Ecohydrological feedbacks in subarctic and arctic ecosystems: deep soil water buffers ecosystems from climate variability

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INTRODUCTION
- Interior Alaska is dry (MAP 25.4 cm) and warm (27°C) during the growing season
- BUT, plants experience little water stress & ecosystems support high vegetation cover
- In this context, this study addresses the question: Are plants buffered from climate variability by relying on water sources other than precipitation? This question will be examined by quantifying the uptake of water from shallow, surface layers vs. deep layers. The contribution of permafrost derived water to the deep layers will also be assessed.

This study focuses on active layer water dynamics

METHODS
- Sampled in subarctic, interior Alaskan tussock tundra & black spruce ecosystems across a gradient in permafrost temperatures
- Collected plant stems, soil at different depths, frozen ground & rain water
- Sampled in 2009 (mid-August) & 2009 (throughout the summer)
- Captured variation in topography in tussock tundra by sampling from mounds and troughs (mounds are drier than troughs)
- Cryogenically extracted water & analyzed water for δD and δ18O
- Measured leaf-level transpiration (2009)

ANALYSIS
Goal: estimate contribution of deep vs surface water to plant water uptake
Approach: Isotope mixing model implemented in a Bayesian modeling framework

DATA DISTRIBUTION (for stem observation)

δD and δ18O are the stem data, which are assumed to follow a bivariate normal (N) distribution with mean (μ) and covariance matrix (Σ). A similar model is used for the sources (or end-member) data associated with the soil water, permafrost, and surface soil water δD and δ18O values.

Mixing model (for mean stem & soil water isotopes; for soil layer k, species, %, topography type t, and X = D or O)

δD = qD,δD,δD + (1-qD),δD,δD

δ18O = qO,δ18O,δ18O + (1-qO),δ18O,δ18O

Propagated uncertainty in end-member (deep and surface water)

RESULTS

SEASONAL WATER DYNAMICS & WATER SOURCES
- As the active layer deepens (thaws) over the summer, there is more volume for root growth and the relative amount of deep water versus surface water inputs to the active layer soil volume changes.
- Water sources over a growing season vary isotopically, spatially, and temporally
- Snow: beginning of the season, snow melts and runs off quickly
- Rain: variable over the summer, primarily confined to surface layers
- Thaw: active layer: less variable over the summer, gets deeper as summer progresses
- Permafrost thaw: if occurring, then interannually variable but consistent within a summer: happens late in the summer, deep in the soil

HYPOTHESES
Species with different rooting distributions will differ in their use of these water sources:
- shallow rooted species will use rain but will be most responsive to climatic variation
- deeply rooted species will use water from thawing ground and will be less responsive to climatic variation

DISCUSSION
- Transpiration rates are highest during the driest and hottest period of the summer
- Plants tend to use more surface or rain water on mounds compared to troughs, where they use more deep water
- Important species differences:
  - 50% of water taken up by B. nana (shrub) is deep water (likely permafrost derived), even on mounds
  - 70% of water taken up by R. chamaeomorus (herbaceous) is surface water, even in troughs
  - V. uliginosa and C. bigelovii have different water use strategies on mounds vs troughs (strong topographic effects)
- Water that appears to be permafrost derived is predominantly found in soil layers deeper than 20cm
- These results suggest:
  - Plants can get up to half their water from deeper, less variable water sources (frozen sources such as permafrost)
  - R. chamaeomorus is likely shallowly rooted, B. nana is likely deeper rooted, V. uliginosa and C. bigelovii likely have dynamic rooting systems that can adjust to water availability

Are these species & ecosystems buffered from climate variability via access to “deep” water?

The seasonal trend in water use strategies has not been completed yet, but this initial assessment suggests that the thawing of frozen ground (permafrost) supplies water to deeper soil layers that sustain plant function during a dry year (2007). The seasonal transpiration data also suggests that the plants maintain (or even exhibit higher) fluxes during very dry periods.

FUTURE DIRECTIONS
- Assess the seasonal dynamics of species-specific water use strategies (2009 data pending)
- Determine seasonal rooting & water uptake profiles of each species via RAPID Bayesian model

Acknowledgements: We thank Danali Natural Park (Discovery Danali Educational Fellowship) and the National Science Foundation Office of Polar Programs for funding. We thank Sarah Bachman, Jessica Ennskoch, Bill Cable, and Kelley Ryan for field assistance.