Measuring the Impact of Wildfire on Active Layer Thickness in a Discontinuous Permafrost Region using Interferometric Synthetic Aperture Radar (InSAR)

R. J. Michaelides[1], H. A. Zebker[1], K. M. Schaefer[2], A. Parsekian[3], L. Liu[4], J. Chen[5], S. Natali[6], S. Ludwig[6], S. Schaefer[7]

1: Stanford University 2: University of Colorado 3: University of Wyoming 4: The Chinese University of Hong Kong 5: University of Texas at Austin 6: Woods Hole Oceanographic Institution 7: DePaul University

rmich@stanford.edu , Department of Geophysics, Stanford University

1. Background and Goals

1. The Yukon-Kuskokwim (YK) delta lies within the discontinuous permafrost zone, and has experienced numerous wildfires over the last 40 years
2. An estimate of the post-fire recovery response of permafrost would provide a more complete understanding of wildfire/active layer interactions
3. Characterize ALT over the study site with InSAR using the ReSALT algorithm as in [1], [2], and validate with field GPR and probing measurements
4. Determine the long-term deformation rate of burned areas at different times during wildfire recovery.
5. Approximate a permafrost recovery function

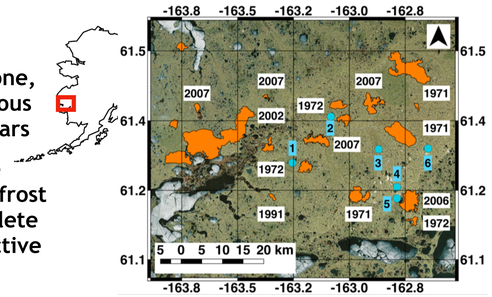


Figure 1: The Yukon-Kuskokwim delta field study area. Blue dots are the locations of in-situ field measurements from the 2016 field campaign; Wildfire burn zones are outlined and orange and labeled by year of burn.

2. Active Layer Fire Model

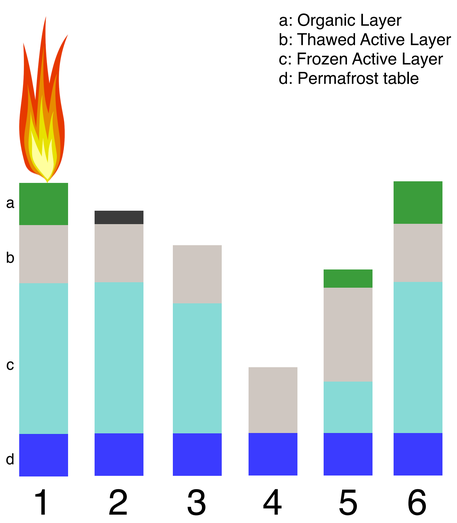


Figure 2: Simplified model of the behavior of ecosystem-driven permafrost to a wildfire, as described in [3]:

1): Wildfire removes a certain fraction of the overlying organic layer

2): Fire perturbs the permafrost system from its state of thermal equilibrium.

3): The change in organic layer thickness and albedo induces a gradual increase in seasonal thaw depth and subsidence.

4): The soil column eventually reaches a point of maximum seasonal thaw depth.

5): The organic layer gradually reaccumulates as a result of vegetation succession, retarding and eventually reversing the thickening of the active layer.

6): The permafrost system returns to its pre-fire state of thermal equilibrium, or reaches a new thermal equilibrium.

3. Results

Figure 3: Results from application of the ReSALT algorithm to the YK study region.

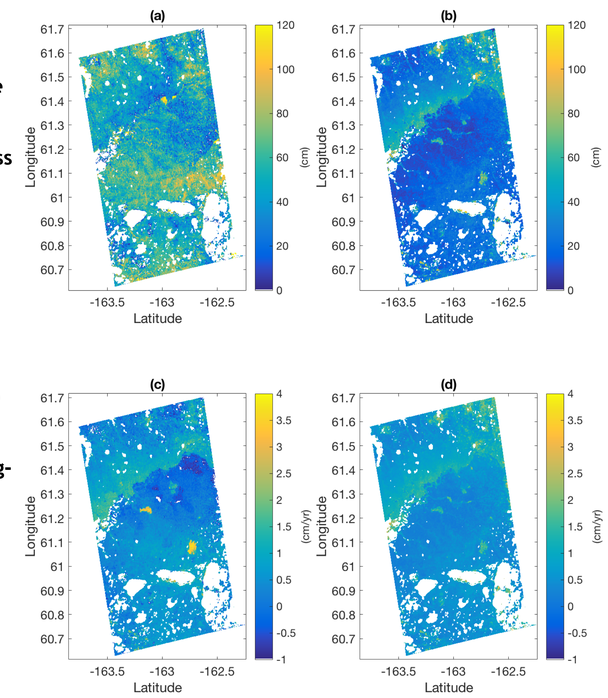
a): active layer thickness (cm).

b): Uncertainties in active layer thickness.

c): Long-term linear trend in active layer thickness; positive values correspond to subsidence, negative to uplift (cm/yr).

d): Uncertainties in long-term linear trend in active layer thickness.

Note: Fire scars and long-term rates of ALT change are spatiotemporally correlated



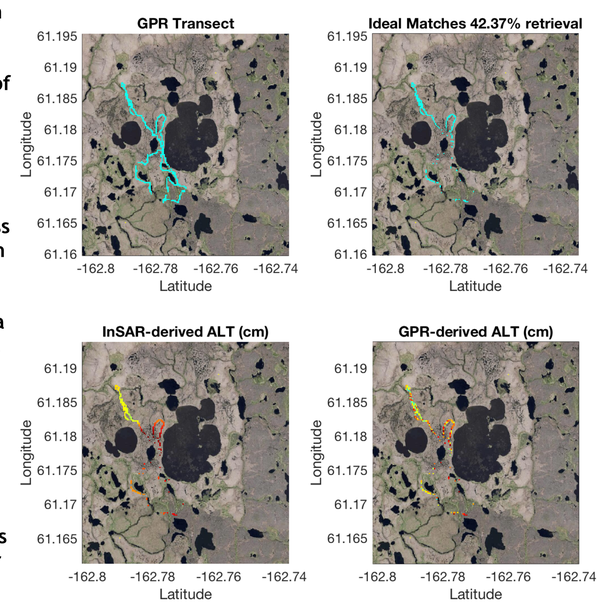


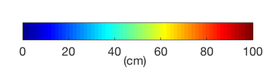
Figure 4: Comparison between GPR-derived and InSAR-derived ALT at site 5.

a): Total path of GPR.

b): All ideal matches between GPR and InSAR.

c): InSAR-derived ALT from ReSALT technique.

d): GPR-derived ALT. Both techniques capture fine spatial variability of ALT and yield mutually consistent results.

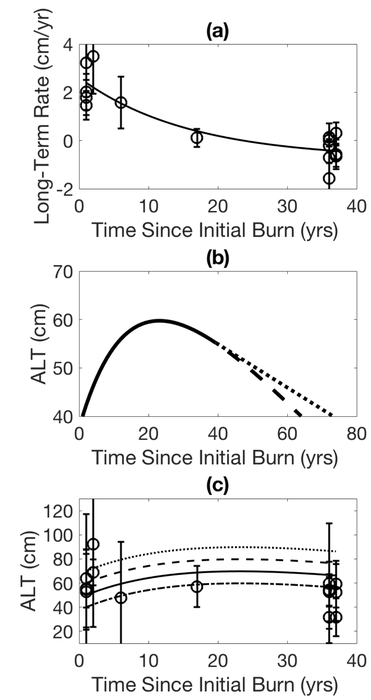


4. Post-fire Active Layer Recovery

Figure 5: a): We perform a nonlinear least-squares best-fit to the mean long-term linear trend in each fire zone assuming a simple exponential model for post-fire recovery.

b): A simple simulated history of post-fire active layer thickness using the exponential post-fire recovery curve from figure 5a, for an initial active layer thickness of 40 cm. Recovery is extrapolated into the future for two conditions: 1. Recovery rate does not exceed the current minimal value of recovery; 2. Exponential model is extrapolated until total recovery. Each case predicts a full recovery to pre-fire active layer thickness in approximately 65 or 75 years, respectively.

c): Exponential post-fire recovery curves are plotted for various initial active layer thicknesses alongside the mean active layer thickness within each fire zone (with associated uncertainties).



5. Conclusions

1. InSAR can be successfully employed to measure ALT and active layer dynamics in the discontinuous permafrost zone
2. InSAR and GPR both capture local heterogeneity in ALT
3. We construct an empirical recovery curve that captures the active layer dynamics in permafrost after wildfire burn
4. At the study site in the YK delta, a total return to a pre-fire active layer state may take at least 65-75 years

6. References

[1] L. Liu et al. 2012, JGR 115, 3. [2]. Schaefer et al. 2015 Remote Sensing, 3. [3]. Schur and Jorgensen 2007, Permafrost and Periglacial Processes 18, 1.