National CZO Program

Southern Sierra CZO

Seeing the Forest through the roots: A bottom up approach to forest hydrology

NatureBridge

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Research question/objectives

- How do trees utilize water? What is the timing of their water use? How does soil depth relate to these two questions?
- Monitoring of surface and subsurface water budgets in remote landscapes, with specific attention to moisture and temperature variability in near surface soils
- Study the interactions between soil hydrology and tree root water uptake in a forested catchment, as part of a wider effort to analyze changing ecosystem response to changing environmental inputs.

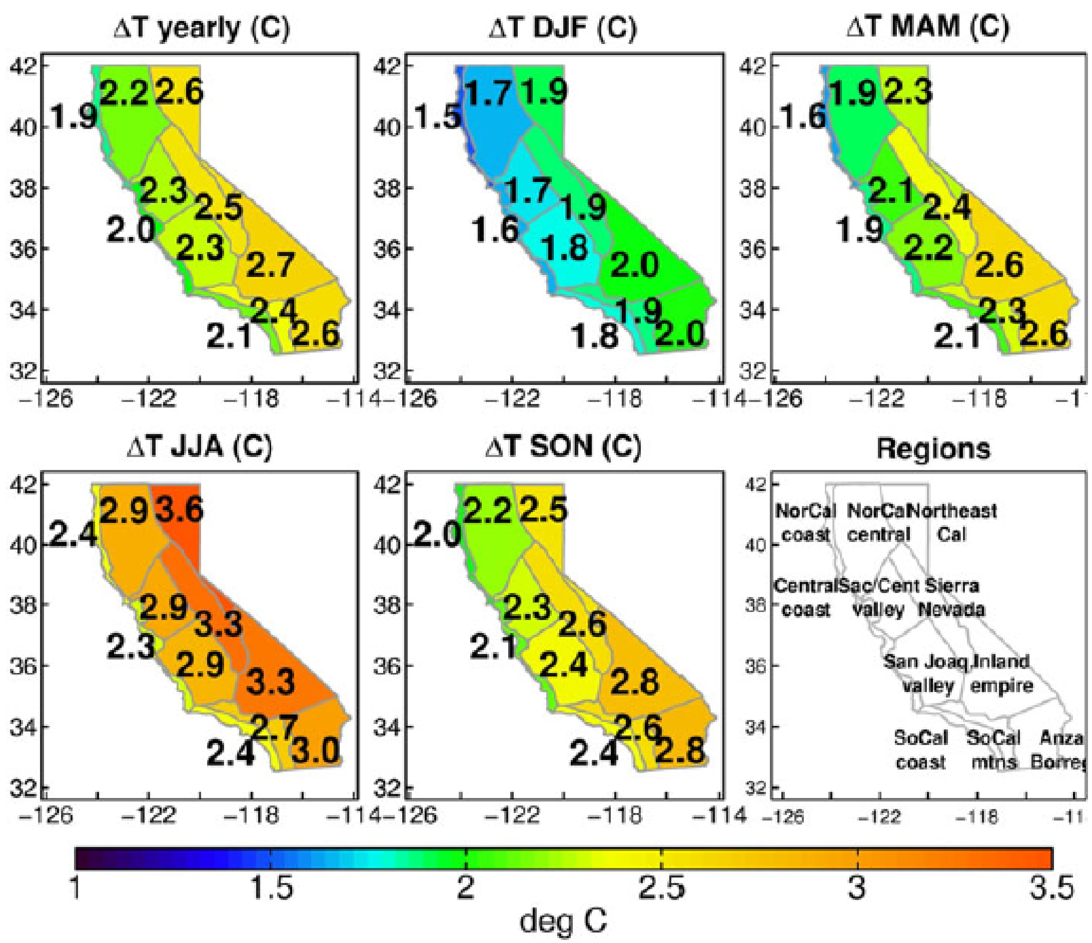
Climate Change in the Sierra

- The Sierra Nevada provides water to over 10% of the U.S. population and about 40% of the runoff for California as a whole.
- Climate warming will shift the elevation of the rain snow transition, the seasonal timing of snowmelt runoff, soil-water dynamics, plant water-use and growing-season temperatures, thus dramatically altering the water cycle, weathering processes and ecosystem function.
- Snowmelt and stream flow timing are already occurring earlier each spring in response to warming (as much as +2 ºC in recent decades) .

Sierra Climate Change cont.

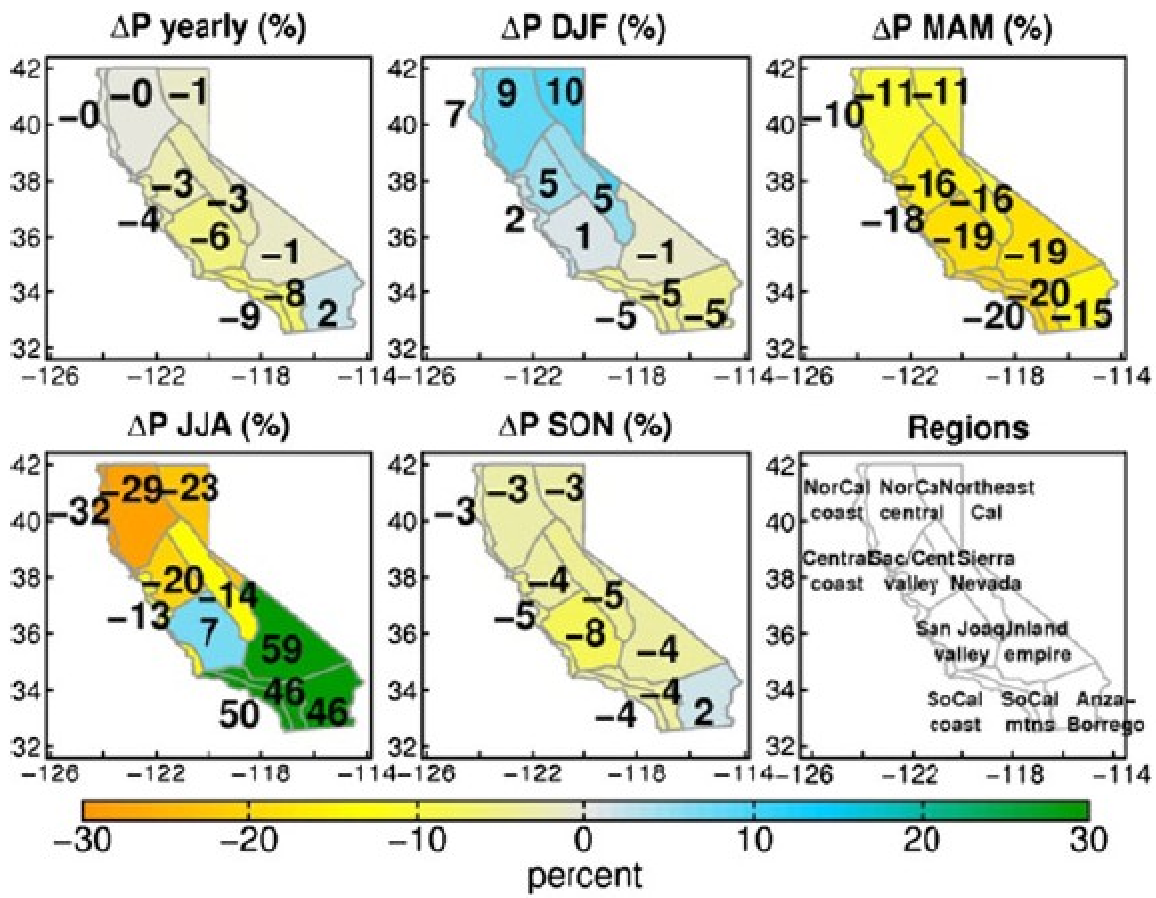
- This will likely increase the risks of springtime floods and late summer moisture stress. Increased frequency of multi-year droughts and higher-intensity rainfall events have been predicted and may compound the hazards associated with seasonal shifts.
- A range of forest disturbances including drought-related dieback , fire , disease , and background mortality , are expected to intensify with increasing drought frequency and severity.
- Short to medium-term effects of climate change (floods and drought) will interact with long-term processes, including species shifts, with as yet poorly understood consequences for ecosystem function and material fluxes

Temperature Predictions

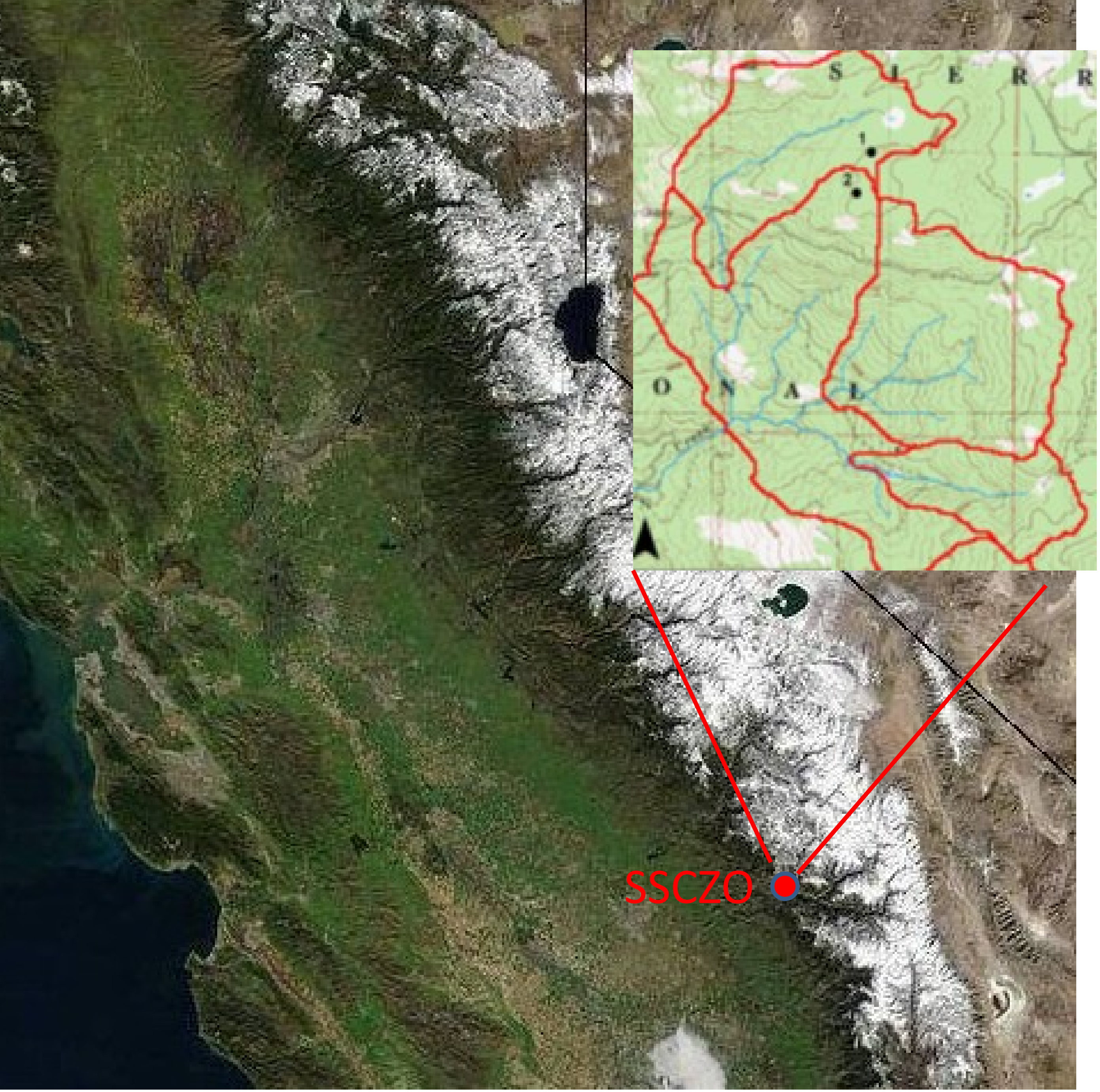


Pierce et al 2012

Precipitation Predictions



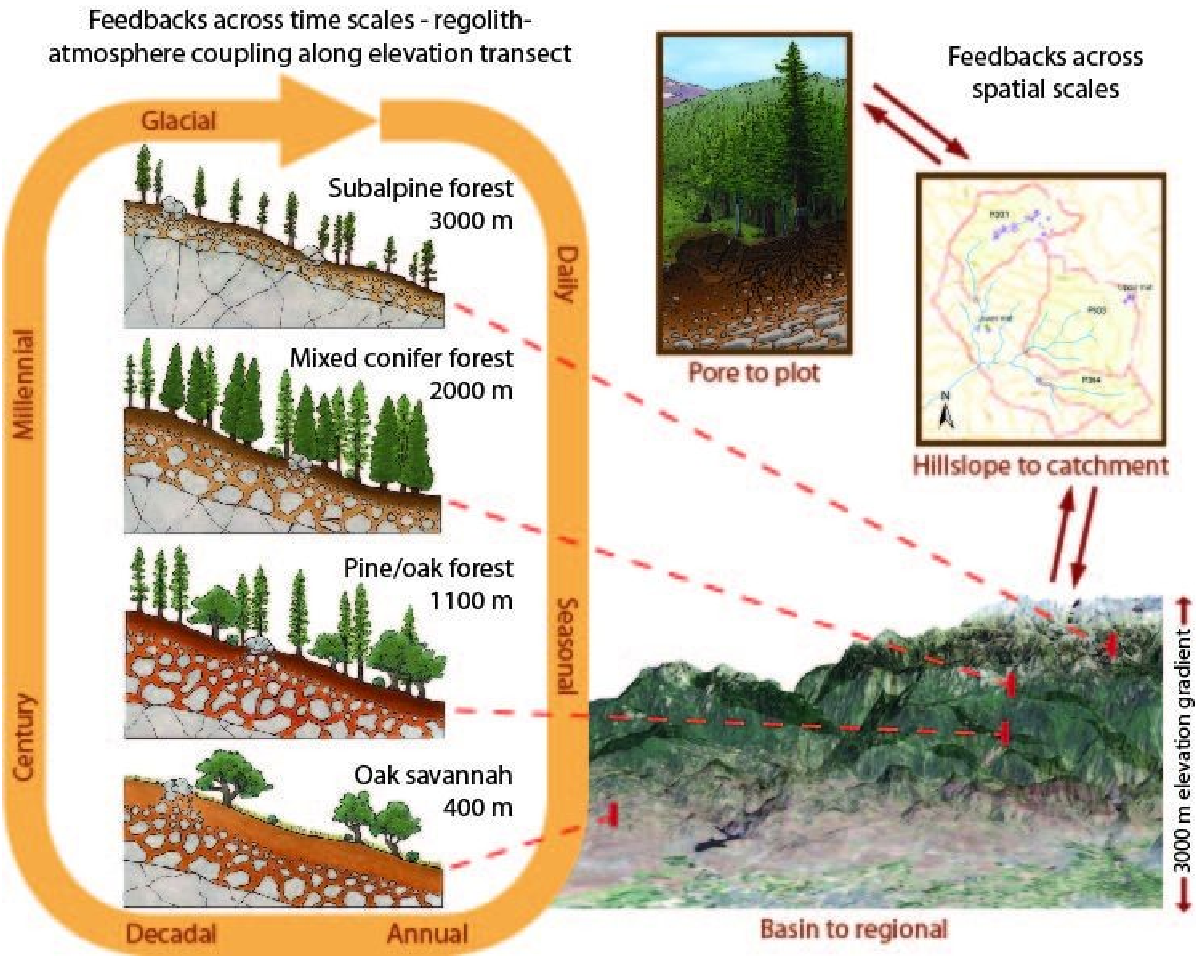
Pierce et al 2012



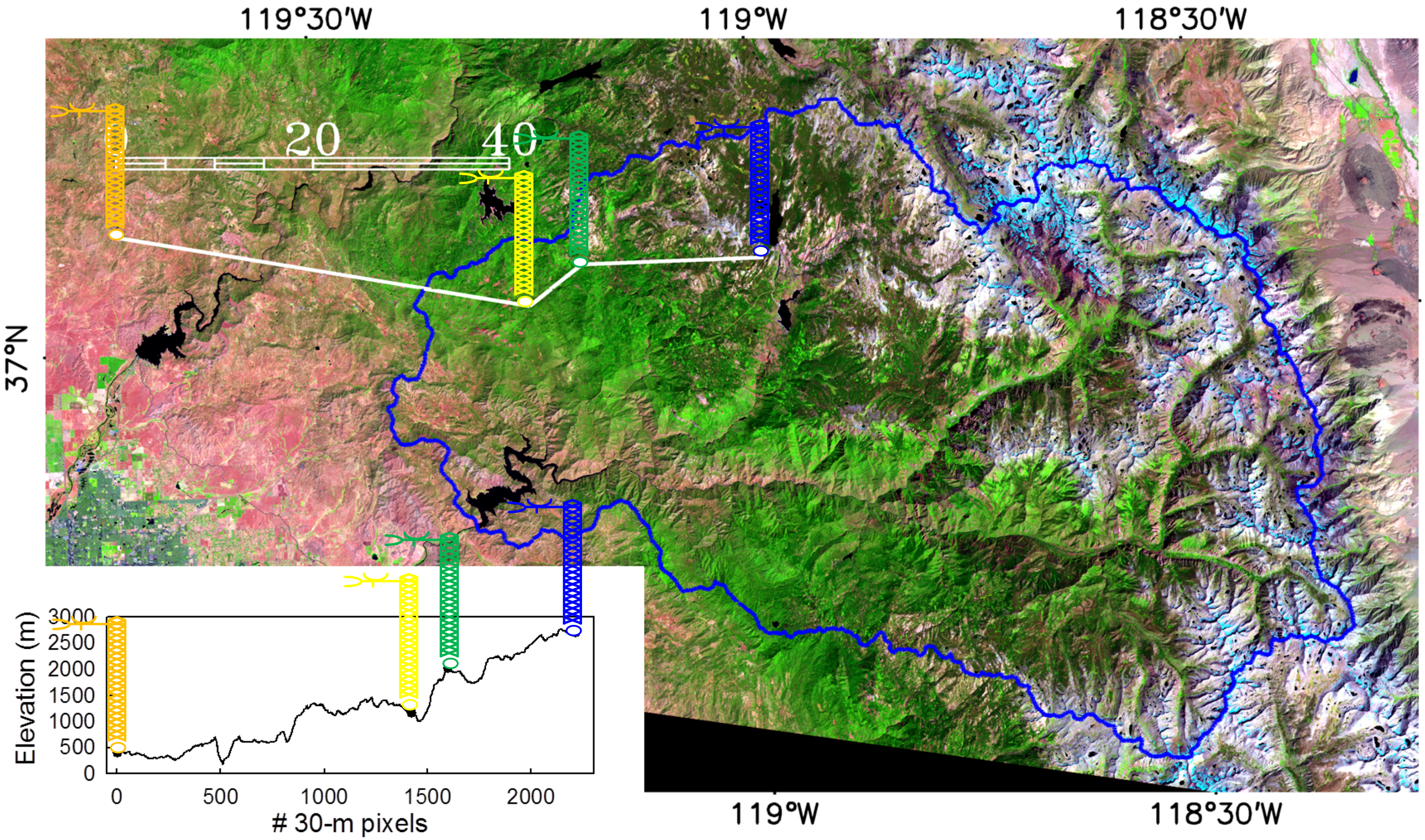
Location

Southern Sierra CZO is located at elevations 400-2700 m, across the rain-snow transition, in a very productive mixed-conifer forest, with extended measurement nodes across various gauged watersheds.

Conceptual model of project

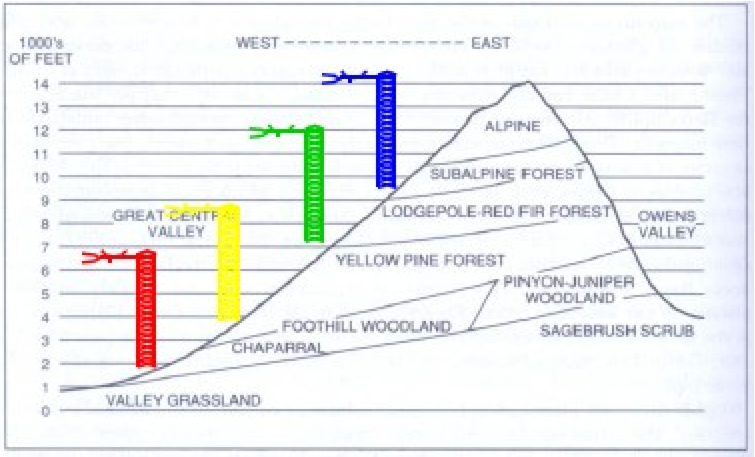


Broad framework of the research

- 

modified from Goulden et al. 2012

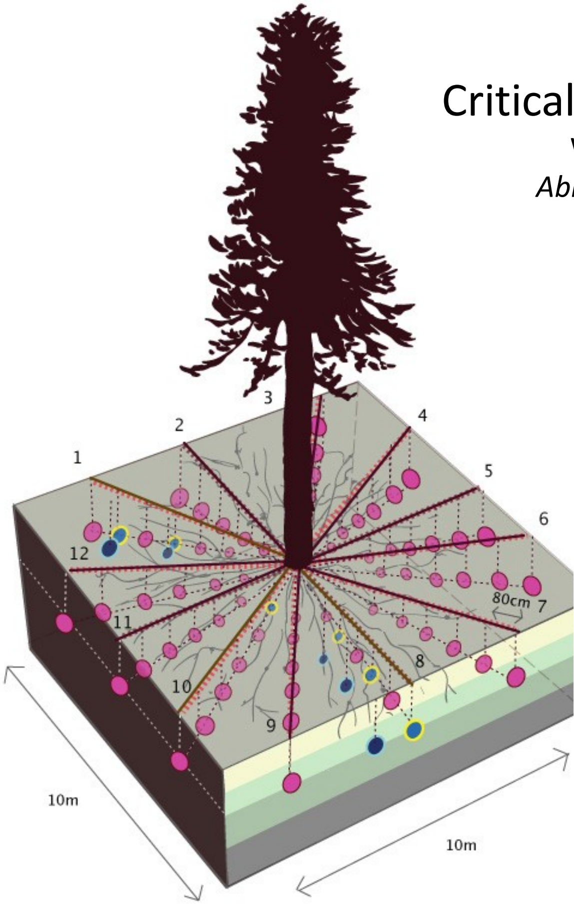
Flux tower transect

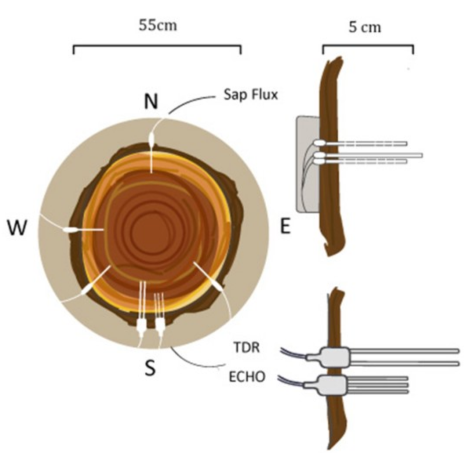


modified from Goulden et al. 2012

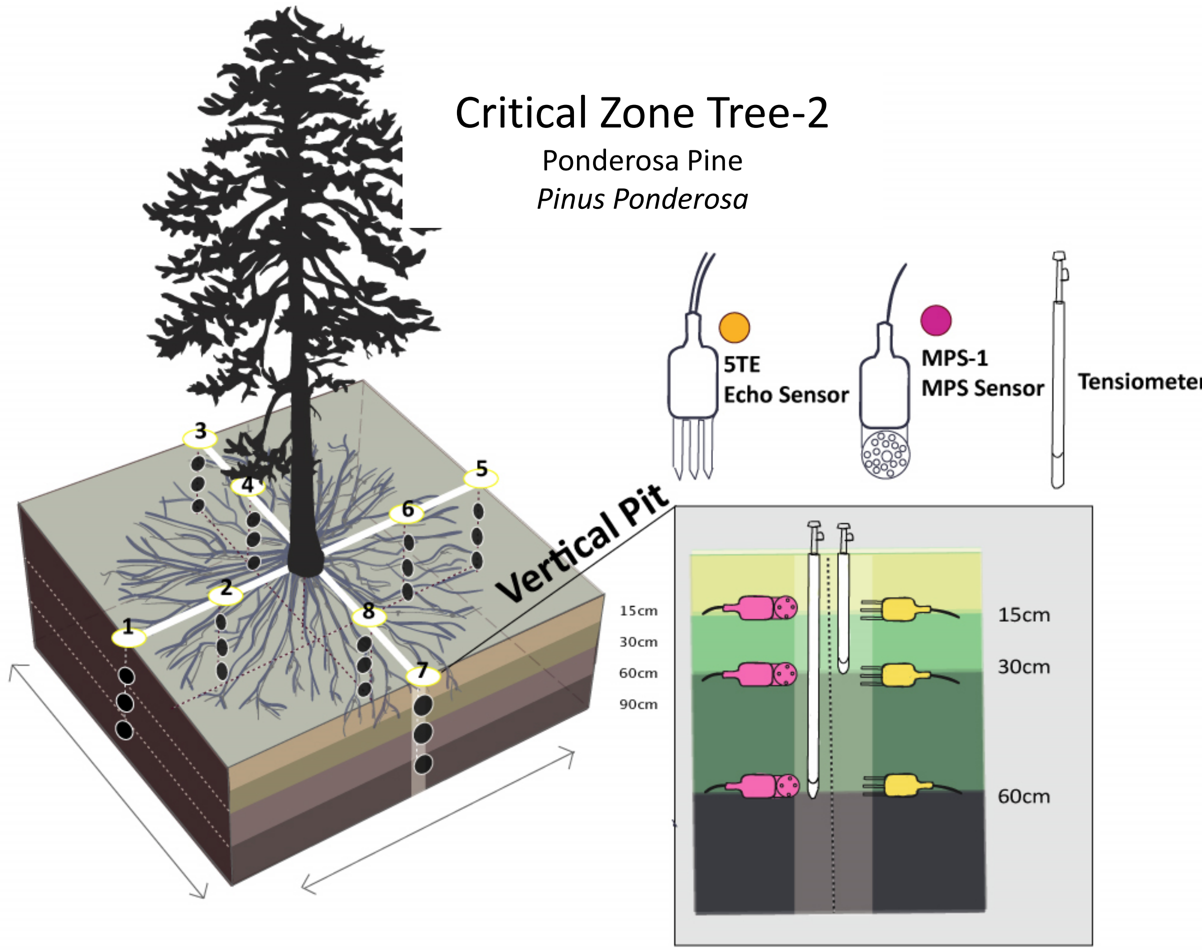
Instrumentation

Critical Zone Tree-1
White Fir
Abies concolor



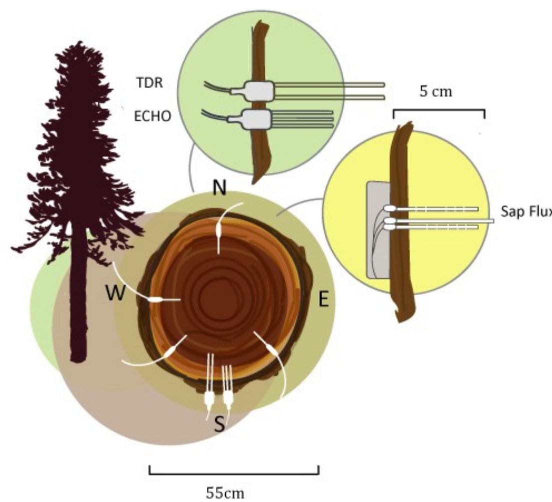


Critical Zone Tree-2
Ponderosa Pine
Pinus Ponderosa



Tree Trunk & Canopy Measurements

Needle Water Potential

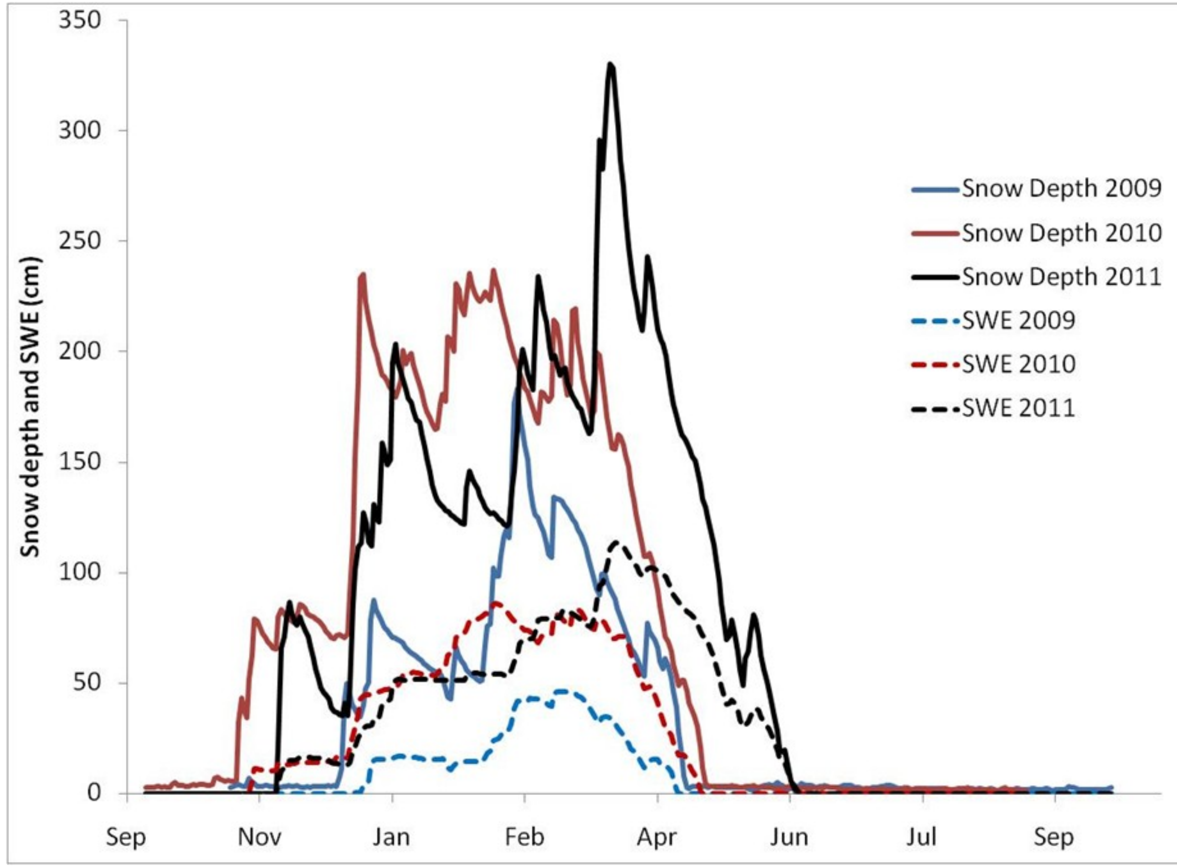


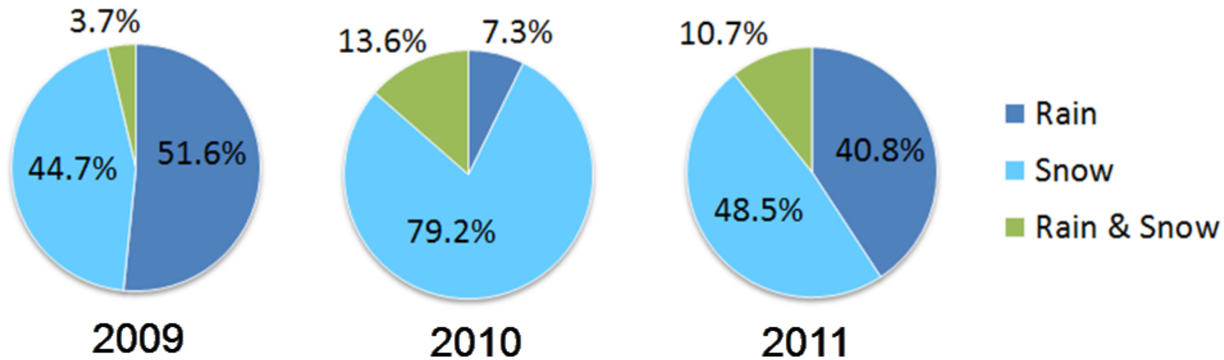
Sap Wood Water Content

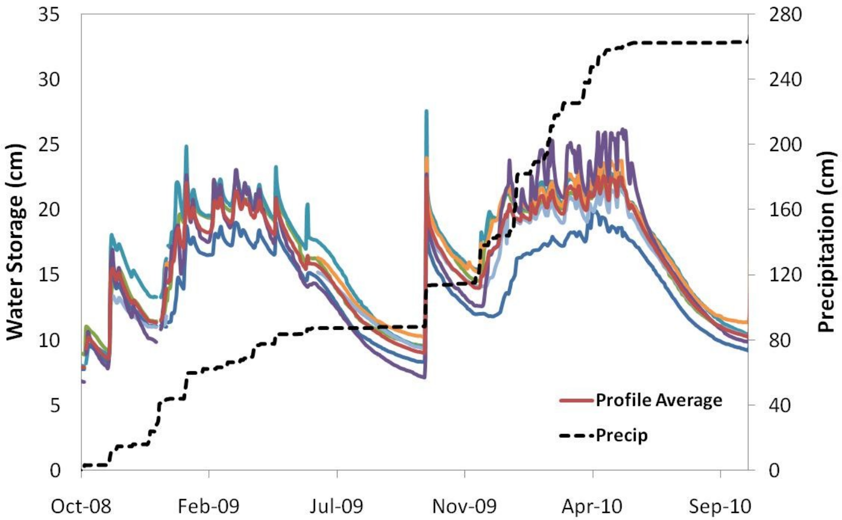
Sap Flow

Snow tree movie


TREECAMERA APR 05, 2009 08:00 276K
TREECAMERA APR 08, 2009 08:00 270K
TREECAMERA APR 18, 2009 08:00 281K


Snow depth and SWE (cm)
350
300
250
200
150
100
50
0
Sep
Nov
Jan
Feb
Apr
Jun
Jul
Sep
Snow Depth 2009
Snow Depth 2010
Snow Depth 2011
SWE 2009
SWE 2010
SWE 2011

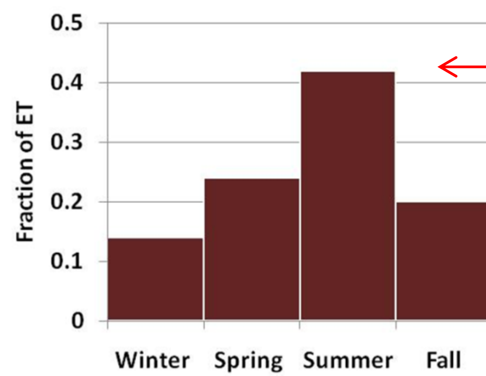

3.7%
44.7%
51.6%
2009
13.6%
7.3%
79.2%
2010
10.7%
40.8%
48.5%
2011
Rain
Snow
Rain & Snow



Dec 07

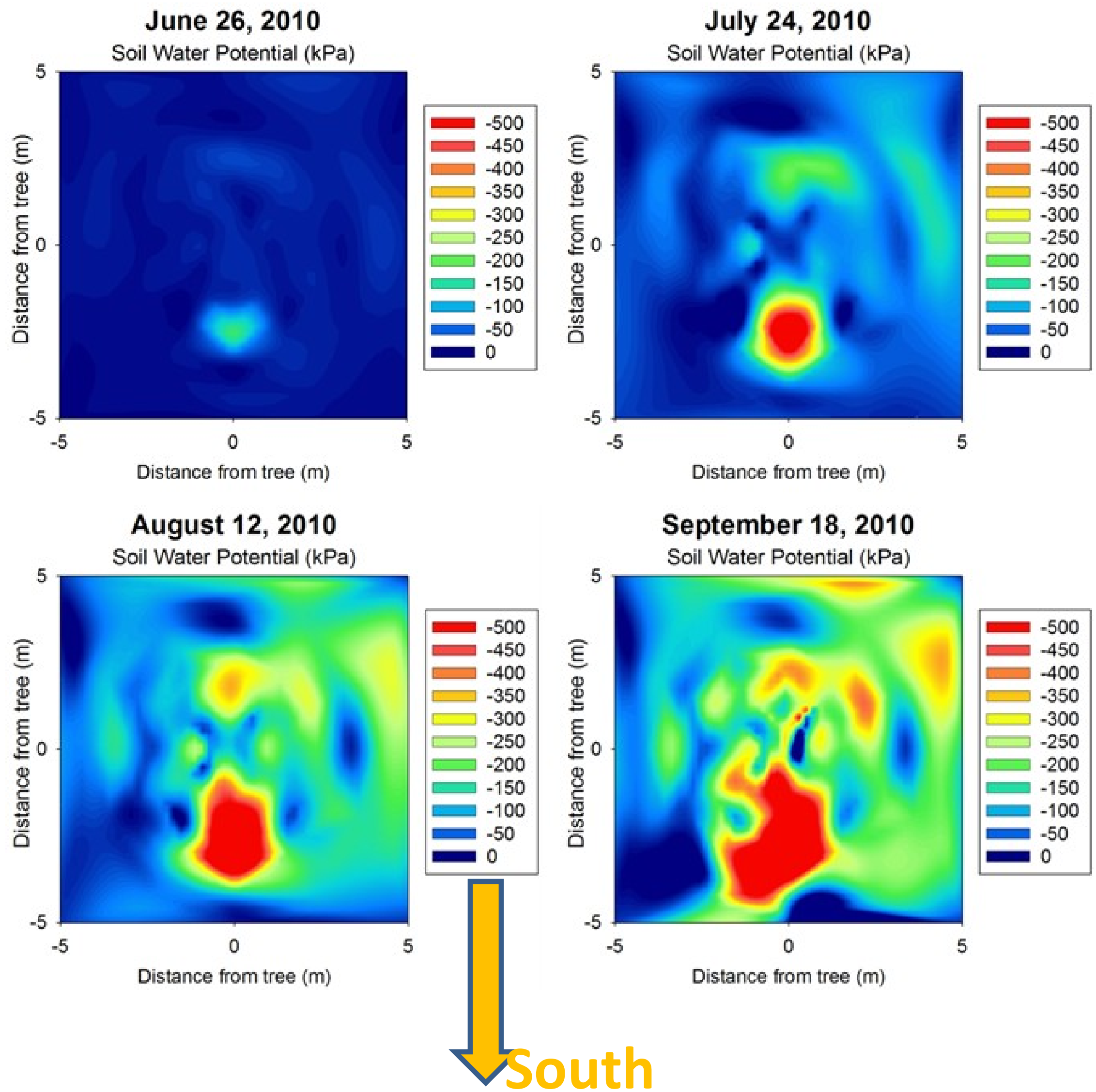
Jan 15

- Summer characterized by dry conditions, soil moisture drawn down by ET
- Winter characterized by many snowmelt events which enter the soil profile
- Some as drainage and some winter ET
- Flux estimates using sap flow data



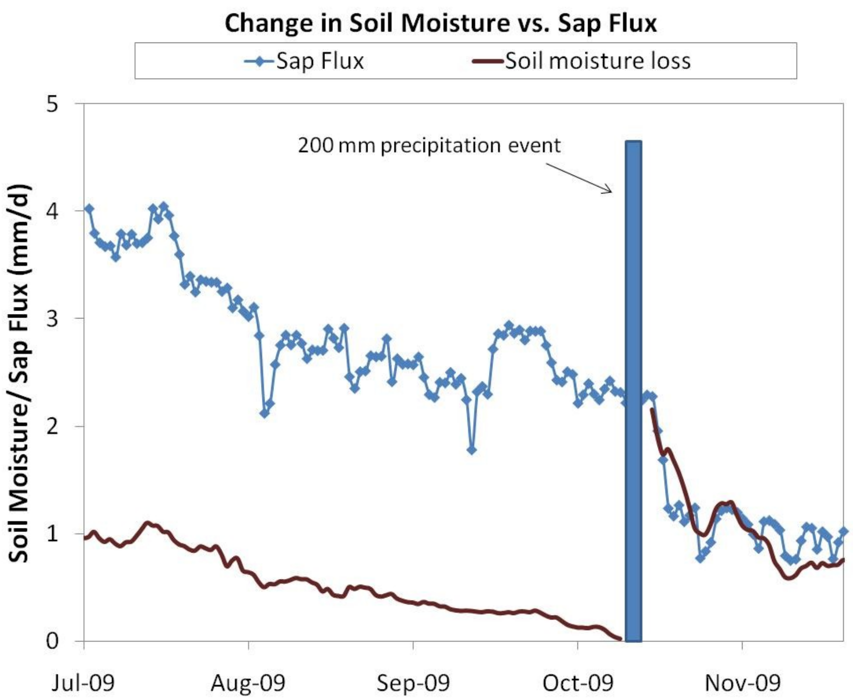
20-30cm of Summer ET

Spatial patterns of soil water potential at 30 cm soil depth <u>How do these patterns affect tree ET and canopy stress?</u>

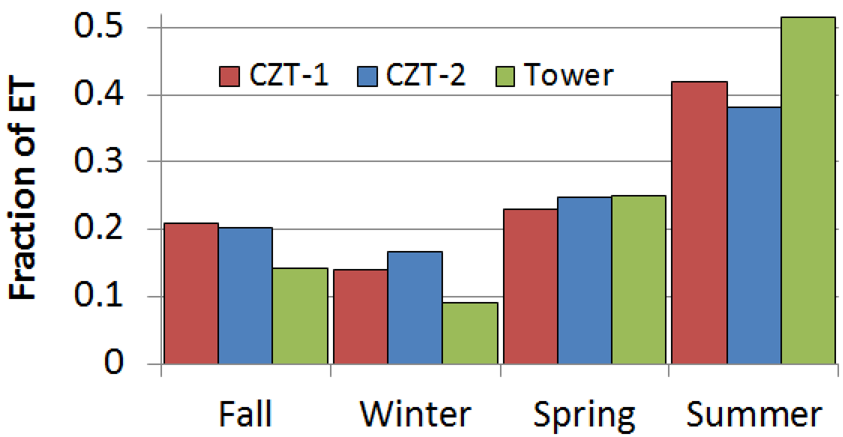


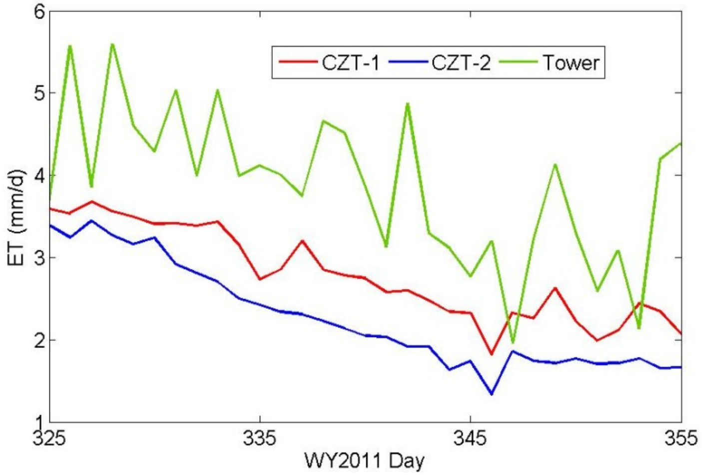
Various methods of estimating ET

- Sap flow
  - Sensors must be moved periodically, uncertainty in the low flow range
- Flux tower
  - Uncertain fetch, uncertain contributions from various community members
- Water content monitoring in the VZ after drainage
  - Uncertainty in spatial variability of water content measurements and texture of soils. Uncertainty in partition between drainage and ET
- Calculating fluxes
  - Need water potential measurements across a gradient, difficult to measure accurately, conductivity as a function of water content
- Modeling
  - Complex model with many parameters, need to couple processes in the SPAC



By late summer, the trees are clearly transpiring more water than we measure as lost from the shallow soil



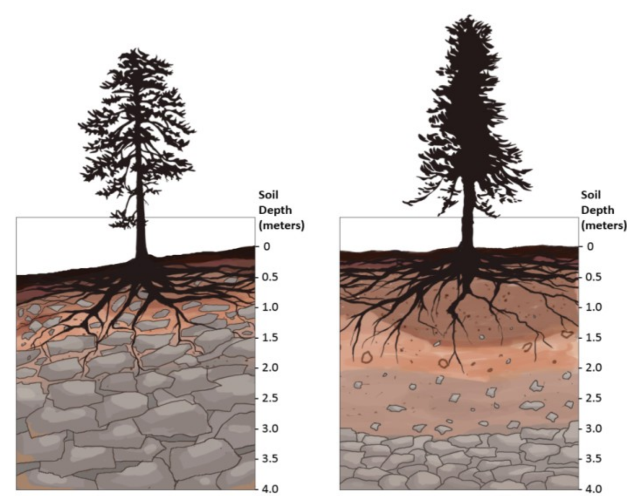


Water balance on regolith

<u>Change in storage</u> between shallow (S) and deep (D) soil compartments

$$\Delta S_S = Rain + Snowmelt - ET_S - Deep\_drainage$$

$$= Deep\_drainage - ET_D - Streamflow - gw\_loss$$




Sap Flux Daily Sums
Sap Flux (L/d)
0
5
10
15
20
25
30
35
40
45
50
11-Jul
21-Jul
31-Jul
10-Aug
20-Aug
30-Aug
9-Sep
19-Sep
0-20 cm


0-60 cm


0-100 cm


0-150 cm


200 cm

Saprolite-soil interface


Sap rock

Weathering Sequence with Depth
Soil - Saprolite – Saprock – Granitic Bedrock

increasing porosity and water holding capacity

Deep regolith hold significant amounts of water.

Saprolite contains little or no clay minerals.

Saprock is consolidated and holds original rock fabric.

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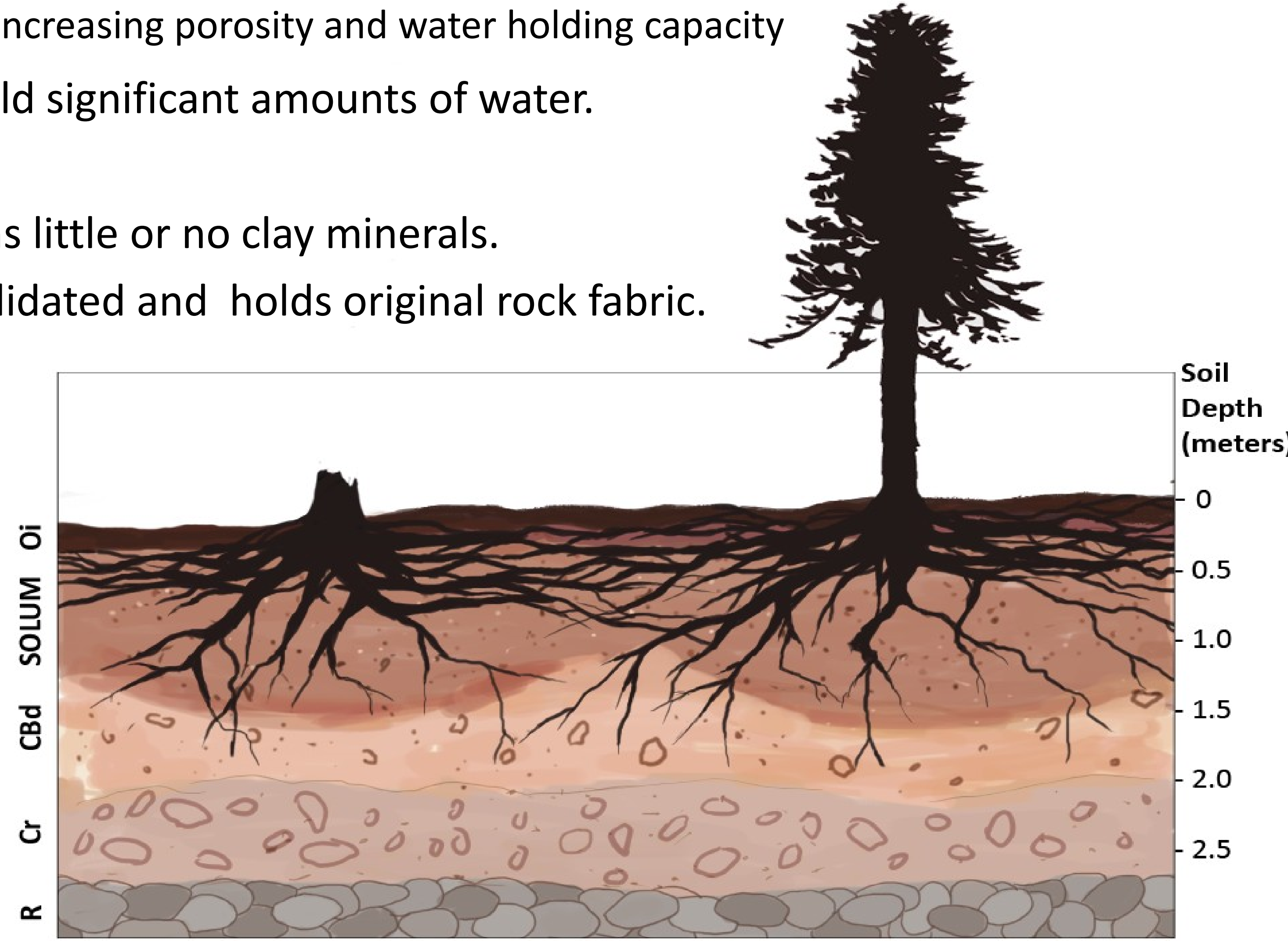


Solum

Saprolite

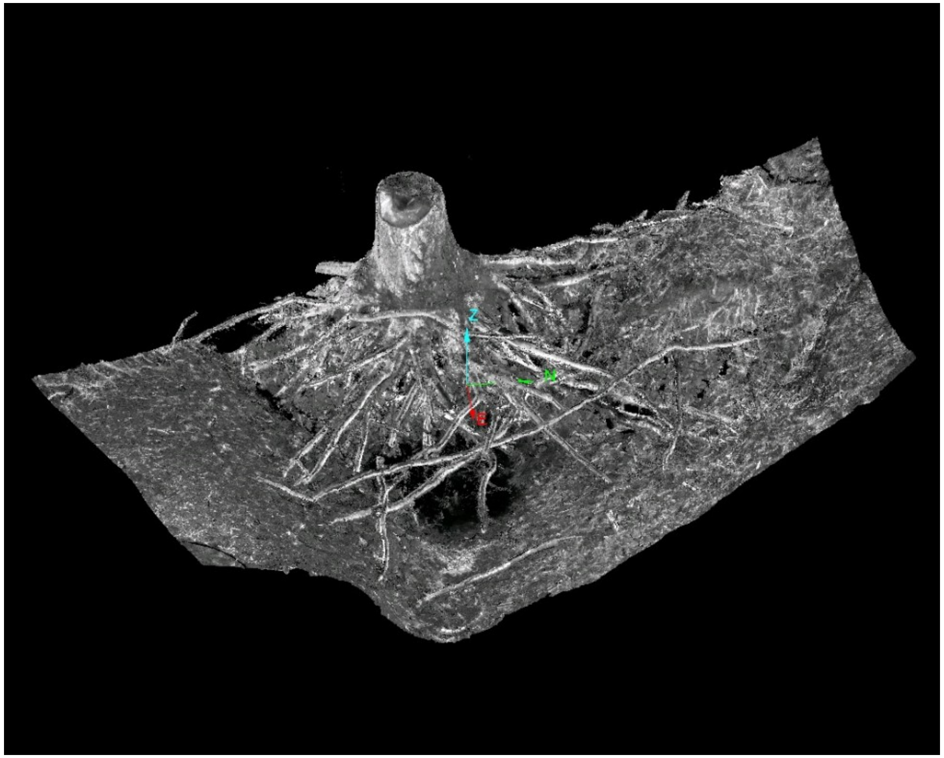
Sap rock

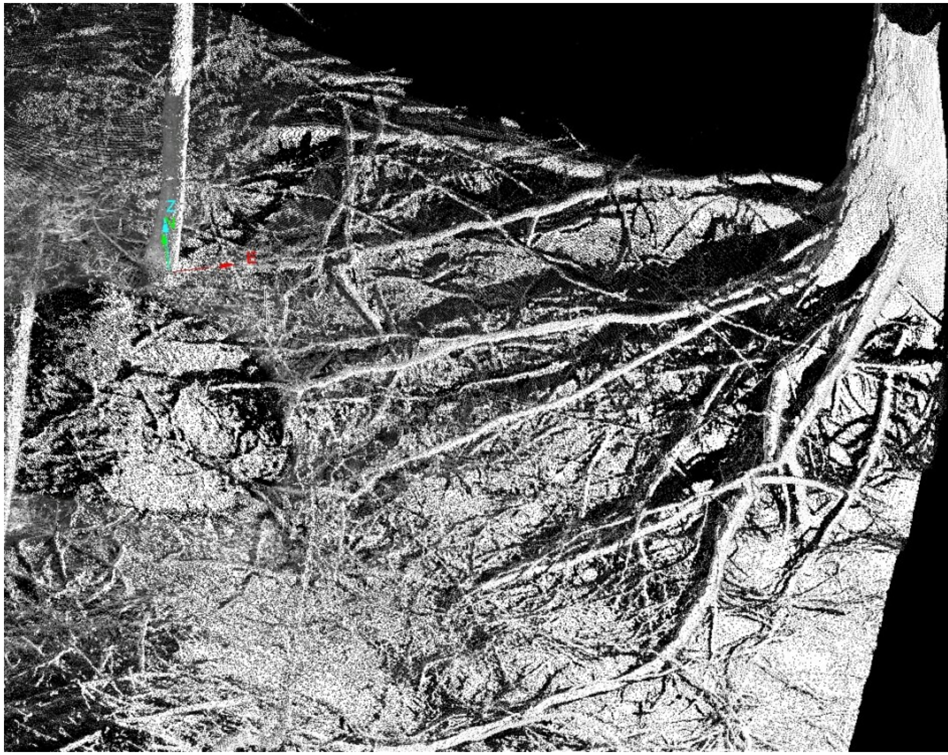
Unweathered Granite

Courtesy: Ekaterina Roudneva

Terrestrial LIDAR Measurements

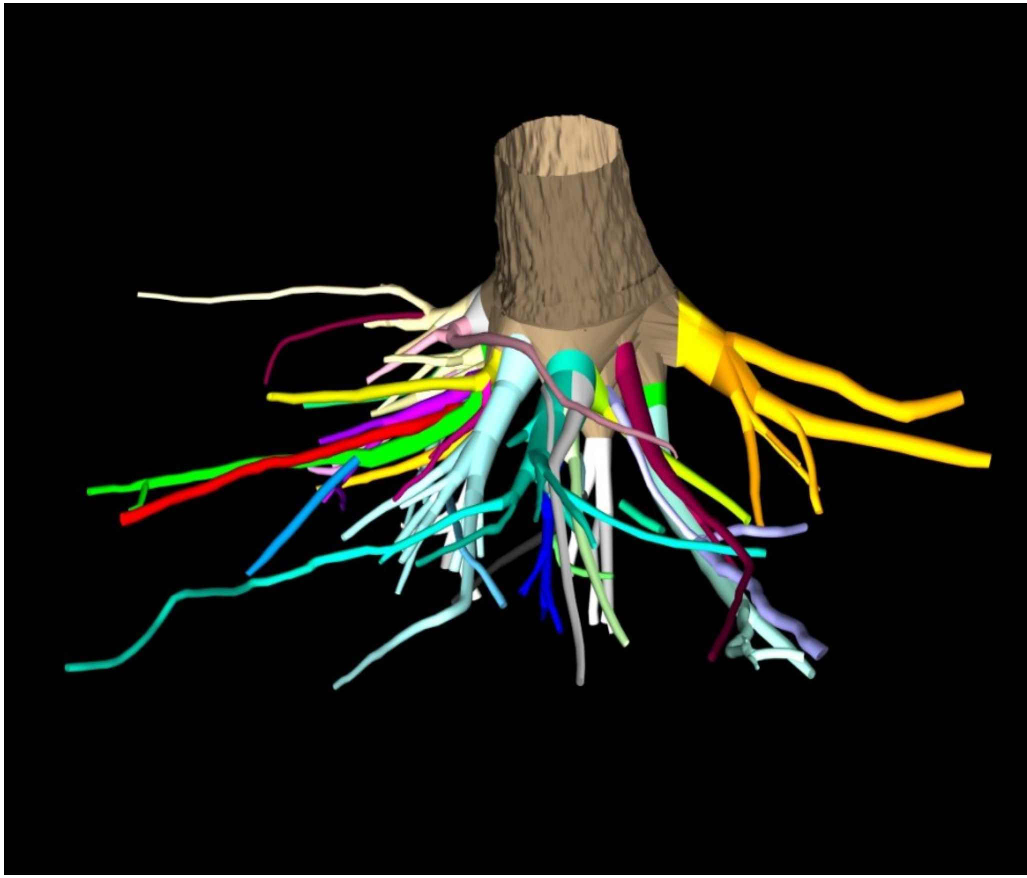
Raw Scans



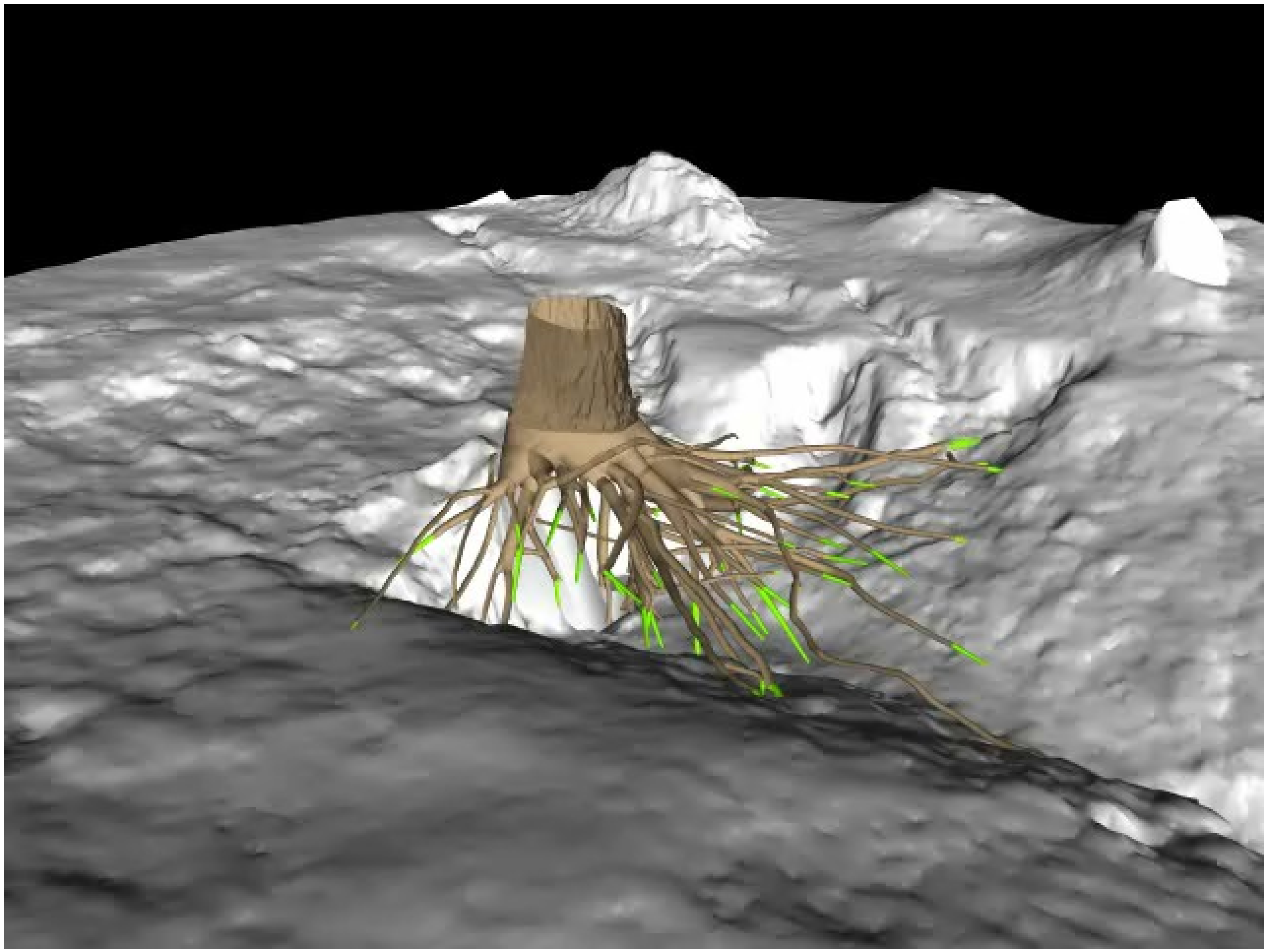


Root Modeling of LiDAR data

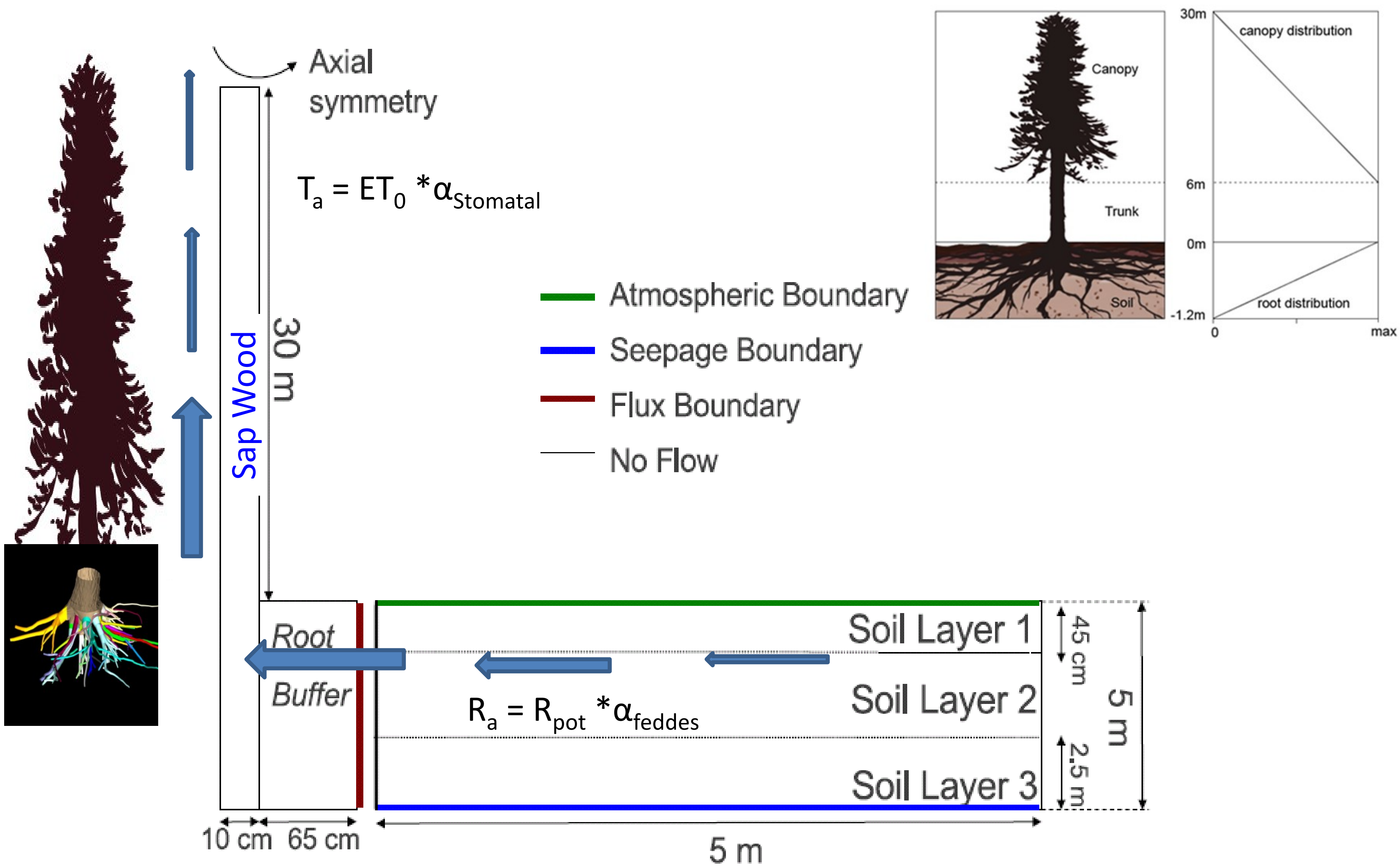
- Two systems, large roots and small roots
  - Assume axial symmetry
  - Calculate root density, root location relative to the ground surface and various soil horizons
  - Correlate with changes in water content from instrumented tree CZT-1



Root model movie

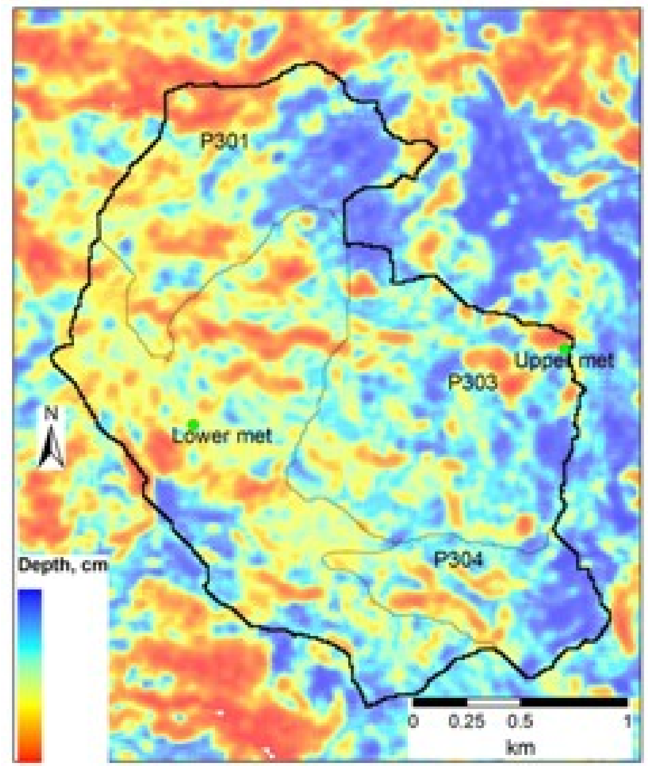


Future Directions
1. Modeling

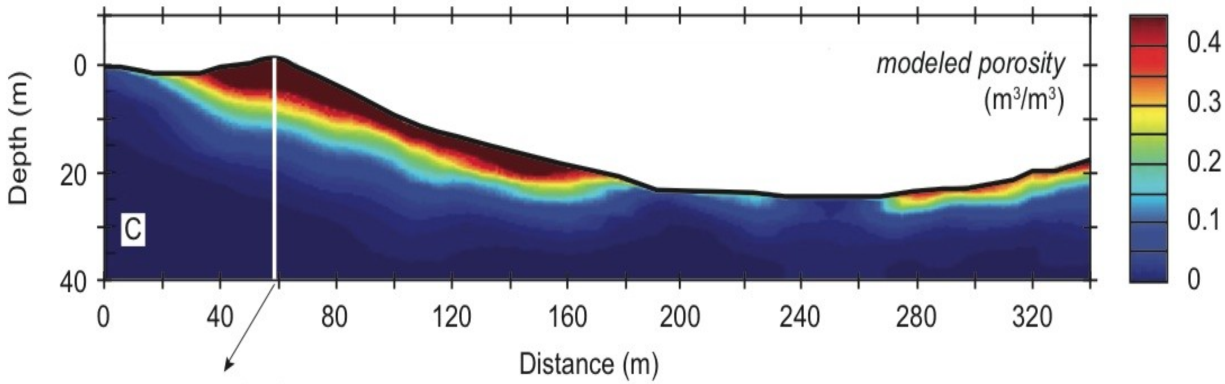


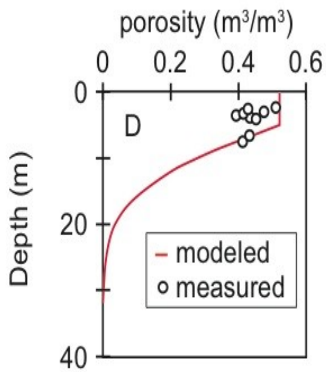
Future Directions
2. Upscaling- Soil depth and water storage

- NASA soil moisture (SMAP satellite) expand soil moisture monitoring
- COSMOS sensors
- Depth to bedrock
- Better tools for soil depth assessment
- Better understanding of snow distribution across the landscape



Holbrook et al (in review)





Results from surveys of resistivity (A) and seismic refraction (B) along a transect spanning a forested slope and saturated meadow in catchment P301. Porosity (C) inferred from P-wave velocity data assuming vertical variations in velocity stem solely from variations in porosity. Porosity profile (D) near the CZ tree shows good agreement between measurements from regolith samples (open circles) and modeled porosity from the P-wave data (red line), illustrating how geophysical data can shed light on subsurface water storage potential.

Future Directions
3. Deep monitoring

- Deep(er) vadose zone monitoring
- Recharge to/into saprolite and bedrock
- Continued root measurements-Expensive!

The fourth dimension: The influence of time

- Regolith resonance times 10^5-10^6 years
- Current regolith formation decoupled from current climate
- Geochemical measurements indicate that the presence of soil is regulated by bedrock nutrient content through its influence on vegetation.

Research directions/interesting questions: Where are we going with this?

- Applicability over larger scales?
- Decoupling of scales of species migration and regolith decomposition
- Deeper understanding of late season water use
- If summers are longer and drier, how will the trees survive? Where will trees survive? Which trees will survive?

Acknowledgements

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and many others . .. .

http://criticalzone.org/sierra/