GIANTS IN THE MIST:
the ecophysiology, land-sea interface, and climate change connections for California's Redwoods

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-Vegetation distribution is closely linked to plant response (physiological & ecological) to climate = temperature, precipitation, aridity, & combinations of ….

-Western North American ecosystems show a marked association with local or regional hydrological regimes that are also intimately linked to climate

-Redwood trees and redwood forests demonstrate some unique relationships to coastal climate regimes defined by a very powerful land-sea interface that impacts coastal hydrology and much more

-Climate change threatens to significantly alter these regimes;

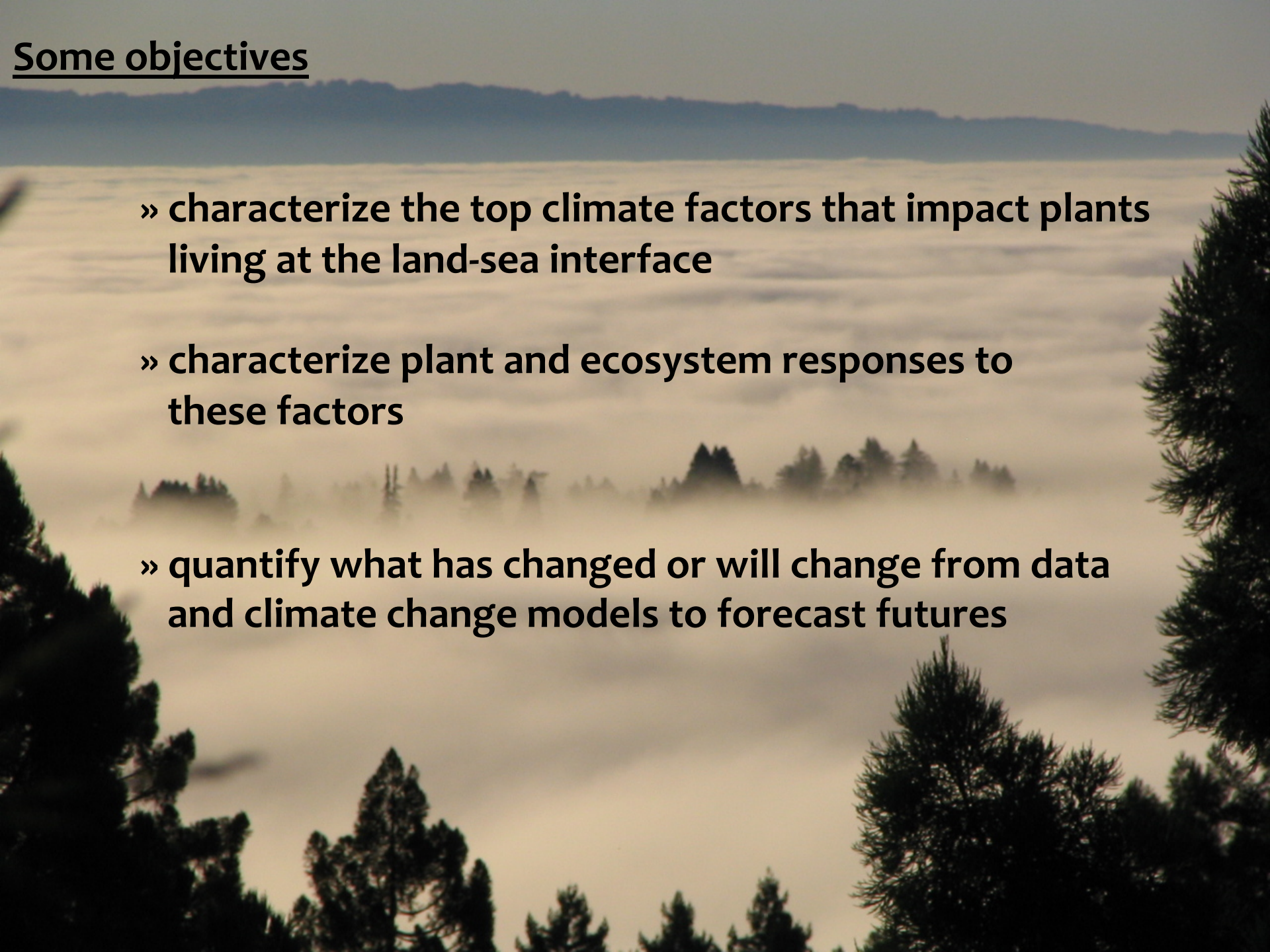
- what will change?
- how will it impact trees and ecosystems?
- how will it impact the climate-tree-hydrology nexus?

Approach

We've been investigating plant/ecosystem response to climate and climate change requiring us to know:

» how plants function in response to current and also past climate changes to forecast possible future responses

» what climatic factors shape function and ecology most and what will change most significantly



Some objectives

» characterize the top climate factors that impact plants living at the land-sea interface

» characterize plant and ecosystem responses to these factors

» quantify what has changed or will change from data and climate change models to forecast futures

Land-Sea Interfaces

Are the Earth's largest "**ecotone**"

Comprise ~8% of the Earth's surface - between 0.6 and 1.5 million km's of coastline (estimates vary because coastlines are fractal) - **largely ignored by terrestrial ecologists**

Are well known sites of material exchange and the water, organic matter / nutrients subsidize communities so significantly that **organismal diversity** and **densities** are enhanced (e.g., Gary Polis and co-workers, 1997, 1999, 2003) and therefore the conditions for **plant performance** are also likely altered in positive ways

Land-Sea Interfaces

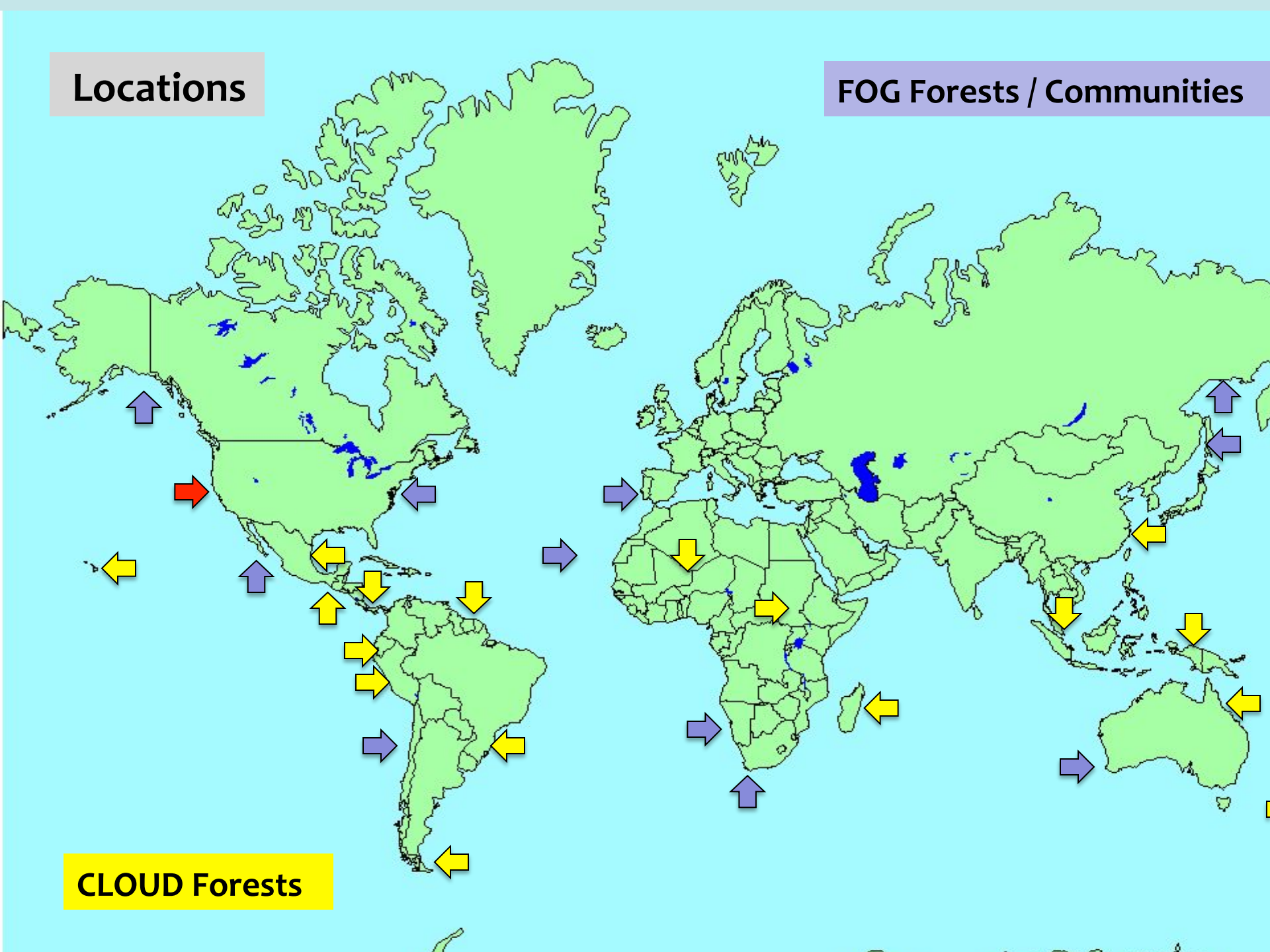
Additionally, **near-shore**, redwood forests occur near "upwelling zones" and these zones **receive nutrients** that influence the nutrient pools (+ productivity)

Some cyanobacteria in upwelling zones **fix atmospheric N_2**, adding to nutrient stocks in these zones

Q: do these subsidies enhance **on-shore** biogeochemical cycles, productivity and/or organsimal function?

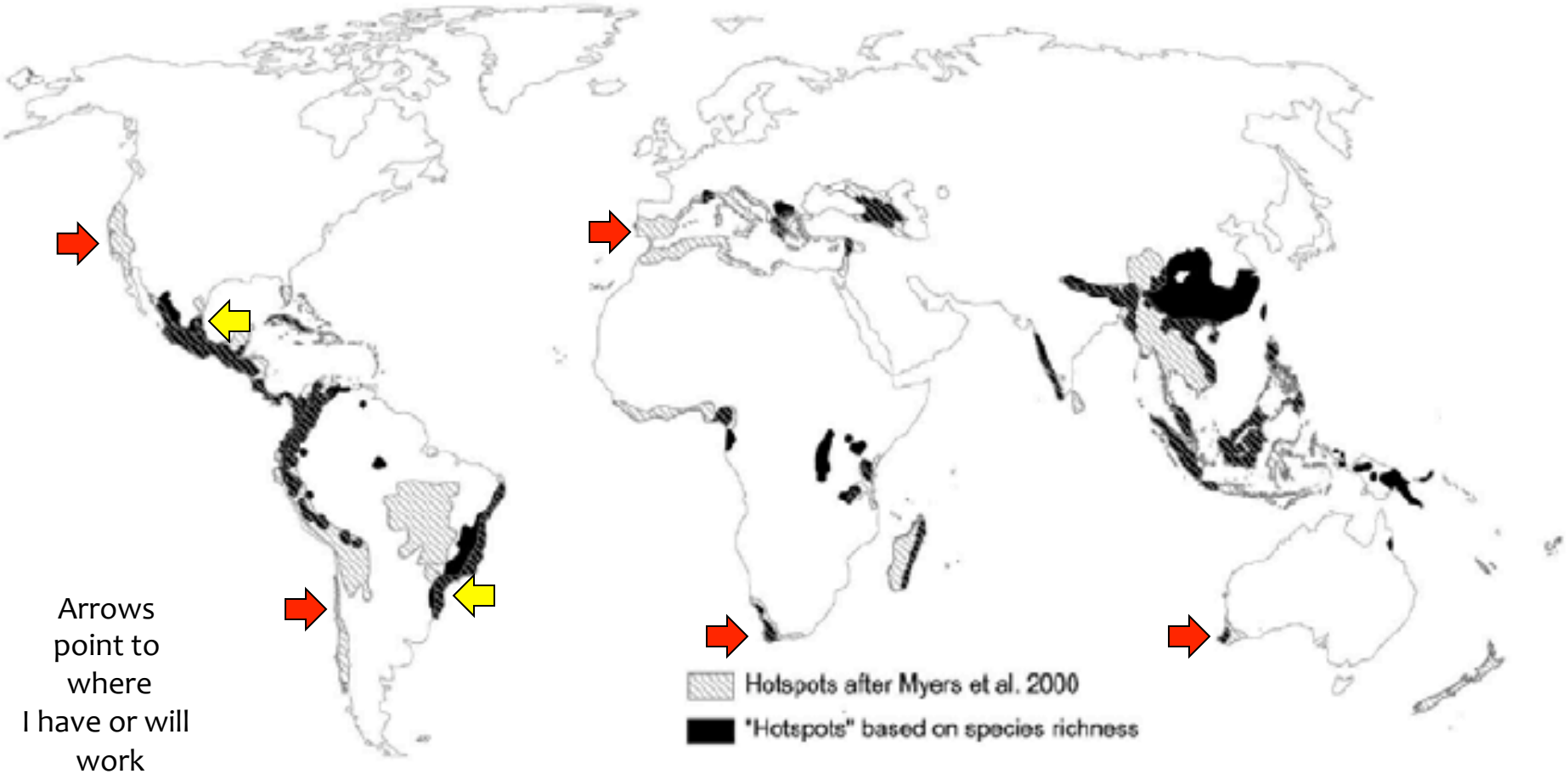
-- and --

Q: if climate changes and the strength of the land-sea connection weakens, what will this mean for **coastal redwoods**?


Locations
FOG Forests / Communities
CLOUD Forests

A very large fraction of the Global Biodiversity Resides in Cloud and Fog Forest Regions

~ MANY are at a land-sea interface ~



Arrows point to where I have or will work

Fog Forests in **red** Cloud Forests in **yellow**

COAST REDWOOD
Sequoia sempervirens

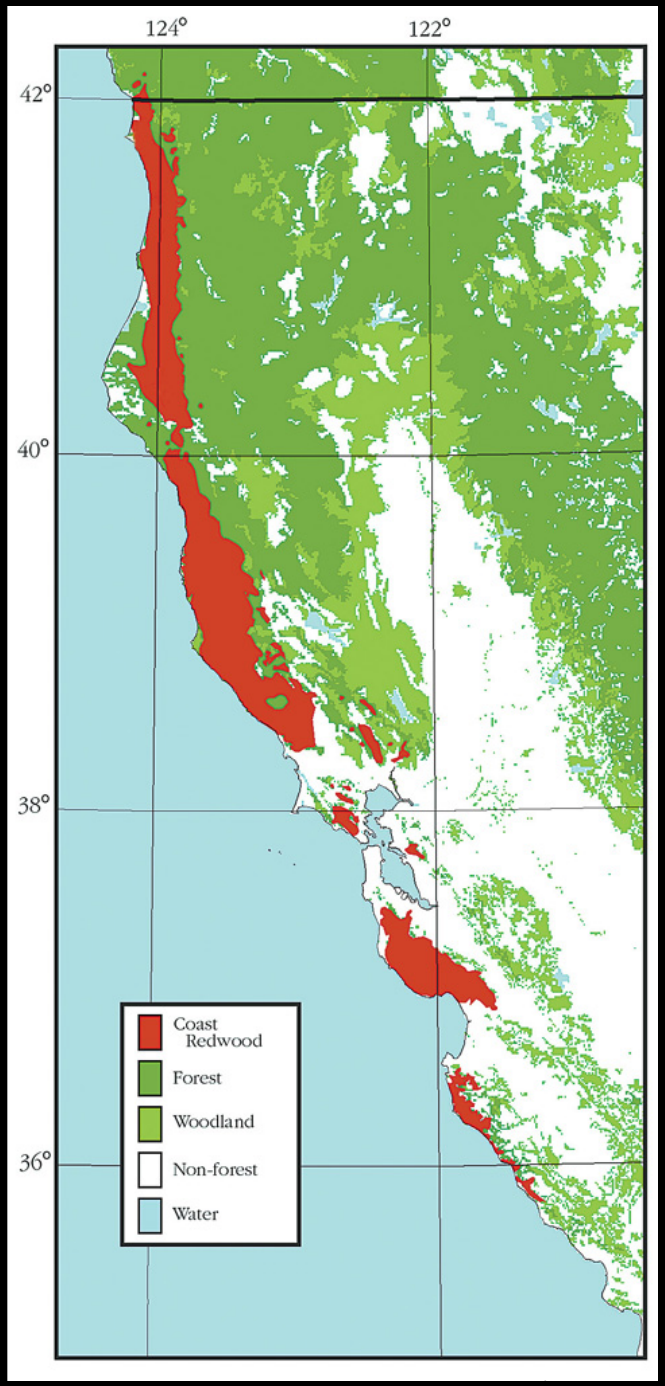
Maximum height: 115.82 m / 380 ft

Maximum diameter: 7.68 m / 25.2 ft

Maximum volume: 1,205 m^3 / 42,554 ft^3

Maximum age: 2,520 years

Remaining old-growth: 4%

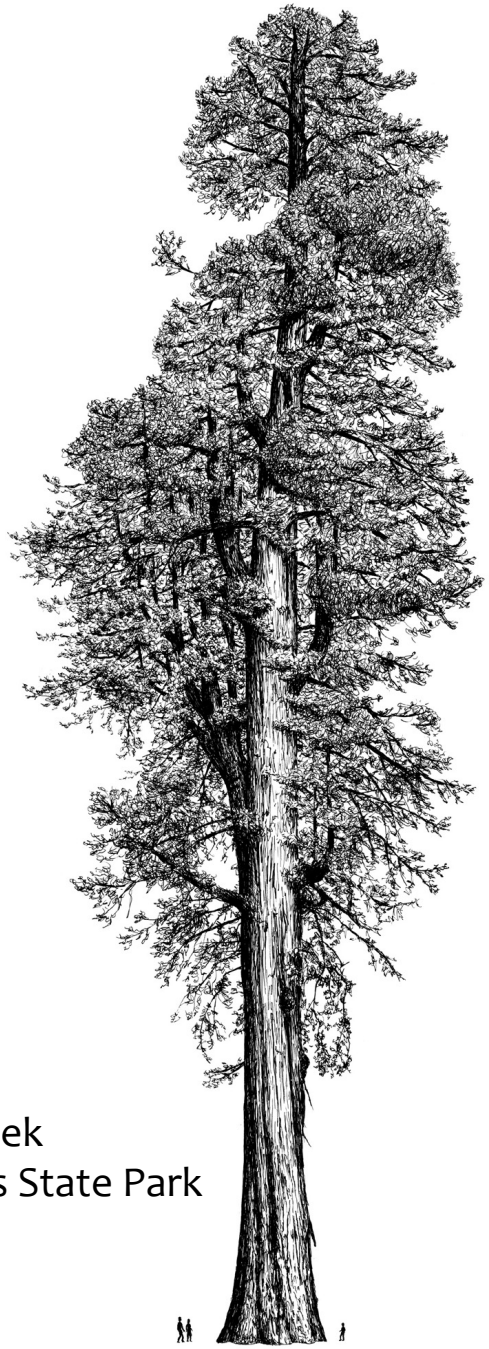


Tallest known tree on Earth;
Hyperion
(115.8m / 380 ft.)

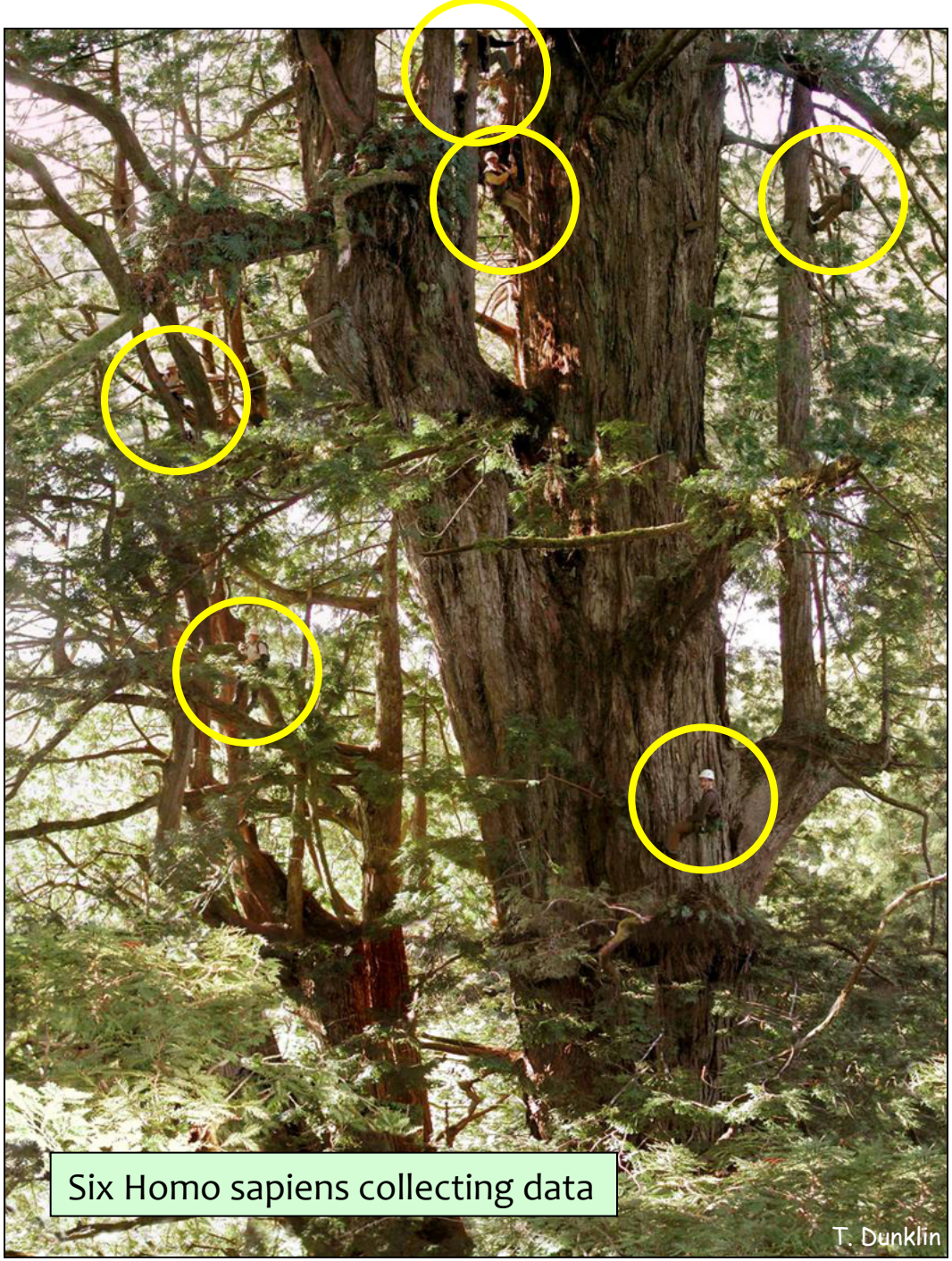
Redwood
National Park

Tree crowns harbor entire ecosystems ‘aloft’ and create their own microclimate


Leather fern
Polypodium scouleri



Illuvatar
Prairie Creek
Redwoods State Park



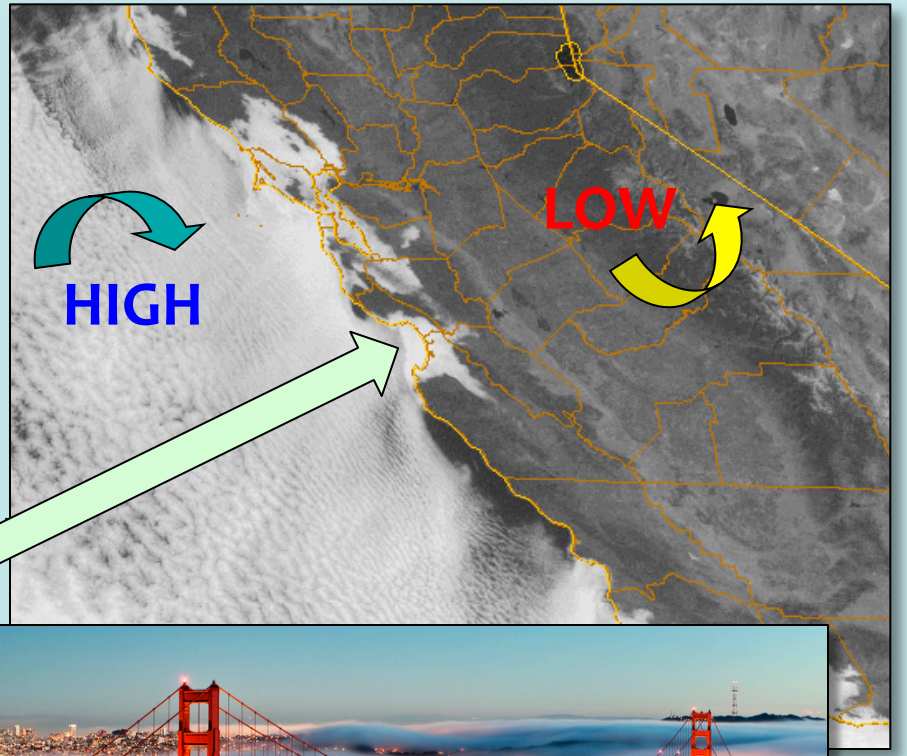
S. sempervirens – Coast Redwood
NOW occupies a Mediterranean Climate Zone (*cf.* water limited), yet :

- Tallest tree on Earth (115.8 m)
- 2nd largest tree by mass on Earth
- Fastest growing conifer ever measured
- Sequestering the highest amount of carbon of any known tree [forest?]

Cool coastal temperatures and fog are defining features of today's Coast Redwood Ecosystem

Present-day Coast Redwood Geographical Distribution

Fog Formation



Cold Subarctic Currents

Cold

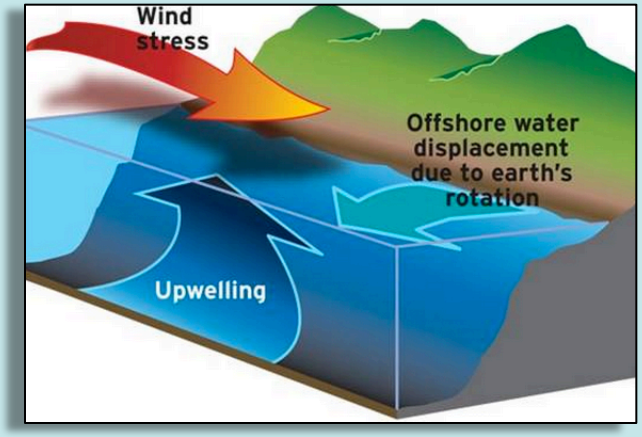
Central Pacific High

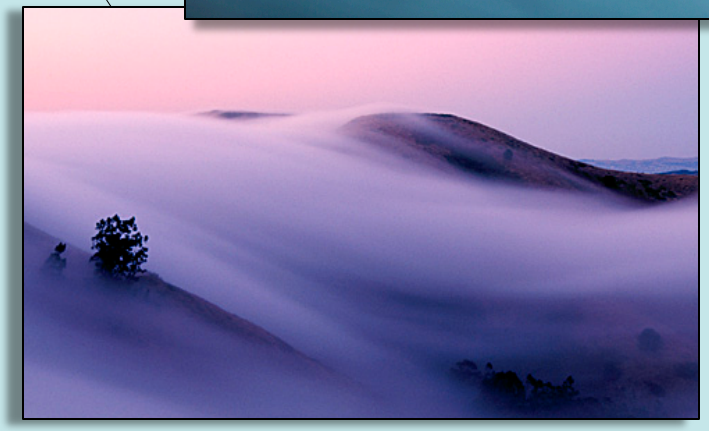
Warm & moist

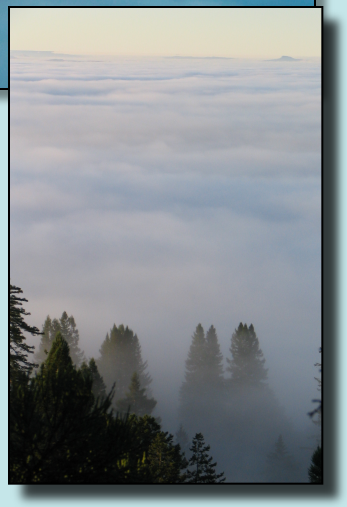
Hot & Low Pressure Air Rises

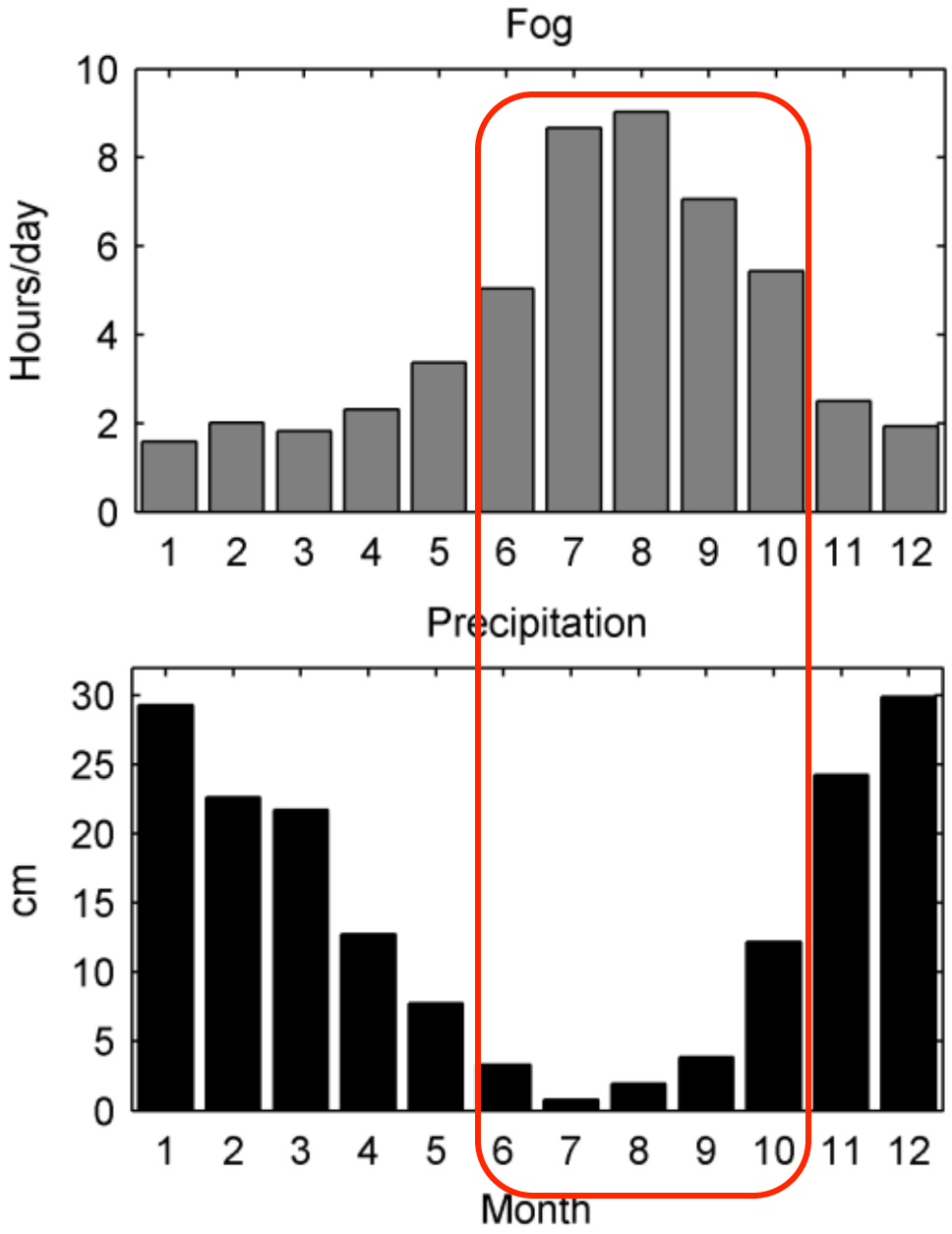
Cold

Upwelling









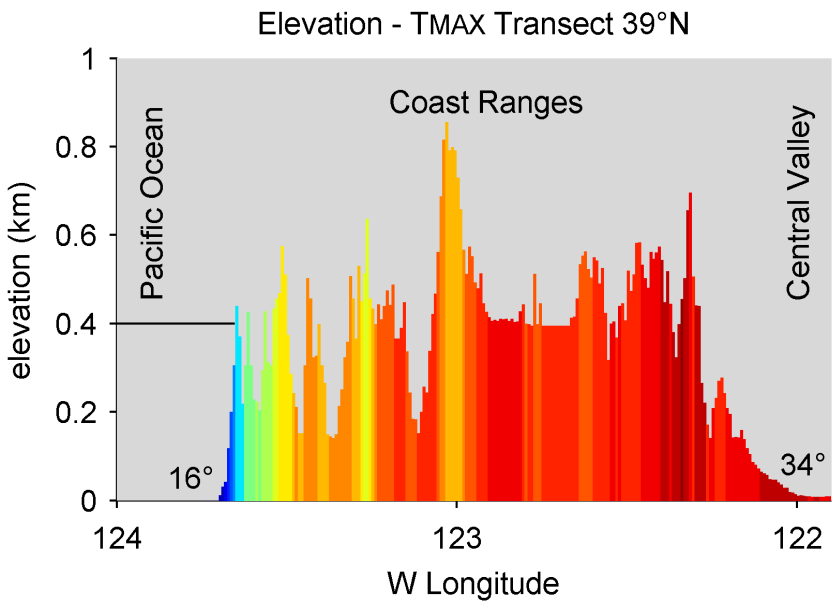
Fog water inputs occur when summer water deficits are highest (no precipitation)

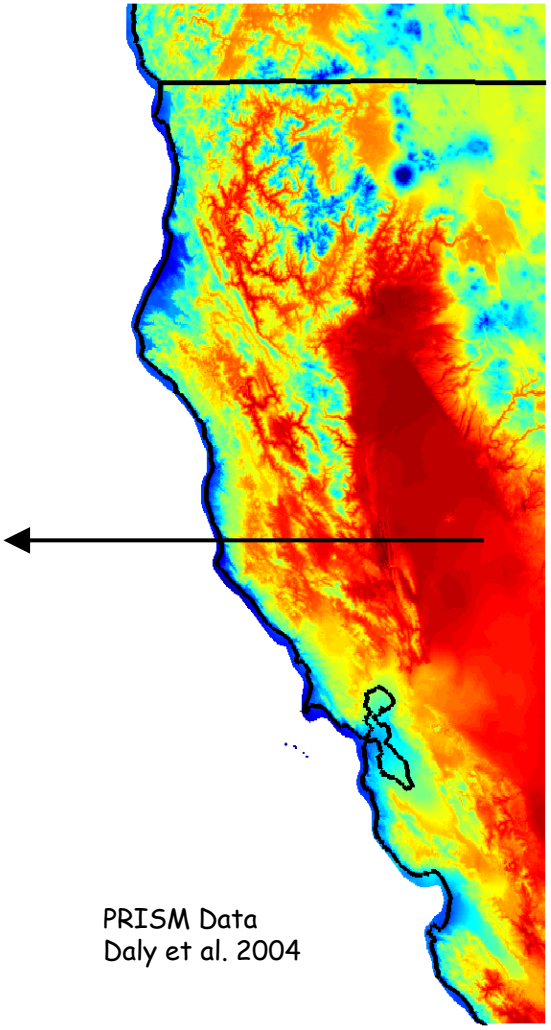
Plants like water and this subsidy occurs just when they need it most = summer

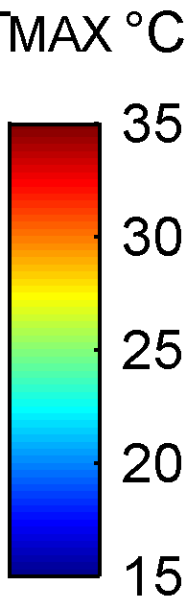
Long, dry days when their demands for water peak

Johnstone, Roden & Dawson JGR-B (2013)

Summer Daily Maximum Temperatures: Northern California



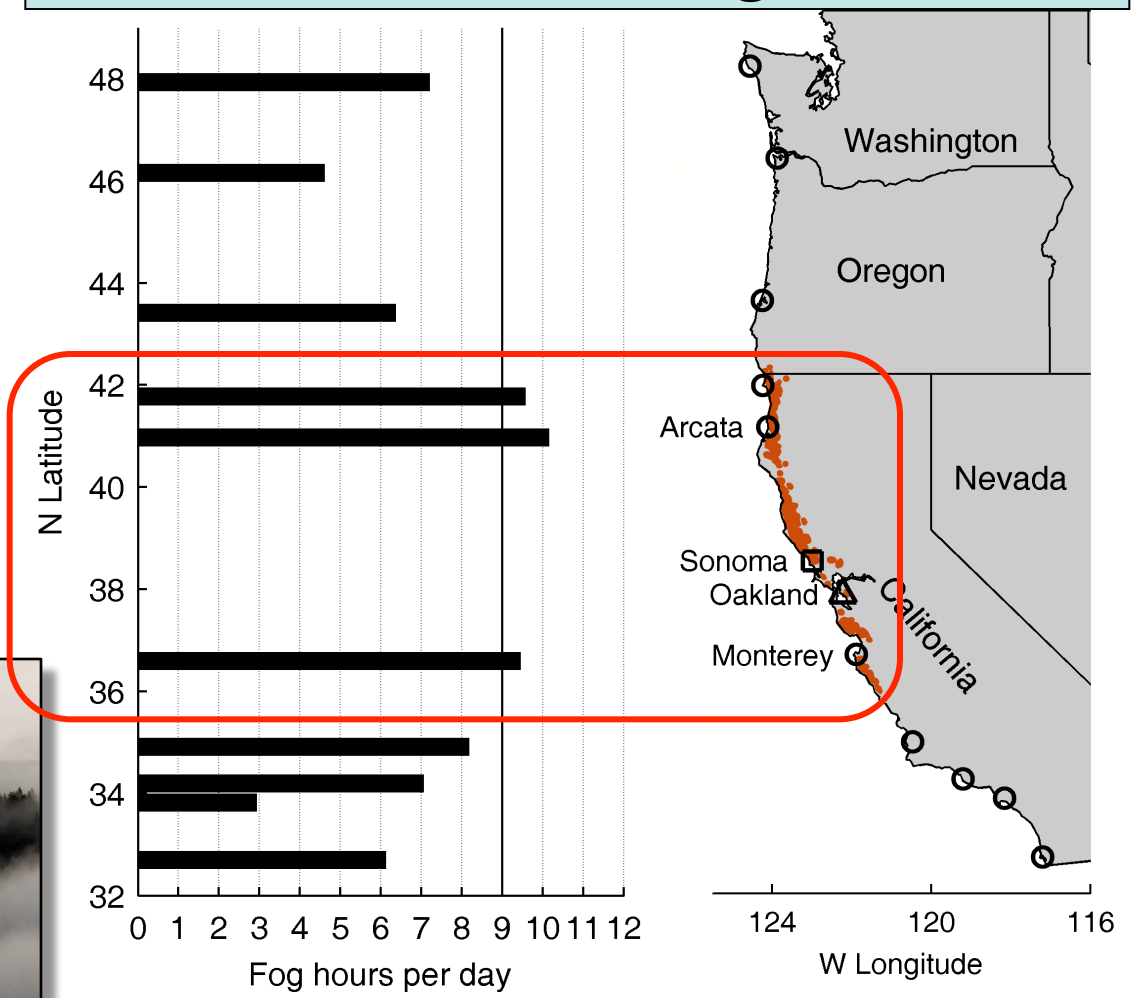




Capping inversion restricts marine layer to coastal elevations below ~ 400m

Johnstone & Dawson, *PNAS*, 2010

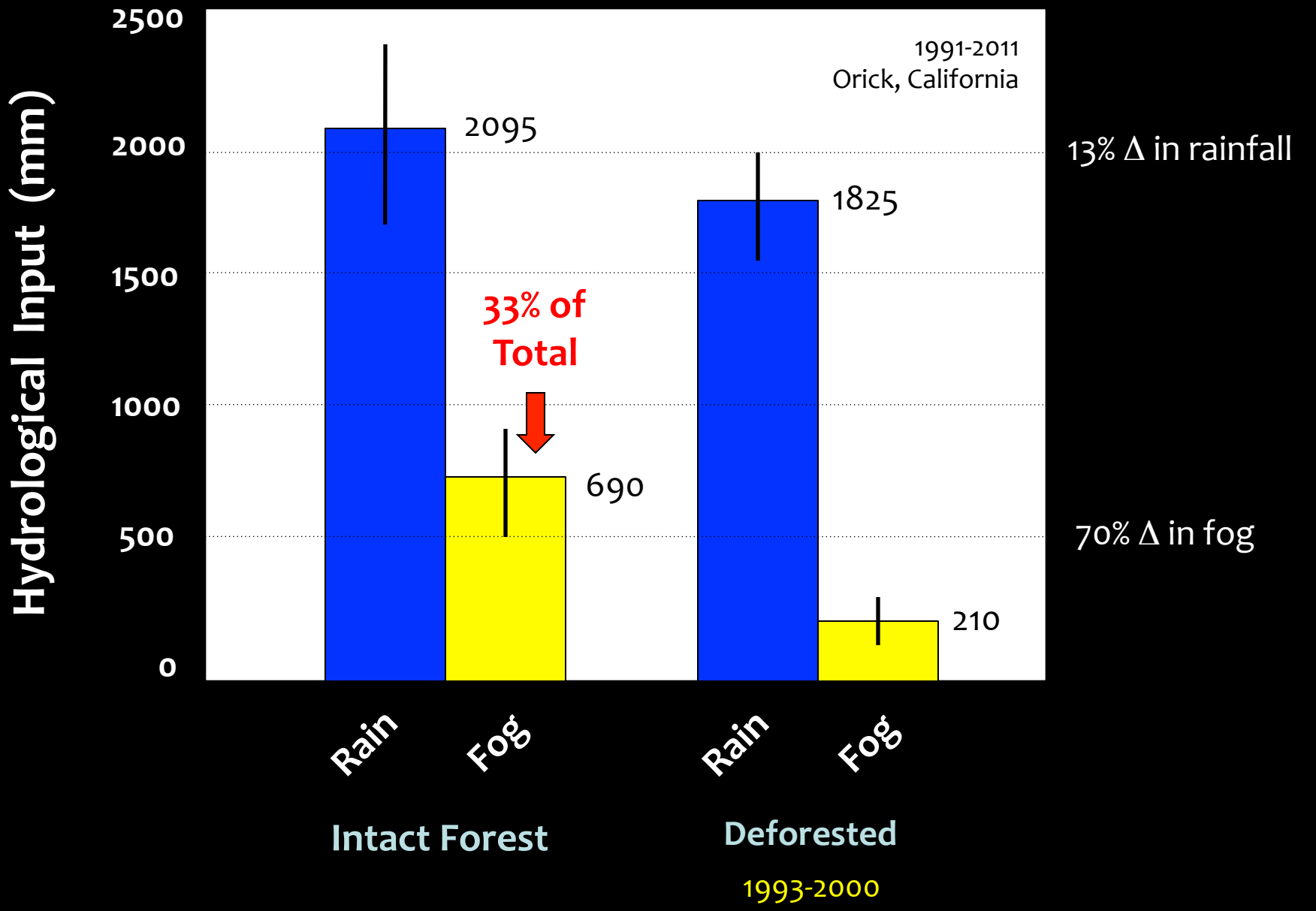
Summertime mean fog frequency



Fog frequency = days with 12 hours or more with ceiling heights <400 m

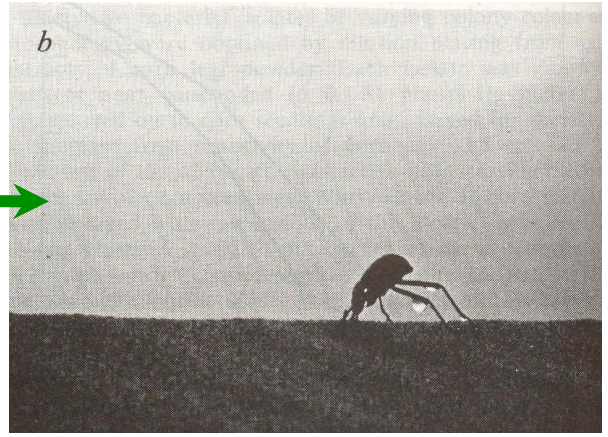
Redwood distribution is at the >9 hrs/day (30% of all days) coastal fog threshold

Fog and precipitation input data as a proportion of total annual water balance



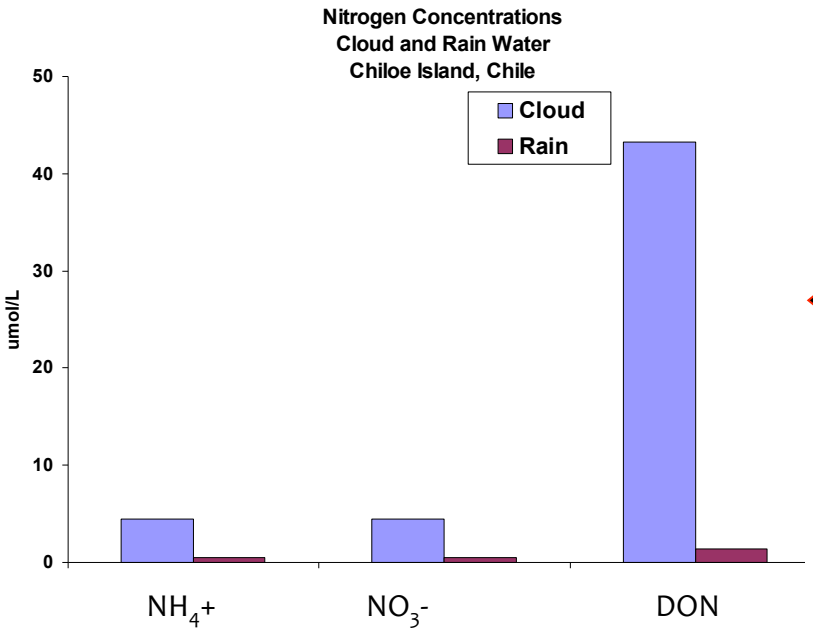
Fog Water as a Percentage of Total Precipitation

Where	Percent
Hawai'i, N.E. & S.W. Australia	32-43
Columbia, Peru	61-93
Costa Rica, S.E, Brazil	28-41
Panama, S. Africa	8-20+ [27]
California, N. Chile	33-90+ (summer only)
S. Chile, N.E. Mexico	3-25
Namibia	97-100



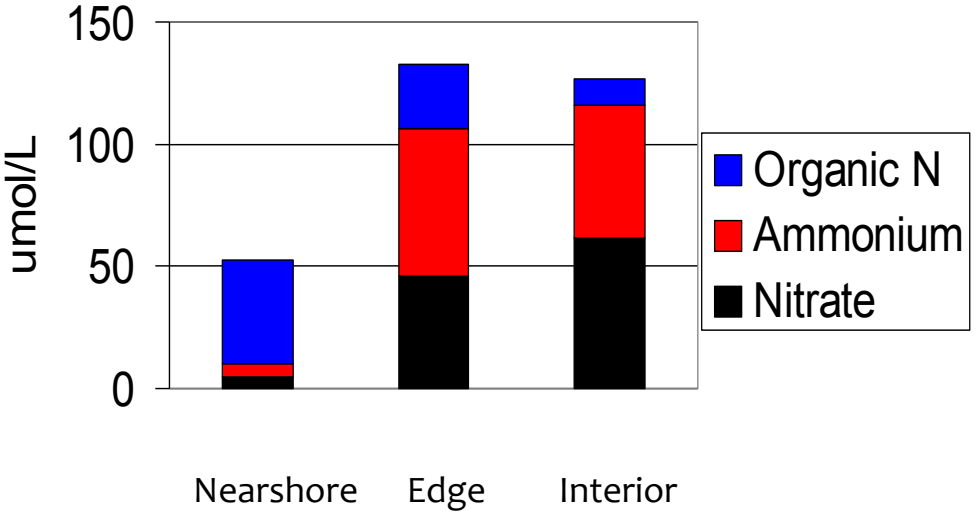
SOURCES: Clark et al. 1998 ; Dawson 1998; Vitousek 2004 Weathers et al. 1988-2006; Ewing et al. 2009, Bruijnzeel 1992-2010, Dawson and West 2013

Ecosystem Nitrogen inputs – California and Chile



Temperate Cloud Forest (*Nothofagus*); Chile

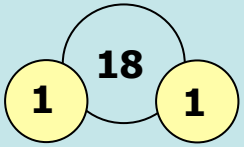
Coastal Fog Forest (*Sequoia*); California

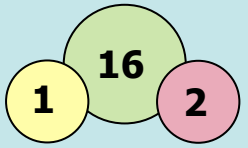


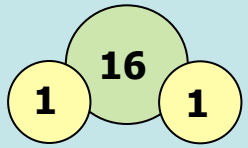
Dawson and Weathers, *unpublished*

Next: **Determine the importance of fog water to plant water status and balance over time and space**

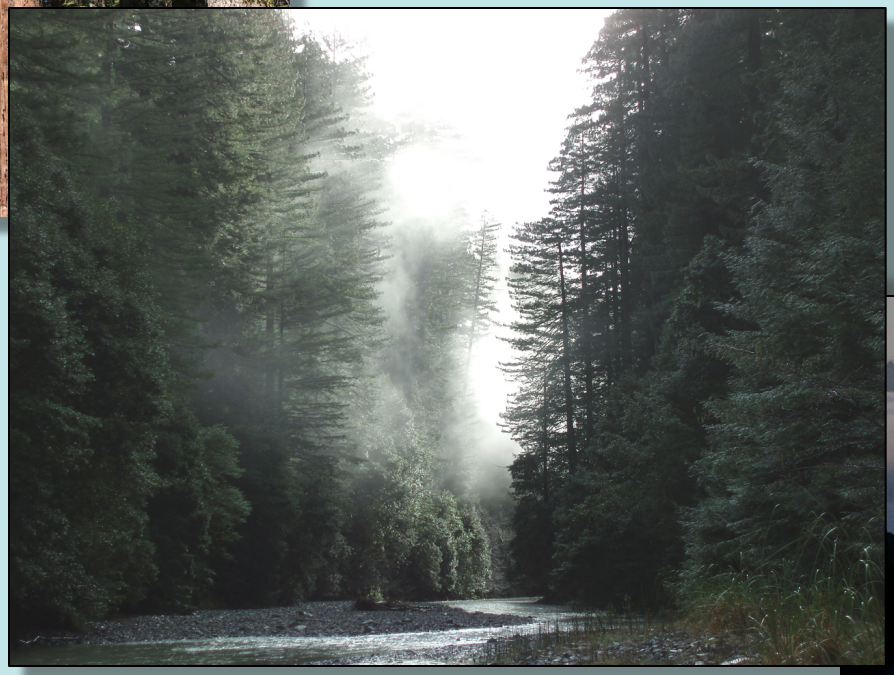
Approach: **Stable isotope analyses of water sources and plant water**







Key point: **Winter rainfall has a distinct H and O isotope ratio compared to summertime fog**



Study Species

Gaultheria shallon

Sequoia sempervirens

Rhododendron macrophyllum

Polysticum munitum

Oxalis oregana

+ 8 others species

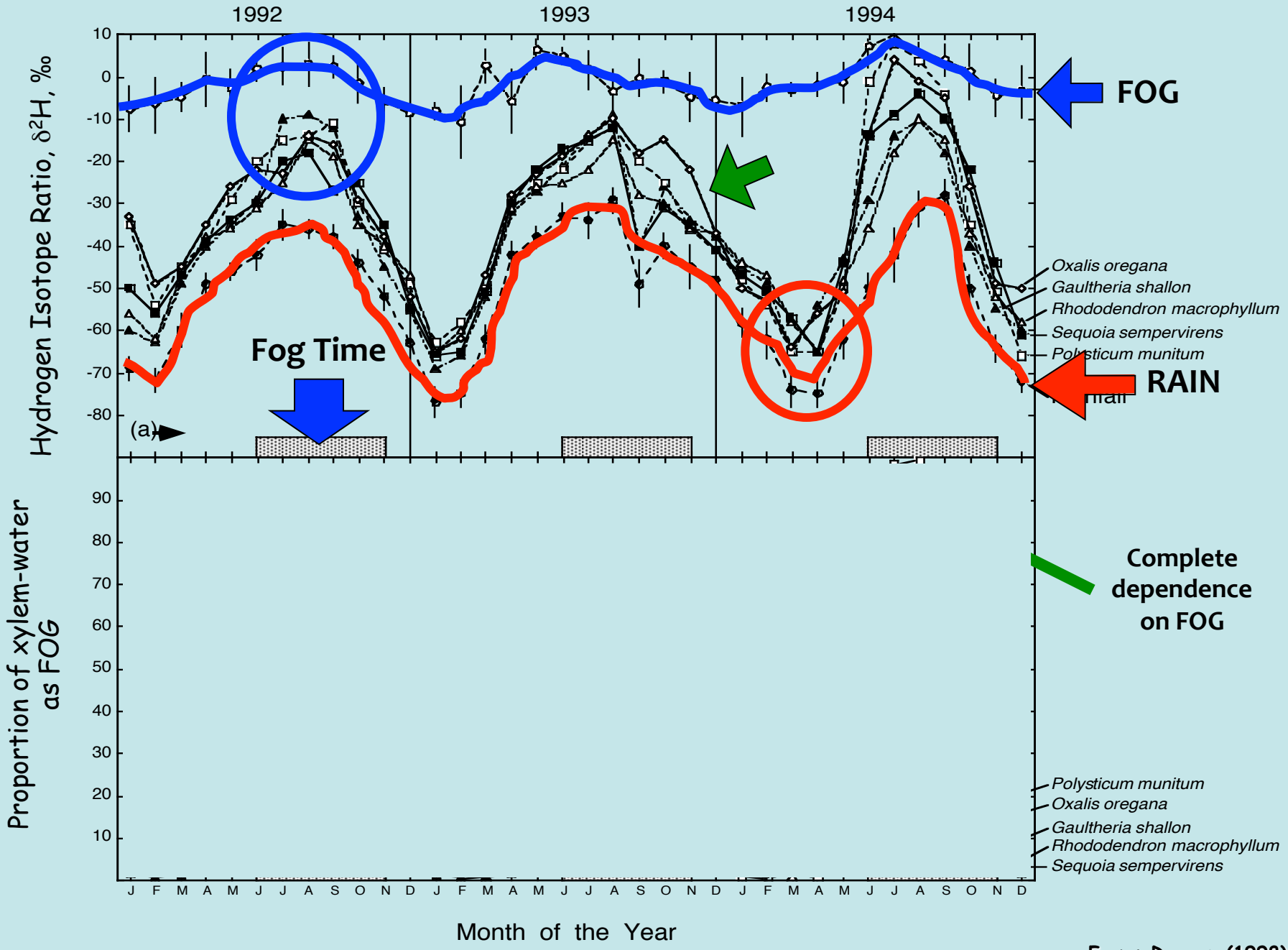
Methods and analyses

Two-source mixing model was used to determine **proportion of fog** (using H and/or O) from DRIP

$$P_{fog} = (\delta^{18}O_{vegetation} - \delta^{18}O_{rain}) / (\delta^{18}O_{fog} - \delta^{18}O_{rain})$$

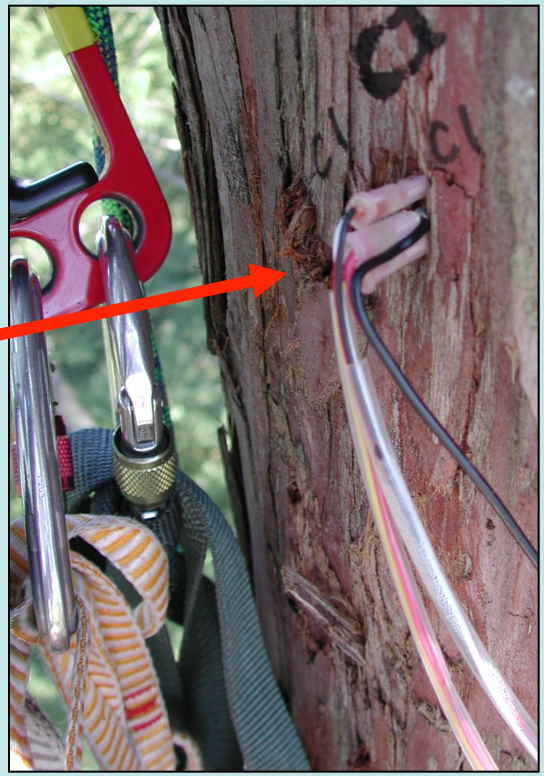
Where: $\delta^{18}O_{fog}$ = mean isotope value for each site (e.g., +5.0 to -2.0‰)

$\delta^{18}O_{rain}$ = mean isotope value for each site (e.g., -8.0 to -19.0‰)

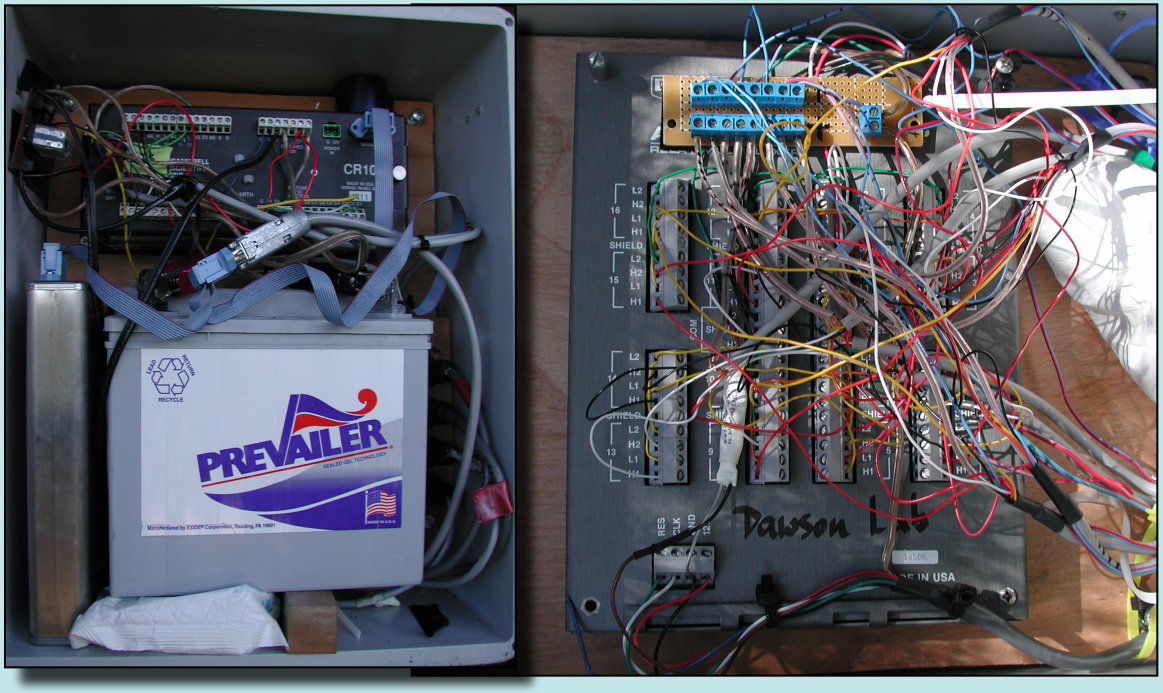


From: Dawson (1998)

Transpiration: Heat Ratio Sapflow method (Burgess et al., 2000, 2001, 2004, 2010)



Probe set



Data logger, storage module & battery in tree

"Well-organized" multiplexer & wiring set-up

Solar power

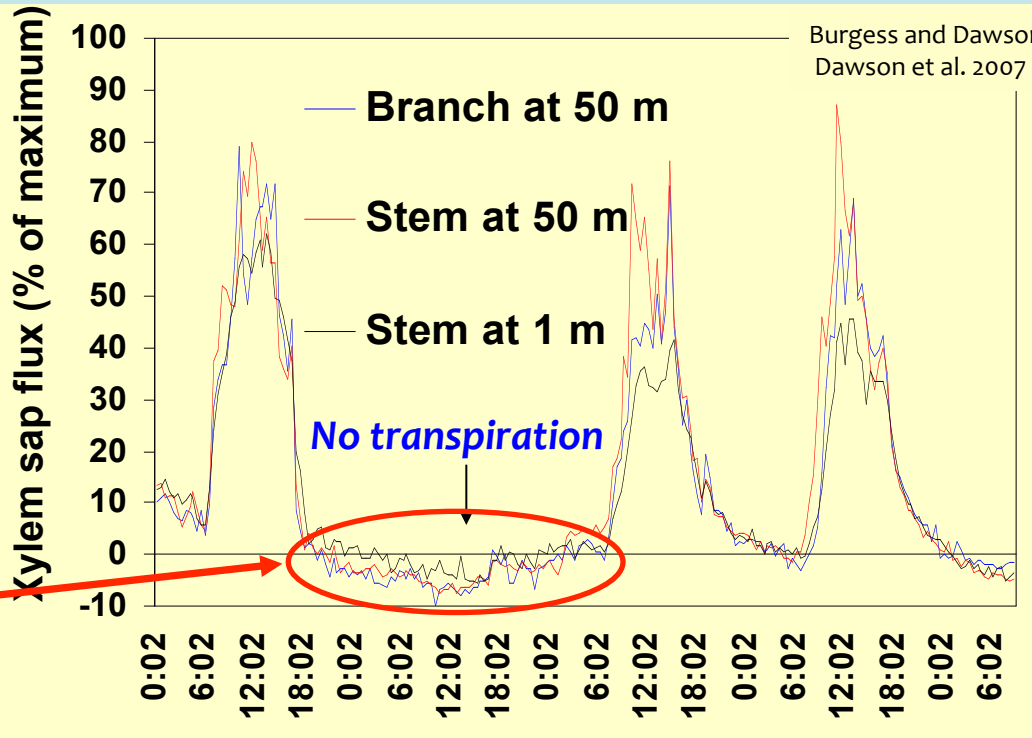
Are trees 'breaking' the rules?

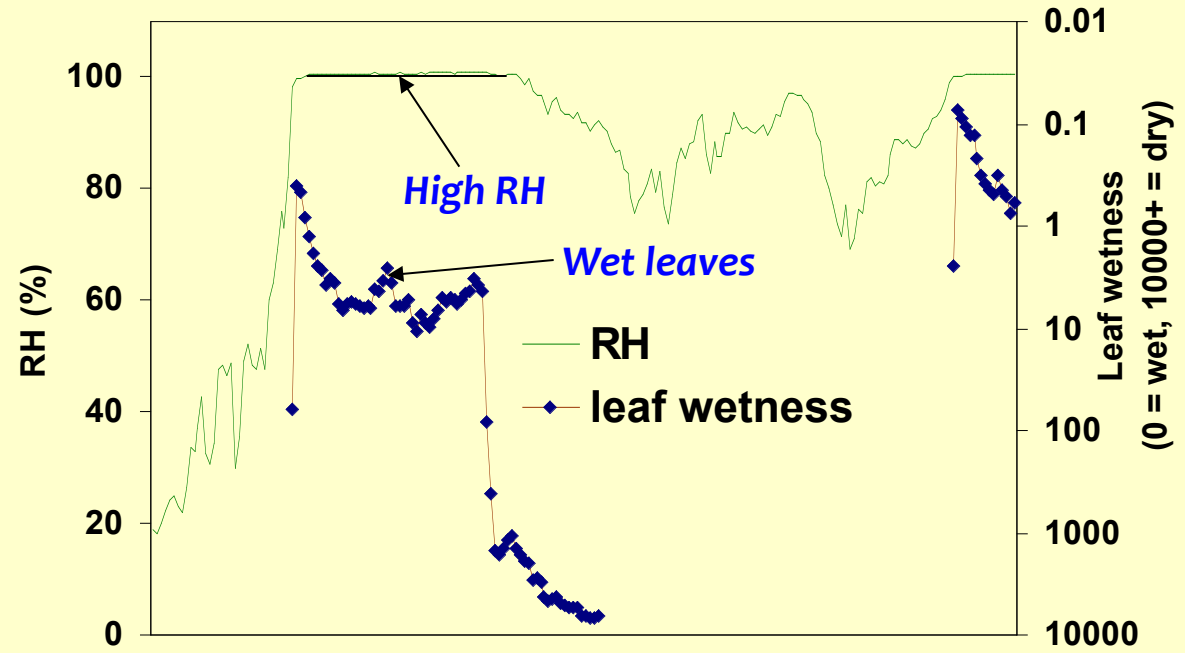
DIRECT foliar uptake of H_2O occurs

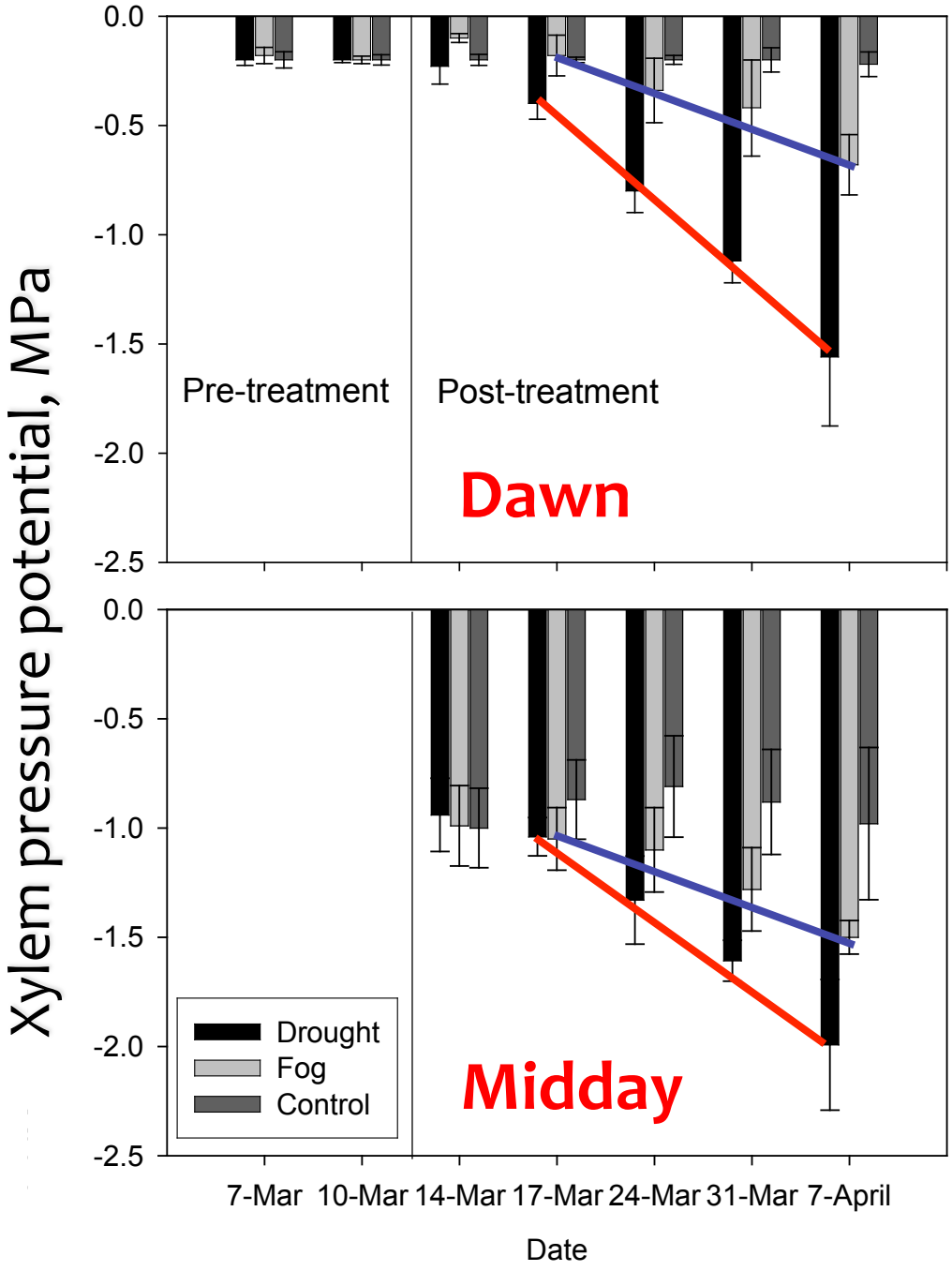
Reverse flow

[night & day]

5-7% of daily max

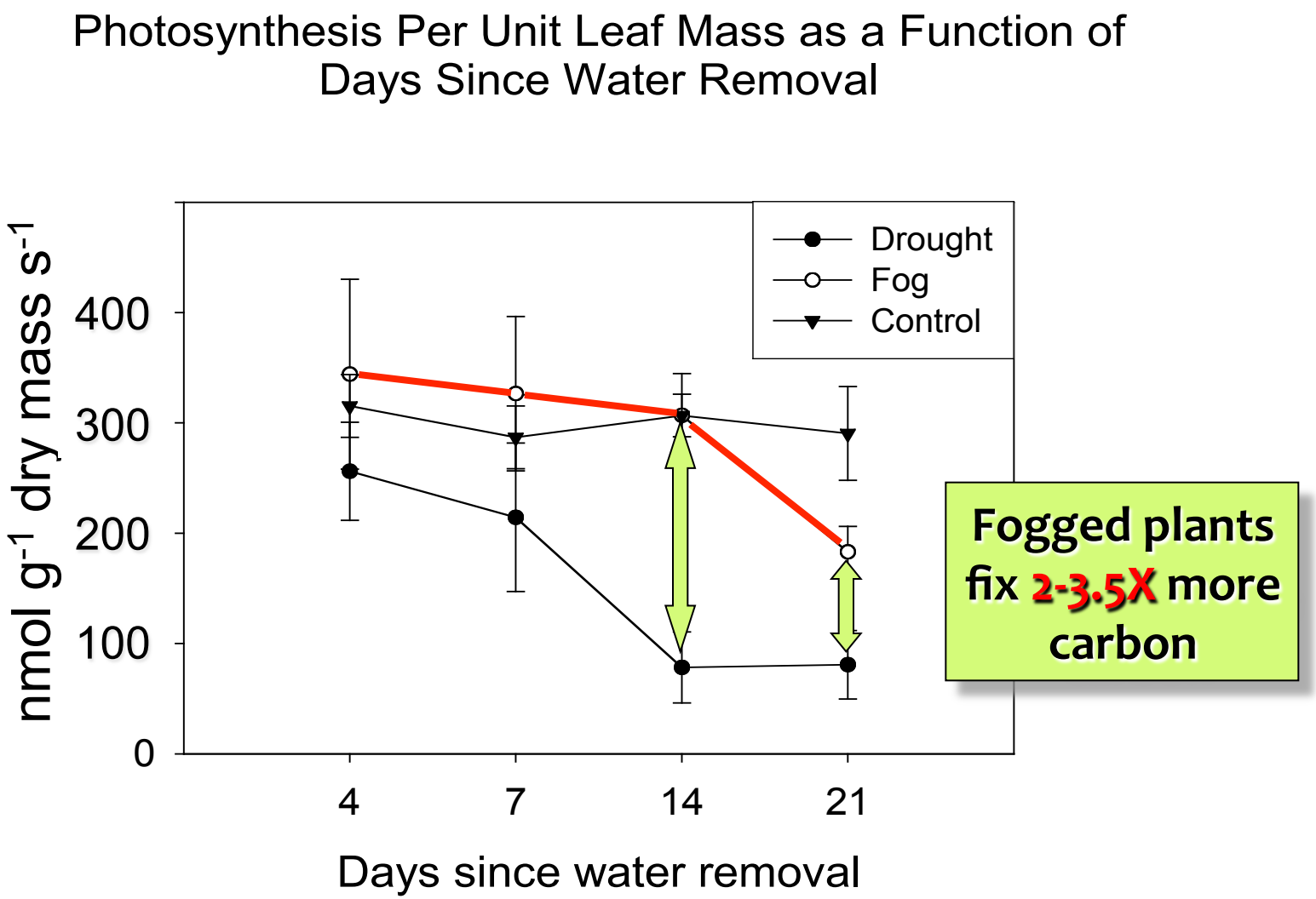






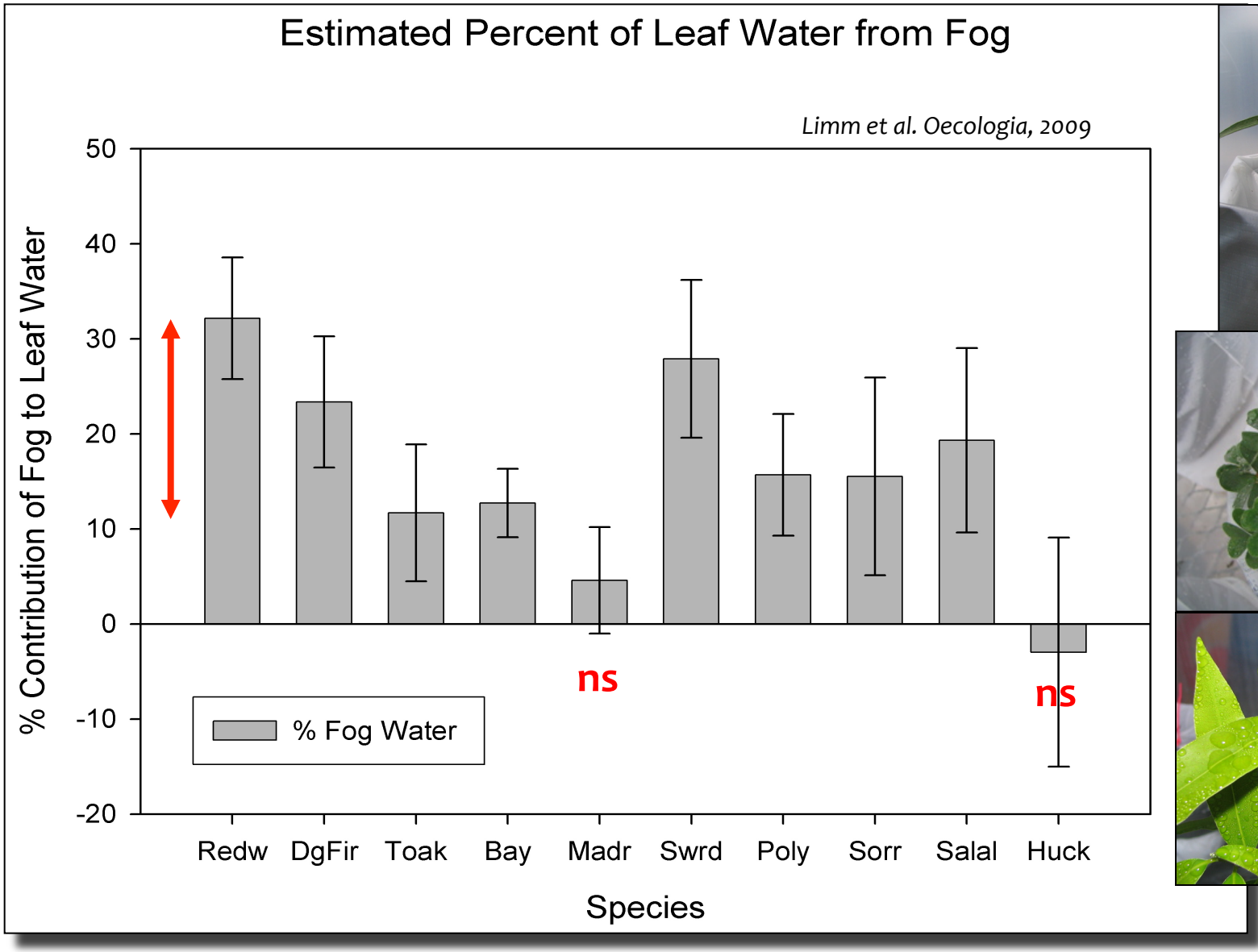
Simonin, Santiago & Dawson, *PC&E*, 2009

Photosynthesis is enhanced with fogging (no drip)



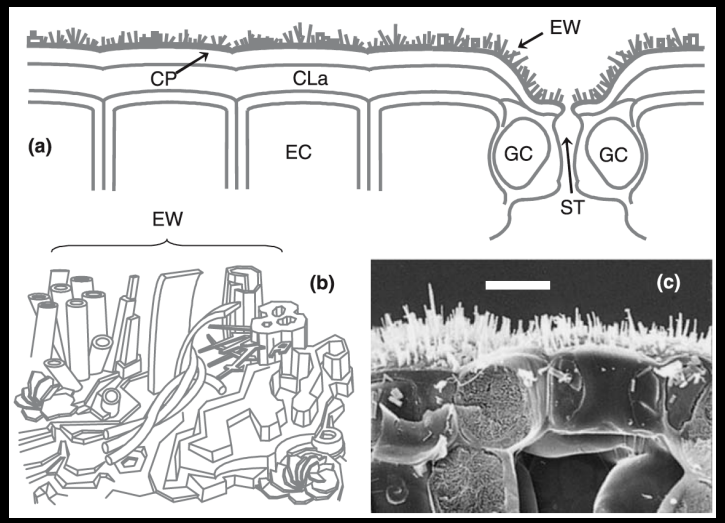
Simonin, Santiago & Dawson, *PC&E*, 2009

Isotope labeling water to estimate foliar uptake over a full 10-hour night for all forest species



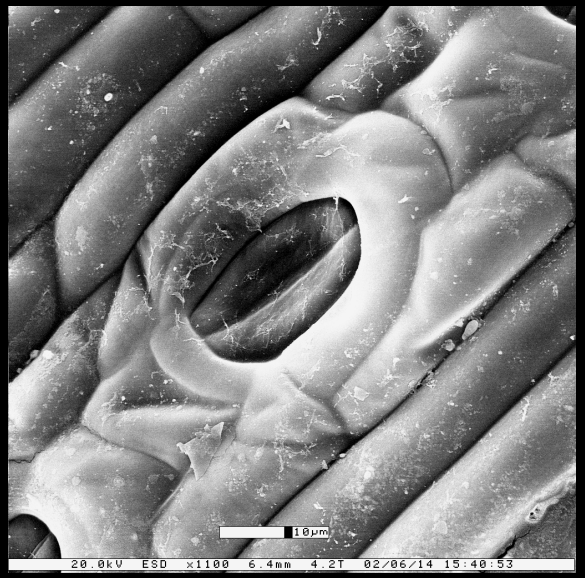
How does the water get into leaves?

- ✓ Via the **cuticle**? - transcuticular transport
- ✓ At the **leaf bases**? - transport at "leaky" spots
- ✓ Via the **stomata**? - transport through the pore

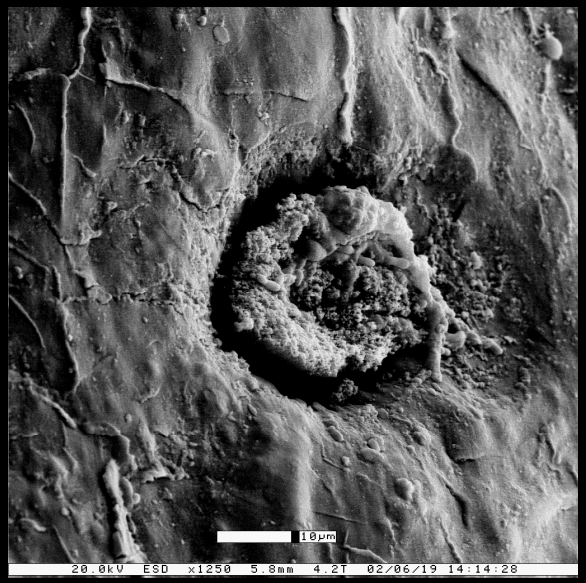


Cuticle xs

stoma



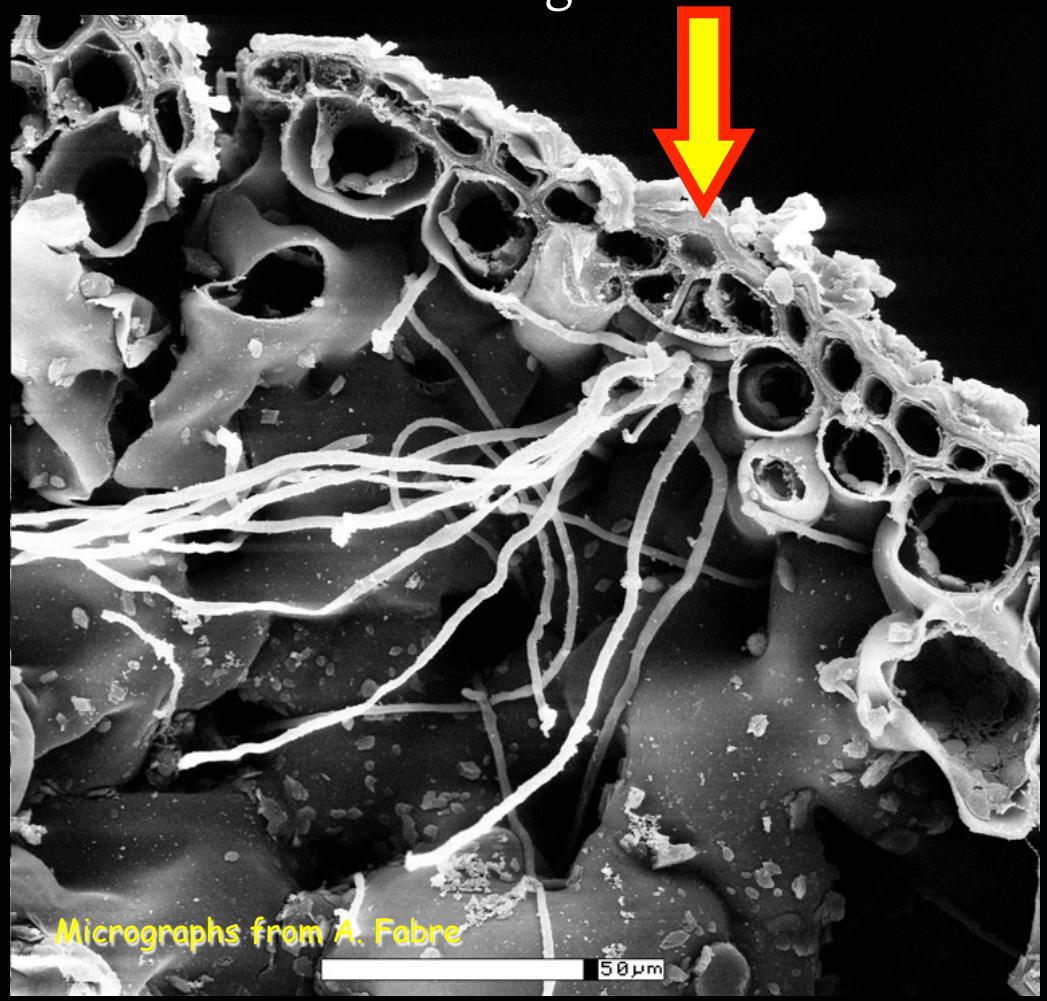
"plugged" stomata



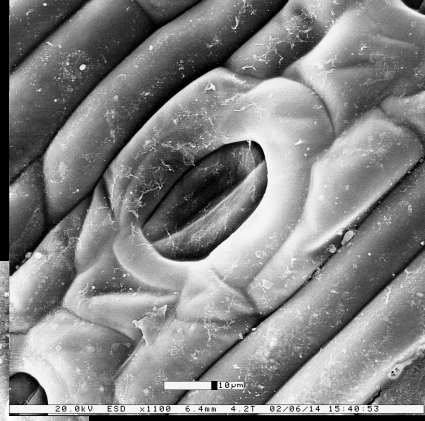
Fungal endophytes:

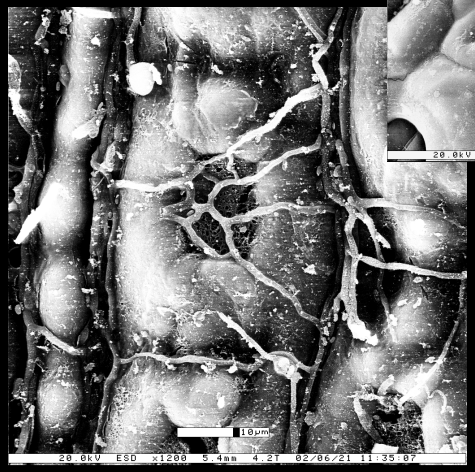
are they water wicks?

With hyphae the wettability angles change

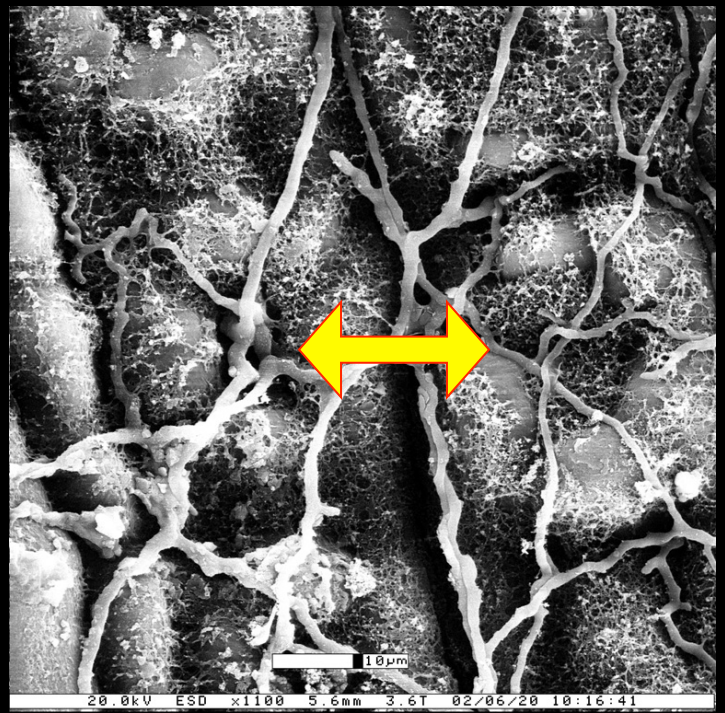


Stomate on new leaves





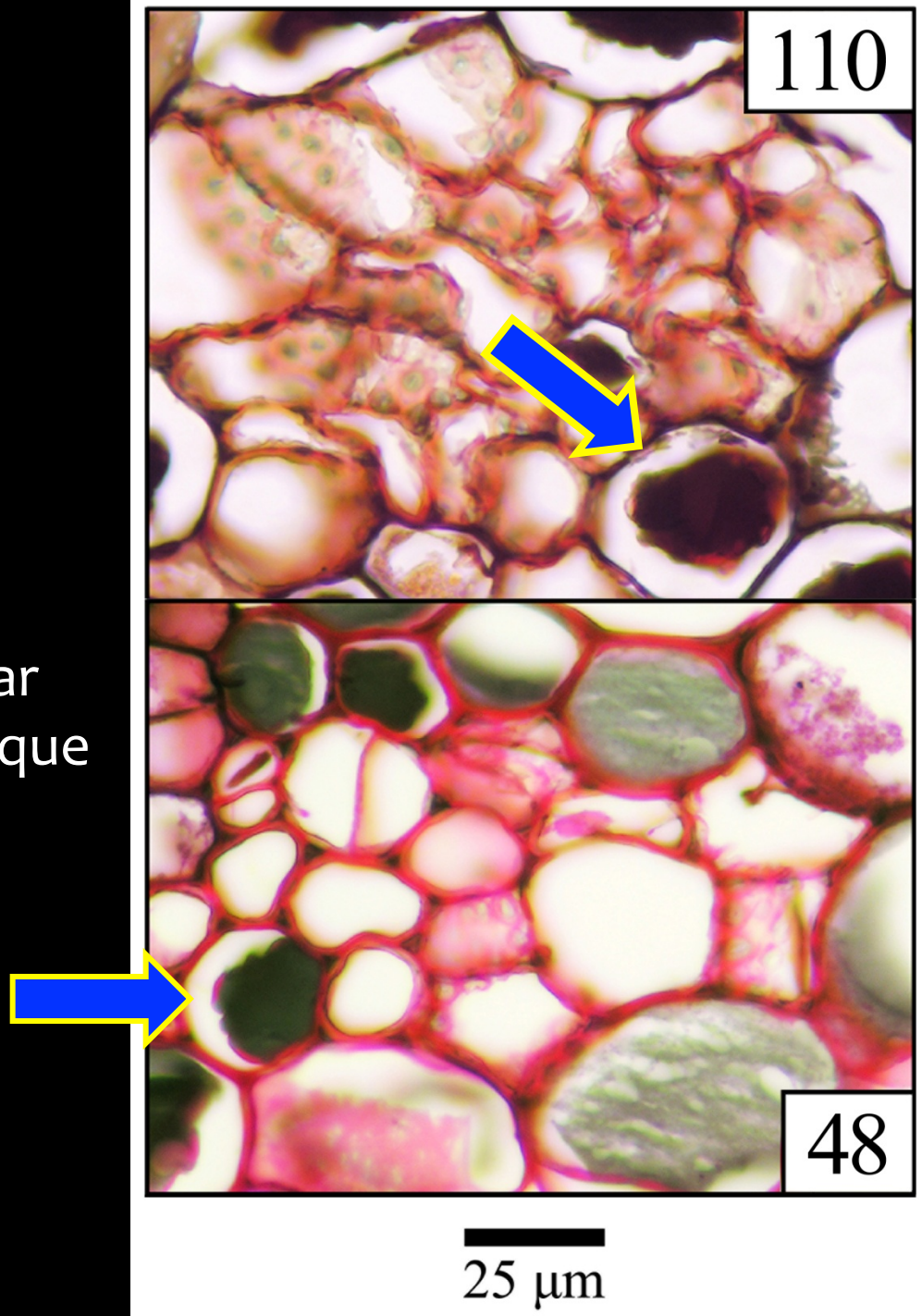
Stomate on 2 year old leaf



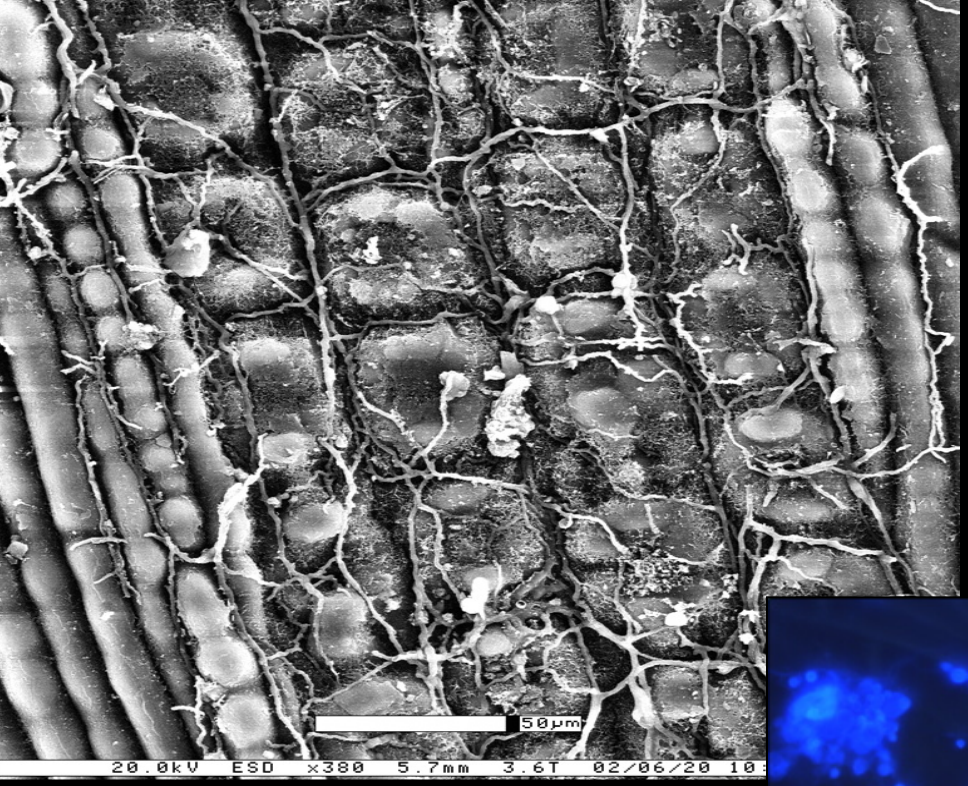
Transfusion tracheids,

Colonized by fungal ‘endophytes’,

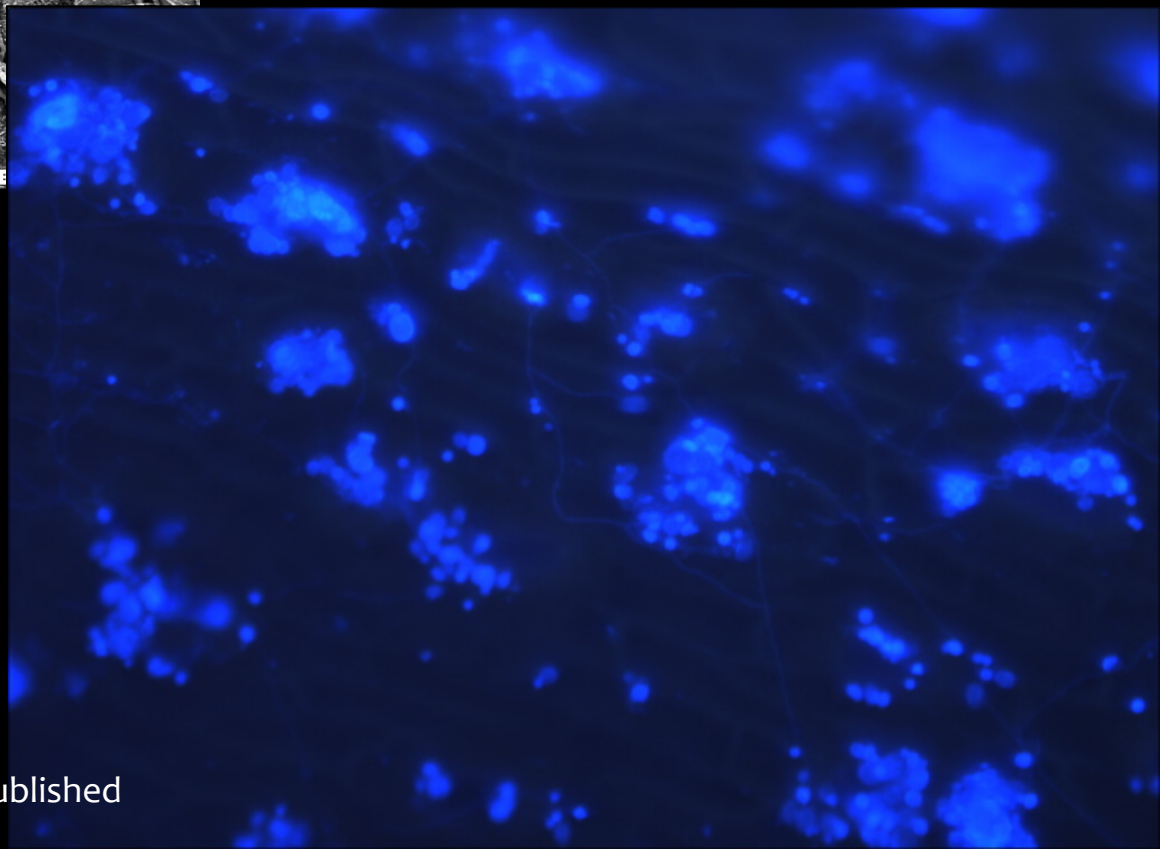
Do no harm and appear to be involved in a unique leaf-level symbiotic relationship



Dawson & Lindow
October 2013, unpublished



Unique plant-based metabolites taken up by genetically modified microbes will "fluoresce" when present and utilized



BLUE fluorescence indicates a C-based metabolite moved into groups of fungal hyphae and bacterial-fungal consortia (quorum sensing)

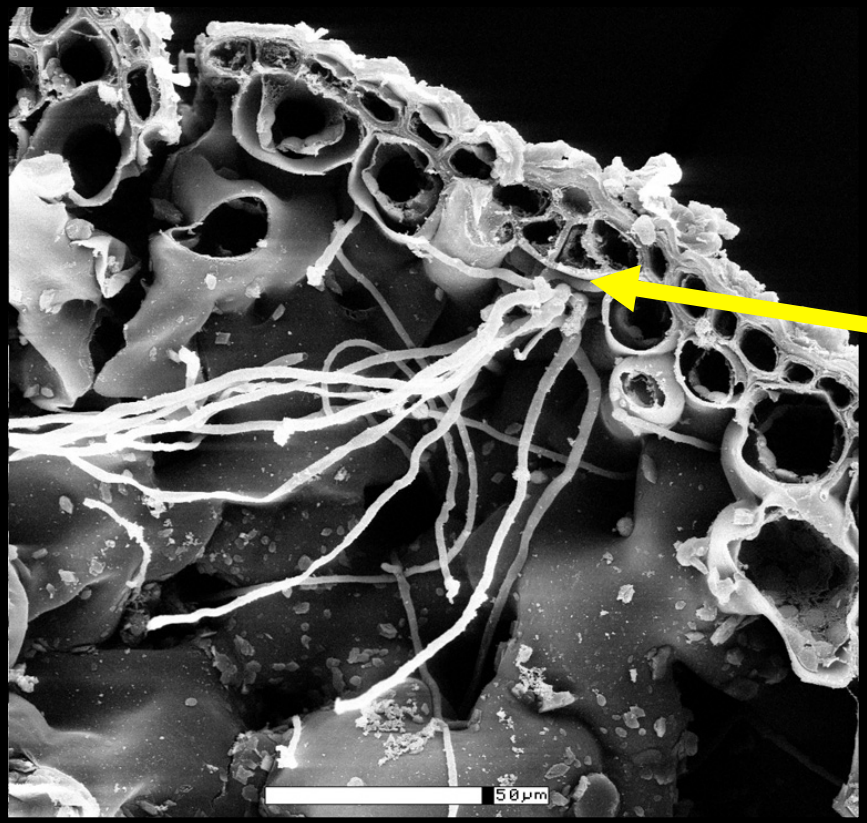
Dawson & Lindow
October 2013, unpublished

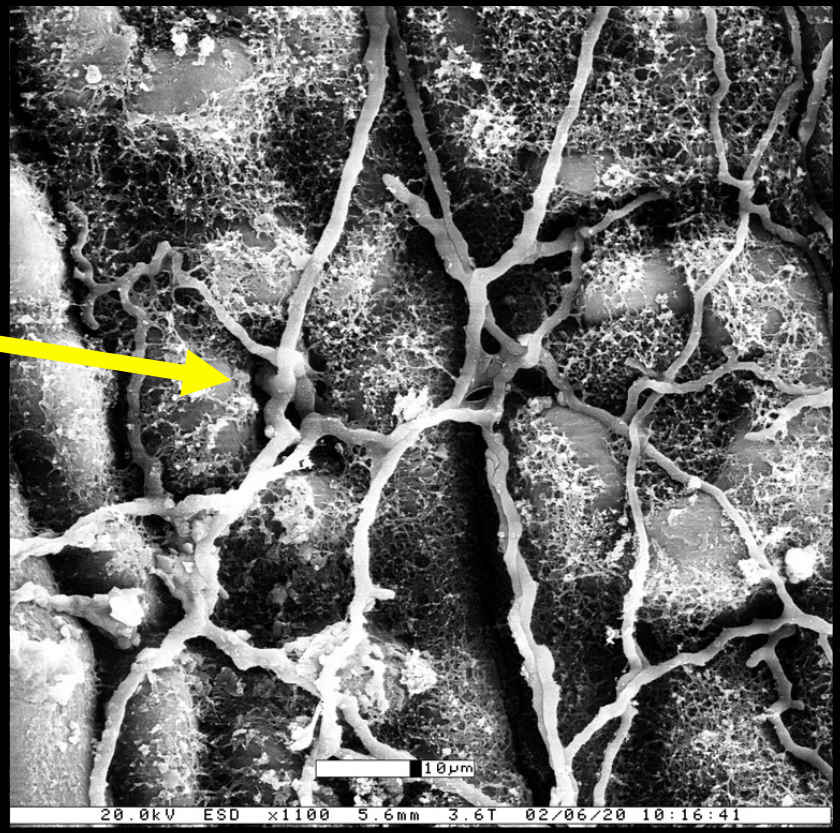
Fungal endophyte research (two PhD's @ UCB):

Who are the fungal groups and taxa are [molecular methods]? - 11 taxa

Can they be cultured? - Yes, 4 can and will be used in targeted inoculations on trees & foliage to understand their role(s)

What do the fungi get out of it ? - H_2O [yes] N [^{15}N says yes], C [using ^{13}C labeling and fluorescence assay's suggest yes and the promise for quantification]



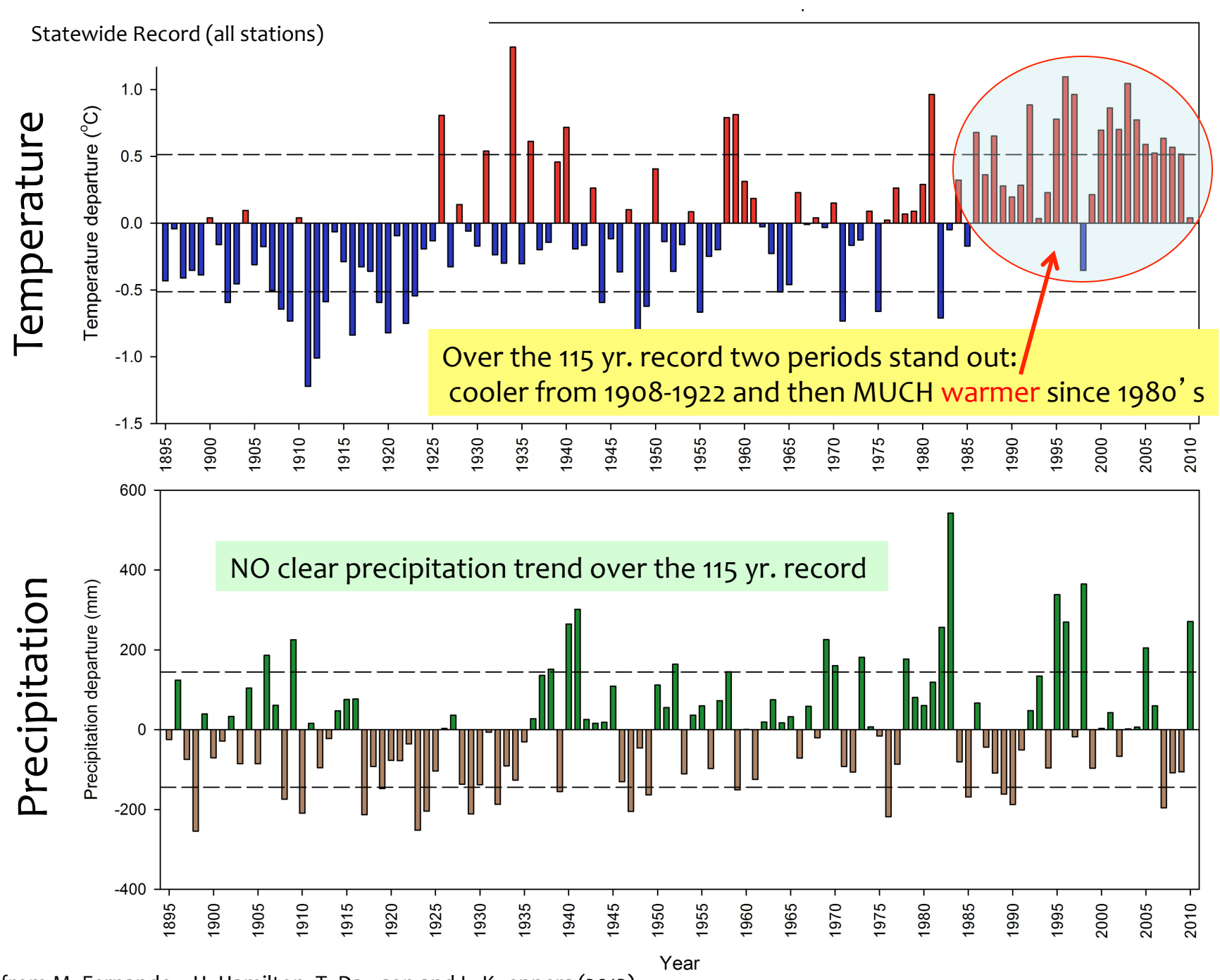


Land-Sea Interface investigations since 1991

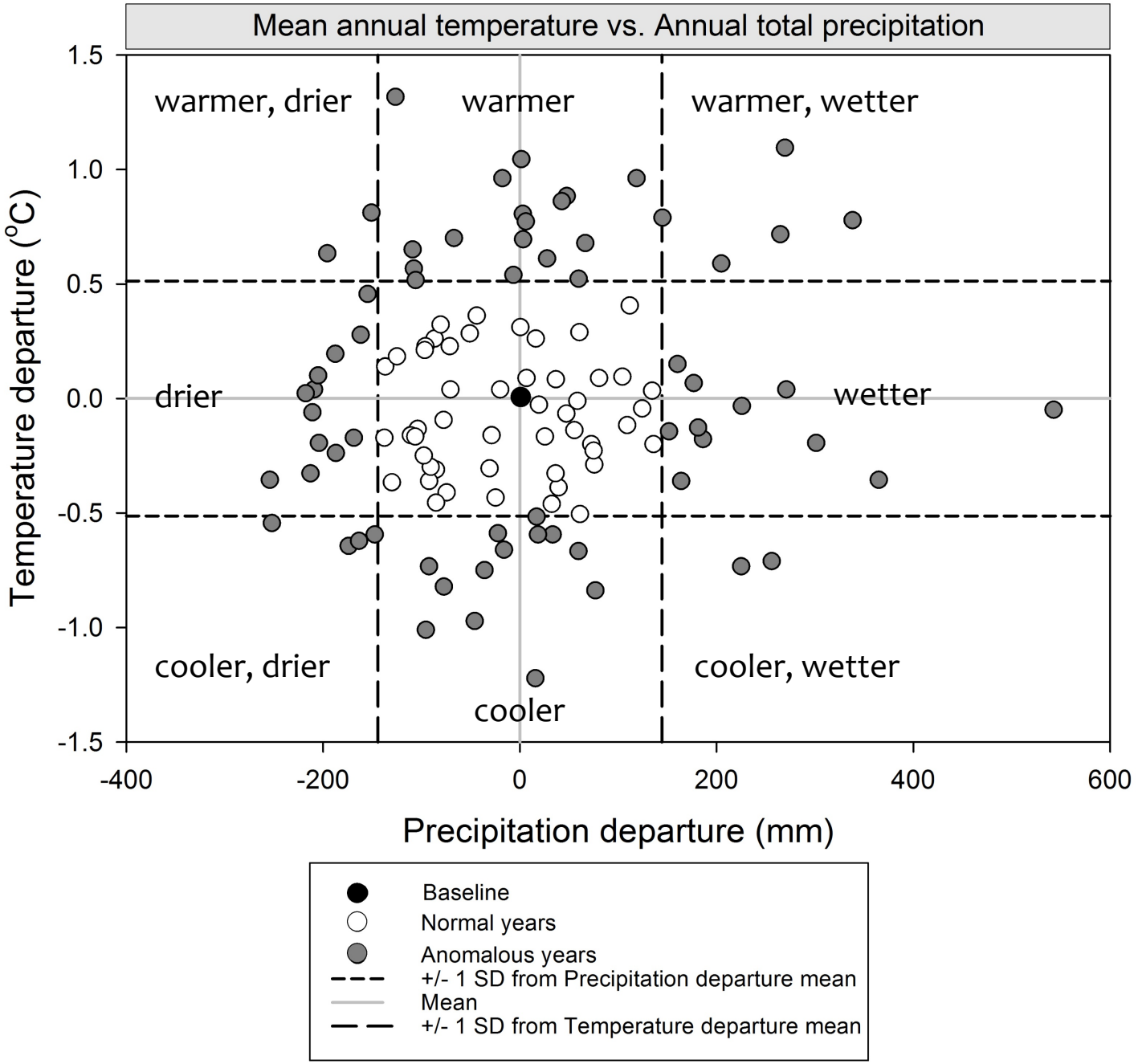
Fog input and importance for plants and watersheds (isotopes)
Fog and its impact of water use, water relations of all plants
Fog and plant carbon balance (trees, forests, in the greenhouse)
Fog and nutrients (N inputs and types)
Fog and foliar physiology including fungal endophytes
Fog climatology and past coastal climatic change
Fog and isotope dendrochronology
Fog and the future of coastal ecosystems

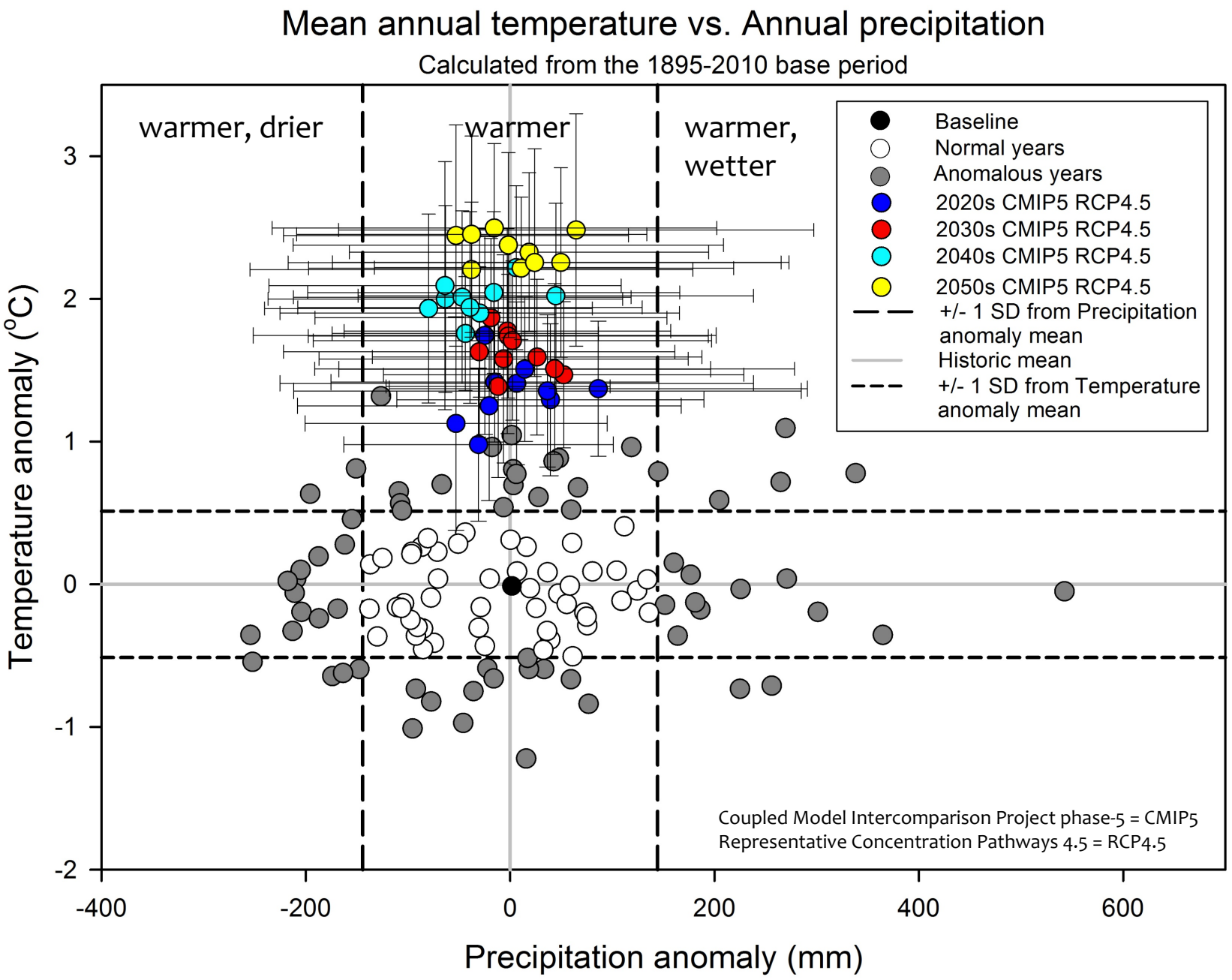
What does the future hold and how do we manage for it?

~ Temperatures, Precipitation, Fog, Evaporation ~



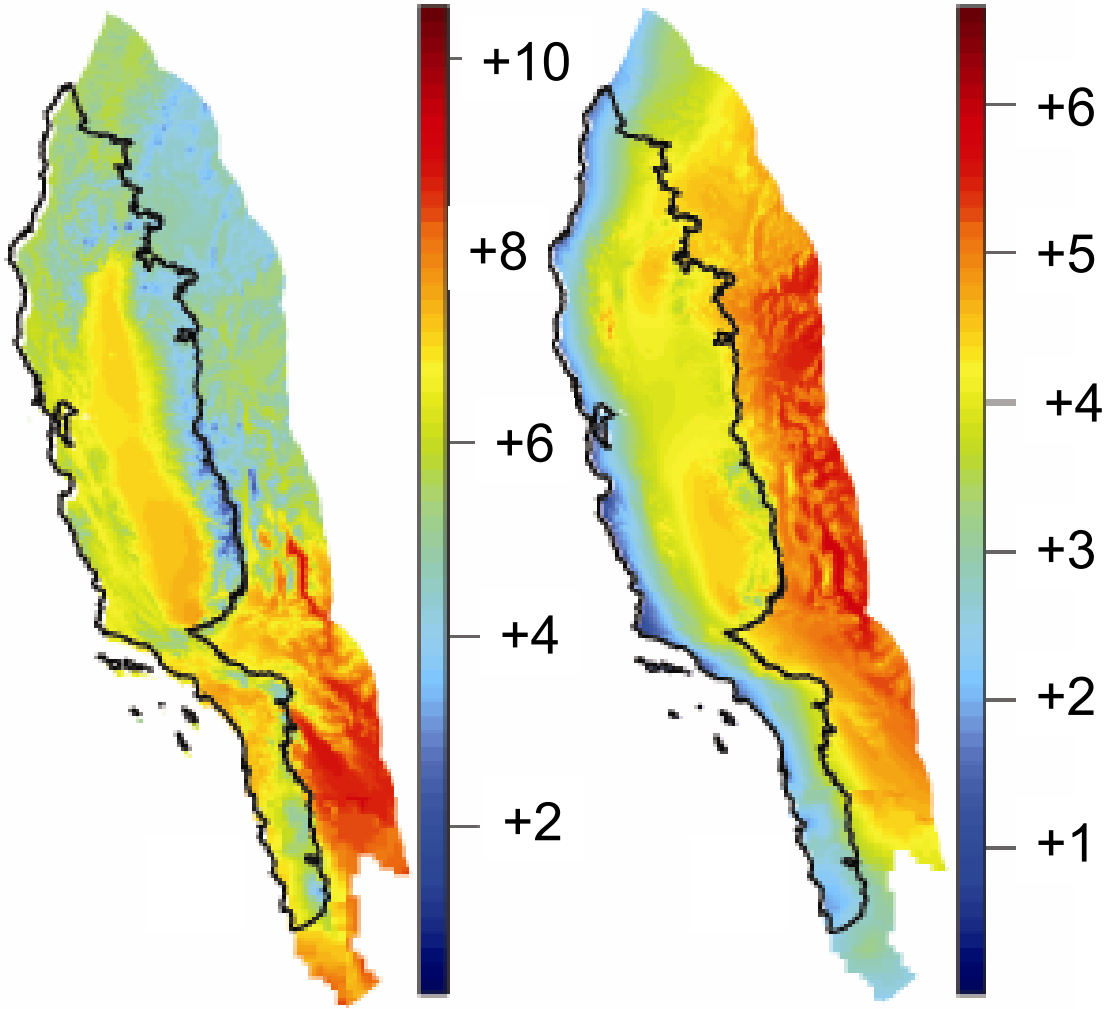
From: from M. Fernandez, H. Hamilton, T. Dawson and L. Kueppers (2013)


Mean annual temperature vs. Annual total precipitation
warmer, drier
warmer
warmer, wetter
drier
wetter
cooler, drier
cooler
cooler, wetter
Temperature departure (°C)
Precipitation departure (mm)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-400
-200
0
200
400
600
Baseline
Normal years
Anomalous years
+/- 1 SD from Precipitation departure mean
Mean
+/- 1 SD from Temperature departure mean



From: from M. Fernandez, H. Hamilton, T. Dawson and L. Kueppers (2013)

Predicted temperature increases in the California Floristic Province relative to 100-year averages

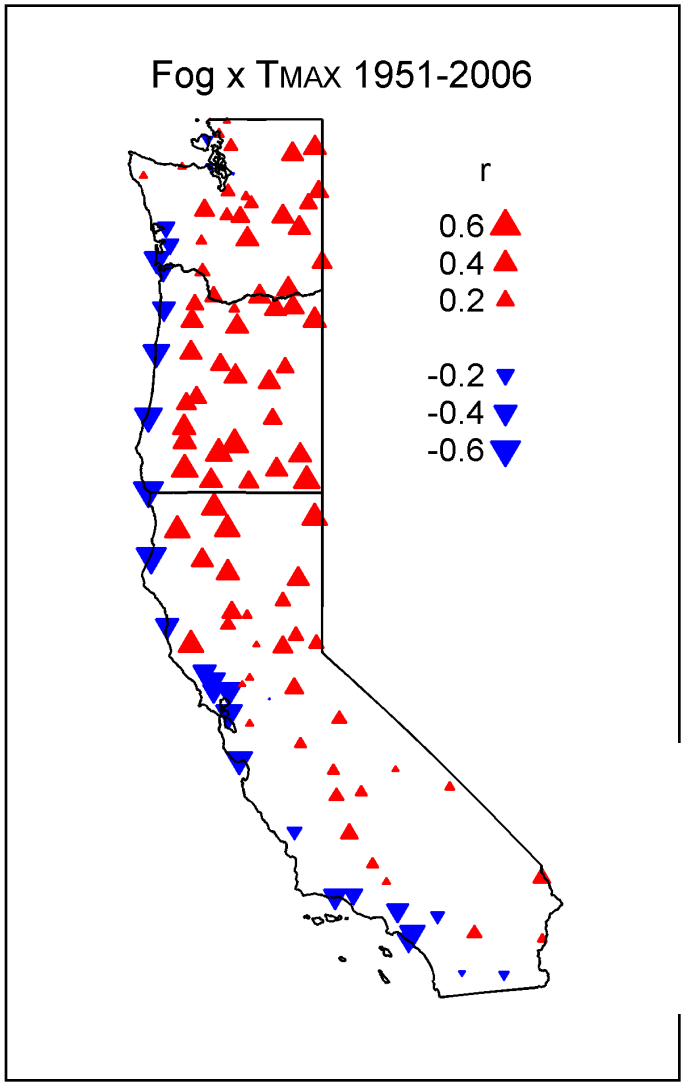


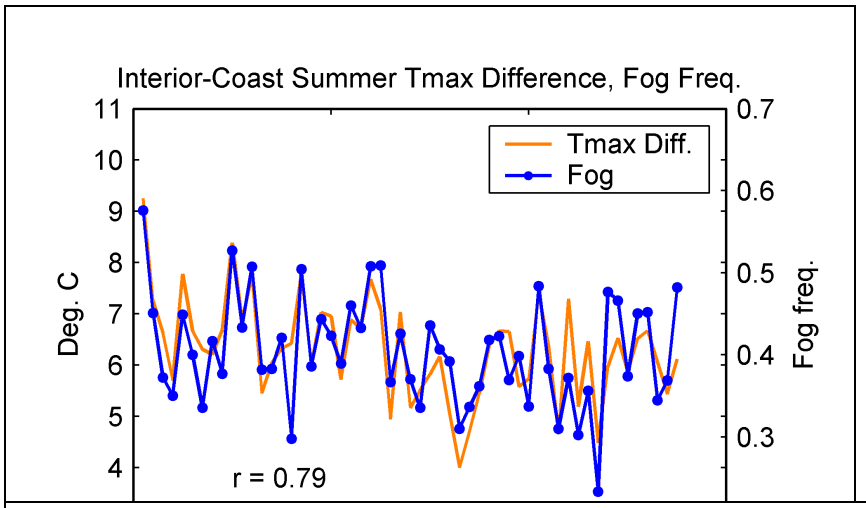
July

January

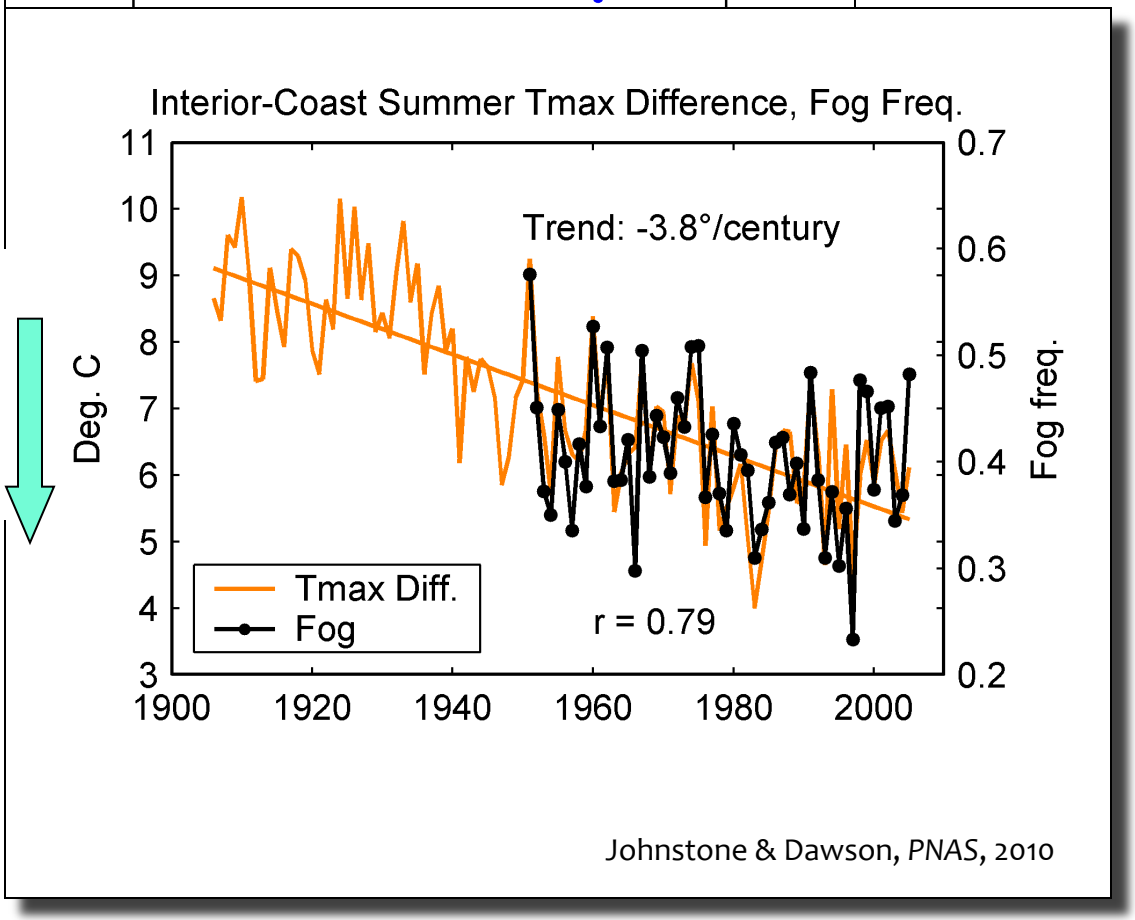
10 °C = 50 °F

Source: Loarie *et al.* 2008



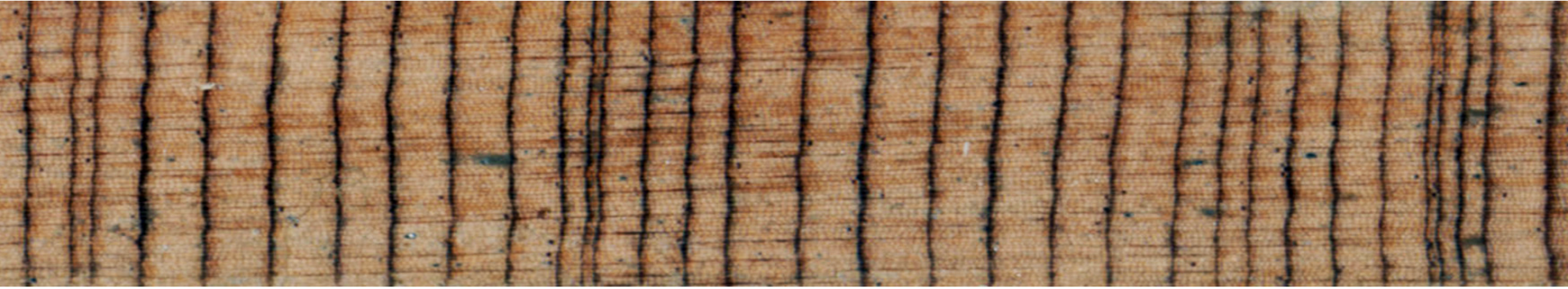


decreasing

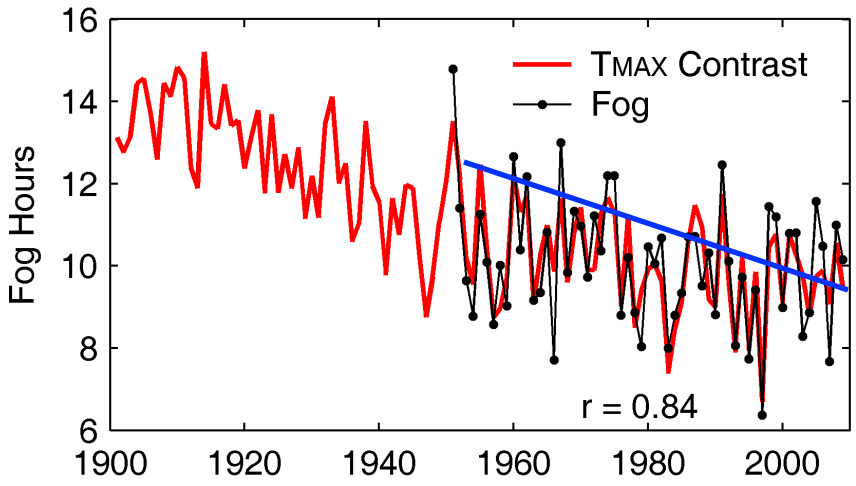


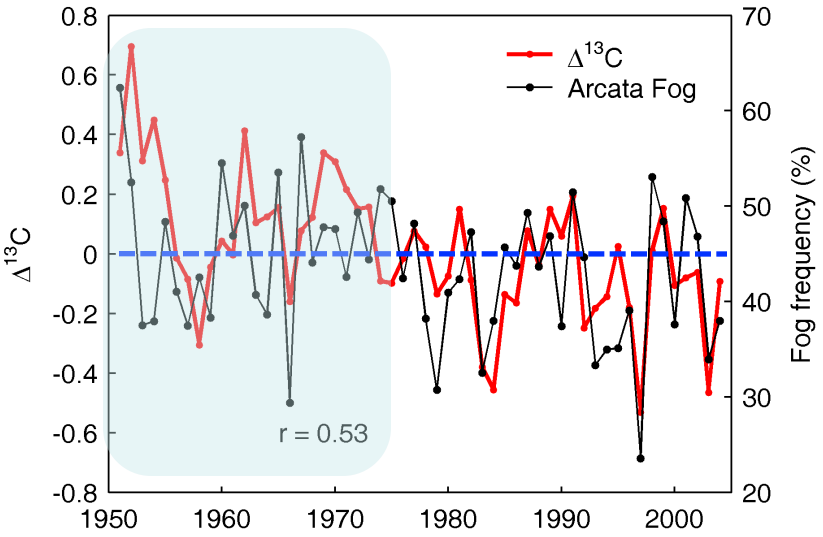
An average 33% reduction in fog frequency since 1951

Johnstone & Dawson, *PNAS*, 2010



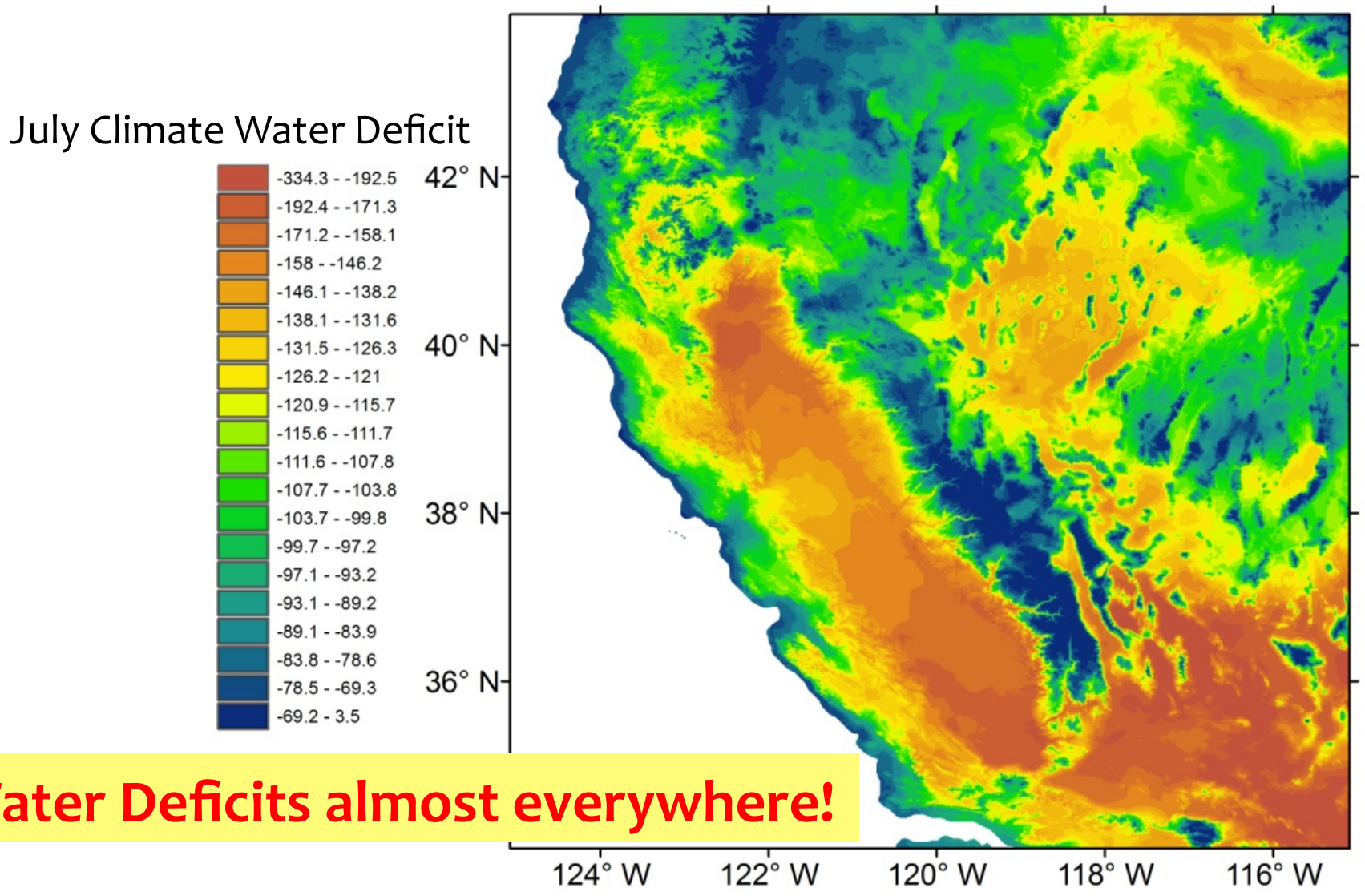
Use stable isotope dendrochronology coupled with climate analyses





Fog duration was ~3 hrs greater (+30%) in the early 20th century

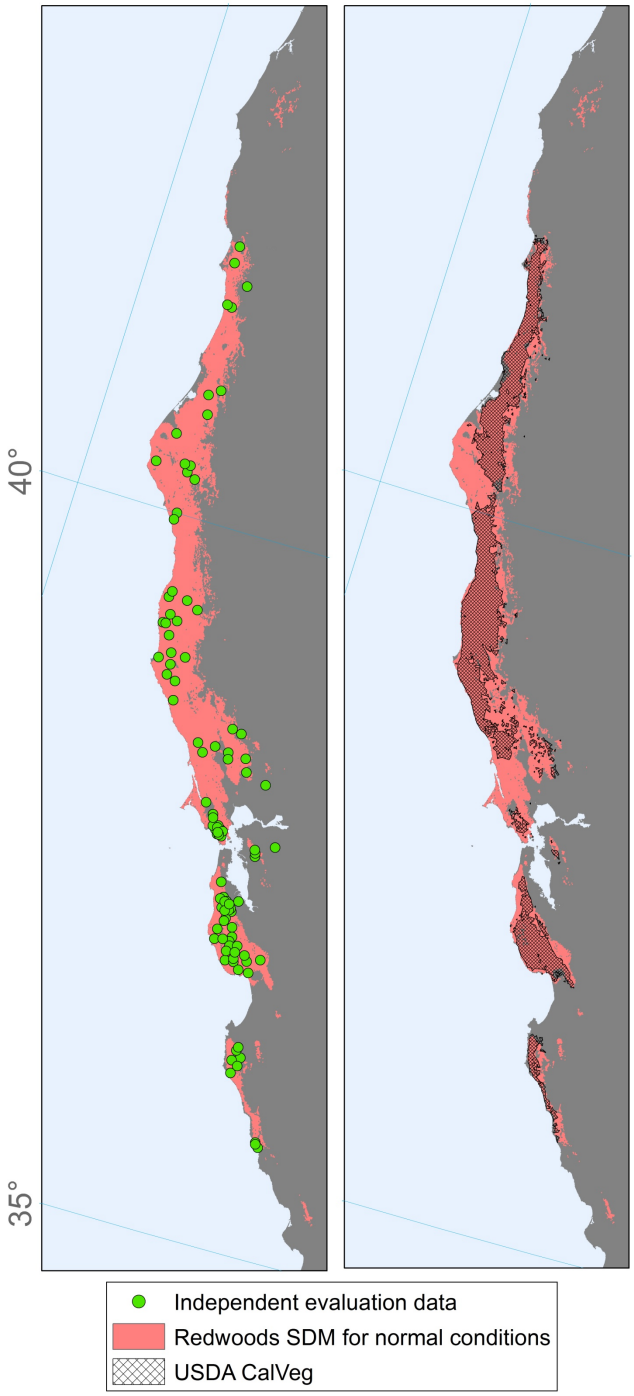
More fog, less water stress and more favorable physiology (+$\Delta^{13}C$)



Water Deficits almost everywhere!

High resolution climatic water deficit (balance between potential of the atmosphere to evaporate water and water availability, 1895-2010) projection relevant to redwoods (From M. Fernandez, *in prep.*)

Step 1: create a model of the "**bioclimatic envelope**" for coast redwoods under normal climate conditions, based on the observed current distribution



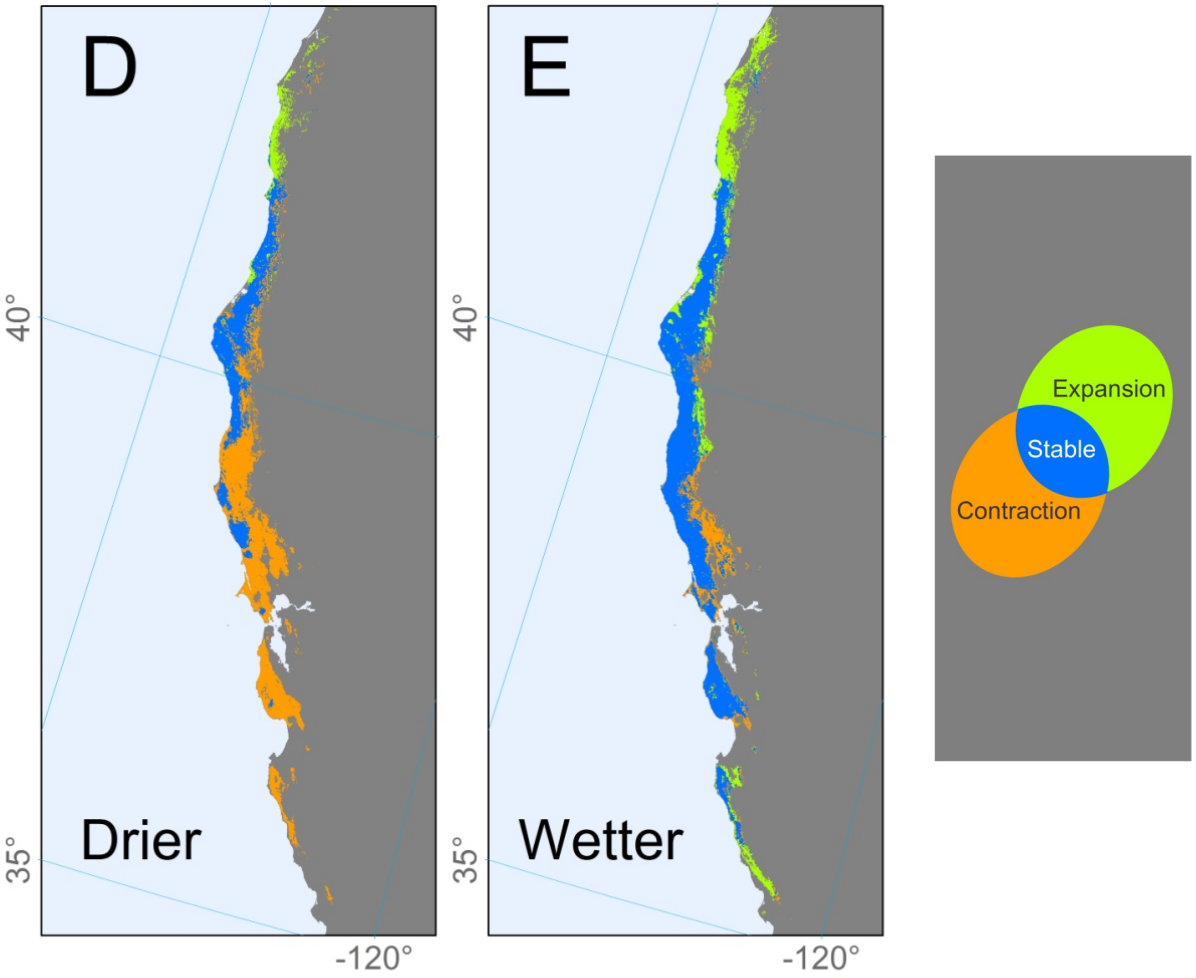
Step 2: project the **bioclimatic envelope** model in geographic space to identify where the climate conditions exist that coast redwoods require

Step 3: project the geographic distribution of the **bioclimatic envelope** model in geographic space *under past conditions of climate extremes*

From: from M. Fernandez, H. Hamilton, T. Dawson and L. Kueppers (2013)

S. sempervirens

"Wet" vs. "Dry" only scenarios

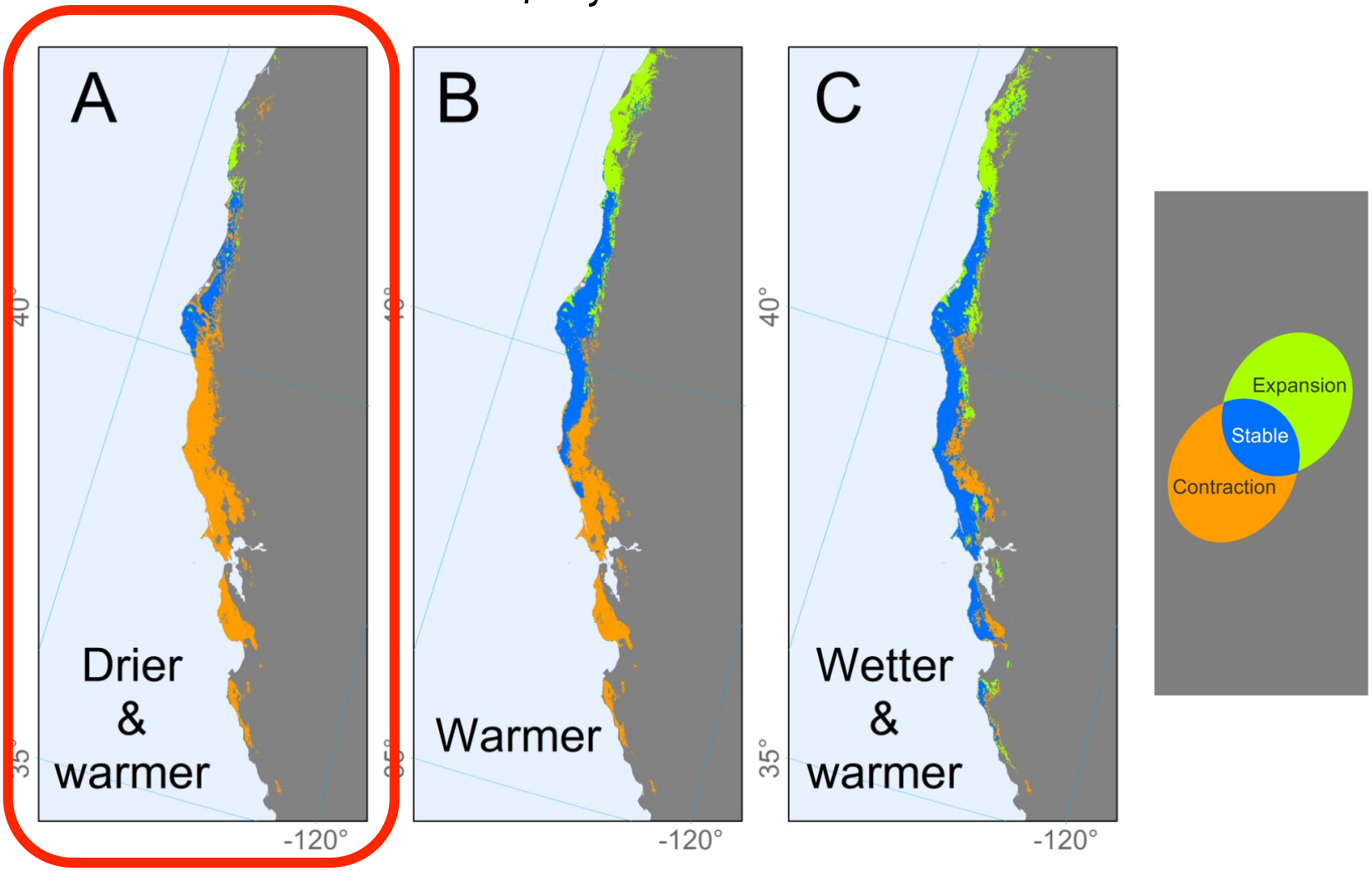


WATER really matters!

From: from M. Fernandez, H. Hamilton, T. Dawson and L. Kueppers (2013)

S. sempervirens

"Warmer" X "Wet/Dry" world scenarios



Temperature x Water really, really matter!!

From: from M. Fernandez, H. Hamilton, T. Dawson and L. Kueppers (2013)

Looking ahead

- Conservation of large tracks of ecosystem the will be essential
- Ecosystems, not just species, must be protected
- Water resource protection and management must improve
- Assisted migration should be considered and active (forest) ecosystem management designed and implemented NOW

Thanks to my collaborators:

Steve Burgess, Eric Dubinsky, Adeline Fabré, Mary Firestone, Damon Bradbury, Kevin Tu, Stefania Mambelli, Jia Hu, Primrose Boynton, Jim Johnstone, Anthony Ambrose, Kevin Simonin, Emily Burns, Vanessa Boukili, Lou Santiago, Jarmila Pittermann, Pam Templer, Kathie Weathers, Holly Ewing, John Roden, Wendy Baxter, Chris Wong, Adam West, John Roden, Cameron Williams, Rikke Naesborg, George Koch, Bob Van Pelt, Steve Sillett

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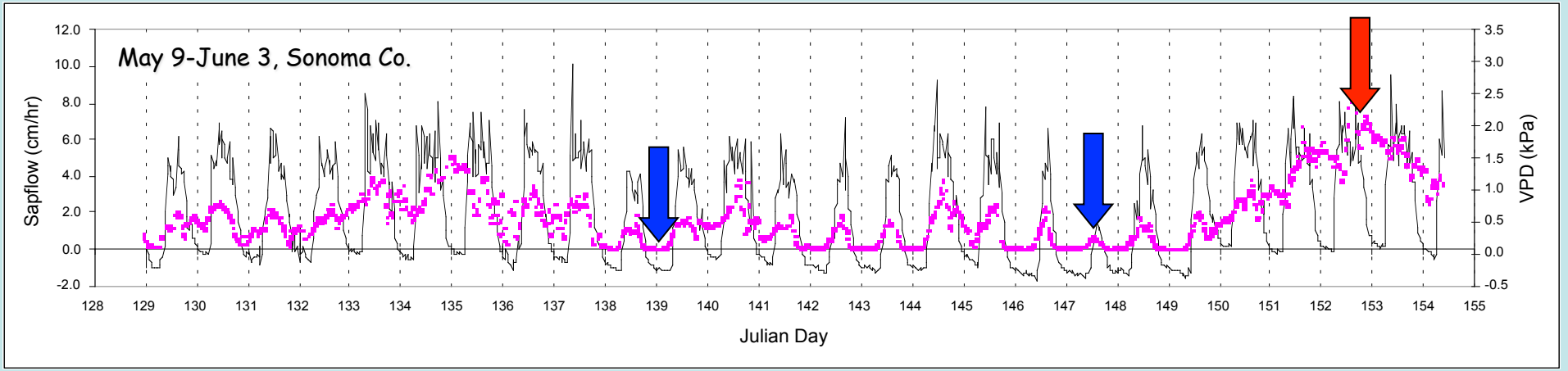
Photos: M. Nichols

Thank you

Questions?

Comments?



Sapflow at the base of the live-crown in *Sequoia* during both spring 'fog' events when vapor pressure deficits (VPD; shown in **pink**) are:

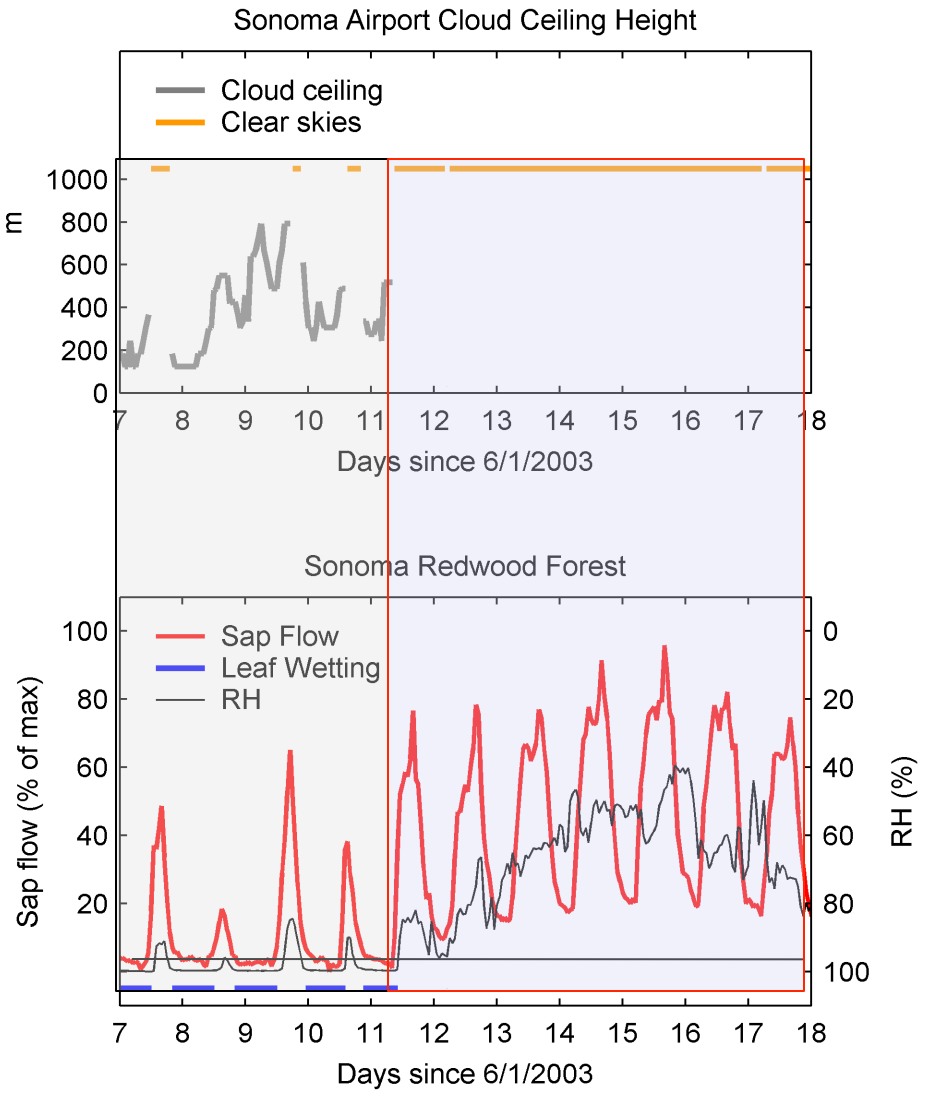
LOW [**wet leaves** = fog, **blue** arrows] VPD massive reverse flows some 38-55 m away from the sites of foliar absorption are observed]

-- or --

HIGH [**red** arrow] VPD one observes higher day- and **nighttime** sapflow (water loss) velocities (from Dawson *et al.* 2007)

June 7-18, 2003

Hourly cloud height Sonoma County Airport



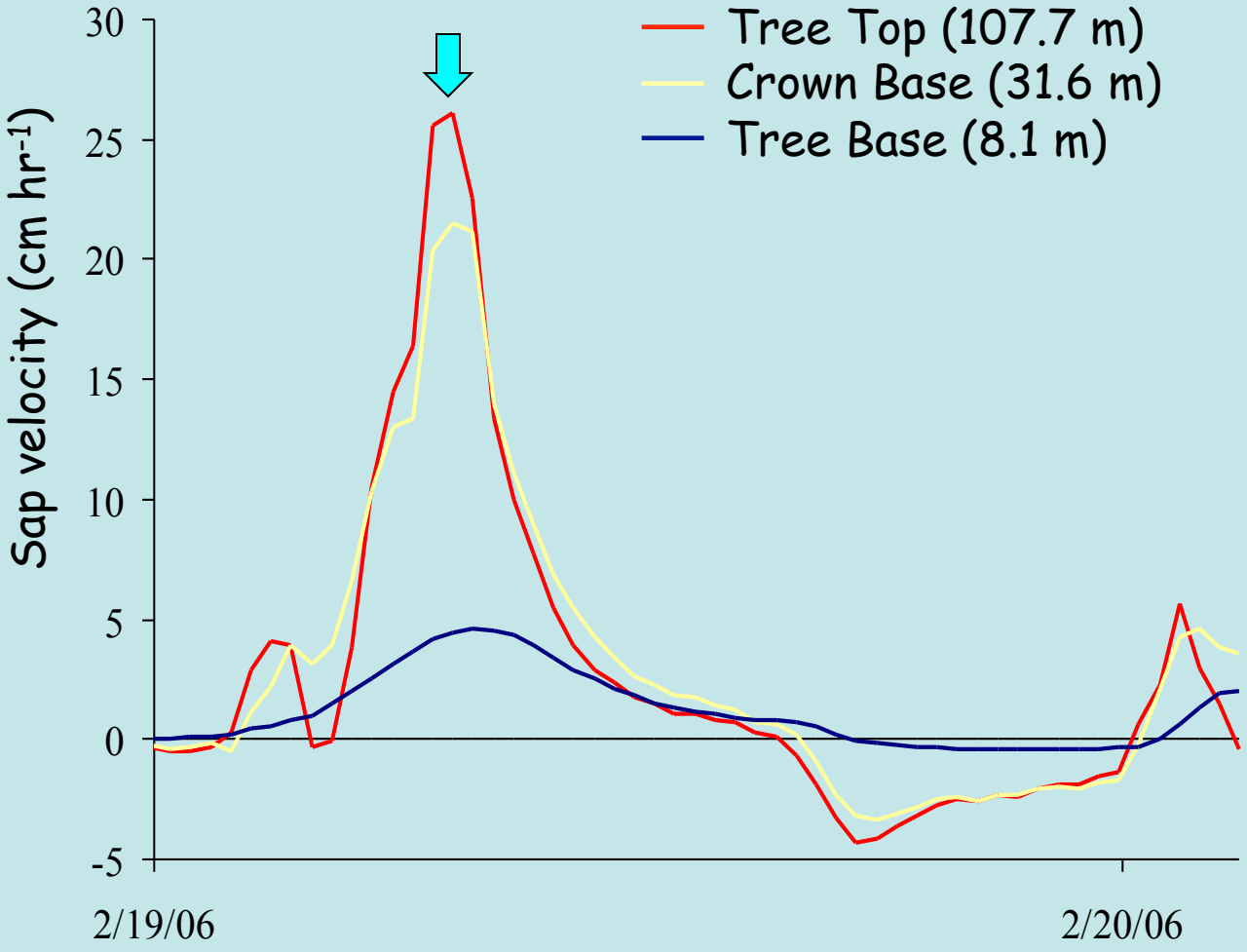
Trunk sap flow (-)

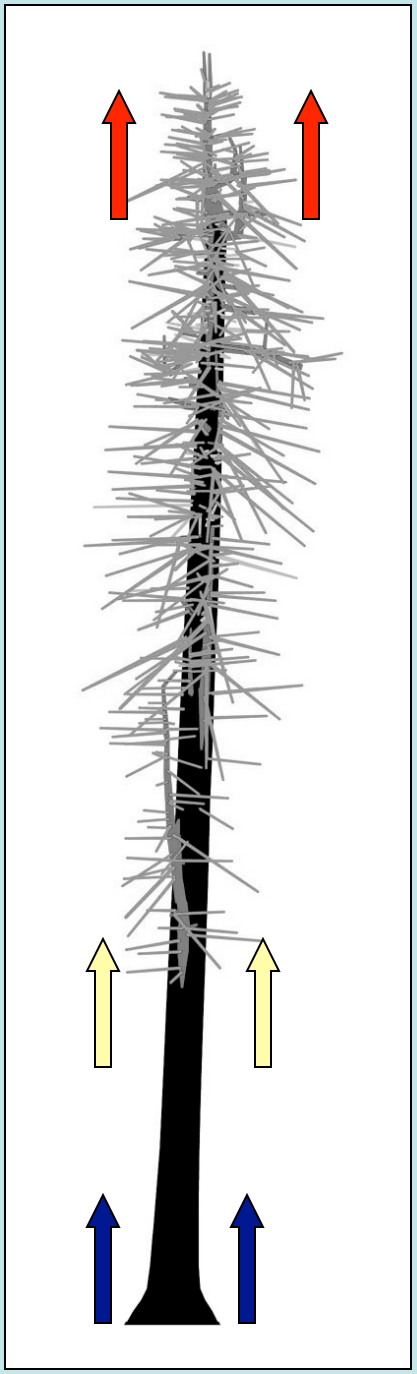
Leaf wetness (-)

Fog raises humidity, controls evaporative demand and **tree water use** – day & night

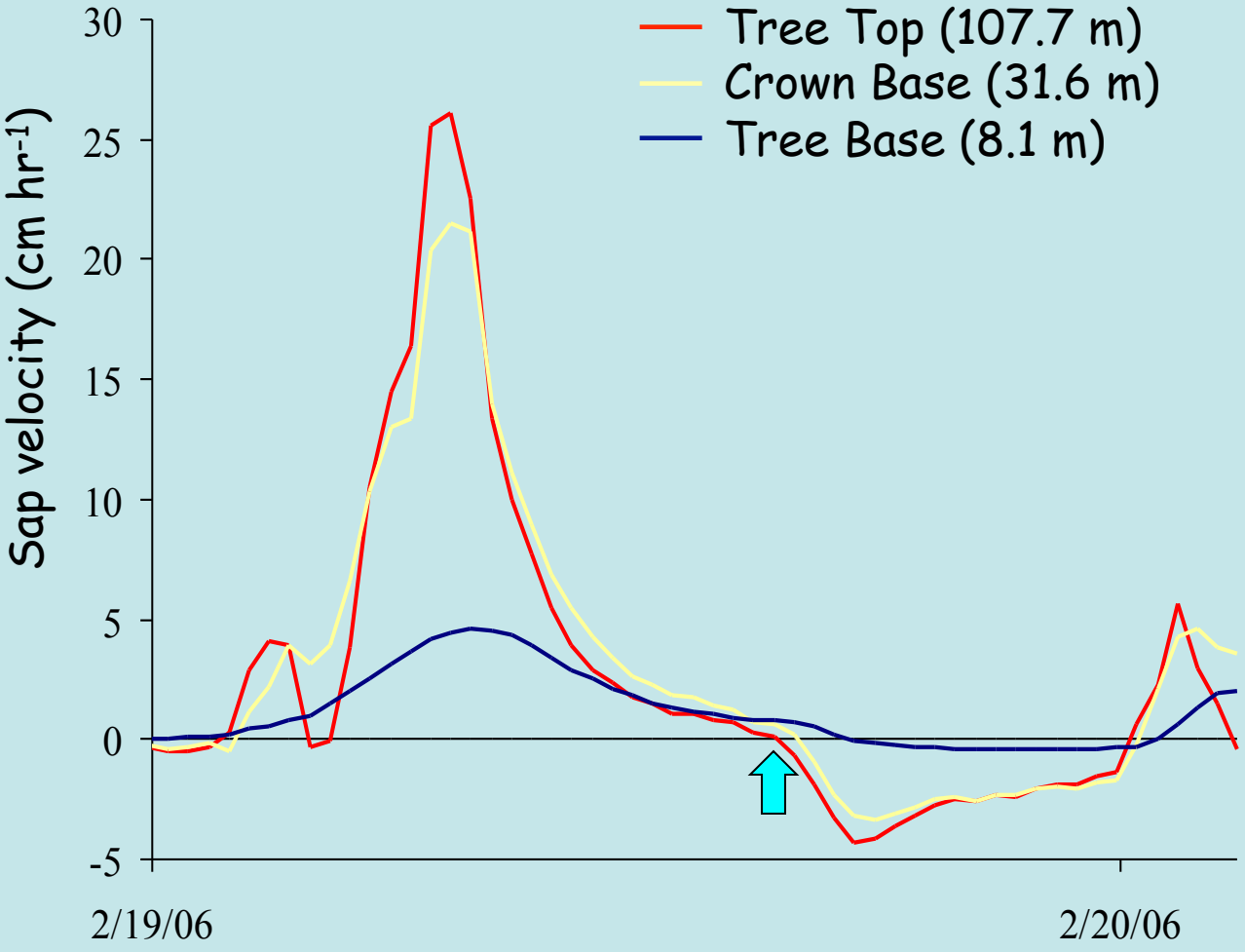
Johnstone & Dawson, PNAS, 2010

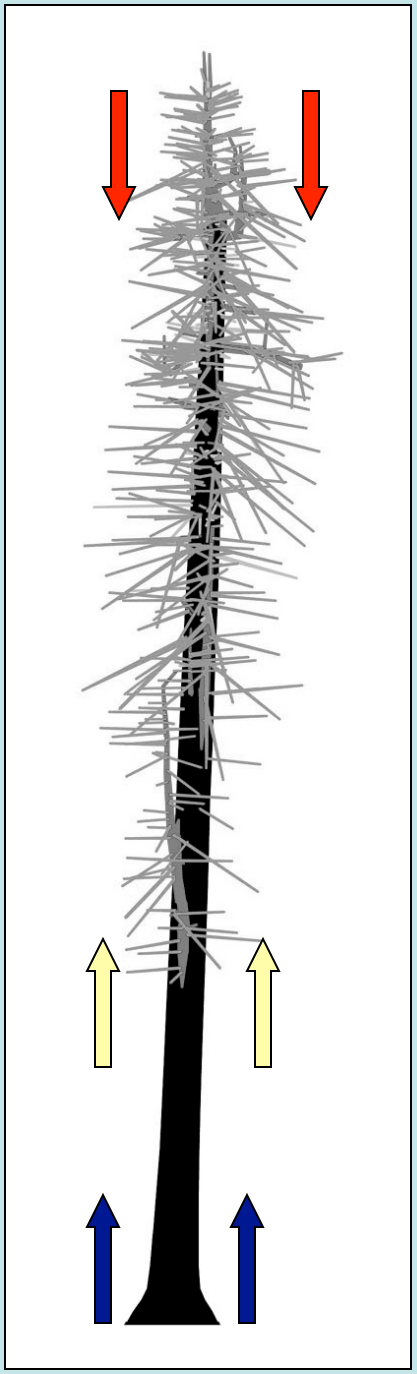
Watch where the blue arrow below is and the flow direction arrows on the tree model



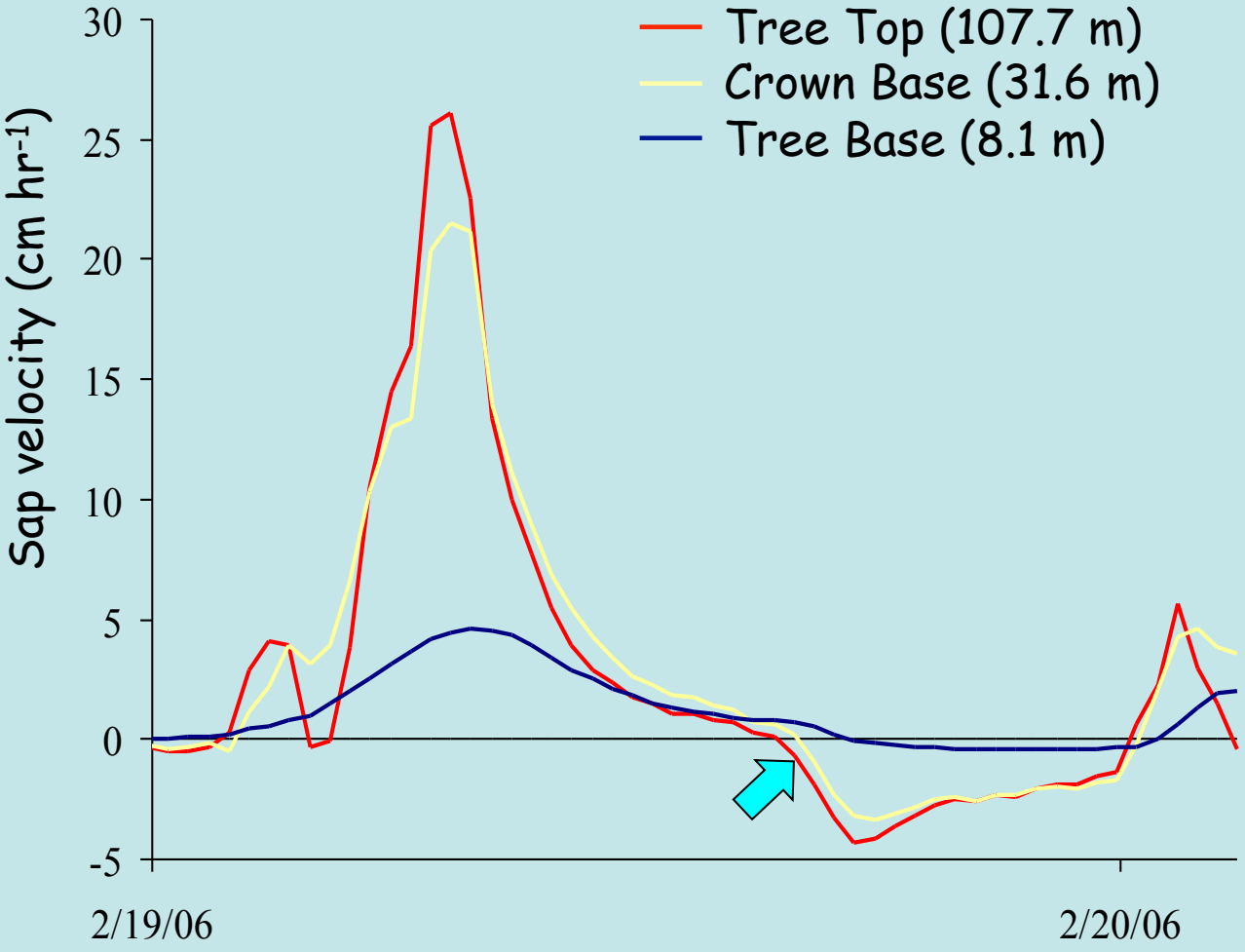


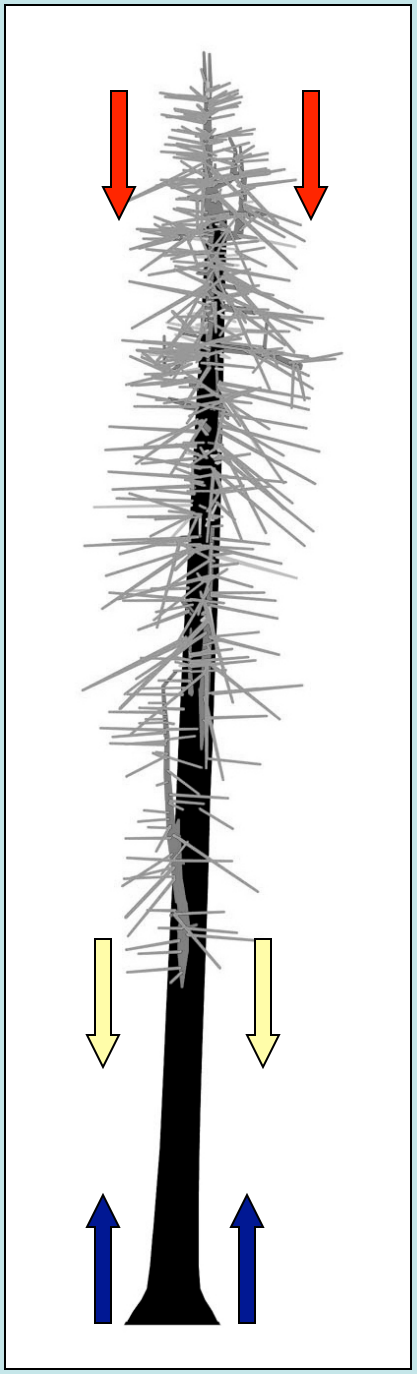
From: Ambrose et al., *Tree Physiology* 2010





From: Ambrose et al., *Tree Physiology* 2010





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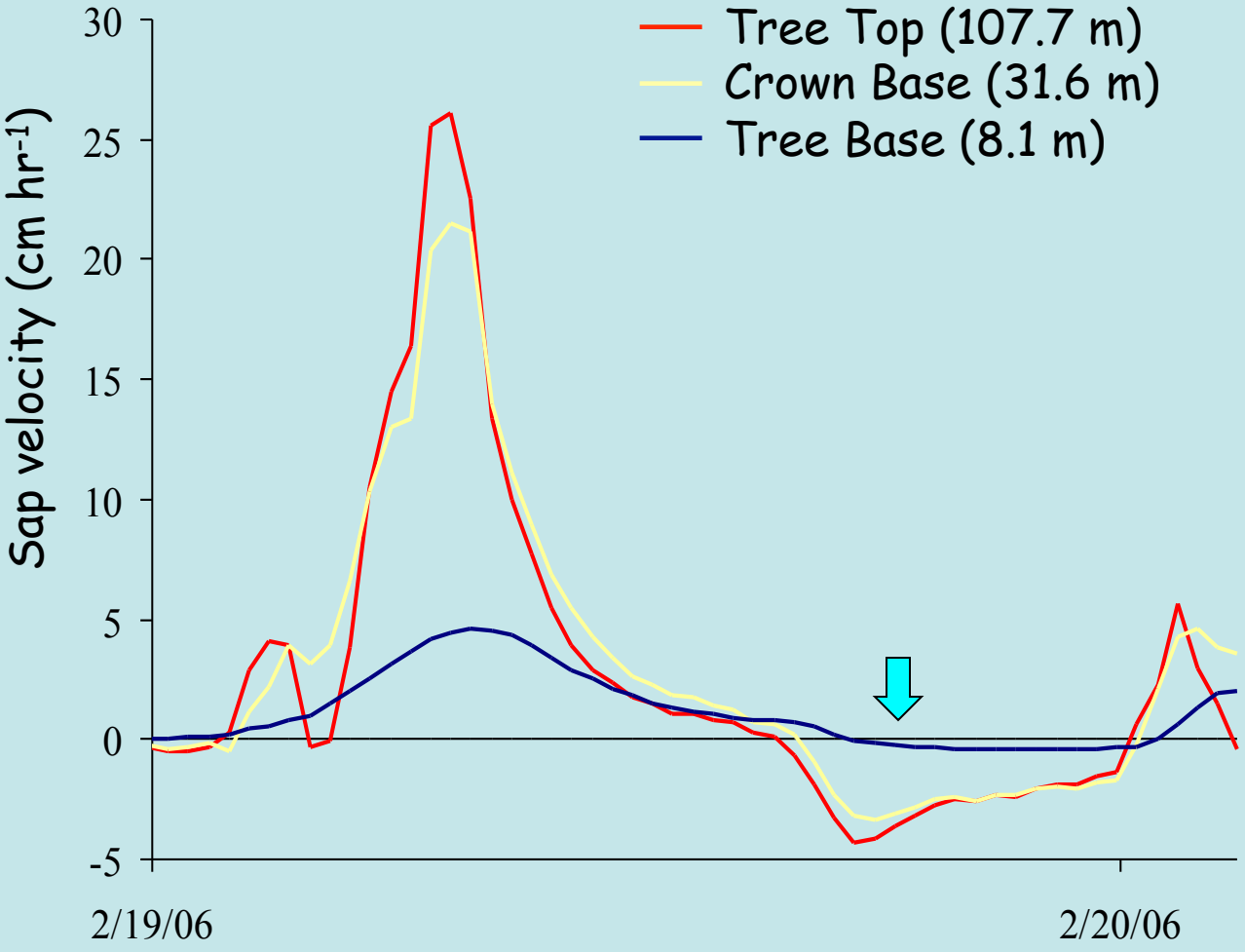
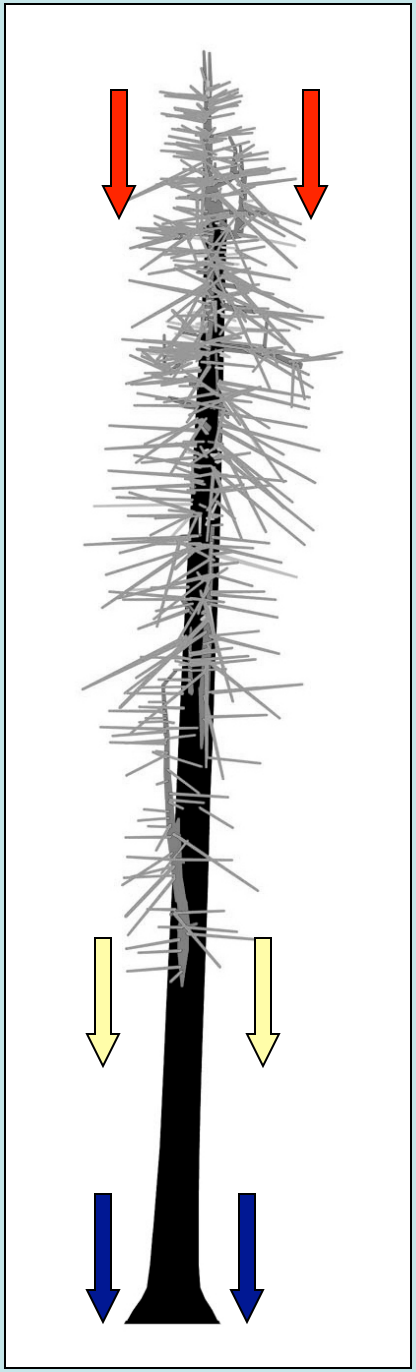
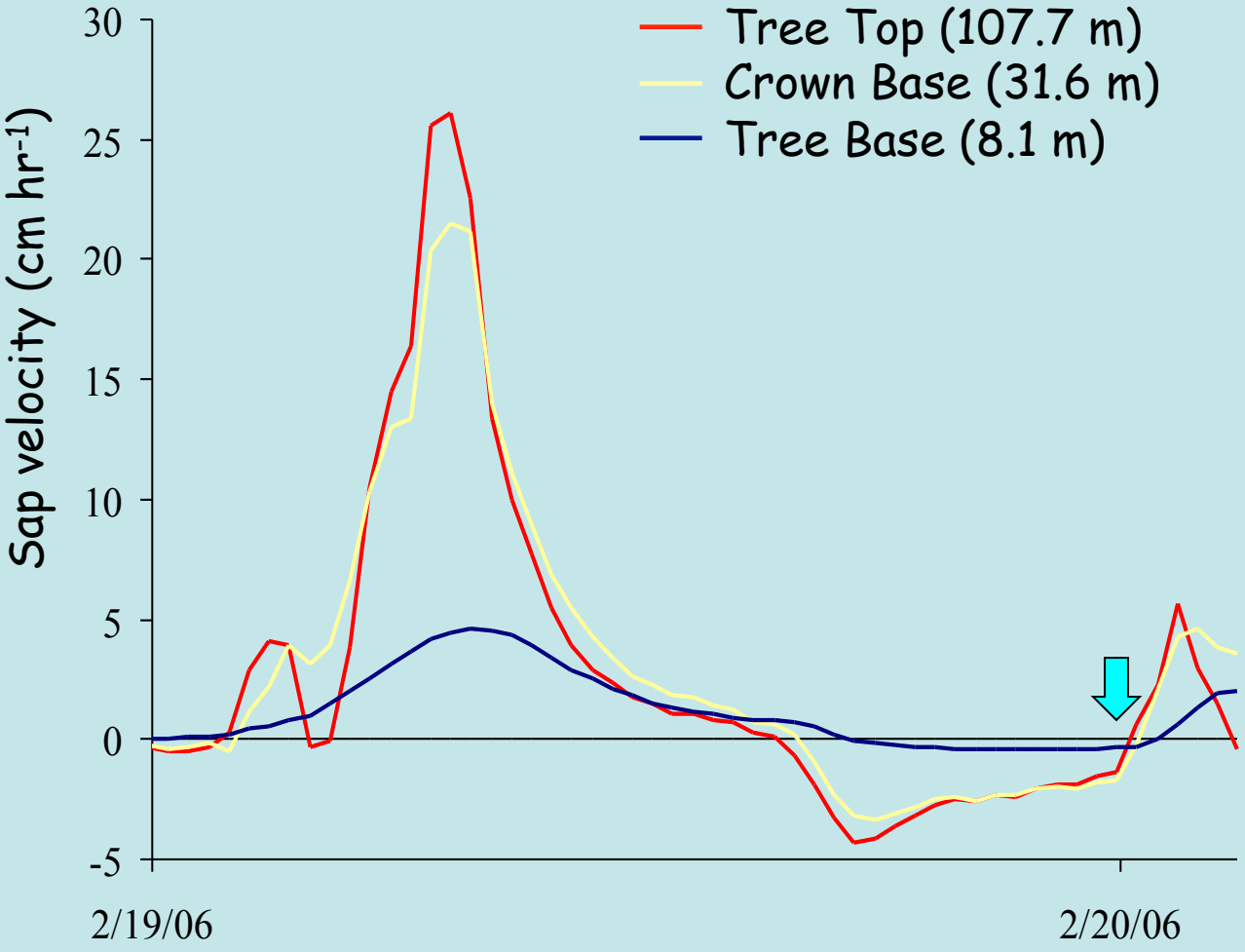
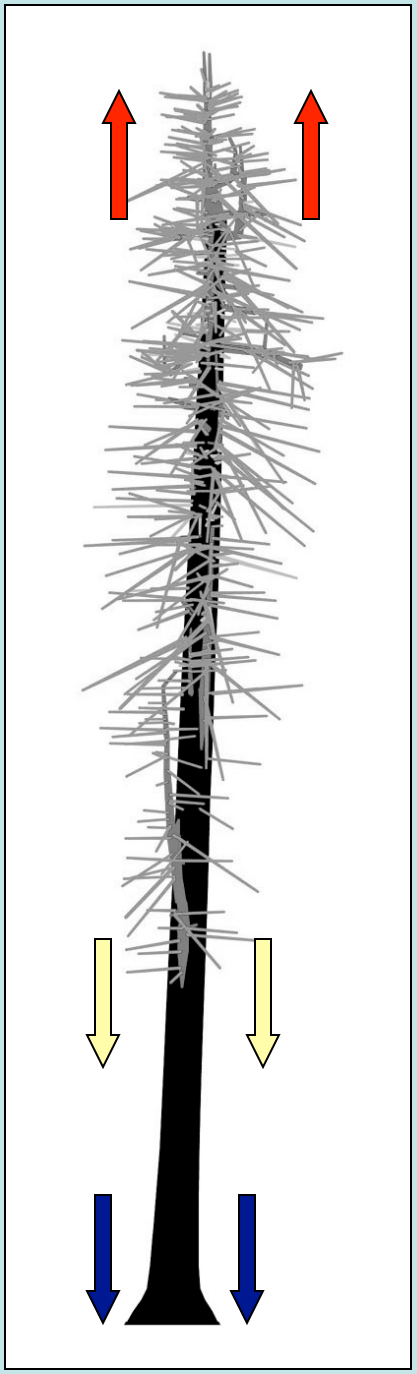


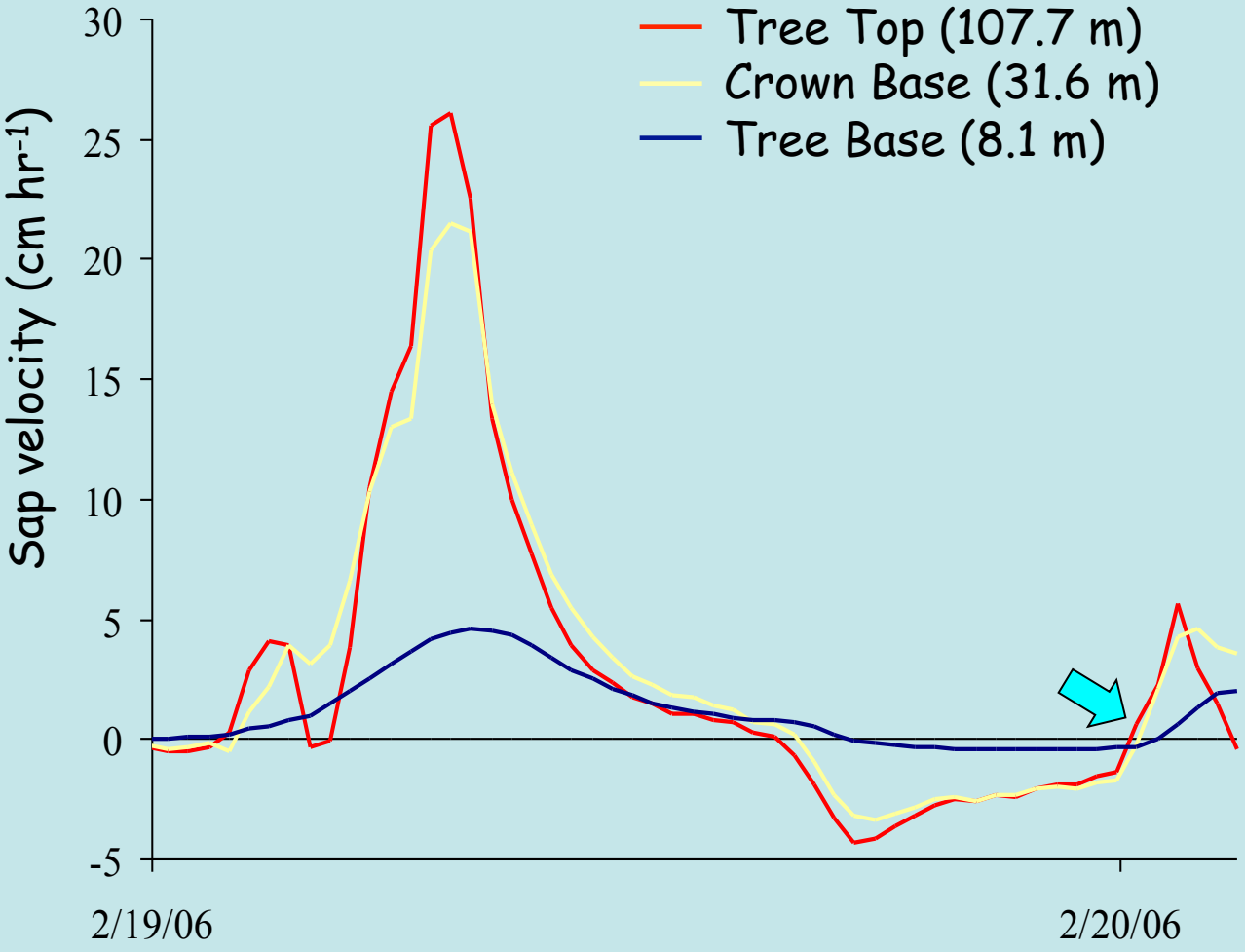


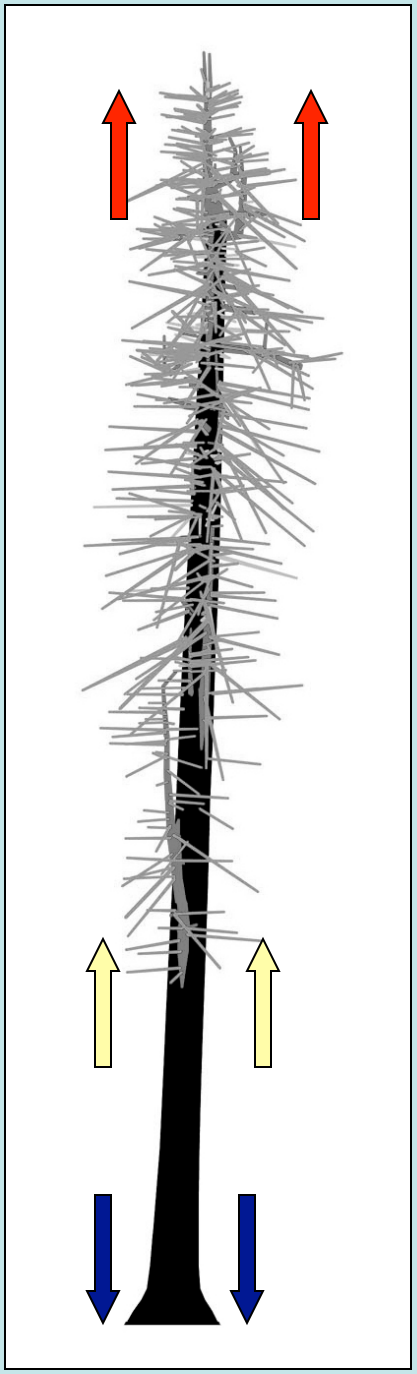
From: Ambrose et al., *Tree Physiology* 2010





From: Ambrose et al., *Tree Physiology* 2010





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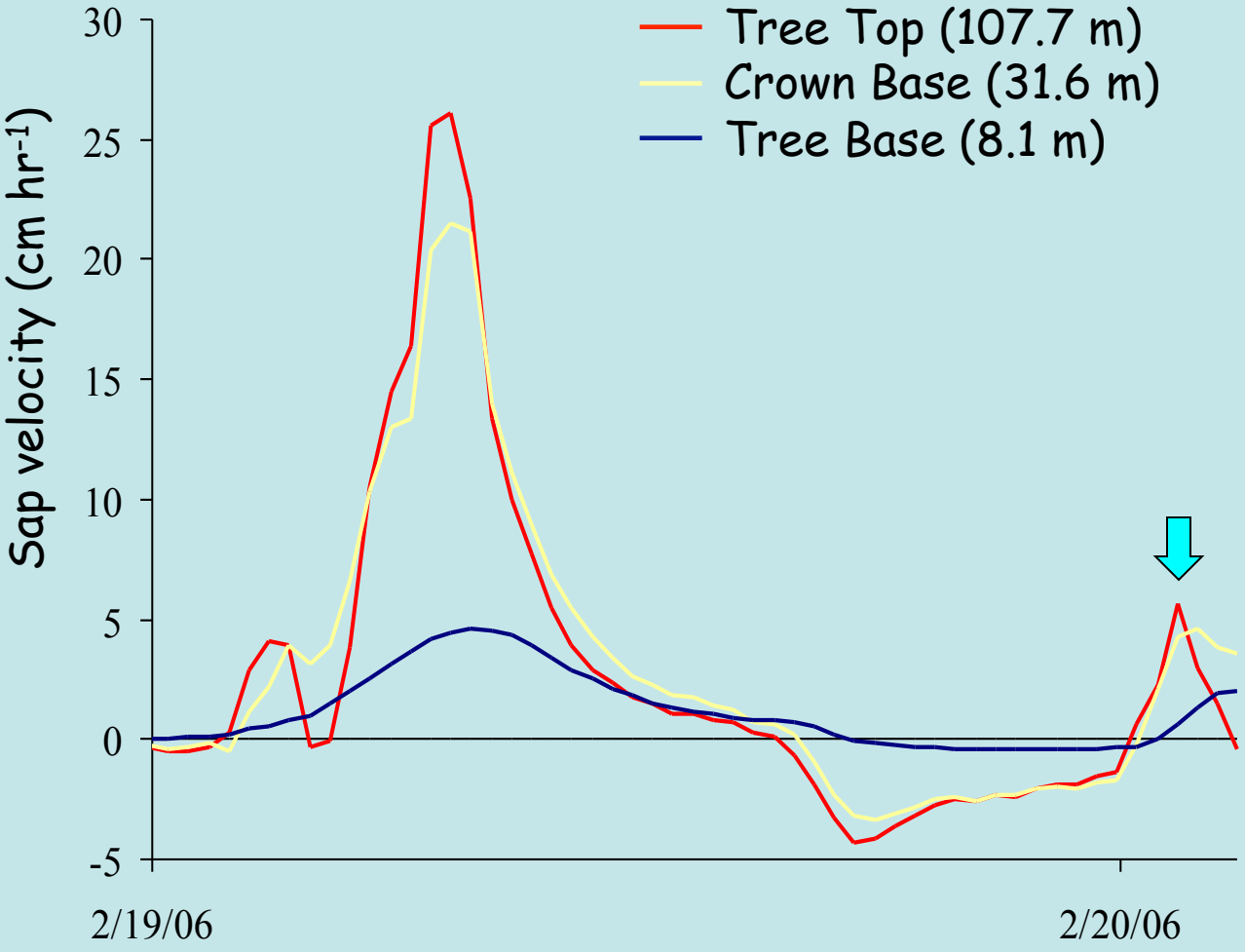
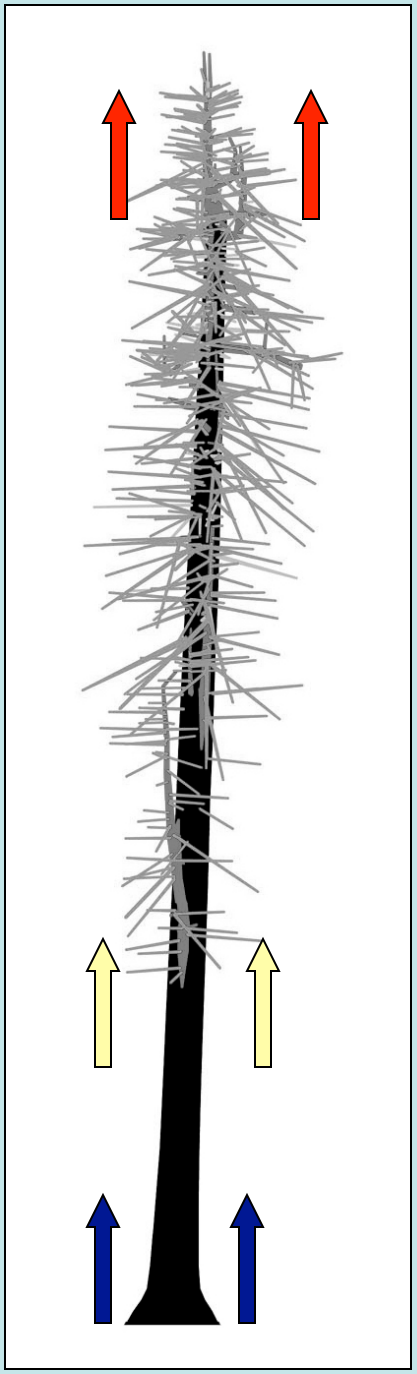
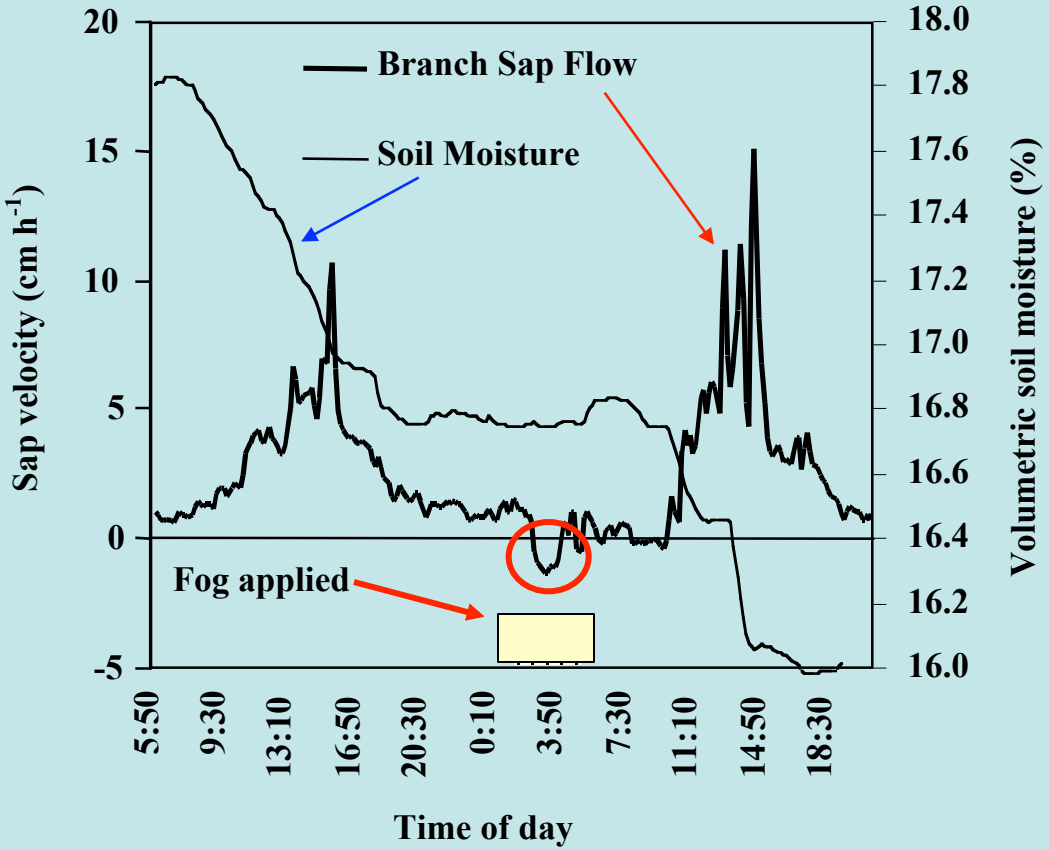




From: Ambrose et al., *Tree Physiology* 2010

Greenhouse Experiment:

Fog-chamber with a water atomizer for experimental fogging



Sap flow in a 5 mm diameter branch of a redwood sapling exposed to 3 hours of fog during the night. Volumetric soil moisture was measured in the pots pot using TDR **and pots were covered**

Burgess and Dawson, 2004

Climate (●) and Eco/phys investgations (●)