The influence of vegetation on shallow soil and air temperature coupling: a Pan-Arctic data synthesis

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November 23, 2022

Abstract

Shallow soil temperatures influence ecosystem carbon cycling and the temperature of deeper soil layers where permafrost thaw occurs. Vegetation affects shallow soil temperatures via impacts on the surface energy balance, hydrology, and soil characteristics. Vegetation may influence the degree to which soil temperatures rise with increases in air temperature under global climate change. However, variability in vegetative influences on soil temperature are not well quantified at a pan-Arctic scale. We compiled data from 235 sites across high latitude permafrost regions to examine the influence of air temperatures and vegetation on shallow soil temperatures. Annual thermal regimes varied across vegetation types characterized by dominant plant functional cover. The overall magnitude of soil temperature maxima and minima varied across plant functional types. Ecosystems dominated by vegetation with tall statured canopies such as evergreen needleleaf boreal forests and tall shrub tundra tended to have warmer soil warmer temperatures than tundra sites dominated short statured vegetation such as graminoid or short shrub species. Soil temperatures increased with air temperature similarly within tundra vegetation types, and rising air temperatures from global climate change may result in similar increases in soil temperatures regardless of vegetation type in the tundra. Soil temperatures were highly variable and decoupled from air temperature in boreal forest sites.

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Background:

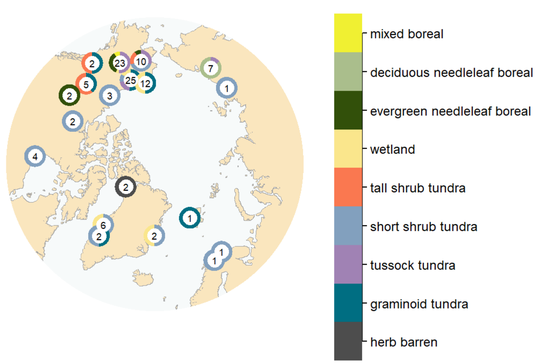
- Shallow soil temperatures influence carbon cycling and the temperature of deeper soil layers that affect permafrost thaw
- Vegetation influences soil temperature through multiple mechanisms such as canopy shading, snow redistribution, and heat movement throughout the soil via influences on soil moisture.
- Field studies focused on the influence of vegetation on soil temperatures are limited to local or regional scales.

Questions:

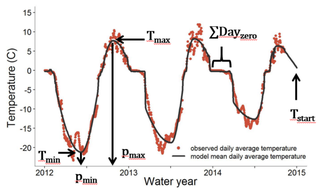
1. **How does soil temperature vary between vegetation types?**
2. **Are there differences in the coupling between air and soil temperatures between vegetation types?**

Data and analysis:

- Vegetation information and daily air and soil data were compiled from 235 sites. 111 sites had data for depths 0-20 cm for at least 75% of a water year. (n= 342,324 soil, 157,649 air) and were used for analysis:



- We fit a model to describe daily average air and soil temperature in a Bayesian framework to make predictions for missing data and estimate parameters that characterize annual air and soil temperature patterns:



$\sum Day_{zero}$	number of days described by a temperature of zero (soil only)
T_{max}	maximum temperature in year
p_{max}	timing of maximum temperature
T_{min}	minimum temperature in year
p_{min}	timing of minimum temperature
T_{start}	temperature at start of water year

- A hierarchical regression of temperature maxima and minima parameters was conducted to examine the coupling with air temperature maxima and minima and account for depth and long term precipitation conditions.

Soil temperature across vegetation type:

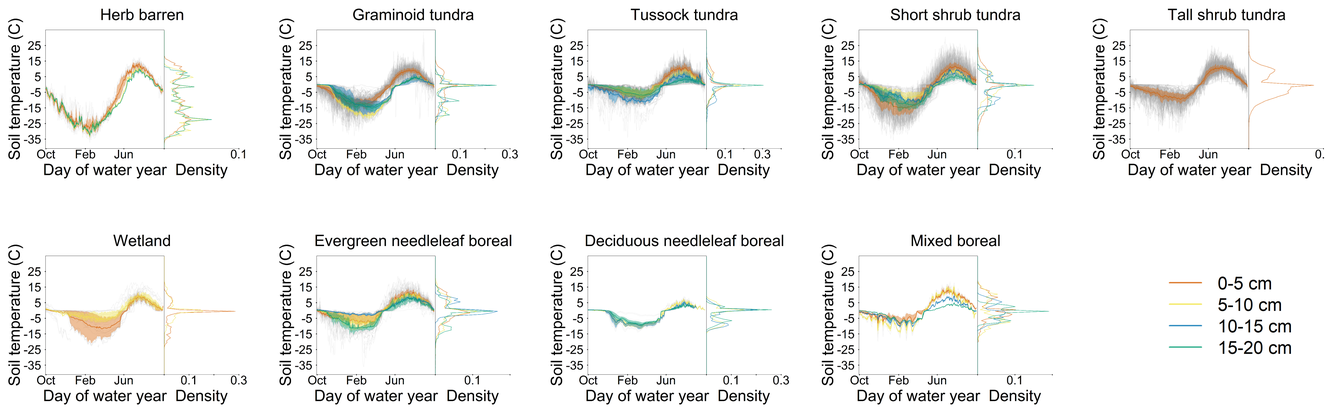


Figure 1. Annual soil temperature for all sites included in the study. Individual site data is indicated by grey lines, and the average soil temperature for depth increments are shown with bold lines (0-5 cm: red, 5-10 cm: yellow, 10-15 cm: blue, 15-20 cm: green) and the 25th and 75th percentile are shaded.

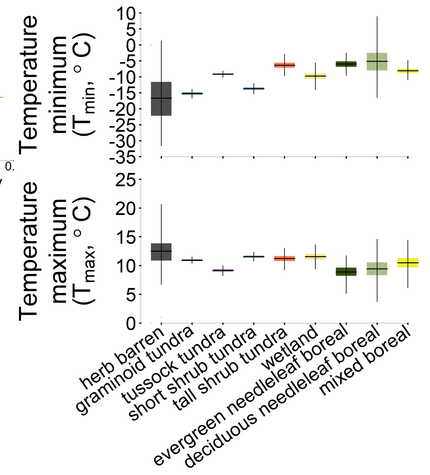


Figure 2. Modeled mean soil temperature maximum and minimum for each vegetation type at a depth of 0 cm, the same air temperature, and precipitation climate

- Soil T_{min} are higher in tall statured vegetation such as tall shrub or tussock tundra and boreal forests
- Soil T_{max} are similar between vegetation types

Soil and air temperature coupling:

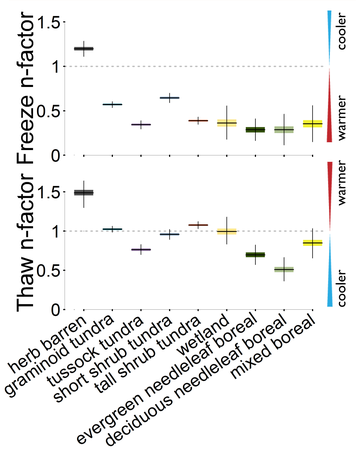


Figure 3. Modeled mean n-factors (degree days of soil / degree days of air) for each vegetation type at a depth of 0 cm

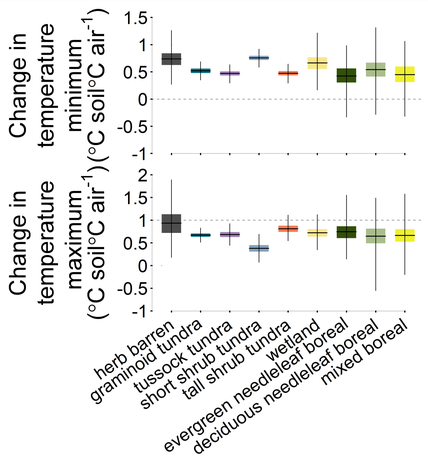


Figure 4. Modeled relationship between annual soil and air temperature maxima and minima

- Freezing n-factors indicate soil temperatures are colder than air temperature for short statured vegetation types (graminoid, bare, and short shrub tundra)
- Soil T_{max} was similar between vegetation types, but thawing n-factors indicate that soils are substantially cooler than the air for tussock tundra and boreal vegetation in above freezing conditions
- Soil T_{max} and T_{min} responses to air T_{max} and T_{min}, respectively, do not differ between vegetation types

Conclusions

- Tree, tall shrub, and tussock vegetation types have similar soil T_{min} and coupling with air temperature under freezing conditions
- Herb barren, graminoid, and short shrub tundra have the lowest T_{min} coldest freezing n-factors
- Thawing n-factors show that boreal forests and tussock tundra soil temperatures are cold relative to air temperature in above freezing conditions
- Vegetation does not affect the relationship between air and soil temperature extremes

Acknowledgements

- Permafrost Carbon Network initiated this synthesis and members have provided thoughtful discussion and input
- NSF PLR-1417745 and PLR-13304464