Hillslope scale patterns of forest drought mortality: the role of sub-surface storage and downslope redistribution

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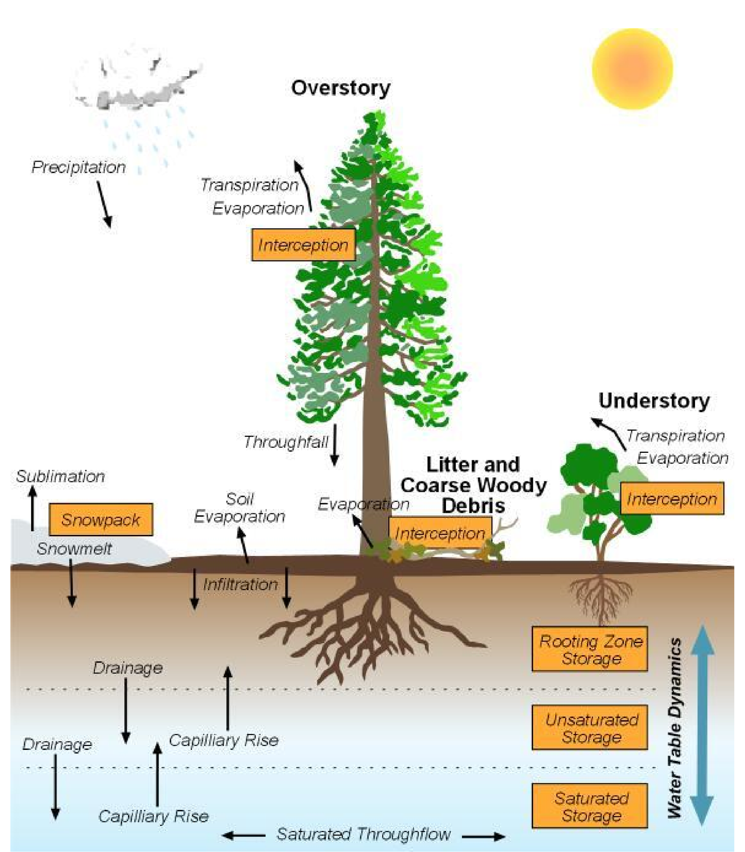
Hillslope hydrology can affect mortality

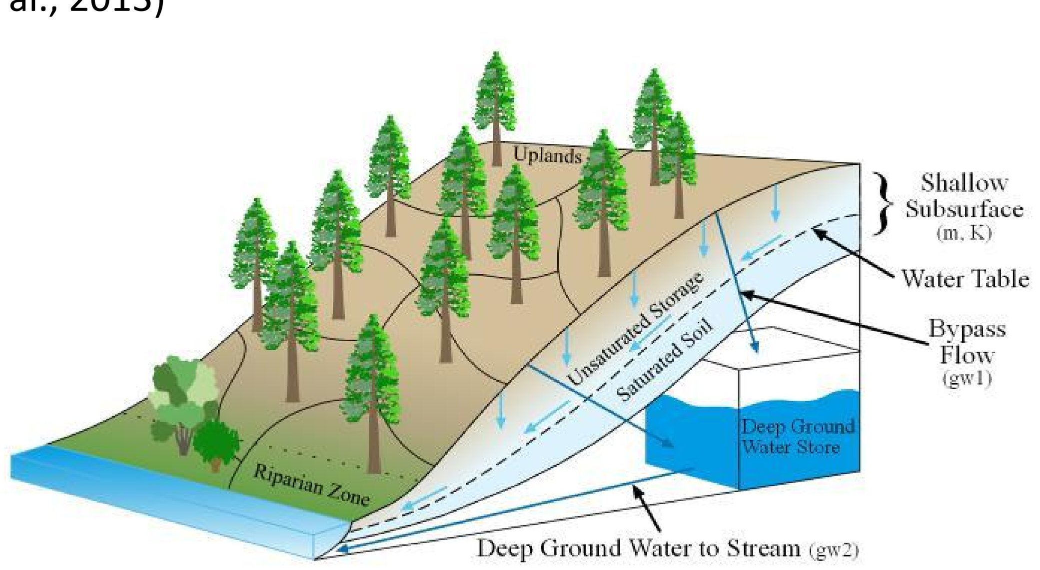
- Even though many mechanisms for forest mortality have been identified, the precursor to all of them is trees running out of water.
- While precipitation amounts are the dominant predictor of when and where trees will run out of water, hillslope level processes including sub-surface water storage and topographical downslope redistribution can significantly alter the amount of water that is locally available.
- Assessing downslope redistribution of water and making spatial measurements of sub-surface water storage capacities has long been a fundamental challenge for hydrologists
- Forest mortality in 2012-2015 California drought across the hihgly instrumented Southern Sierra Critical Zone Observatory (SSCZO) offer a unique opportunity to assess hydrologic controls on spatial patterns

- **In this research we address the question:** how does hillslope patterns of sub-surface water storage capacities combine with downslope redistribution of water to affect hillslope patterns of mortality during the 2012-2015 California drought.

RHESSys

- RHESSys is a mechanistic, spatially explicit, carbon and water cycling model
- The water cycling model includes both vertical (pictured right) and horizontal (pictured below) processes
- Carbon cycling include photosynthesis, respiration, allocation and mortality submodels
- Tree mortality is determined by non-structural carbohydrate stores (Tague et al., 2013)





References

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Tague, C. L., McDowell, N. G., & Allen, C. D. (2013). An integrated model of environmental effects on growth, carbohydrate balance, and mortality of Pinus ponderosa forests in the southern Rocky Mountains. *PLoS One*, *8*(11), e80286.

Tague, C., & Peng, H. (2013). The sensitivity of forest water use to the timing of precipitation and snowmelt recharge in the California Sierra: Implications for a warming climate. Journal of Geophysical Research: Biogeosciences, 118(2), 875-887.

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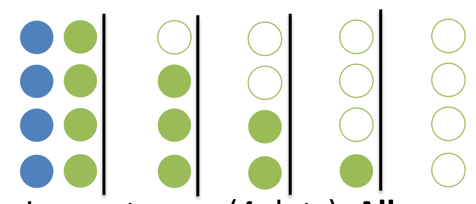
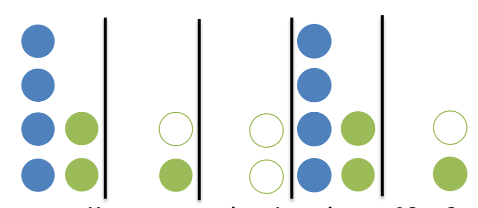
Precipitation and sub-surface storage

Available water: a combination of precipitation patterns and sub-surface storage capacity

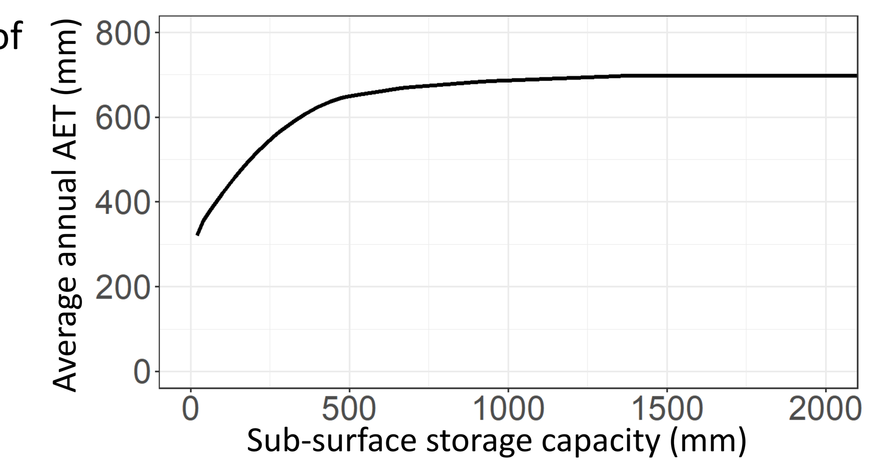
- Precipitation (blue)
- Plant water use (green)



Large storage (4 dots): **All precipitation stored**: 4 days water use with **one storm**



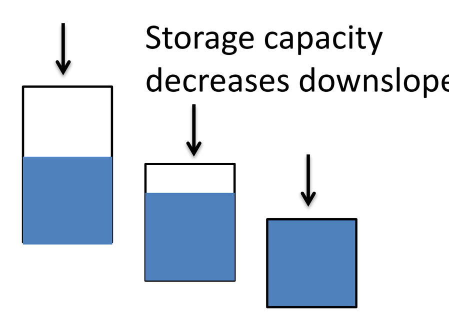
Small storage (2 dots): **Half of precipitation stored**: 4 days water use with **two storms**

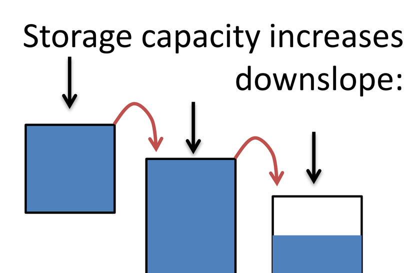


The role of sub-surface storage in the SSCZO (unpublished):

- On average plants utilize ~500 mm of sub-surface storage (blue)
- Plant water use is sensitive to sub-surface storage capacities of up to ~1400 mm, due to the inter-annual effects of the drought (red)

Downslope redistribution

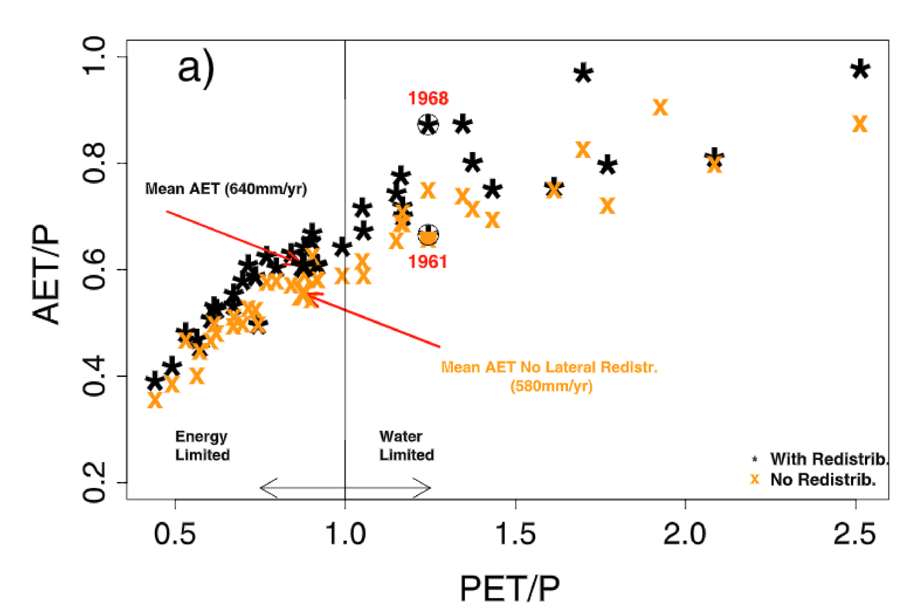




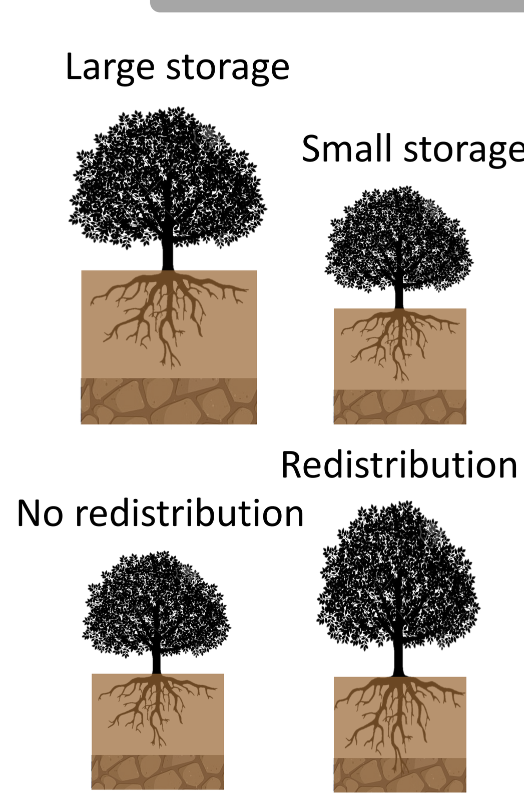
Results in downslope redistribution

- Downslope redistribution occurs when recharge, which is precipitation + downslope redistribution exceeds the local storage capacity
- Therefore the amount of downslope redistribution in part depends on how sub-surface storage capacity varies downslope, which in general is one of three scenarios: homogenous, decreases or increases

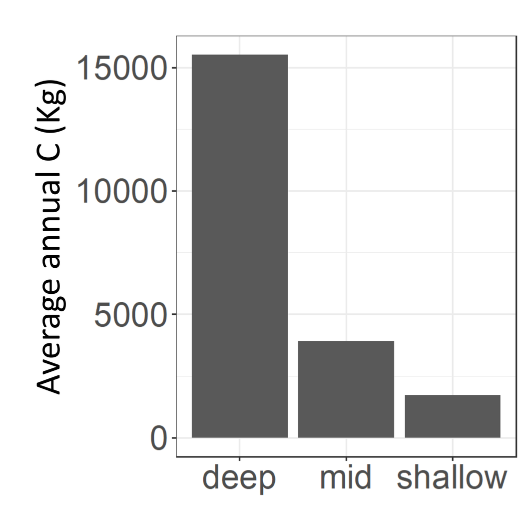
From RHESSys: effects of downslope redistribution on annual AET in a Northern California site (Tague & Peng, 2013)



A priori effects on drought resilience



- Greater access to water = greater size tree = greater water demand
- Greater access to water can occur through larger access to sub-surface storage or downslope redistribution
- During a drought, these a priori adaptations in part define a tree's resiliency because they define how fast a tree will deplete its storage



Preliminary RHEESys runs show that for the climate input, soil depth has a significant effect on average tree size

Methods

Purpose

- Eco-optimality theory says that trees will optimize growth and biomass to maximize the balance between their demand for resources and ability to capture them. Droughts mortality occurs when this balance is significantly disrupted
- Interactions among sub-surface storage and its effects on downslope redistribution can influence the balance of a tree given declines in precipitation

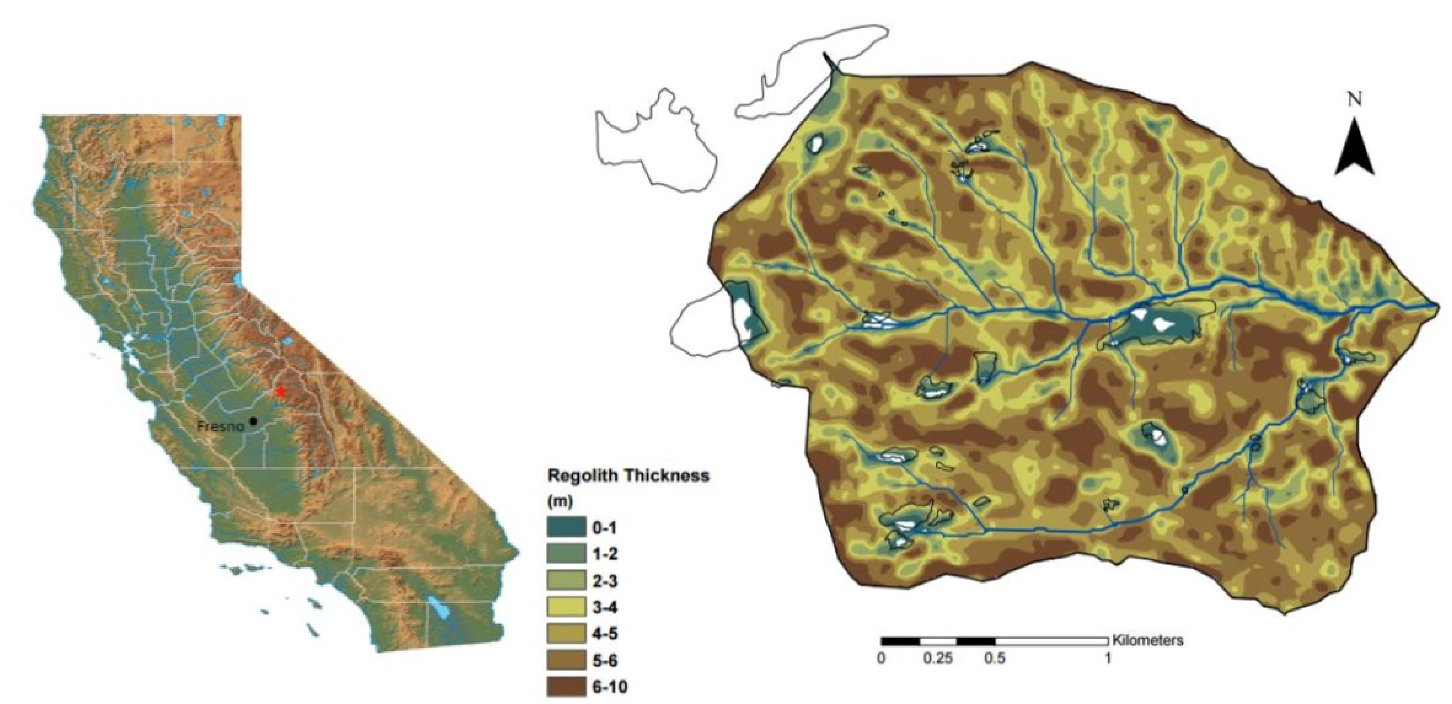
Hypothesis

- Given that sub-surface storage declines as we move downslope (in the site below); trees that rely on downslope redistribution will be disproportionately affected by declines in precipitation

Overall Strategy

* use flux tower, dendrochronology, tree mortality, storage capacity estimates of the SSCZO to parameterize and validate the RHESSys model

- Through a resource allocation function, RHESSys will dynamically determine the size of roots and above ground biomass based upon the historical climate.
- For sample hillslopes assess sensitivity of water demand, growth and morality to drought given a priori resource allocation patterns



Soaproot is located in the Western slope of the Sierra Nevada mountains (red dot, left figure); it is a forested 543 ha watershed with a mean elevation of 1180m.

The figure on the right is the interpolated map of depth to regolith from Ferrel (2017). Note that in general sub-surface storage capacity decrease downslope

RHESSys Sub-surface storage Parameterization

- Ferrel (2017) converted regolith thickness to an available water storage capacity (AWSC)
- RHESSys parameterization of sub-surface storage capacity includes depth of soil (z), porosity (Φ), pore size index (Po), and the psi air entry (Pa). In order to keep the relationship between incremental rooting depth and access to water constant across all depths of AWSC, we fix Po, Pa and Φ, and vary the depth of soil (z) until modeled AWSC matches the observed AWSC.
- We also use previous calibration of RHESSys in a neighboring drainage for parameters of hydraulic conductivity and its decay with depth (Son et al., 2019) and use flux tower measurements and dendrochronology to validate the modeled annual evapotranspiration and primary productivity anomalies

Sensitivity Analysis (for sample hillslopes)

- Estimate sensitivity of forest drought response to interactions among downslope redistribution, AWSC, vegetation ecophysiology parameters on drought resilience and response

Scenarios		Sensitivity Analysis		Analysis
Downslope redistribution	✕	Respiration (Q10)	⇨	Monthly basin averaged ET
No downslope redistribution		Maximum Stomatal Conductance		Annual NPP vs Dendrochronology
		Branch Mortality		Summer time ET shutdown
		NSC model (2 parameters)		Mortality patterns

Acknowledgements: Critical Zone Observatory (CZO)
Grant # EAR 0724958, 1331939