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

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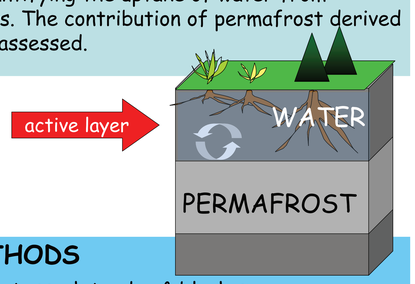
INTRODUCTION

- Interior Alaska is dry (MAP 25.4 cm) & 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
- Species sampled:

- Collected plant stems, soil at different depths, frozen ground & rain water
- Sampled in 2007 (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 $\delta^{18}O$ and δD
- Measured leaf-level transpiration (2009)
- NOTE: 2007 was a very dry summer; 2009 had the driest and 2nd hottest July on record

ANALYSIS

Goal: estimate contribution of deep vs surface water to plant water use

Approach: Isotope mixing model implemented in a Bayesian modeling framework

Data distribution **(for stem observation *i*)**

$$\begin{bmatrix}\delta D \\ \delta^{18}O\end{bmatrix}_i \sim N\left(\begin{bmatrix}\mu\delta D_i \\ \mu\delta^{18}O_i\end{bmatrix}, \Sigma\right)$$

δD and $\delta^{18}O$ 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 $\delta^{18}O$ values.

Mixing Model **(for mean stem & soil water isotopes; for soil layer *k*, species, *sp*, topography type *t*, and X = D or ^{18}O)**

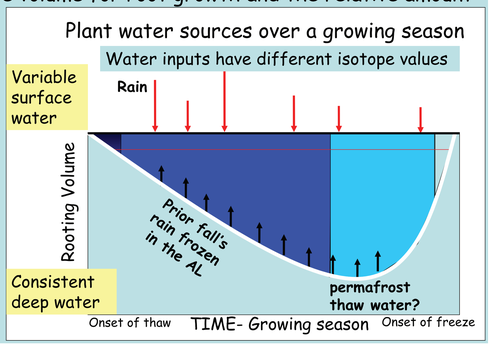
$$\left.\begin{aligned}\mu\delta X_i &= q_{sp,t}\cdot\mu\delta X_{deep} + (1-q_{sp,t})\cdot\mu\delta X_{surface} \\ \mu\delta X_{soil,k} &= q_k\cdot\mu\delta X_{deep} + (1-q_k)\cdot\mu\delta X_{surface}\end{aligned}\right\}$$

Propagates uncertainty in end-member (***deep and surface*** water)

The μ's are a mixture of the δD and $\delta^{18}O$ of the source waters (source), each with their own fractional contribution (p).

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 summer, snow melts and runs off quickly
- **Rain**: variable over the summer, primarily confined to surface layers
- **Thaw of 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

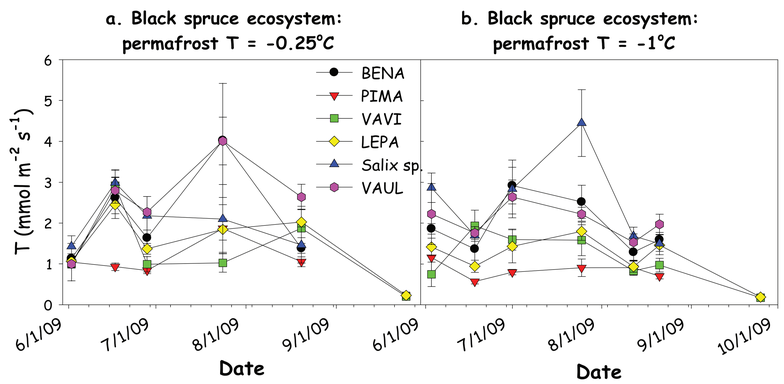


HYPOTHESES

Species with different rooting distributions will differ in their use of these water sources:

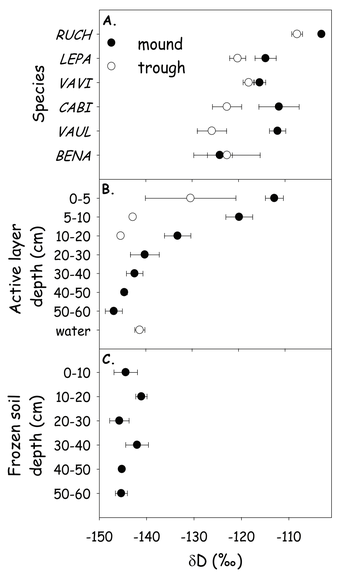
- shallow rooted species will use rain but will be most responsive to climatic variation
- deeply rooted species will use water from thawing ground and will be less responsive to climatic variation

RESULTS

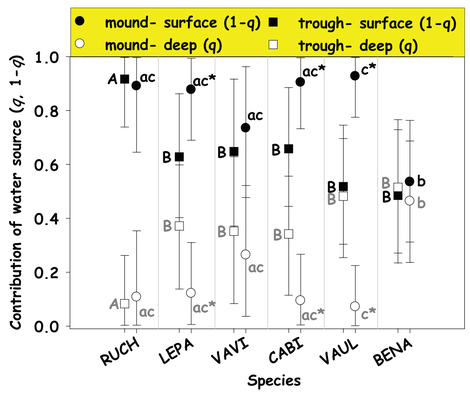


↑ **Fig. 1 TRANSPIRATION**

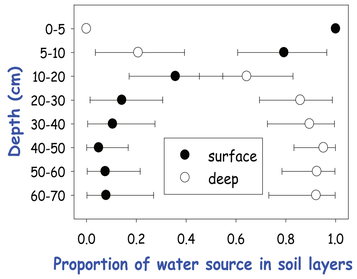
- Compared to evergreens, deciduous species have higher & more variable transpiration rates, and are more coupled to VPD
- Peak transpiration occurs in JULY – the DRIEST and 2nd HOTTEST on record
- Transpiration rates are similar across sites
- **SPECIES GUIDE:** BENA = *Betula nana*, PIMA = *Picea mariana*, VAVI = *Vaccinium vitis-idaea*, LEPA = *Ledum palustre*, *Salix* sp = various willow species, VAUL = *Vaccinium uliginosum*



↑**Fig. 2 ISOTOPE DATA** There is isotopic variation in plant species stem water (A) and active layer water (B), but permafrost-derived water is less variable (C) The bottom of the active layer is similar to permafrost isotope values.



←**Fig.3 STEM WATER** The predicted proportion of surface (A) and deep (B) water taken up by plants that occur on mounds or in troughs. Greater use of surface water (likely rain) on mounds and deep water (likely permafrost derived) in troughs.



→**Fig. 4 SOIL WATER** The predicted proportion of surface and deep water throughout the soil profile. Note that the deep water is actually found from 20 cm to the bottom.

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*
  - 90% of water taken up by *R. chamaemorus* (herbaceous) is surface water, *even in troughs*
  - *V. uliginosum* and *C. bigelowii* have different water use strategies on mounds vs troughs (strong topographic effect)
- 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. uliginosum* and *C. bigelowii* 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

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