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Reduction in lumen area increases the amount of $\delta^{18}O$ exchange with source water during cellulose synthesis

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Motivation

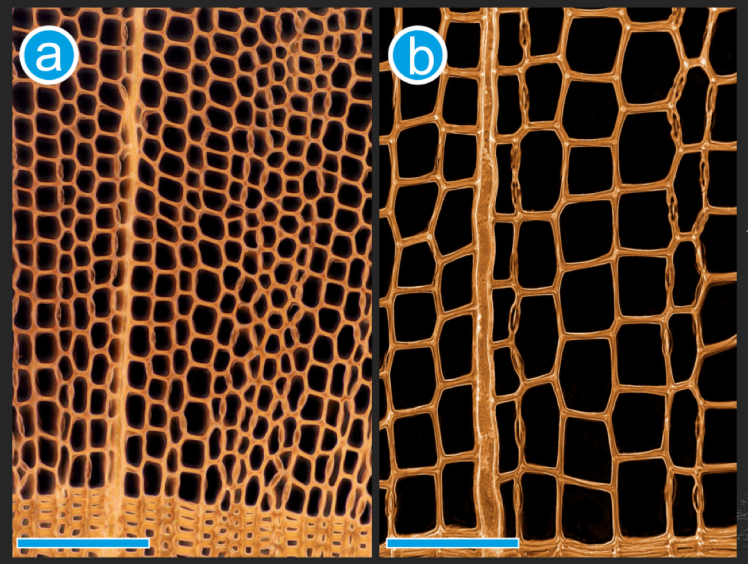
- High resolution xylem anatomical studies, such as wood density, cell wall thickness (CWT), lumen area (LA), and blue wood intensity have been used to understand tree responses to climate.

- Isotopic composition ($\delta^{18}O$ and $\delta^{13}C$) has enabled the study of intra-seasonal tree growth dynamics in response to environmental and ecophysiological processes.

Aim: To link the physical characteristics of cambial development with isotopic composition of cellulose.

Cambial Development

1. Lumen Area (LA)
2. Cell Wall Thickness (CWT)



Rosner S. (2017). *Journal of Plant Hydraulics*, *4*, e001. https://doi.org/10.20870/jph.2017.e001

Cellulose Isotopic Theory and Model

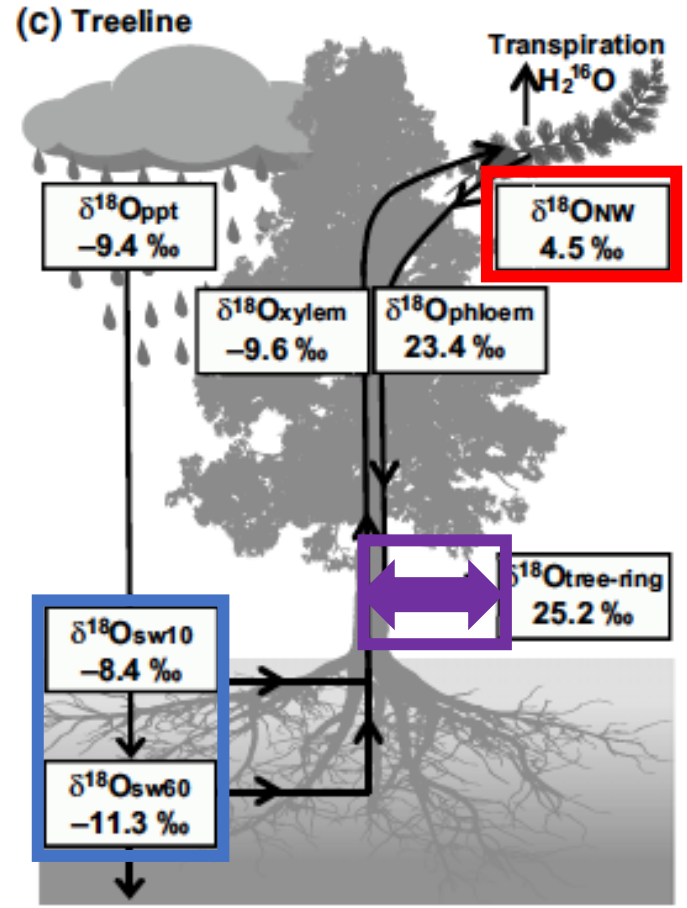
$$1)\ \delta_{cellulose} = P_{ex}\,(\delta_{source} + \varepsilon) + (1- P_{ex})(\delta_{leaf} + \varepsilon)$$

ε = 27 ± 4‰ (DeNiro and Epstein, 1983)
P_{ex} = fraction of sugars exchanging oxygen with xylem water, 0.42 (Roden et al., 2000), 0.34 (Yakir and DeNiro, 1990)

$$2)\ \delta_{leaf} = \delta_{source} + \varepsilon^{+} + \varepsilon_K + (\delta_{vapour} - \delta_{source} - \varepsilon_K)\, e_a/e_i$$

ε^{+} (‰) = $2.664 - 3.206\,(10^3/T_l) + 1.534\,(10^6/T_l)$(Bottinga and Craig, 1969)
ε_K (‰) = $32r_s + 21r_b/r_s+r_b$ (Cappa et al., 2003)

Question: How do the physical characteristics of cambial development (e.g. variation in lumen area and cell wall thickness) interact with the variables that influence $\delta^{18}O_{cellulose}$, specifically $\delta^{18}O_{source}$, relative humidity, and P_{ex}?



relative humidity and leaf water

P_{ex} = fraction of sugars exchanging oxygen with xylem water

$\delta^{18}O$ of source water

Treydte et al. (2014) *New Phytologist* 202: 772–783

Greenhouse experiment: constant $\delta^{18}O$ source water, two levels of relative humidity

75% RH
10 Douglas fir
10 Ponderosa pine

25% RH
10 Douglas fir
10 Ponderosa pine

COLD

ROOM

75% RH
10 Douglas fir
10 Ponderosa pine

25% RH
10 Douglas fir
10 Ponderosa pine

Wood Harvested

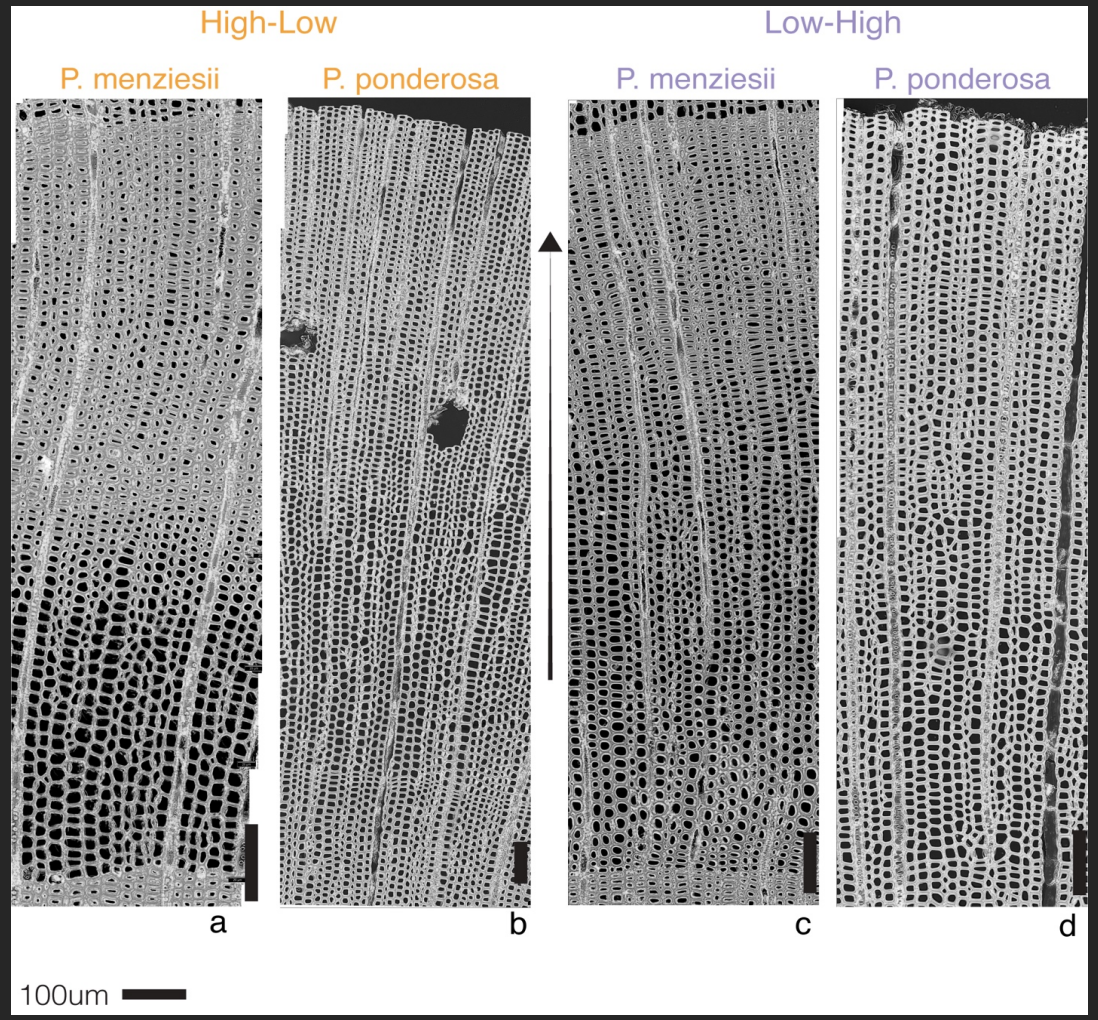
Jan – May

June

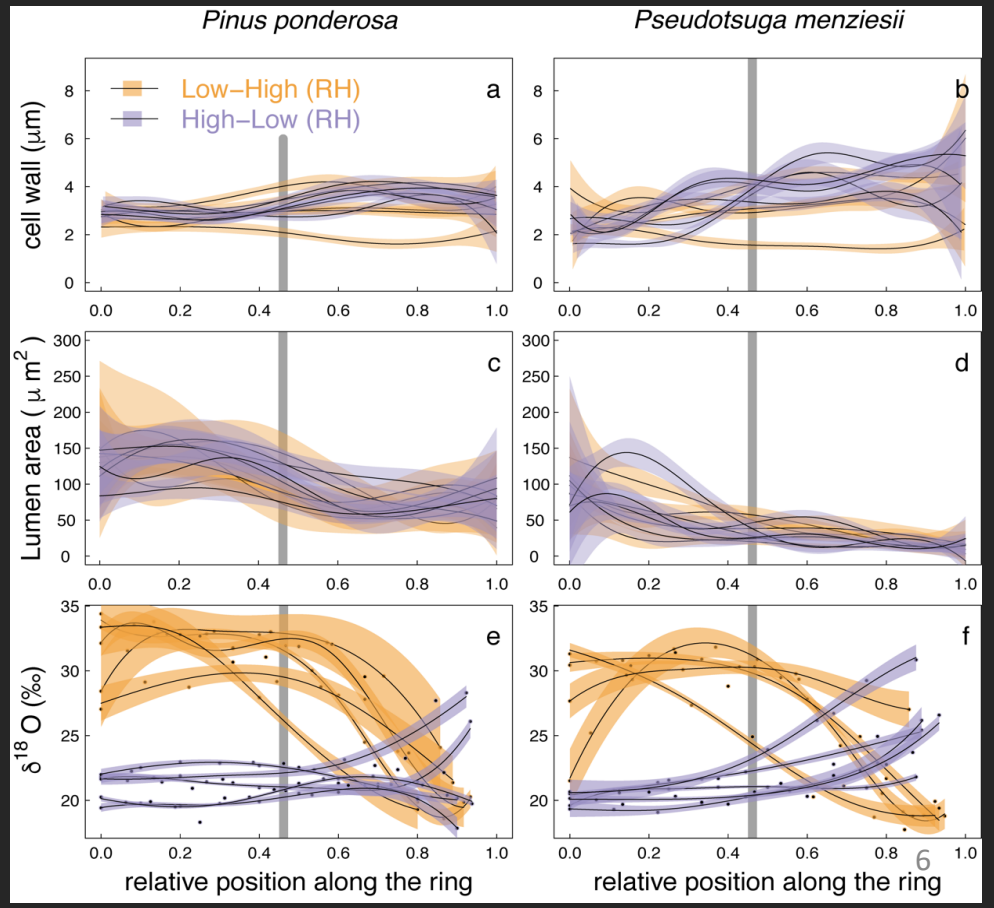
July – Dec

Wood anatomy and isotopic analyses

1. New woody growth was sectioned and scanned. Shown below is only one representative picture for each species from the two treatments.



2. Eight to ten slices were made within each new ring. For each slice, cell wall thickness, lumen area, and $\delta^{18}O$ of cellulose were measured. Trees that went from low to high relative humidity are in orange, and trees that went from high to low relative humidity are in purple.

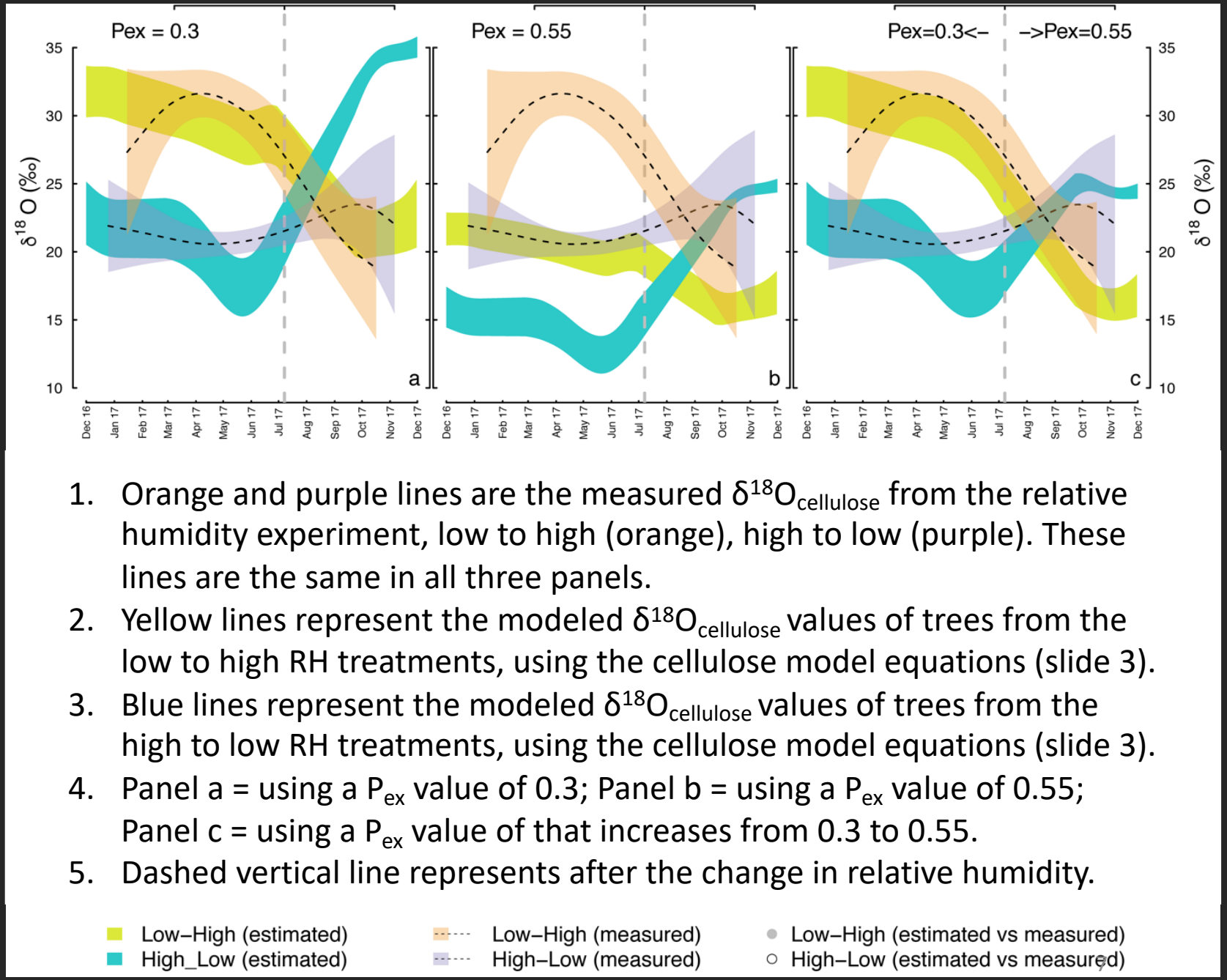


Results: $\delta^{18}O_{cellulose}$

1. Panel a: Modeled and measured values of $\delta^{18}O_{cellulose}$ agreed well during the first half of the ring, but diverged at the second half, especially the high-low RH treatment.

2. Panel b: Modeled and measured values of $\delta^{18}O_{cellulose}$ did not agree well for the first half, but for the second half, there was better agreement in the low-high RH treatment.

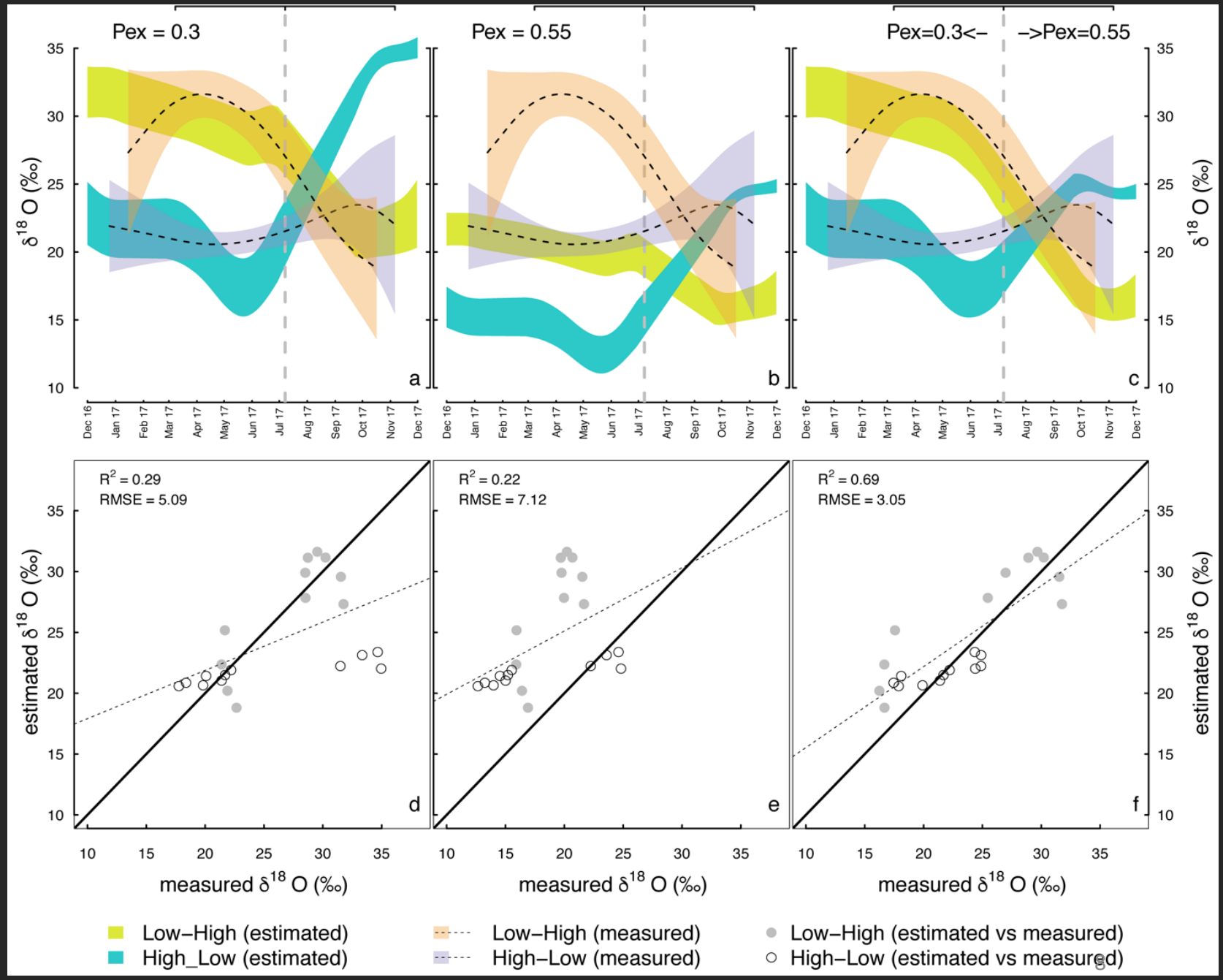
3. Panel c: There was generally good agreement between modeled and measured values of $\delta^{18}O_{cellulose}$ when P_{ex} was allowed to increase throughout the ring.



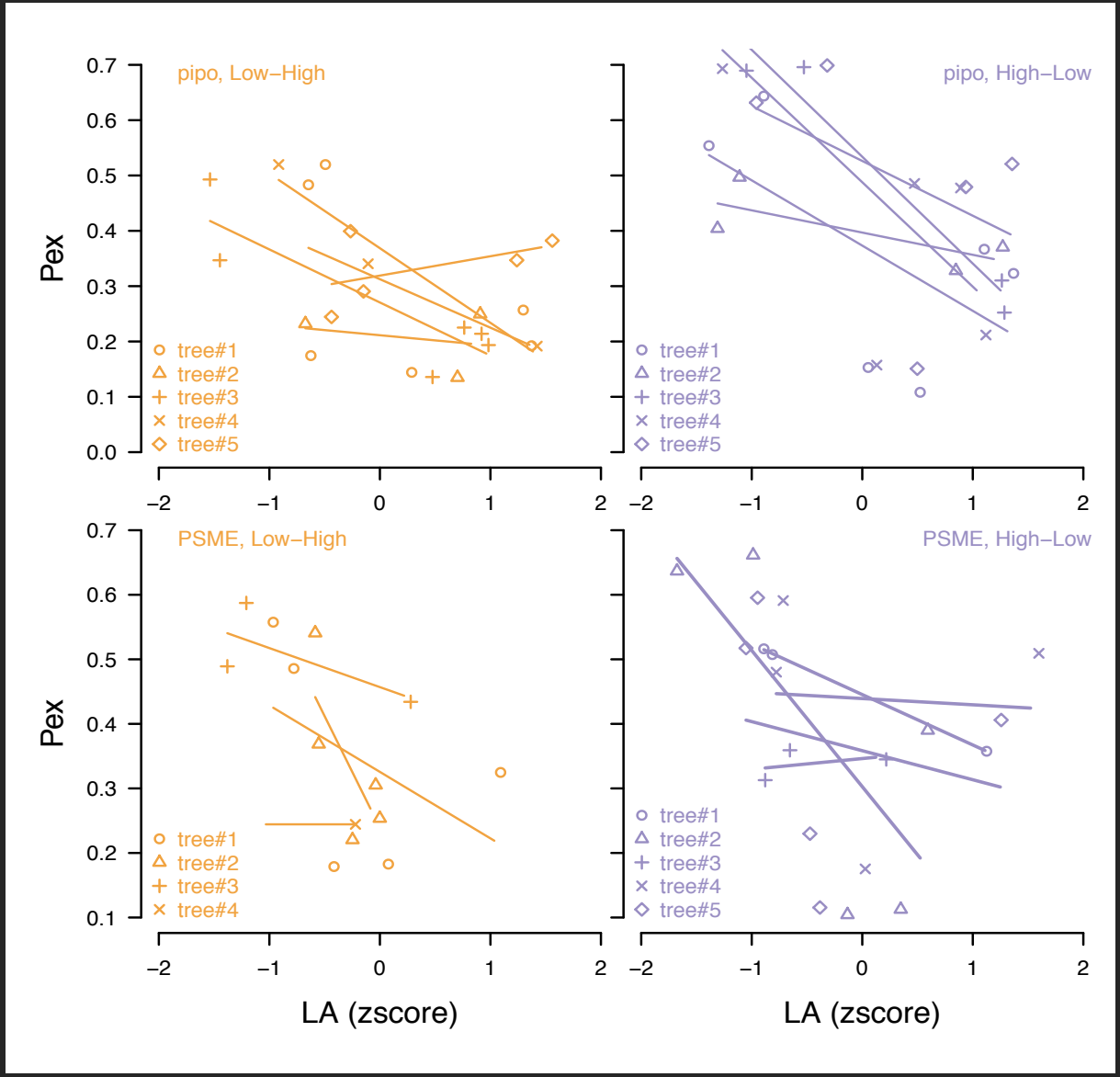
1. Orange and purple lines are the measured $\delta^{18}O_{cellulose}$ from the relative humidity experiment, low to high (orange), high to low (purple). These lines are the same in all three panels.
2. Yellow lines represent the modeled $\delta^{18}O_{cellulose}$ values of trees from the low to high RH treatments, using the cellulose model equations (slide 3).
3. Blue lines represent the modeled $\delta^{18}O_{cellulose}$ values of trees from the high to low RH treatments, using the cellulose model equations (slide 3).
4. Panel a = using a P_{ex} value of 0.3; Panel b = using a P_{ex} value of 0.55; Panel c = using a P_{ex} value of that increases from 0.3 to 0.55.
5. Dashed vertical line represents after the change in relative humidity.

Results: $\delta^{18}O_{cellulose}$

Panels d, e, f: Modeled and measured values of $\delta^{18}O_{cellulose}$ agreed well when P_{ex} was allowed to increase from 0.3 to 0.55.



Results: Relationship between wood anatomy (lumen area) and P_{ex}



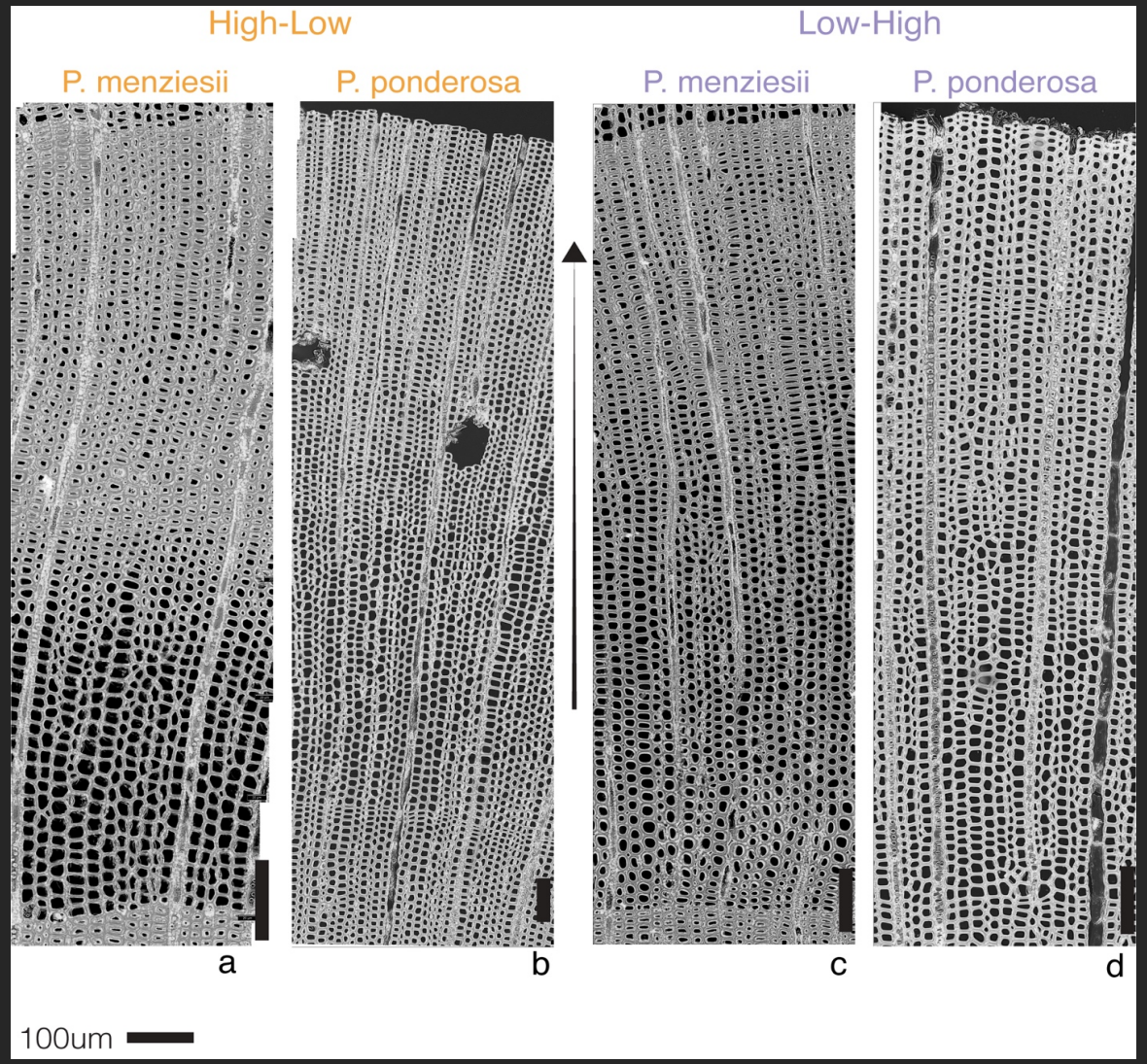
1. Calculated P_{ex} by re-arranging equations:

$$P_{ex} = \frac{\delta^{18}O_{cell} - \left[\delta^{18}O_{wx} + \varepsilon_c + \varepsilon_k + \varepsilon^* + (-\varepsilon^* - \varepsilon_k)\frac{e_a}{e_i}\right]}{-\left(\varepsilon_k + \varepsilon^* + (-\varepsilon^* - \varepsilon_k)\frac{e_a}{e_i}\right)}$$

2. Regressed lumen area (LA; expressed as z-score) and P_{ex}.

3. Results suggest that:
Smaller lumen area = higher P_{ex}
Larger lumen area = lower P_{ex}

TAKE HOME MESSAGE #1

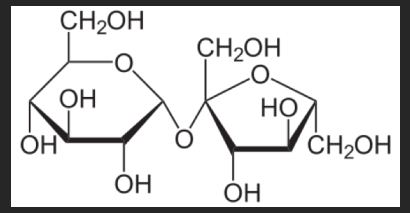


Smaller lumen area, Higher P_{ex}
(more exchange with xylem water)

Larger lumen area, Lower P_{ex}
(less exchange with xylem water)

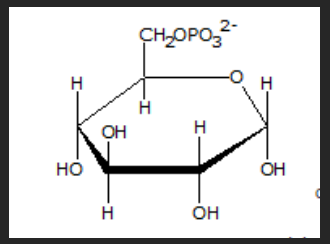
Discussion: Why might there be a correlation between lumen area and P_{ex}? Our working hypothesis:

sucrose



1. Sucrose is cleaved into hexose-phosphates during cellulose synthesis.

hexose-phosphates

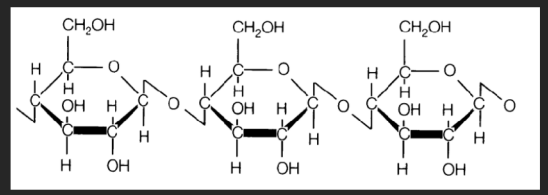


2. There are two pathways for hexose phosphates during cellulose synthesis, depending on the strength of the growth sink.

Fast turnover/strong sink: hexose-phosphates are immediately synthesized into cellulose

→ Low P_{ex} →

Fast turnover/strong sink: ONE oxygen molecule exchanges with xylem water



cellulose

Slow turnover/weak sink: hexose phosphates under-go triose-phosphate cycling before synthesized into cellulose

→ High P_{ex} →

Slow turnover/weak sink: THREE oxygen molecule exchanges with xylem water

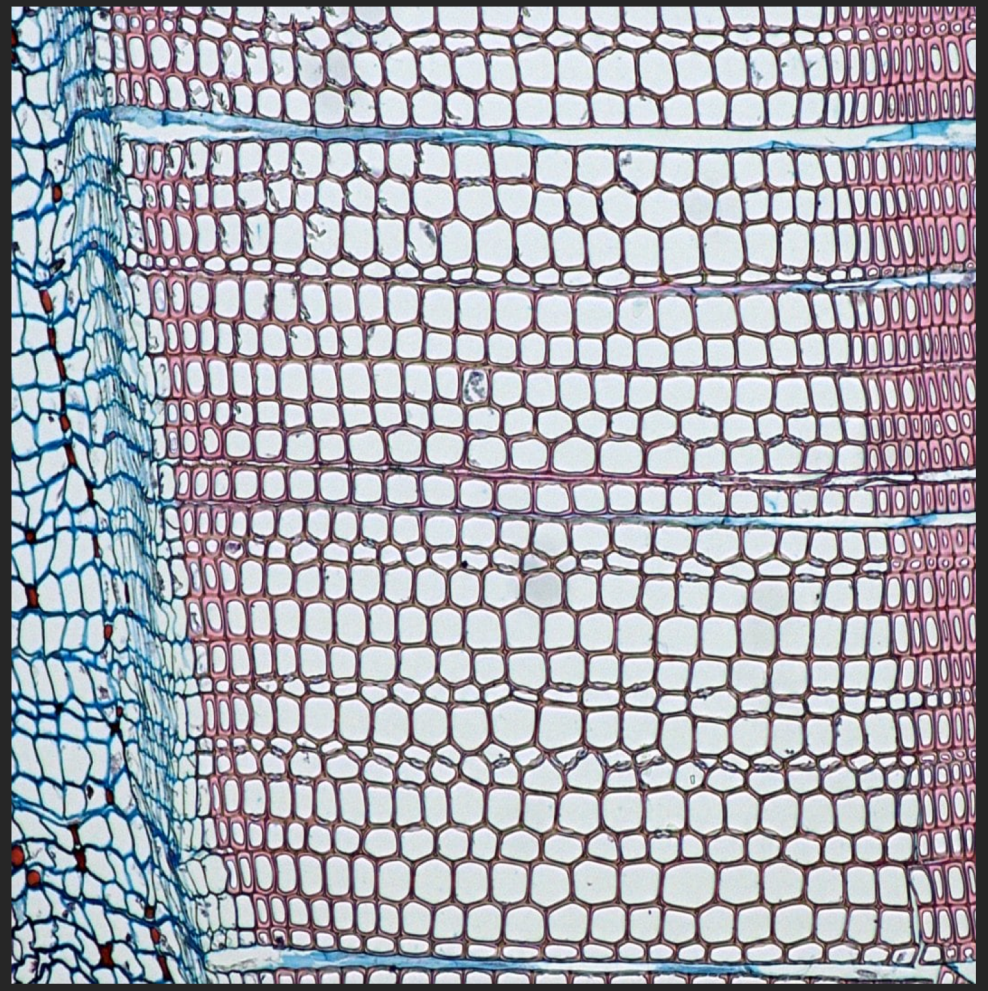
Might different sections of the ring record different climate factors?

LATE WOOD

Slow turnover/weak sink: THREE oxygen molecule exchanges with xylem water

High P_{ex}

Records more of the source water signal.



EARLY WOOD

Fast turnover/strong sink: ONE oxygen molecule exchanges with xylem water

Low P_{ex}

Records more of the relative humidity signal.

Conclusion

1. Changes in relative humidity did not induce anatomical changes in the xylem tissue, but it was recorded in the $\delta^{18}O$ of cellulose.
2. Modeled values did not agree well with measured $\delta^{18}O_{cellulose}$ values unless we allowed P_{ex} to increase throughout the tree ring.
3. We also found a negative relationship between P_{ex} and lumen area; larger lumen area were correlated with lower P_{ex}, while smaller lumen area were correlated with higher P_{ex}.
4. We hypothesize that the relationship between lumen area and P_{ex} is due to changes in source/sink dynamics during cellulose synthesis (and therefore the fraction of hexose-phosphate sugars that undergo triose-phosphate cycling).
5. We propose that this relationship between lumen area and P_{ex} could help targeted sampling for reconstruction of source water (latewood) or atmospheric aridity (earlywood) within an annual tree ring.

Thanks You!

Szejner, P., Clute, T., Anderson, E., Evans, M.N., and J. Hu. 2020. Reduction in lumen area is associated with the $\delta^{18}O$ exchange between sugars and source water during cellulose synthesis. New Phytologist doi: 10.1111/nph.16484