An Evaluation of Ecotypes as a Scaling-up Approach for Permafrost Thermal Regime in Western Alaska

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Introduction

In many regions, permafrost temperatures are increasing due to climate change and in some cases permafrost is thawing and degrading. In areas where degradation has already occurred the effects can be dramatic, resulting in changing ecosystems, carbon release, and damage to infrastructure. Yet in many areas we lack baseline data, such as subsurface temperatures, needed to assess future changes and potential risk areas. Besides climate, the physical properties of the vegetation cover and subsurface material have a major influence on the thermal state of permafrost. These properties are often directly related to the type of ecosystem overlaying permafrost. Thus, classifying the landscape into general ecotypes might be an effective way to scale up permafrost thermal data.

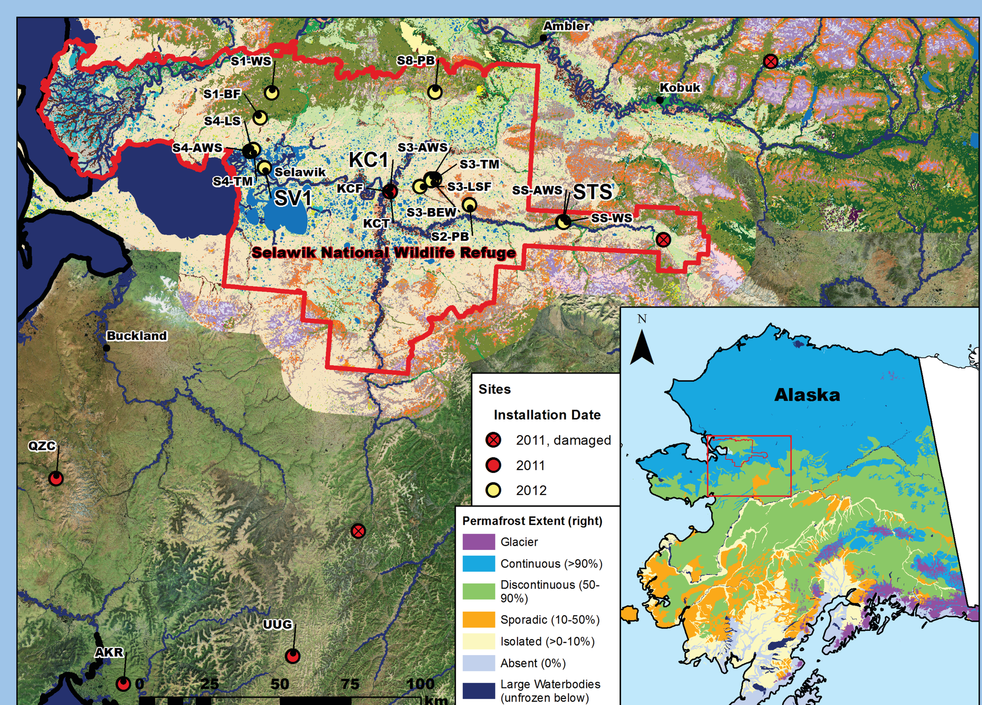
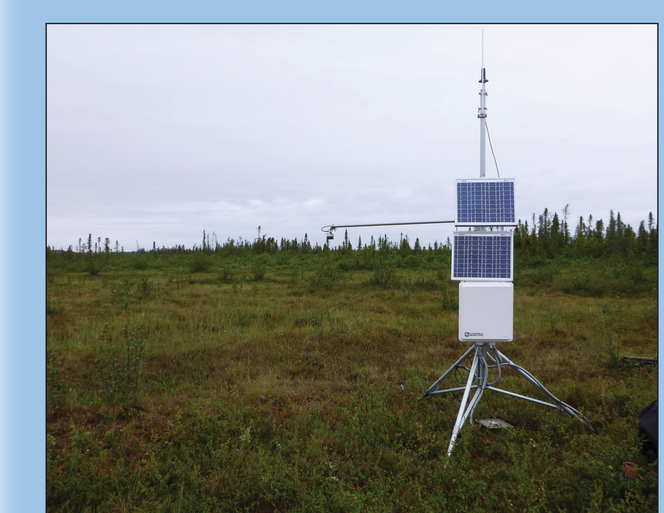


Figure 1. Locations of the measurement sites installed in 2011 and 2012. The ecotype class map (Jorgenson et al, 2009) is also shown, where available (legend in Figure 2). The reference map of Alaska shows the permafrost distribution (Jorgenson et al, 2008).

Ecotype Classes	Code	% Cover
Alpine Alkaline Barrens		0.1
Alpine Mafic Barrens		0.0
Alpine Acidic Barrens		0.1
Alpine Dryas Dwarf Shrub		0.2
Alpine Ericaceous Dwarf Shrub		0.0
Alpine Wet Sedge Meadow		0.0
Alpine Lake		0.0
Upland Mafic Barrens		0.0
Upland Sedge-Dryas Meadow		0.0
Upland Willow Low Shrub		1.9
Upland Birch-Ericaceous-Willow Low Shrub	BEU	3.2
Upland Dwarf Birch-Tussock Shrub	TS	28.4
Upland Alder-Willow Tall Shrub	AWU	4.4
Upland Birch Forest	BFU	0.6
Upland Spruce-Birch Forest		0.8
Upland White Spruce Forest	WSE & WSW	6.6
Upland Sandy Barrens		0.0
Upland White Spruce-Lichen Woodland		0.2
Lowland Sedge-Dryas Meadow		0.5
Lowland Sedge Fen	SFL	3.6
Lowland Ericaceous Shrub Bog	ESB	1.0
Lowland Birch-Ericaceous-Willow Low Shrub	BEL	7.3
Lowland Willow Low Shrub		1.3
Lowland Alder Tall Shrub	AWL	4.0
Lowland Black Spruce Forest		1.0
Lowland Lake		5.7
Riverine Barrens		0.1
Riverine Dryas Dwarf Shrub		0.0
Riverine Willow Low Shrub		0.6
Riverine Birch-Willow Low Shrub	BWR	3.3
Riverine Alder or Willow Tall Shrub		1.1
Riverine Poplar Forest		0.4
Riverine White Spruce-Poplar Forest		0.1
Riverine White Spruce-Willow Forest		1.6
Riverine Wet Sedge Meadow		4.0
Riverine Water		2.8
Coastal Barrens		0.0
Coastal Dunegrass Meadow		0.0
Coastal Crowberry Dwarf Shrub		0.0
Coastal Brackish Sedge–Grass Meadow		0.7
Coastal Water		0.2
Snow		0.0
Shadow/Indeterminate		0.0
Human Modified Barrens		0.0

Figure 2. Legend for the map created by Jorgenson et al (2009) with ecotype abbreviation codes for ecotypes where measurements were obtained and percent areal coverage within the Selawik NWR.



Typical Core Installation

- Air Temperature
- Snow Depth
- High vertical resolution subsurface temperature (16 measurements to 1.5m)
- Shallow borehole to 3m
- Near-real-time data transmission

Typical Distributed Installation

- Subsurface temperature measurements at 3, 50, 100, and 150 cm.

Methods & Study Area

We selected an area in Western Alaska, the Selawik National Wildlife Refuge, which is on the boundary between continuous and discontinuous permafrost (Figure 1). This region was selected because an ecological land classification had been conducted and a very high-resolution ecotype map was generated (Figures 1 & 2). Using this information we selected 18 spatially distributed sites covering the most abundant ecotypes and three additional core sites (see above). The sites were installed in the summers of 2011 and 2012; consequently, we have two years of data from most sites.

Figure 3. Example of mean daily ground temperature data from one distributed site (KCT, Riverine Birch-Willow Low Shrub, BWR).

Results

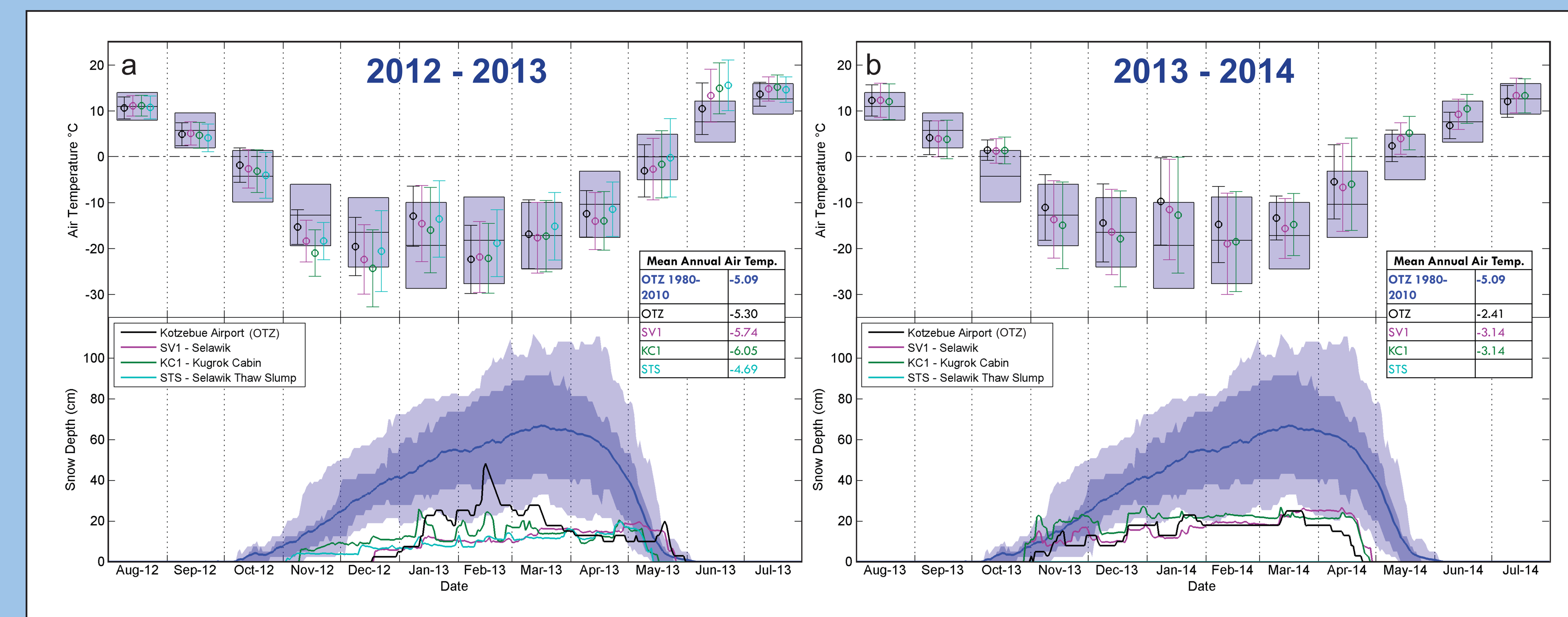


Figure 4. Summary of air temperature and snow depth for the periods August 2012 to July 2013 (a) and August 2013 to July 2014 (b). The top panel shows the mean monthly air temperature and standard deviation for our core sites and the Kotzebue (OTZ) airport; the blue boxes represent the long-term (1981-2010) monthly mean and standard deviation from the Kotzebue airport. The bottom panel shows the snow depth on the ground for our core sites and Kotzebue airport; the dark blue line is the long-term (1981-2010) average snow depth from the Kotzebue airport, the dark blue shading represents the 75th to 25th percentile, and the light blue shading represents the 90th to 10th percentile.

Climate Summary

- Mean monthly and mean annual air temperature (MAAT) and snow depth for all three core sites and a nearby meteorological station (Kotzebue Airport, OTZ) are similar within the 2011-2014 period (Figure 4).
- 2011 - 2012 Colder than average MAAT and above average snow depth.
- 2012 - 2013 Near average MAAT and late, below average snow depth (Figure 4a).
- 2013 - 2014 Warmer than average MAAT and below average snow depth (Figure 4b).
- The effect of these three very different winters can be seen in the measured ground temperatures (Figures 3 & 6).

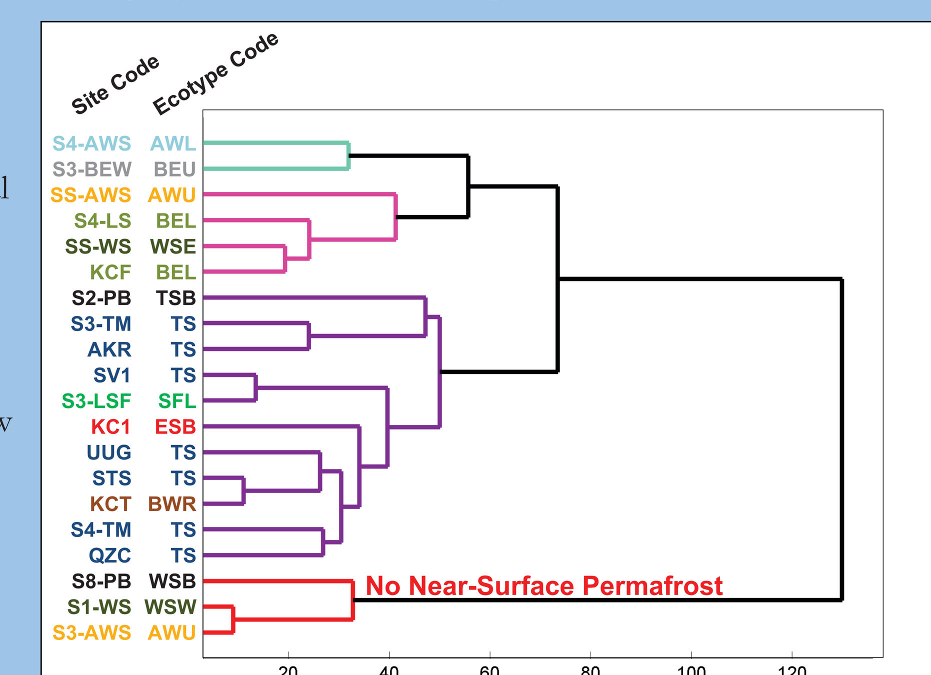


Figure 5. Dendrogram of the Cluster Analysis based on the Euclidean distance.

Ground Temperature Analysis

- A Cluster Analysis based on the Euclidean distance between the time-series of daily average ground temperature at 1 meter from each site was used to group sites (Figure 5).
- Our results indicate that it is possible to obtain information about subsurface temperature, active layer thickness, and other permafrost characteristics based on these ecotype classifications (Figure 6).

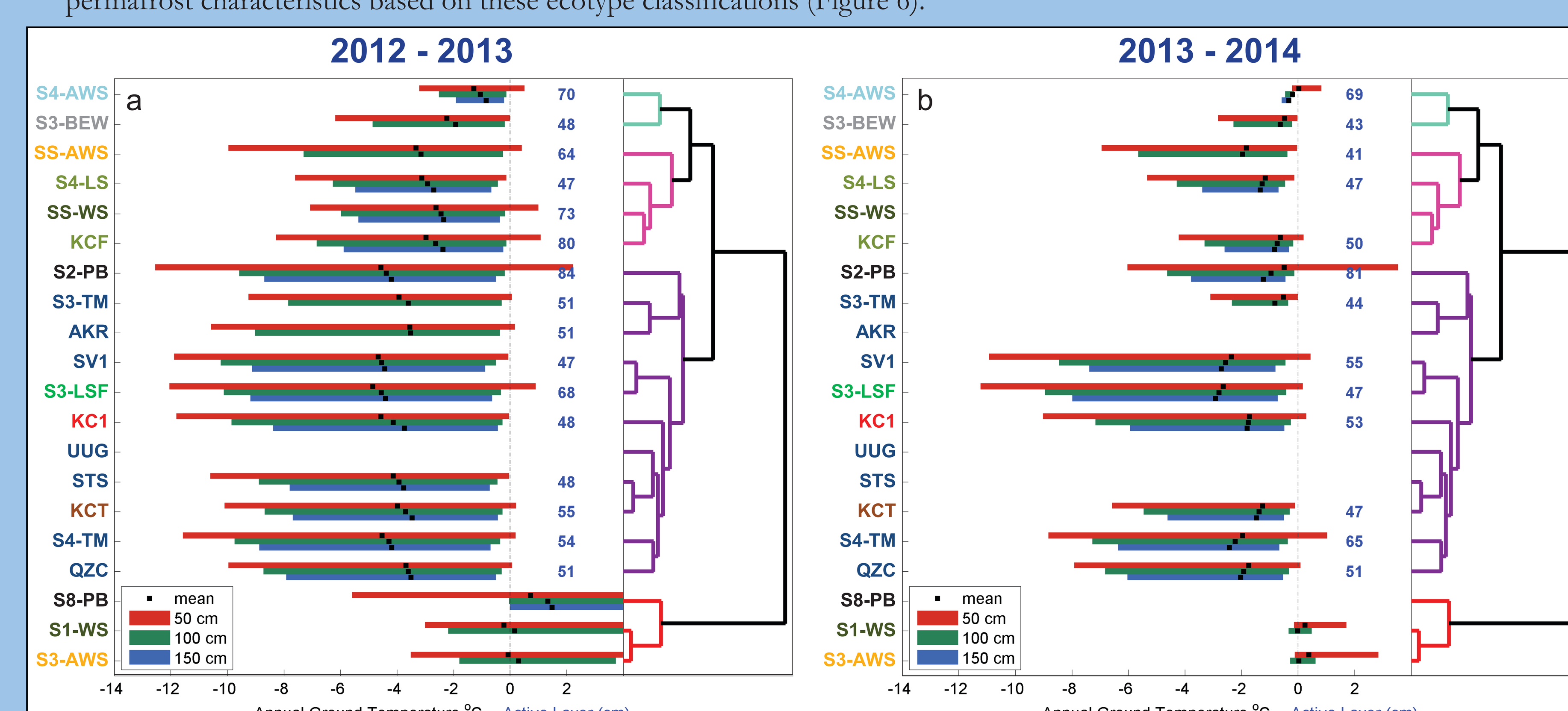


Figure 6. Annual summarized ground temperature data for (a) August 2012 to July 2013 and (b) August 2013 to July 2014. The vertical colored bars show annual range of the daily averages at 3 depths and the black squares the annual mean; the numbers in the center are the calculated active layer depth; and on the right the Dendrogram from Figure 5.

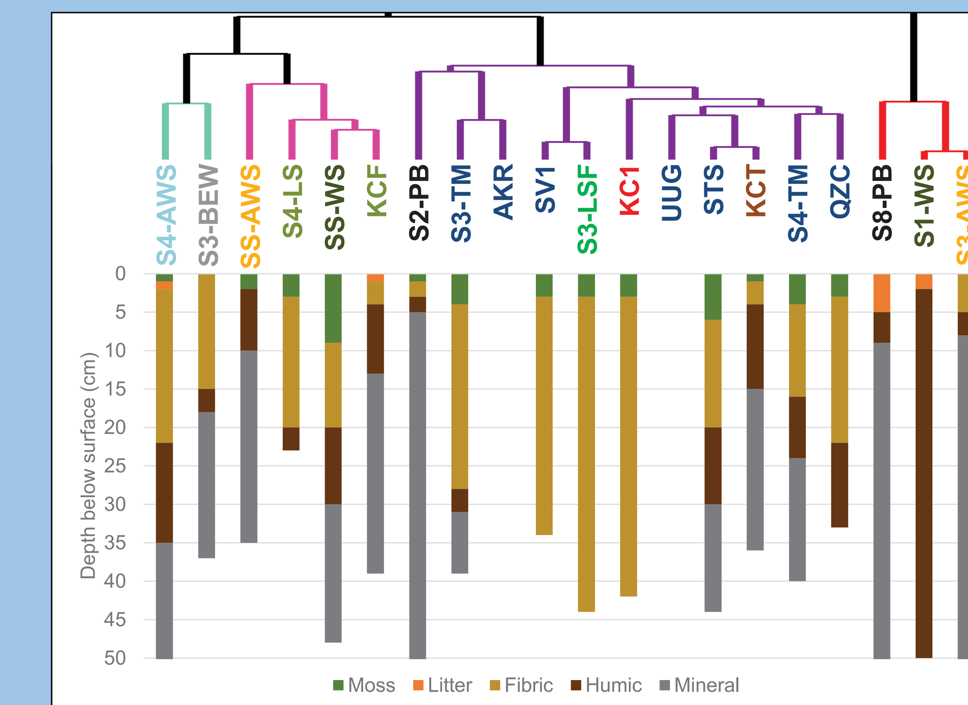


Figure 7. Profile of soil layers in the active layer at each site.

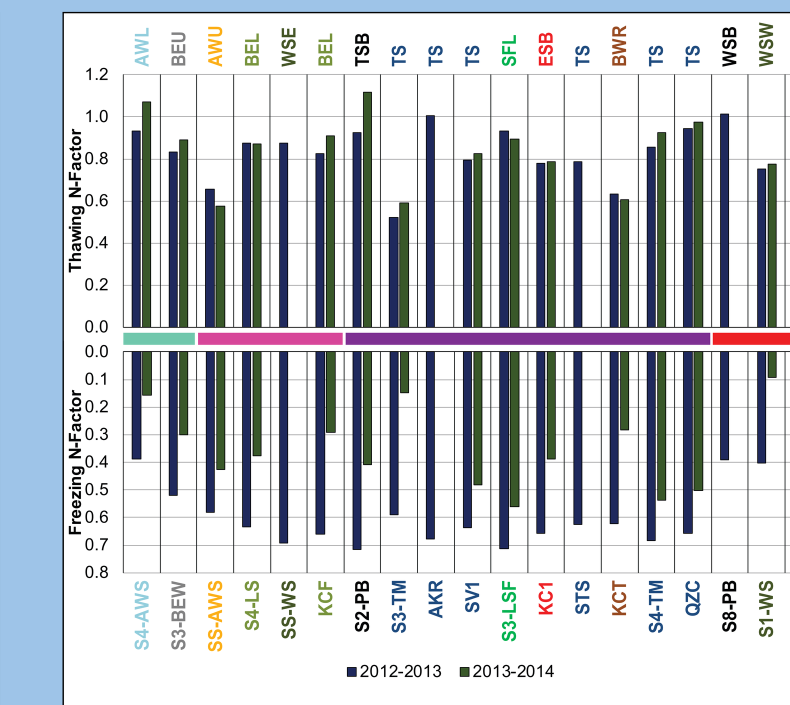


Figure 8. Thawing N-Factors (top) and Freezing N-Factors (bottom) for each site and measurement period.

Ground Temperature Analysis (continued)

- Within some ecotypes (WSW/WSE and AWU) the absence of a moss layer is indicative of the absence of near surface permafrost (Figure 7).
- Thawing and Freezing N-Factors, calculated as the ratio of surface temperature degree days (freezing or thawing) to air temperature degree days (freezing or thawing), help identify why some ecotypes have colder permafrost than others and why some sites lack near-surface permafrost (Figure 8).
  - For example, S1-WS (WSW) has a slightly lower Thawing N-Factor than the other White Spruce site (SS-WS, WSW), meaning it receives less heat input during the summer; however, it also has a much lower Freezing N-Factor meaning it is not able to loose heat during the winter as easily.
- As a proof of concept, we used this information to translate the ecotype landcover map into a map of mean annual ground temperature ranges at 1 m depth (MAGT1.0) (Figure 9). While this map is preliminary and would benefit from additional data and modeling exercises (both ongoing), we believe it provides useful information for decision making with respect to land use and understanding how the landscape might change under future climate scenarios.

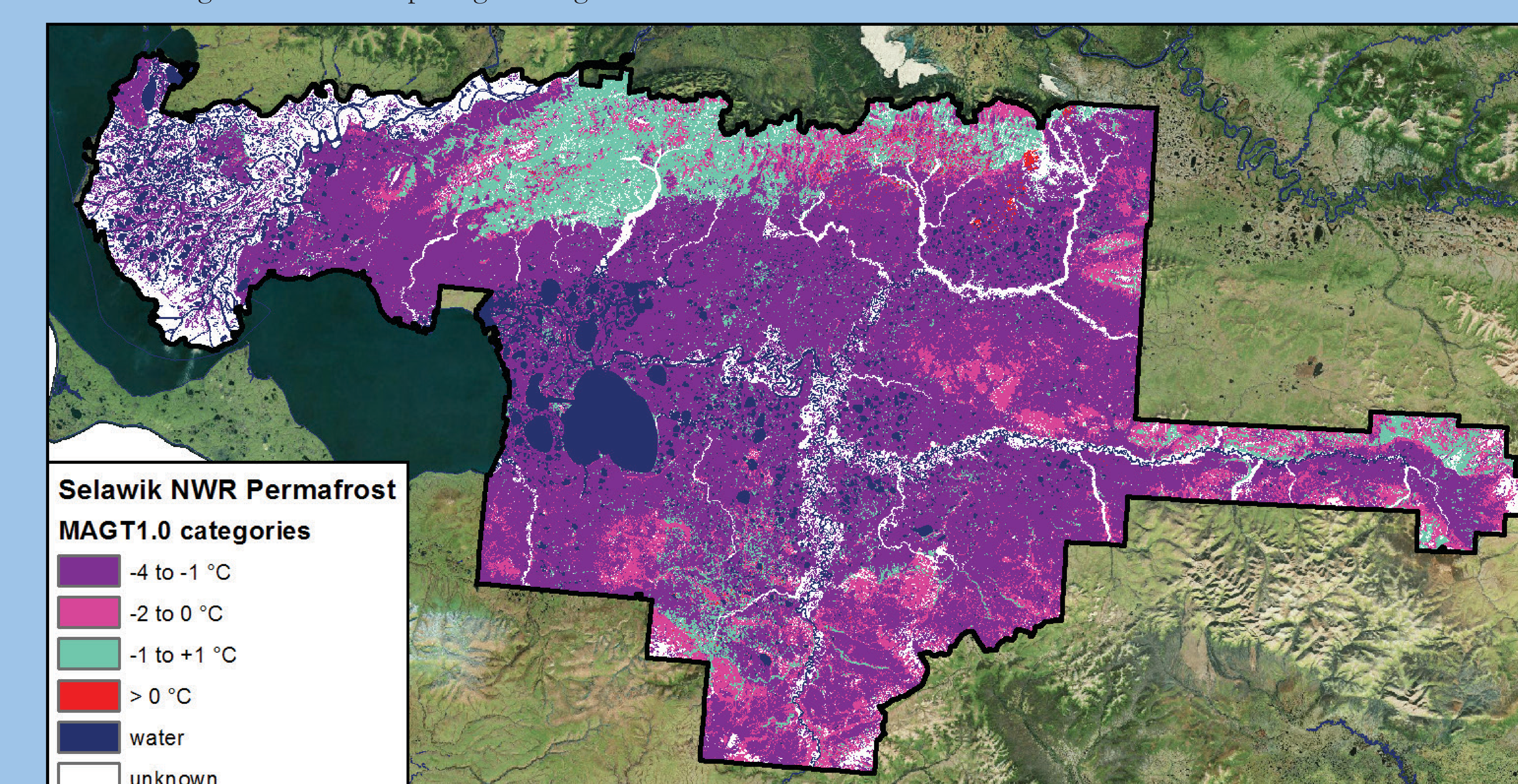


Figure 9. The result of reclassifying the ecotype map (Jorgenson et al. 2009) into a map of MAGT at 1 meter depth for the Selawik NWR. The ecotypes for which we do not have measurements are shown as unknown.

References

Romanovsky, V.E., Smith, S.L. & Christiansen, H.H. 2010. Permafrost thermal state in the polar Northern Hemisphere during the international polar year 2007-2009: a synthesis. Permafrost and Periglacial Processes 21: 106–116. DOI: 10.1002/ppp.689

Jorgenson, M. T., J. E. Roth, P. F. Miller, M. J. Macander, M. S. Duffy, E. R. Pullman, E. A. Miller, L. B. Attana, and A. F. Wells. 2009. An Ecological Land Survey and Landcover Map of the Selawik National Wildlife Refuge. Final Report to U.S. Fish and Wildlife Service, Kotzebue, AK by ABR, Inc., Fairbanks, AK, 238 p.