Influence of Topography and Disturbance on Water Flow in the Active Layer

Taylor Sullivan*[1], Andrew Parsekian[1], Kevin Schaefer[2], Roger Michaelides[3], Sean Schaefer[4],
University of Wyoming[1], Colorado University, Boulder[2], Stanford University[3], DePaul University[4]
*Email: tsulli12@uwyo.edu

Abstract: We examine how relative elevation influences Active Layer Thickness and soil moisture on North Ridge—a slope near Toolik Lake, AK—by investigating the relationship of ALT and elevation above the bottom of a ravine. We measured ALT and soil moisture using ALT probes, Ground Penetrating Radar (GPR), Electromagnetic Induction (EMI), and hand-held soil moisture probes to learn about ALT and soil moisture trends on hill slopes. These data, in conjunction with ABoVE airborne measurements and digital elevation data, will help inform and validate Remotely Sensed Active Layer Thickness techniques. This study addresses the science question: can a relationship between ALT and slope gradient improve ReSALT calculations? This study hypothesizes that a correlation between ALT and hill slope characteristics can be predicted in permafrost regimes, and this implemented correlation can improve ReSALT models. In the case of North Ridge, we observe a 35% decrease in soil moisture as elevation increases 93 meters above a wet ravine. We will use these and similar relationships to create topographically-based correction factors to remotely sensed retrievals of ALT.

Research Site: North Slope, Alaska

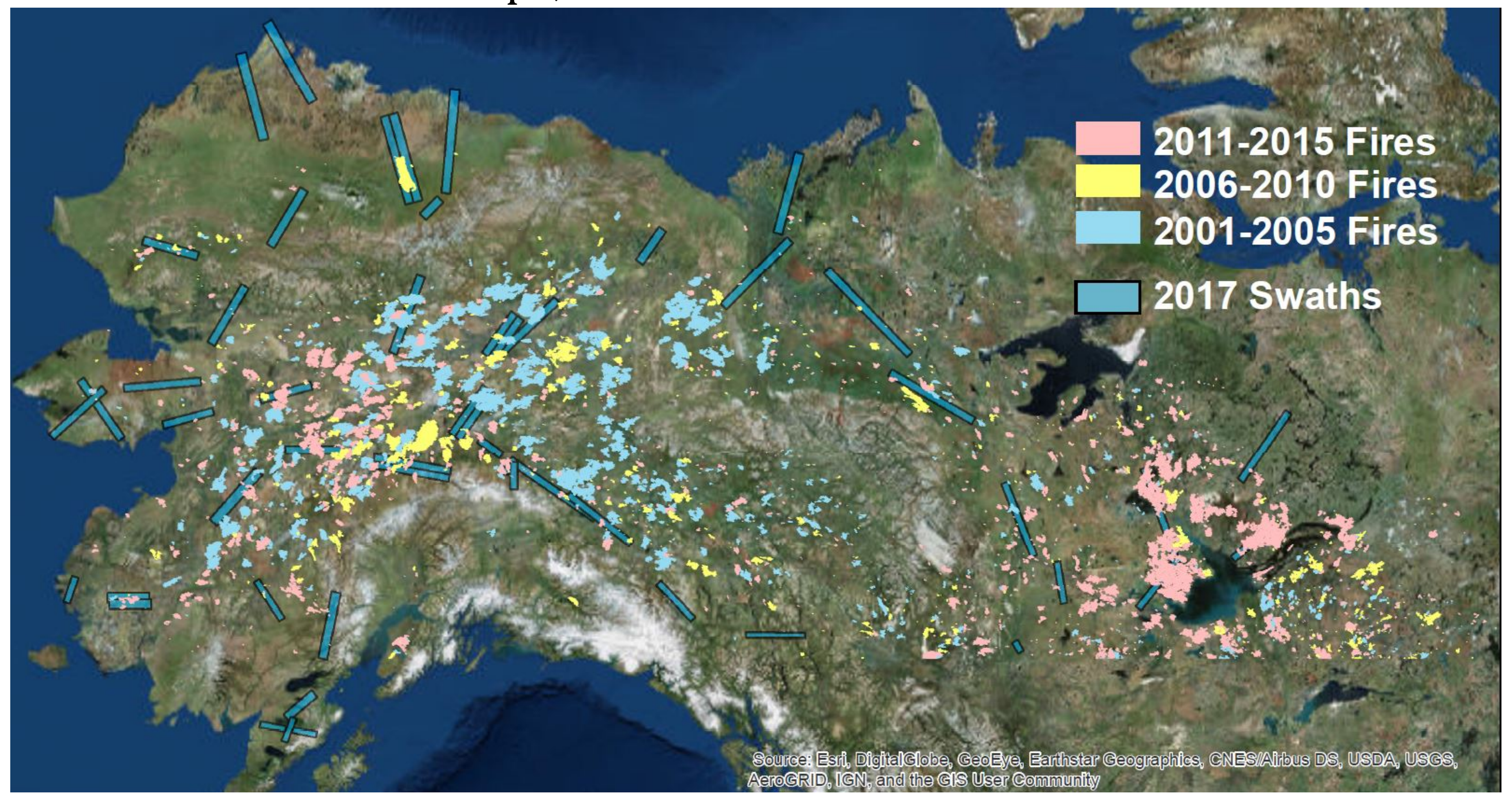

Figure 1: Shows a satellite image of Alaska and Northern Canada with overlain flight swaths from aerial measurements. Burned areas from 2001-2015 are grouped and highlighted to show disturbance extent and overlap with ABoVE Swaths.

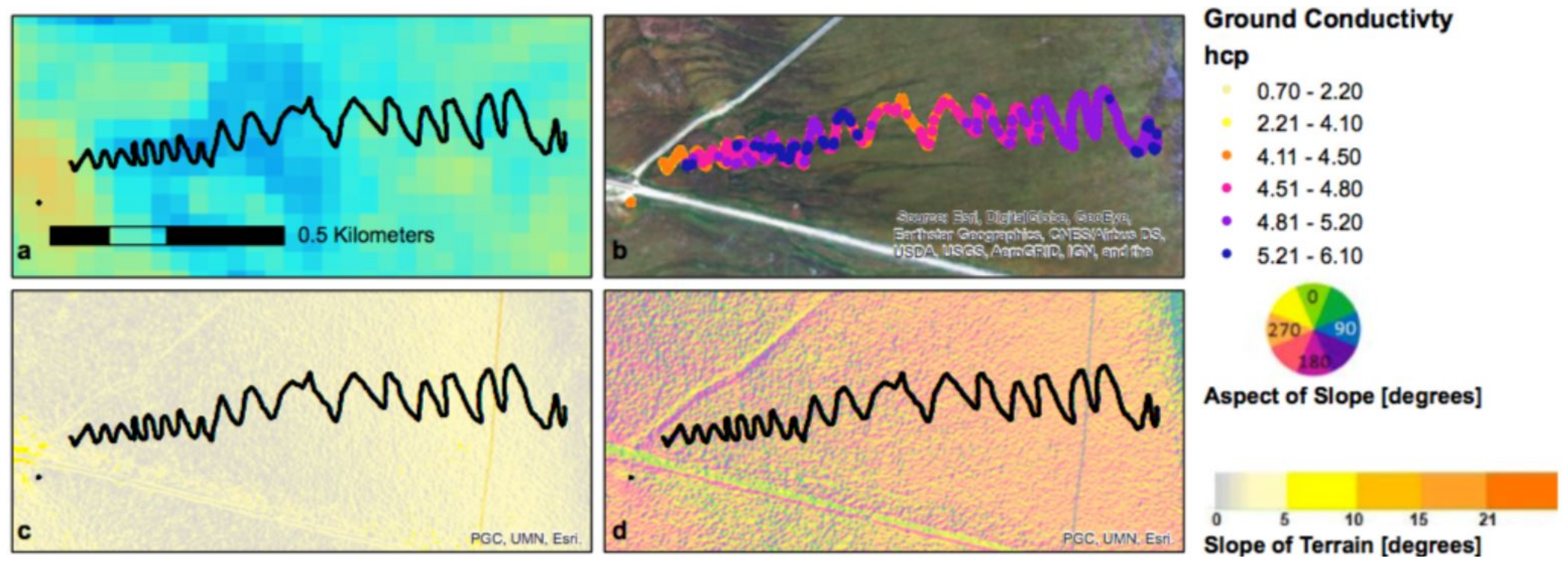

Figure 2: Shows remotely sensed and geophysically-mapped data from North Ridge. Panel **a** shows calculated Active Layer Thickness, **b** shows satellite imagery of North Ridge. The Alaskan pipeline and the Dalton Highway can be seen running off the top and bottom of the panel, respectively. Panel **c** shows the gradient map from ArcticDEM, and panel **d** shows the aspect map, also from Arctic DEM.

Methods

Ground-based geophysical measurements including GPR and EMI were taken during the thaw season in nine ABoVE flight swaths in interior and northern Alaska.

Figure 3: Measuring ALT on North Ridge using active layer probe. Right: Collecting soil moisture data using hand-held HydroSense II soil moisture probe.

Each of the following measurements were taken every meter along seven 20m survey lines of increasing elevation up North Ridge.

- GPR: Utilizing a MALA 500MHz Antenna with an affixed handle to for relocation and ground-antenna coupling as seen in Figure 4, two-way-travel times are measured from which ALT and soil moisture can be calculated.
- Active Layer Probe, as seen in Figure 3. manually measures ALT to compare to GPR results and obtain VWC from GPR.
- 12 and 20 cm water content probes (Hydro Sense II) measured volumetric water content of the top of the Active Layer, seen in Figure 3.
- Conductivity measurements were performed using the DualEM1 electromagnetic induction instrument at every survey point and in a mapping mode up the slope
- NASA ABoVE Aircraft flew swaths over selected areas in Alaska and Northern Canada to obtain P and L-band radar measurements (locations shown in Figure 1).

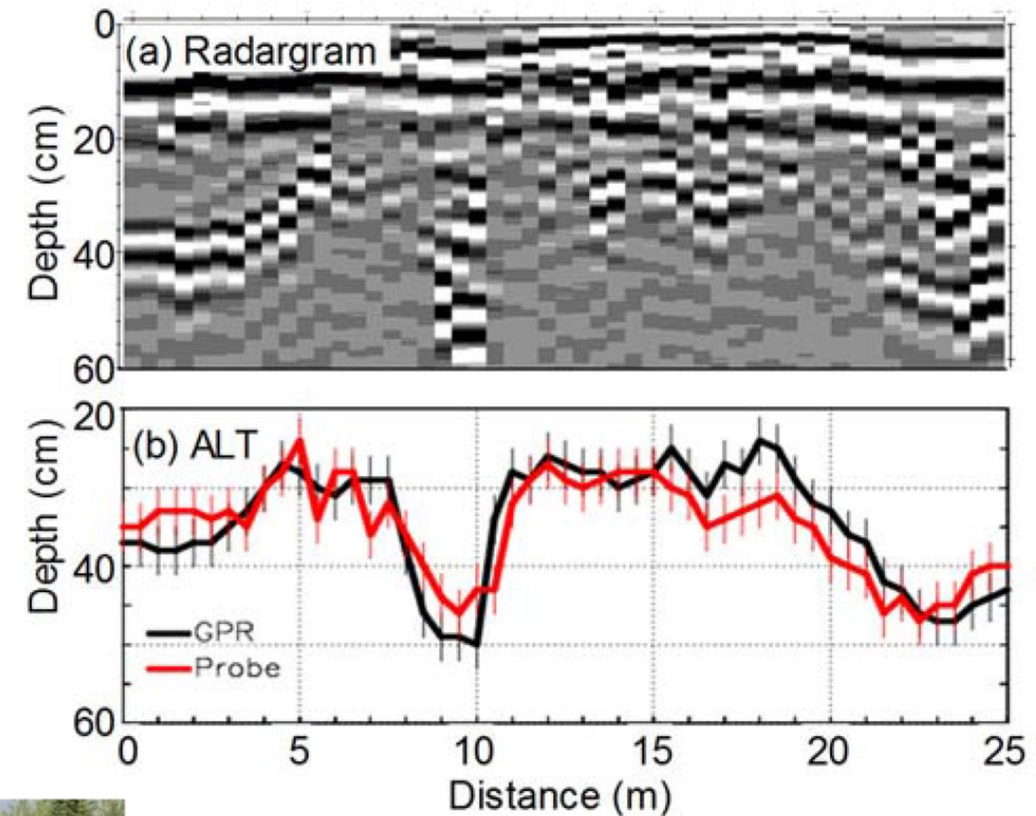

Figure 4: Shows (a) Radargram from a MALA 500MHz GPR near Barrow, AK. Two-way-travel-times have been converted to depth by estimating the dielectric permittivity of the subsurface. (b) Shows ALT probe measurements plotted above ALT values calculated from GPR. (Schaefer et al. 2015)

Figure 5: Shows the GPR with handle in use. The control unit and monitor are attached to the backpack, and the 500MHz antenna is attached to the handle. August 2017 Photo from survey line near Delta Junction, AK.

Soil Moisture as a function of Dielectric Permittivity

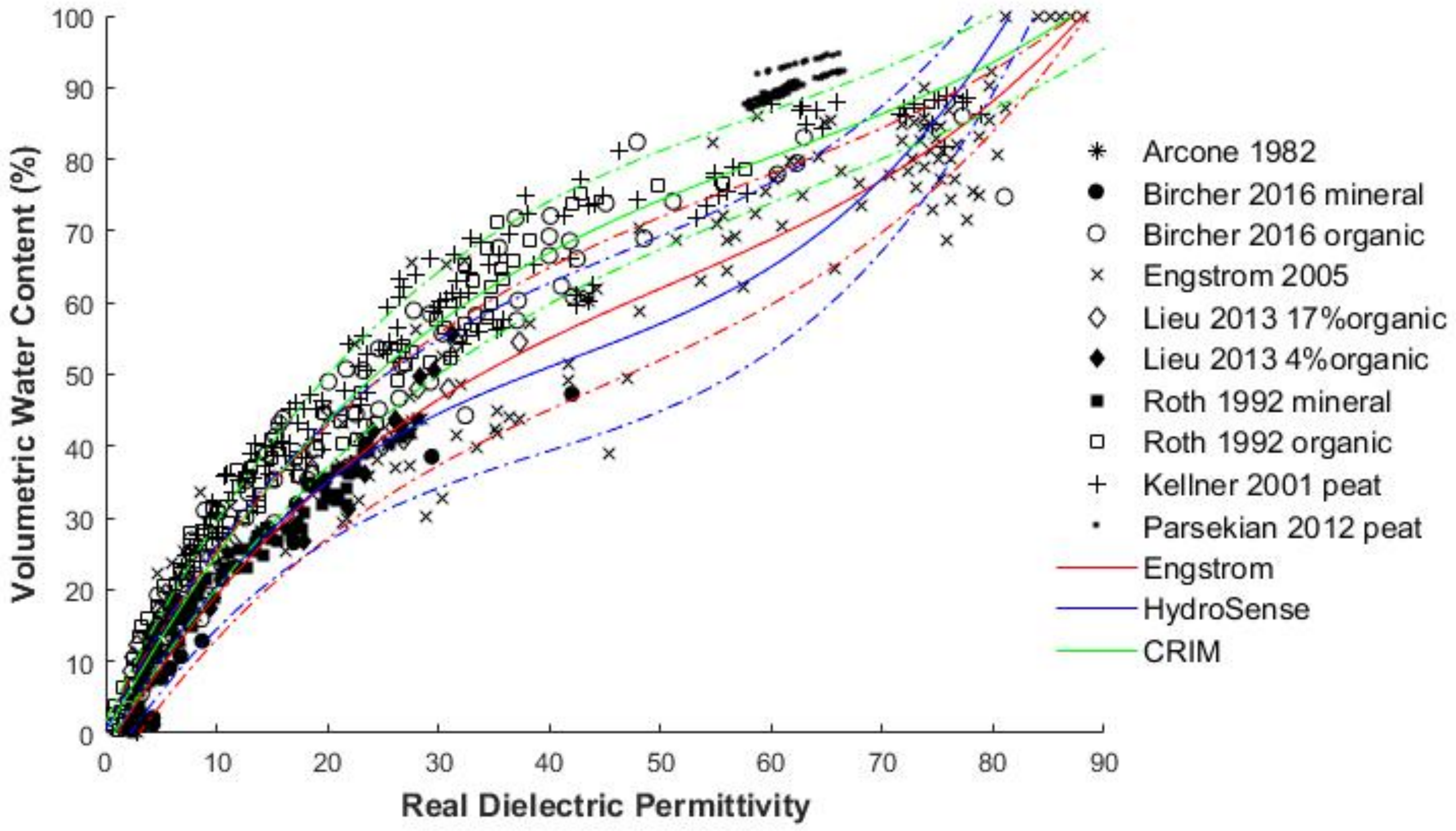

Figure 6: Shows synthesized data from Volumetric Water Content to Dielectric Permittivity studies. Mineral-type soils are represented by filled-in shapes, and organic samples are represented as hollow shapes. Proposed relationships are shown in red (Engstrom et al. 2005), blue (Topp et al. 1980), and green (complex refractive index mixing (CRIM) model from Parsekian et al. 2012. The dashed lines represent uncertainties for each model calculated from a third-order polynomial fit of residuals.

Soil Moisture as a Function of Elevation

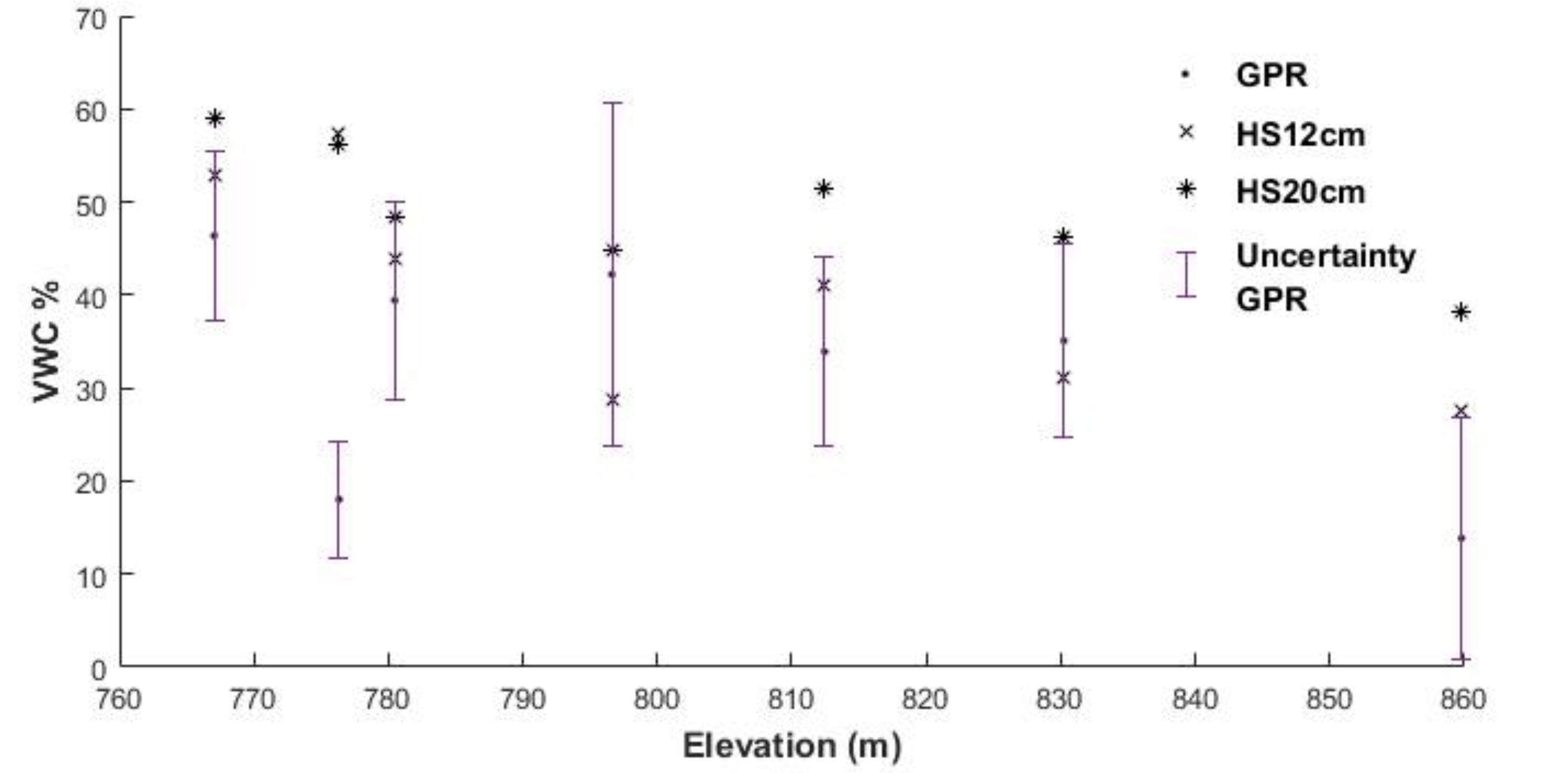

Figure 7: Soil moisture measurements averaged from seven survey lines are displayed as a function of elevation above the bottom of a wet ravine. The disparity in deep (GPR) soil moisture compared to shallow soil moisture (from Hydrosense Probes) suggests non-uniform distribution of water content in the active layer.

Future

Next steps in this study include optimizing the Volumetric Water Content to Dielectric Permittivity relation for permafrost regions. This will eliminate uncertainty in estimating soil moisture content from geophysical and remote sensing techniques. Geophysical techniques will be employed to inform water distribution models to predict ALT in a warming climate.

References

Engstrom, Ryan & Hope, A & Kwon, Hyojung & Stow, D & Zamolodchikov, D. (2005). Spatial distribution of near surface soil moisture and its relationship to microtopography in the Alaskan Arctic Coastal Plain. Nordic Hydrology. 36. 219-234.
Parsekian, A. D., L. Slater, and D. Giménez, 2012, Application of ground- penetrating radar to measure near-saturation soil water content in peat soils: Water Resources Research, 48, W02533, doi: 10.1029/ 2011WR011303.
Schaefer, K.; Liu, L.; Parsekian, A.; Jafarov, E.; Chen, A.; Zhang, T.; Gusmeroli, A.; Panda, S.; Zebker, H.A.; Schaefer, T. Remotely Sensed Active Layer Thickness (ReSALT) at Barrow, Alaska Using Interferometric Synthetic Aperture Radar. *Remote Sens.* **2015**, *7*, 3735-3759.
Liu, S. Zhao, L. Jiang, L. Chai and F. Wu, "The influence of organic matter on soil dielectric constant at microwave frequencies (0.5–40 GHZ)," *2013 IEEE International Geoscience and Remote Sensing Symposium - IGARSS*, Melbourne, VIC, 2013, pp. 13-16. doi: 10.1109/IGARSS.2013.6721080
Kellner and Lundin. "Calibration of Time Domain Reflectometry for Water Content in Peat Soil." Hydrology Research Aug 2001, 32 (4-5) 315-332
Bircher, Demontoux, Razafindratsima, Zakharova, Drusch. "L-Band relative permittivity of organic soil surface layers—A new dataset of resonant cavity measurements and model evaluation. *Remote Sensing*, MDPI, 2016, 8 (12), pp.1-17.