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

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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.

2. Active Layer Fire Model

- a: Organic Layer
- b: Thawed Active Layer
- c: Frozen Active Layer
- d: Permafrost table

- 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 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 labeled by year of burn.
- 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.
- 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.

4. Post-fire Active Layer Recovery

- 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.

- 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