The theoretical basis for tree hydraulics

Dr. Ashley M. Matheny
Department of Geological Sciences
University of Texas at Austin 😊

Keck Institute for Space Studies
Sensing Forest Water Dynamics From Space: Towards Predicting the Earth System Response to Droughts
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Vegetation-atmosphere feedbacks

Atmospheric processes

Vegetation

Below ground processes

\[ R_n = G + H + \lambda E \]

Nevada.usgs.gov
How much water is flowing?

Sap leaks from a birch tree during sensor installation in real time.
Water transport: the basics
Water movement inside of a plant

- From Bohrer et al 2005, WRR
The onset of hydraulic limitations

- From Brodribb et al. 2015, New Phytologist
Cavitation and hydraulic vulnerability

From Maherali et al. 2006, PC&E
Trading safety for efficiency?

- A perfect tradeoff of safety and efficiency doesn’t exist (Gleason 2016, New Phytologist), because compounding variables abound

> From Manzoni 2013, New Phytologist
Trading carbon for water: Carbon maximization theory

\[ MXTE = \frac{\partial A_n}{\partial \psi_L} \]

- From Anderegg et al. 2018, Ecology Letters
Consequences of hydraulic strategies

Matheny et al. 2017, Ecohydrology
Diurnal leaf water dynamics

*Note: 10 bar = 1 MPa

- Thomsen et al. 2013, Forests

Measuring leaf water potential with Alyssa Wunderlich (REU), summer 2014
Reliance on biomass capacitance

- Matheny et al. 2015, Ecosphere

Capacitance sensor in maple, 2016
Water storage dynamics with declining soil water

Diurnal water withdrawal (kg) vs. Soil water potential (MPa)

- Maple

$R^2 = 0.53$

$P < 0.0001$
Differential access to water in the root-zone

- D-excess:
  \[ \delta^{D-8} \times \delta^{18}O \]

➢ Matheny et al. 2016, Ecohydrology
The framework for a whole plant hydraulic strategy

- McCulloh et al. 2019, PCE
Isohydricity as a whole plant response

- Martinez-Vilalta & Garcia-Forner 2017, PCE
Isohydricity as a whole plant response

\[
\frac{d \psi_L}{d \psi_S} = \frac{\delta \psi_L}{\delta \psi_S} + \frac{\delta \psi_L}{\delta VPD} \frac{\delta VPD}{\delta \psi_S} + \frac{\delta \psi_L}{\delta A_L} \frac{\delta A_L}{\delta \psi_S}
\]

\[
\frac{d g_s}{d \psi_S} = \frac{\delta g_s}{\delta \psi_S} + \frac{\delta g_s}{\delta VPD} \frac{\delta VPD}{\delta \psi_S}
\]

- Novick et al. 2019, PCE
- McCulloh et al. 2019, PCE
Can we classify species based on hydraulics?

- Meinzer et al. 2016, Ecology Letters

Blue Oak

Scouler’s Willow

- $\Psi_{\text{min}} = \Psi_{pd}$
- $r^2 = 0.96$, $P < 0.0001$
- $\Psi_{\text{min}} @ \Psi_{pd} = 0$
- $r^2 = 0.86$, $P = 0.0008$
Correlations among hydraulic traits?

- Fu et al. 2019, PCE

Hydroscape area
Hydraulic “trait spaces”

- Mursinna, et al. *Forests* 2018
Underrepresented parameters: Roots

It's not just about depth anymore

➢ Agee, et al. In prep
Hydraulic strategy influences growth

- Matheny et al. 2017, Ecohydrology

- 2001-2014
- Maple: n = 423
- Oak: n = 114

Dendrometer (Saskatchewan)

- \( R^2 = 0.36 \)
- \( P = 0.02 \)
Changes to canopy structure and composition

Control

Disturbance

- Control LAI ≈ 3.89 m²m⁻²
- Disturbance LAI ≈ 3.68 m²m⁻²
Water limitation produces largest plot-scale differences
Within ecosystem divergent hydraulic function is common!

Contrasting strategies of hydraulic control in two codominant temperate tree species

Ashley M. Matheny¹ | Richard P. Fiorella²,³ | Gil Bohrer¹ | Christopher J. Poulsen² | Timothy H. Morin¹ | Alyssa Wundel

Hydraulic architecture of two species differing in wood density: opposing strategies in co-occurring tropical pioneer trees

KATHERINE A. MCCULLOH¹, DANIEL M. JOHNSON², FREDERICK C. MEINZER³, STEVEN L. VOELKER⁴, BARBARA LACHENBRUCH⁵ & JEAN-CHRISTOPHE DOMEÇ²³

Differential use of spatially heterogeneous soil moisture by two semiarid woody species: Pinus edulis and Juniperus monosperma

DAVID D. BRESHEARS, ORRIN B. MYERS, SUSAN R. JOHNSON, CLIFTON W. MEYER and SCOTT N. MARTENS*

Environmental Science Group, Mail Stop J495, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Boreal tree hydrodynamics: asynchronous, diverging, yet complementary

Christoforos Pappas¹,¹⁰, Ashley M. Matheny²,³, Jennifer L. Baltzer⁴, Alan G. Barr⁵, T. Andrew Black⁶, Gil Bohrer³, Matteo Detto⁷,⁸, Jason Maillet⁹, Alexandre Roy¹, Oliver Sonnentag¹ and Jilmarie Stephens⁶
The difficulties of scale

Can we connect hyper-local measurement to big-picture understandings of ecosystems?
Scaling from tree to ecosystem level

- Trees within the same histogram ‘bin’ are assumed to transpire similarly.
Scaling from tree to ecosystem level

![Bar chart showing total seasonal flux (W m$^{-2}$ ground) for different types of trees: Oak, Pine, Maple, Aspen, Birch, Other, Beech, and LE. The chart compares Sap flux, Latent heat, and Control.]
Intra-specific trait variation

- Anderegg 2015, New Phytologist
New challenges

How does drought effect the trees that live?

- Bohrer, et al. *AGU* 2018
Hysteretic responses to water stress

Bohrer, et al. AGU 2018
A deeper perspective on xylem networks

Mrad, et al. 2018 PCE
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Restrepo Acevedo, Austin Rechner, A. Rio
Mursinna, Airborne LiDAR – NCALM
(UMBS data)
P.E.O. Chapter AV
Vegetation plays a central role in water, energy, and nutrient cycles.

Plants control hydraulic function dynamically!

New measurements and models can improve our understanding of hydrosphere-biosphere-atmosphere exchange.