Shrub expansion in boreal forest ecosystems has received less attention compared to arctic ecosystems but the consequences may be just as significant. Alder and willow shrubs are expanding their range in the boreal forest, particularly in areas experiencing permafrost thaw. An understudied aspect of shrub expansion is their water use dynamics, and deciduous vegetation have high levels of water use that dry the soil, impacting the conditions that affect permafrost stability. This study quantifies boreal shrub (alder) water use dynamics (stem water content, transpiration, water stress) in a permafrost ecosystem that is thawing and in a permafrost-free ecosystem. The shrubs in both ecosystems take up snowmelt water prior to leaf out to support early season physiological processes but rely on rainfall as the growing season progresses. Shrubs growing in the thawing permafrost system were more water stressed, had lower stem water content, and transpired less water than the shrubs growing in the permafrost-free system. These findings are surprising because soils underlain by permafrost are generally wetter than soils without permafrost, suggesting that water availability should not be a limiting factor for these plants in permafrost soils. However, the moss and organic layers in this ecosystem become dry because water from thawing soils exits this system via lateral subsurface flow (the site is on a hillside). Although this creates stressful conditions for the shrubs, they have continued to thrive and expand into this area. Additionally, the shrubs use significantly more water than the black spruce and contribute to drying the soil. This study demonstrates that alder shrubs can tolerate a range of soil conditions created by permafrost presence and condition. While the stressful conditions in the system with thawing permafrost reduces shrub water use, they still contribute to soil drying and are potentially more tolerant of thawing conditions than black spruce.

Snow, vegetation, and permafrost interactions and advancements in sensing/monitoring technologies

Snow and canopy interception influence on soil thermal regimes

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Precipitation plays a crucial role in shaping ecosystem structures and functions. Snow, specifically, has an outsized influence on the Boreal and Arctic ecosystems' hydrological and thermal energy budgets. When present, snow shields the ground from low winter temperatures. Its arrival and departure have dramatic impacts on the surface and subsurface ground energy balance. In spring and summer, snow provides the majority of the growing season's liquid water. Snow is a key atmospheric, cryospheric, hydrologic, and ecological component that has been largely ignored. Subsequent feedback effects from reduced canopy are augmented by wind and snow cover interactions, leading to increased spatial variability in snow distribution and snow thermal properties. To investigate the snow and canopy interactional influence on soil thermal regimes, we set up a monitoring network with soil temperature sensors in Fairbanks, AK at numerous locations with varying vegetation (black spruce, deciduous forest, tussocks) and canopy cover. In 2018, the soil temperatures, at 5cm depth, at our sites varied between a low of -15°C and a high of 0°C at the end of January and the range in the summer was 22°C (between 5 and 37 °C). At deeper depths (35 cm) the soil temperatures varied between -6 and 0 °C in the winter and 0 and 17 °C in the summer. At a relatively short (10m) transect with varied canopy cover, displayed the greatest variance in surface soil temperatures with wintertime lows between -21 to -6 °C and summertime highs between 18 to 40 °C. We are currently expanding our monitoring network to include snow depths, snow temperature, volumetric water content, meteorological sensors (air temperature, wind, relative humidity, barometric pressure, solar radiation, precipitation) and soil thermal conductivity. Our study has the potential to greatly enhance our understanding of these changing systems and their delicate interdependence.

Spatial Patterns of Snow Distribution for Improved Earth System Modelling in the Arctic

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The spatial distribution of snow plays a vital role in Arctic climate, hydrology, and ecology due to its fundamental influence on the water balance, thermal regimes, vegetation, and carbon flux. However, for earth system modelling, the spatial distribution of snow is not well understood, and therefore, it is not well modeled, which can lead to substantial uncertainties in snow cover representations. To capture this influence and define key hydro-ecological drivers, we carried out intensive field studies over multiple years for two small (2017-2019, ~2.3 - 2.5 square km) sub-Arctic study sites located on the Seward Peninsula of Alaska. Using an intensive suite of field observations (>22,000 data points), we developed simple models of spatial distribution of snow water equivalent (SWE) using factors such as topographic characteristics, vegetation characteristics based on greenness (normalized different vegetation index, NDVI), and a simple metric for approximating winds. The most successful model was the random forest, which illustrated the complexity and variability of snow characteristics across the sites. Approximately 86% of the SWE distribution could be accounted for, on average, by the random forest model at the study sites. Factors that impacted year-to-year snow distribution included NDVI, elevation, and a metric to represent coarse microtopography (topographic position index, or TPI), while slope, wind, and microtopography factors were less important. The models were used to predict SWE for the whole study area. The characterization of the SWE spatial distribution patterns and the statistical relationships developed between SWE and its impacting factors will be used for the improvement of snow distribution modelling in the Department of Energy’s earth system model, and to improve understanding of hydrology, topography, and vegetation dynamics in the Arctic and sub-Arctic regions of the globe.

TTOP model sensitivity and comparison to random forest permafrost temperature modelling across Western Canada

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The temperature at top of permafrost (TTOP) model is widely used determine equilibrium permafrost distribution due its simplicity and transferability to a variety of permafrost environments. Our study evaluates TTOP model sensitivity to changes in parameters in different permafrost environments across a range of scales, and also examines the importance of variables in the model using random forest analysis. The random forest modelled permafrost temperatures are compared to field observations and those predicted through the TTOP model to assess the feasibility of using a random forest approach to permafrost modelling at both national and local scales. The study area encompasses a substantial portion of northwest Canada with sites extending from the Canadian Arctic Archipelago to northern British Columbia including the Mackenzie Valley and the southern Yukon. The environments sampled range from continuous to discontinuous permafrost with vegetation covers from boreal forest to tundra, and in lowlands and mountains. Preliminary results indicate that the TTOP model is most sensitive to changes in the freezing n-factor (nf) across all the environments sampled. The sensitivity of the model to changes in ground thermal conductivity increases as temperatures approach 0°C, with limited response at the High Arctic sites and a stronger impact in the southern study regions. Preliminary random forest analyses also highlight the importance of nf and the nival offset at High Arctic sites.

Thermal Modelling of Post-Fire Permafrost Change Under a Warming Coastal Subarctic Climate, Eastern Canada

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Forest fires in permafrost areas have lasting thermal impacts on the underlying frozen ground. These impacts are expected to continue to occur as the frequency and intensity of fire disturbance increases with climate change. This study implemented transient one-dimensional thermal modelling using the TEMP/W program to examine changes in the ground thermal regime at two coastal forest fire sites, located in the sporadic discontinuous permafrost zone near Nain (56.5°N) in Nunatsiavut, northern Labrador, Canada. To our knowledge, no previous studies of post-fire permafrost response and resilience have been conducted in the region. Simulations were undertaken for unburned forest and adjacent fire-disturbed sites, which were modelled to have permafrost thicknesses of 15.6-17.5 m in 1965. The simulations incorporated projected climate change modelled under Representative Concentration Pathways (RCPs) 4.5 and 8.5, as well as variation in the regeneration of the surface organic mat. In most scenarios, particularly those with post-fire organic mat regeneration, a supra-permafrost talik developed immediately following disturbance, but frozen ground re-aggraded after several decades before subsequently thinning. Results varied from permafrost thinning by 50% but persisting to 2099 at unburned sites under RCP4.5, to thawing entirely by 2060 when subjected to RCP8.5 and a high severity burn with no post-fire organic mat regeneration. Our findings are broadly consistent with those from climatically dissimilar sites in the western North American boreal forest and demonstrate that fire accelerates permafrost thaw due to climate warming. The results also confirm the importance of considering organic material accumulation in long-term modelling of permafrost change.