Seasonality of subsurface electrical resistivity as a proxy for tree water use inferred from empirical orthogonal frequency (EOF) analysis

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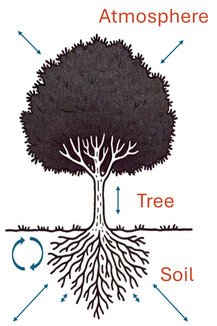
Motivation: seasonality of tree water-use strategies in White-fir trees

Water pathways in **soil-tree-atmosphere continuum** are clear; Seasonal variations, drivers, lags in continuum are less understood

This work informs tree drought response

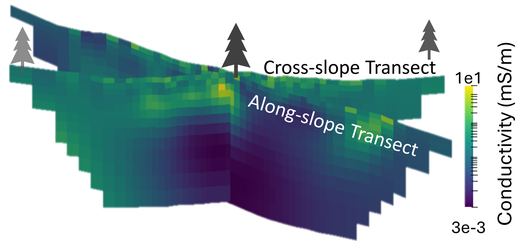


Using electrical resistivity to explore these concepts calls for a novel, clear method to identify spatiotemporal soil moisture patterns

Tree water-use strategies = water-update depth, soil moisture timing, hydraulic redistribution, etc.

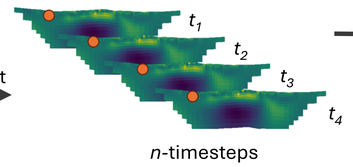
Experimental Question:
How does the water-use strategy of a White-fir tree change over the growing season (water vs energy limited)?

Principal Component Analysis (PCA) with Empirical Orthogonal Frequencies (EOF) as Novel Geophysical Analysis Method

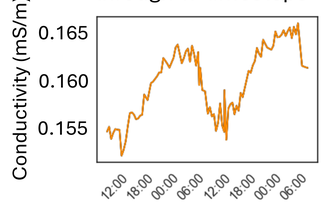


Time-lapse inversion in ResIPy

Take 1 Transect



1 pixel's conductivity through n-timesteps



$$c(t) = [c_1 \quad c_2 \cdots \quad c_n]$$

Normalized each pixel's time series

$$cz(t) = zscore(c)$$

$$= \frac{c - mean(c)}{std(c)}$$

Combine all p-pixels

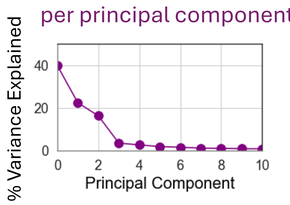
$$C = \begin{bmatrix} cz_{11} & cz_{12} & \cdots & cz_{1n} \\ cz_{21} & cz_{22} & \cdots & cz_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ cz_{p1} & cz_{p2} & \cdots & cz_{pn} \end{bmatrix}$$

Run Principal Component Analysis

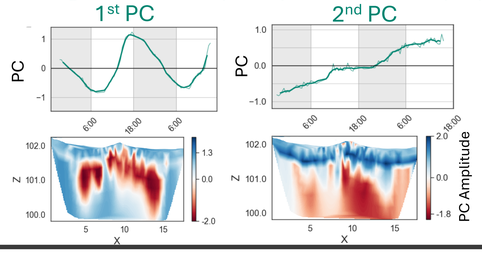
$$cov\_matrix = cov(C, weights = resolution\_matrix)$$

$$eigenvalues,\ eigenvectors = eig(cov\_matrix)$$

Eigenvalues = % variance of inversion dataset explained per principal component



1st Eigenvector = 1st principal component (PC)



Southern Sierra Critical Zone Observatory: P304 Catchment

Location: Sierra Nevada, CA
Climate: Mediterranean
Annual Precip: 1.3m;
61% as snow
Mean Elevation: 1895 m
Vegetation: Mixed-conifer

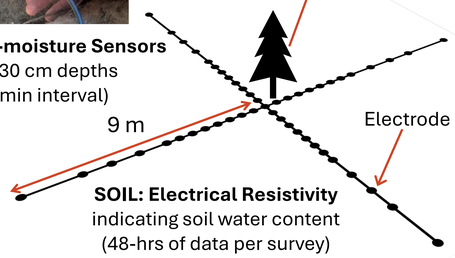
Hydrogeophysical Methods

Field Collection: October 2022, June 2023, October 2023, May 2024

ATMOSPHERE: Vapor Pressure Deficit Sensor indicating air dryness (15-min interval)

SOIL: Soil-moisture Sensors
15 & 30 cm depths
(15-min interval)

PLANT: Sapflow Sensor indicating tree water-use (15-min interval; 4 trees)



SOIL: Electrical Resistivity indicating soil water content (48-hrs of data per survey)

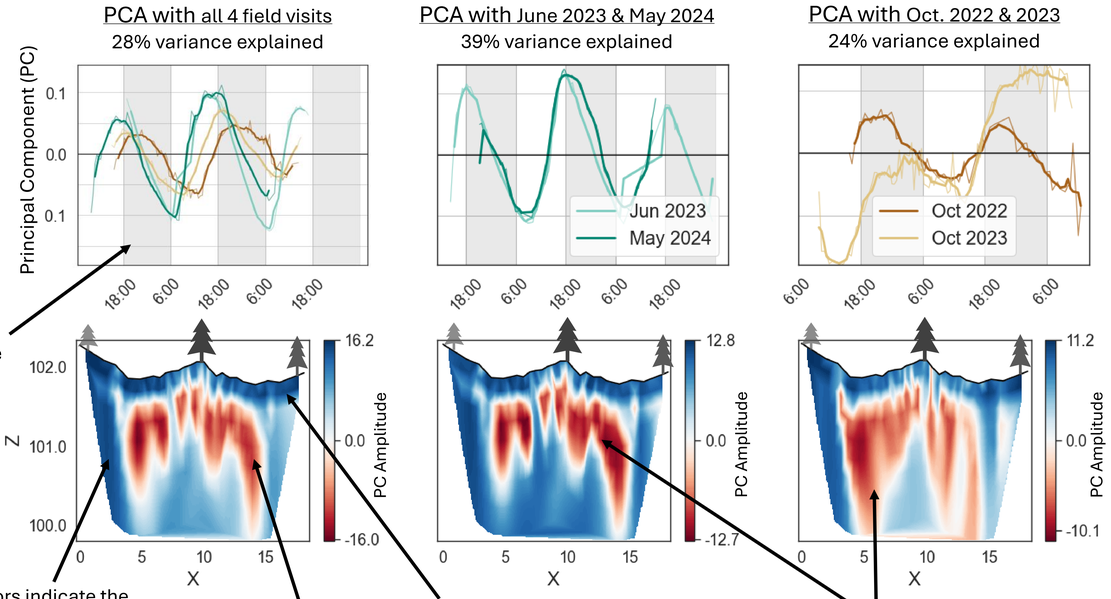
PCA/EOF Captures Daily Soil Moisture Cycles & Seasonal Differences

$$c(t,x,z) = \sum_{k=1}^{p} PC_k(t) \cdot EOF_k(x,z)$$

Conductivity (mS/m) is combo of PC*EOF (unitless) across p-many components

- Dimensionality reduction applied to inverted time-lapse resistivity profiles
- Deconstructs conductivity into key temporal (PC) and spatial (EOF) components
- 1st component explains largest variance, often tree-water uptake cycles
- Flexible statistical tool for large datasets; reduces noise

PC is proxy for soil moisture



Spring/Summer has larger soil moisture cycles than Fall, aligning with increased tree water uptake and transpiration in sunnier, wetter months

The colors indicate the strength of the relationship

Blue areas reflect the time-series above

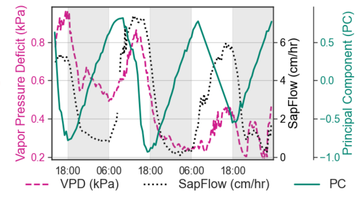
Red areas reflect the inverse of the time-series above

Near-surface zone:
DAY – wets
NIGHT - dries/drains

Active rooting zone:
DAY - dries (tree water uptake)
NIGHT - draws water in (hydraulic redistribution)

The active root zone is shallower in Spring/Summer when soil moisture and sapflow are higher, **and deeper in Fall**, when the system is more water-limited and trees need deep moisture

PCs (~Soil Moisture), VPD, Sapflow are Correlated

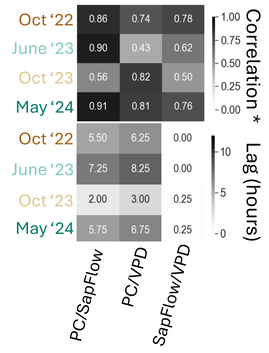


PCs (electrical resistivity proxy of soil moisture) correlate more strongly with tree water than air dryness

Soil moisture lags behind sapflow and VPD, suggesting at drivers of soil moisture

PC has a 1hour + lag to VPD than sapflow

Spring/Summer PCs: longer lag to sapflow and VPD than in Fall → faster response during more water-limited conditions



* all correlations are significant at p-value < 0.05

Take-aways

Principal Component Analysis (PCA) with Empirical Orthogonal Frequencies (EOF) can identify dominant spatiotemporal water cycles in time-lapse electrical resistivity inversions

In more water-limited than energy-limited conditions, tree water-uptake depths are deeper, and soil moisture is more responsive to tree water-use

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