Learning to listen to plants
–
tools for efficient water use

Toby Wheeler
(→ 10x Genomics)

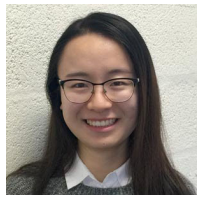
Prof. Lailiang Cheng

Prof. Mike Gore

Vinay Pagay
(→ U. Adelaide)

Olivier Vincent
(→ U. Lyon)

Michael Santiago
(→ FloraPulse Co)


Siyu Zhu

Winston Black

Piyush Jain

Kathryn Haldeman

Prof. Alan Lakso

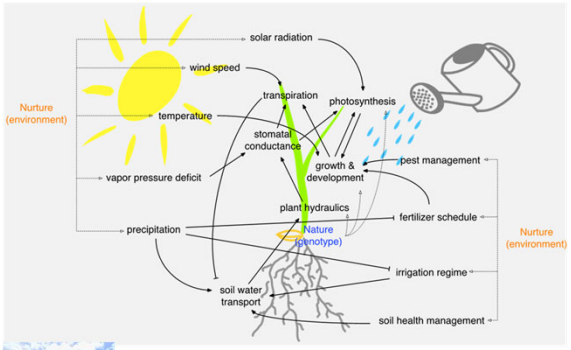
Prof. Fengqi You

Abe Stroock

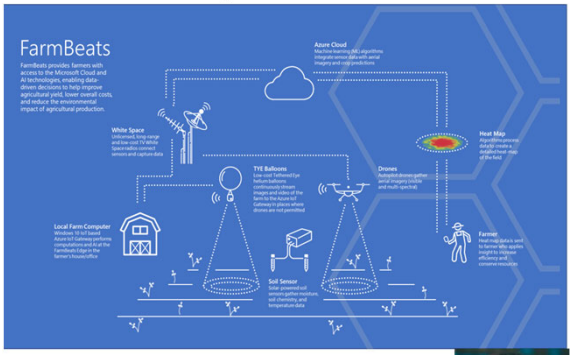
Robert F. Smith School of Chemical and Biomolecular Engineering

Cornell University

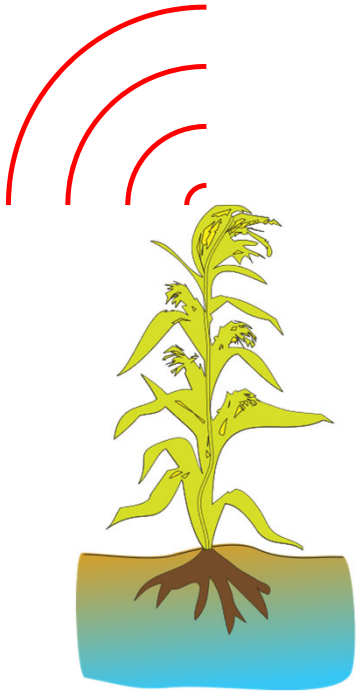
models

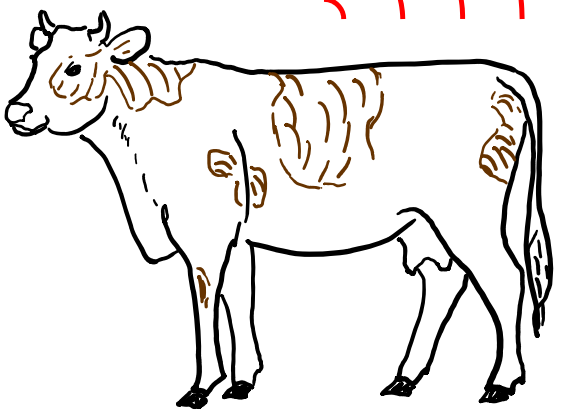


systems

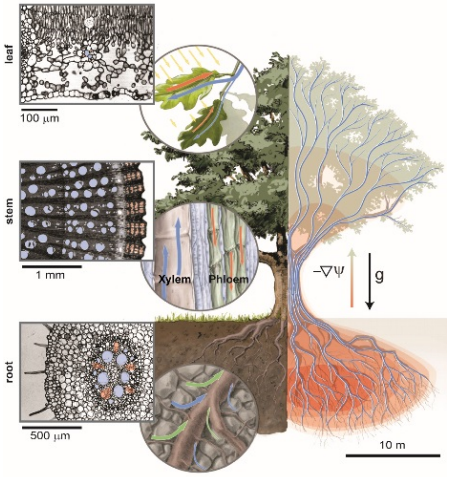


organism-as-sensor

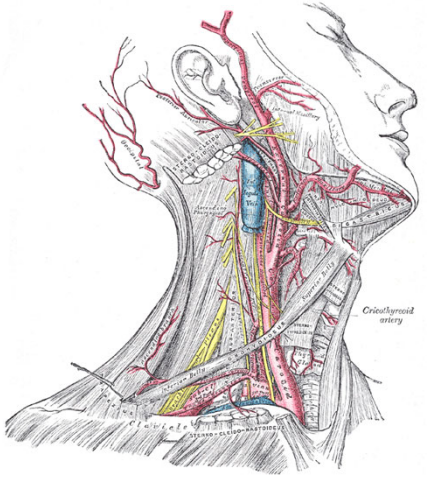




The neglected eukaryote

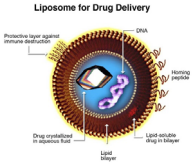


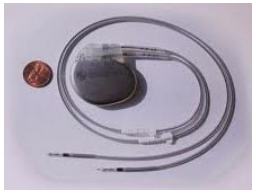
(Stroock et al., ARFM, 2014)

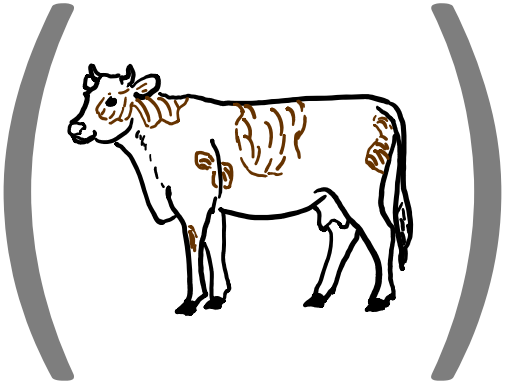


(Gray's Anatomy, 1858)

water stress?
nitrogen status?
root architecture?
microbiome?
stomatal regulation?
metabolic rates?
hormone signals?
…







Water stress controls biology…

GROWTH

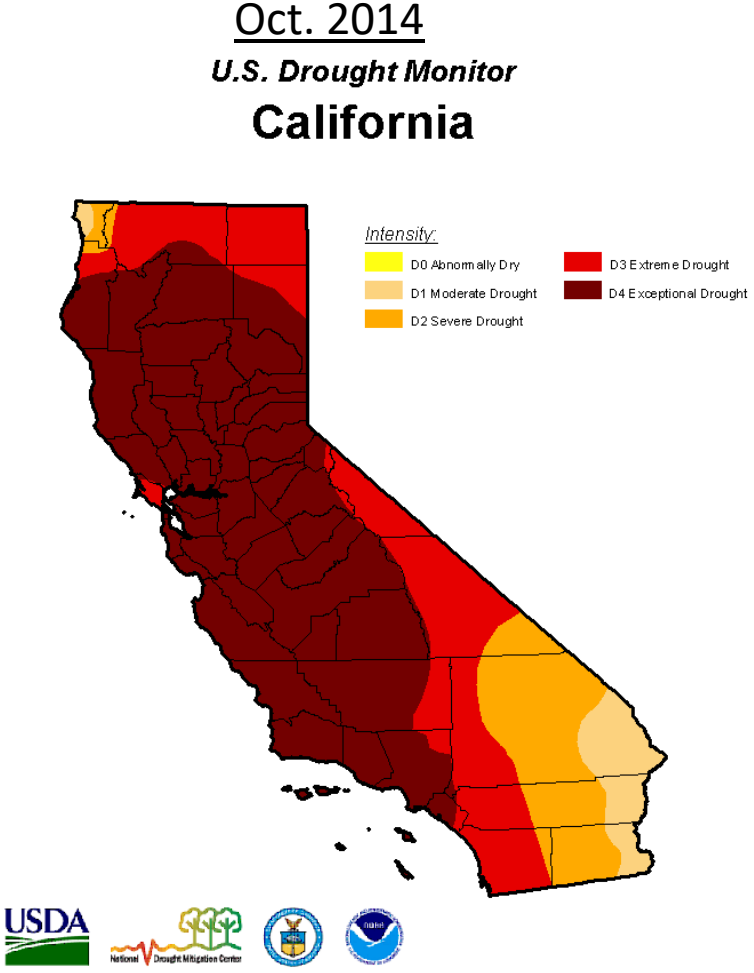
QUALITY

YIELD

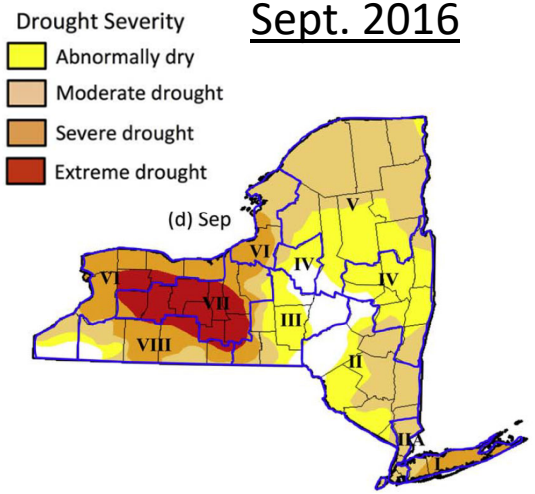
DISEASE

Water stress is increasing

Oct. 2014



Sept. 2016



(a) Rainfed crop yield loss

Region	Fruit% loss	# fruit farms
I	13%	2
II	20%	5
III	75%	4
IV	79%	5
V	30%	4
VI	33%	43
VII	69%	14
VIII	60%	2
Mean% loss	47%	
Total # farms		79

(b) Irrigated crop yield loss

Region	Fruit% loss
I	0%
II	4%
III	14%
IV	13%
V	4%
VI	14%
VII	15%
VIII	25%
Mean% loss	11%
Total # farms	

(Sweet et al., Ag Forest Meteor, 2017)

Water stress is *not* controlled

1 almond

1.1 gallon water

(Mother Jones)

40% of all food crops are irrigated

irrigation accounts for 70% of human use of fresh water.

typical irrigation provides 200% of water needed by crop

(Fereres and Soriano, 2007; United Nations, 2012)

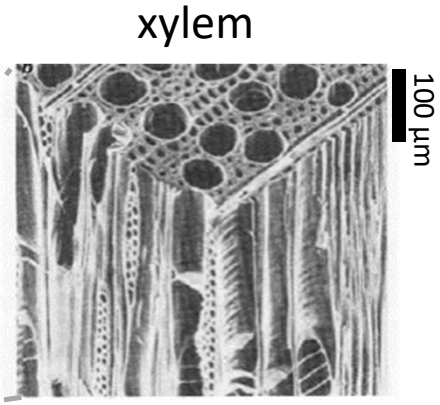
State-of-the-art

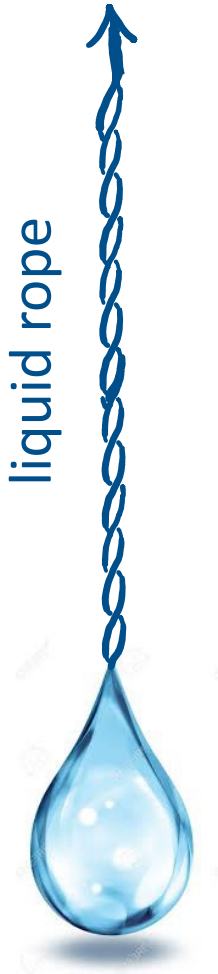
Schölander Pressure Chamber (1965)

www.desertusa.com

thecurrent.org

stress = tension = *negative* pressure





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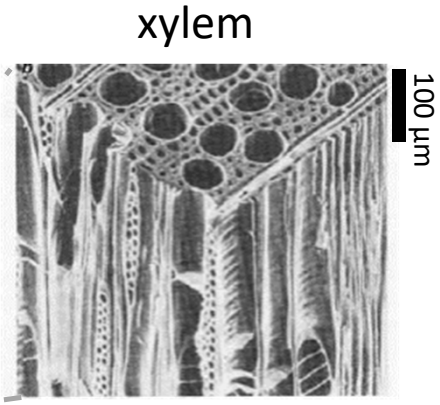
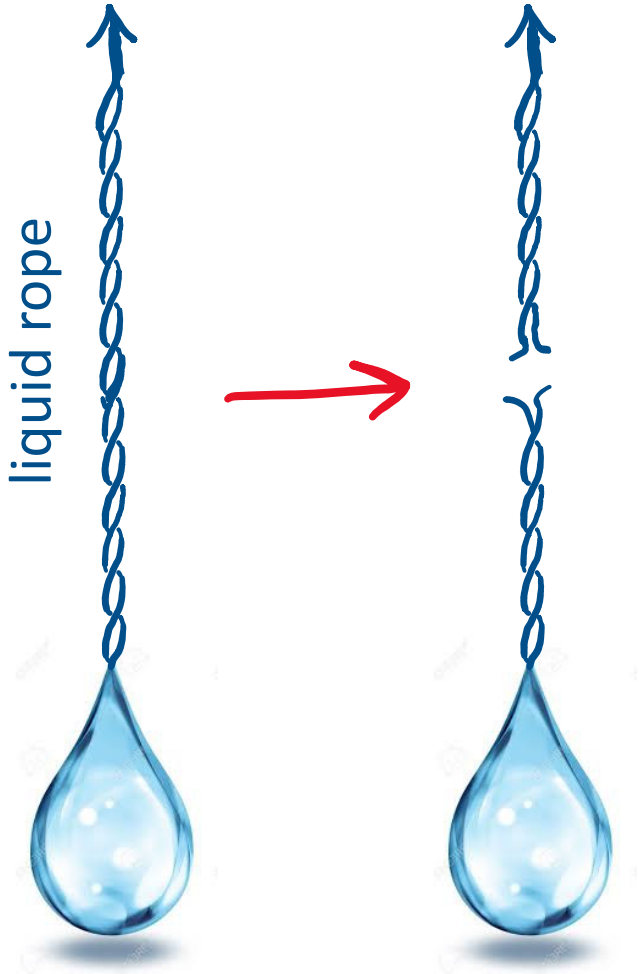
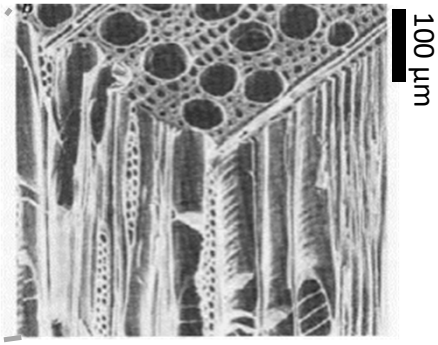


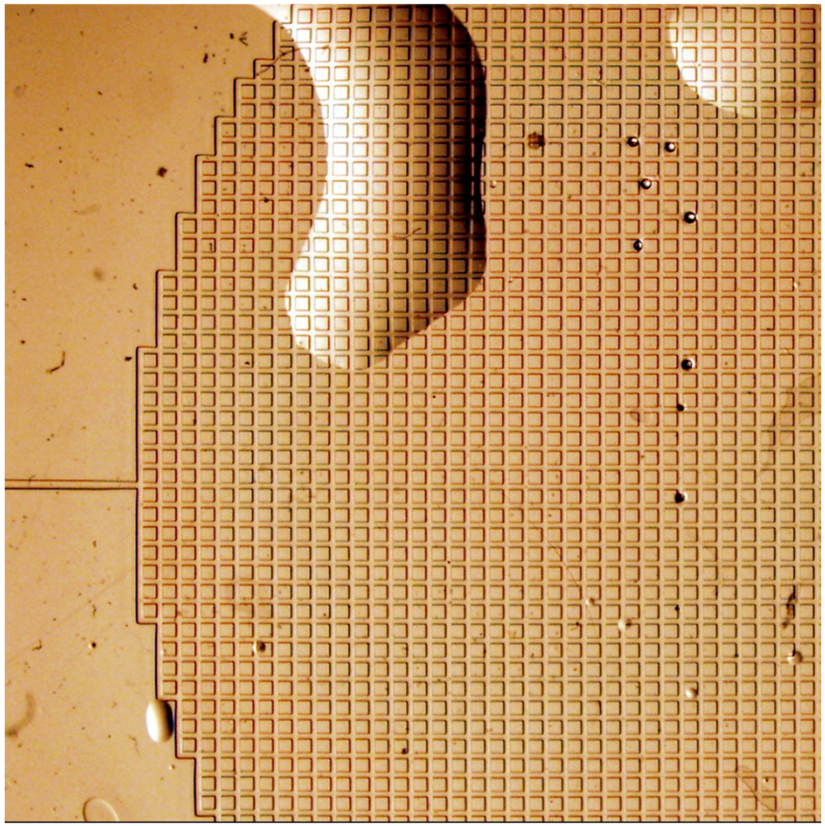


synthetic plants?

xylem

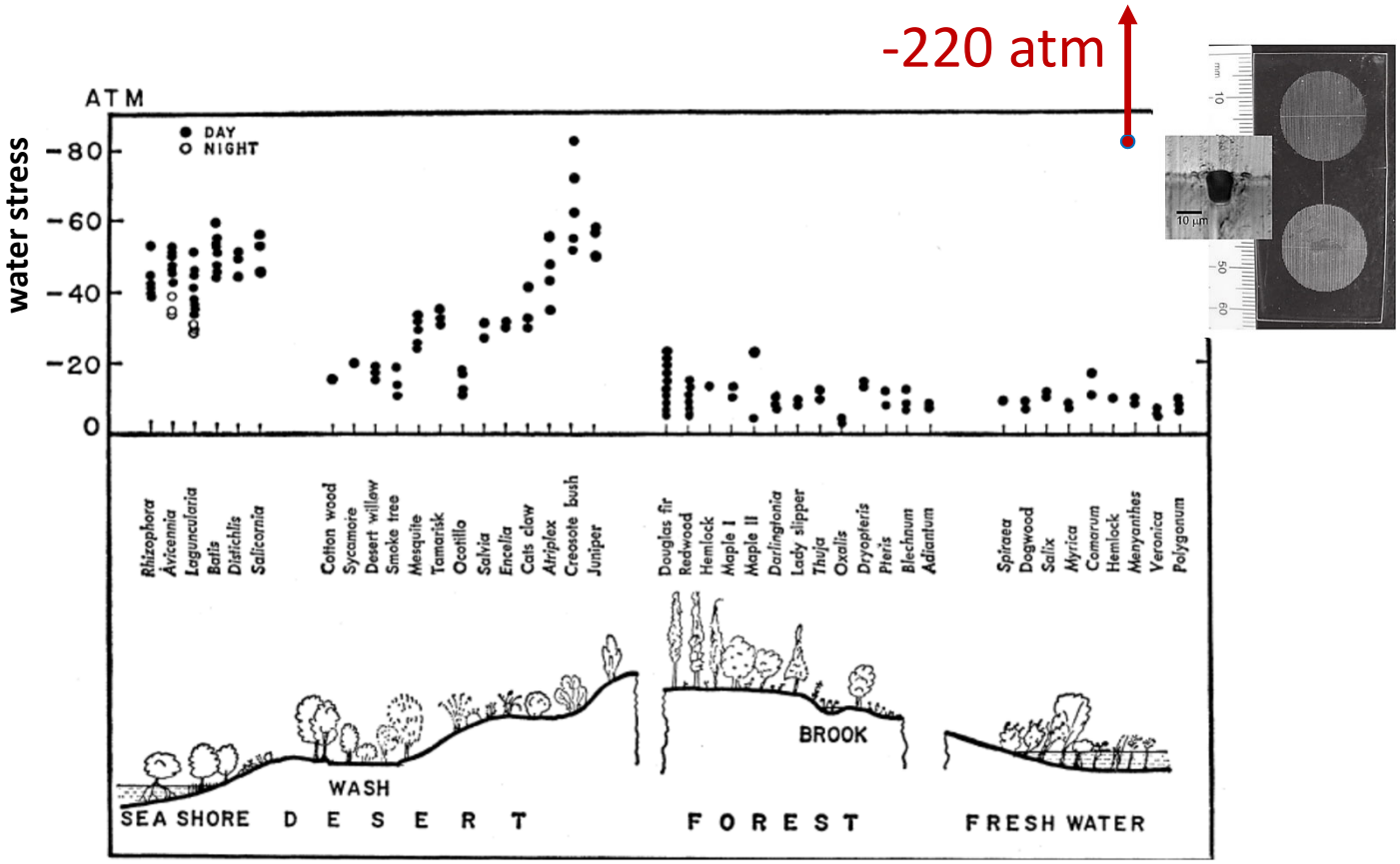


Toby Wheeler



(Wheeler and Stroock, Nature, 2008)

synthetic plants vs. plants



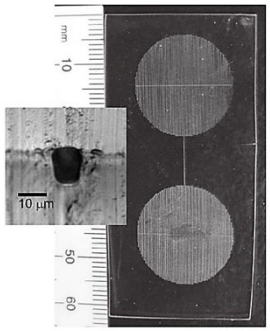
(Schöander et al., *Science* (1965))

(Wheeler and Stroock, Nature, 2008)

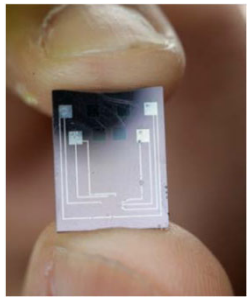
(Larter et al., Plant Phys, 2016)

synthetic plants - development

prototype one
(2007)

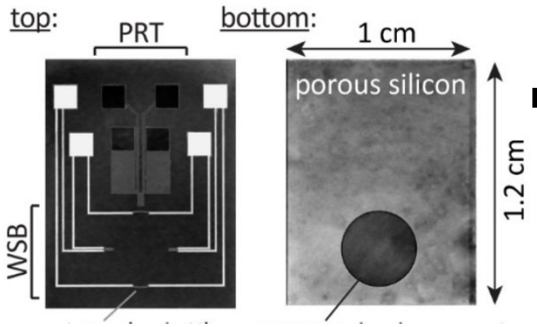


prototype two
(2012-2013)

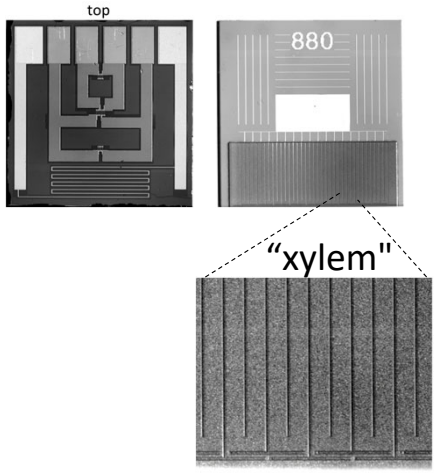


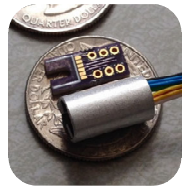
“µTensiometer”

prototype three
(2014)



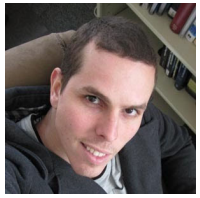
prototype four
(2017)

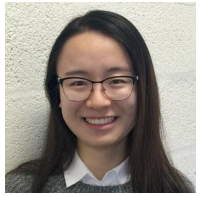




Alan Lakso

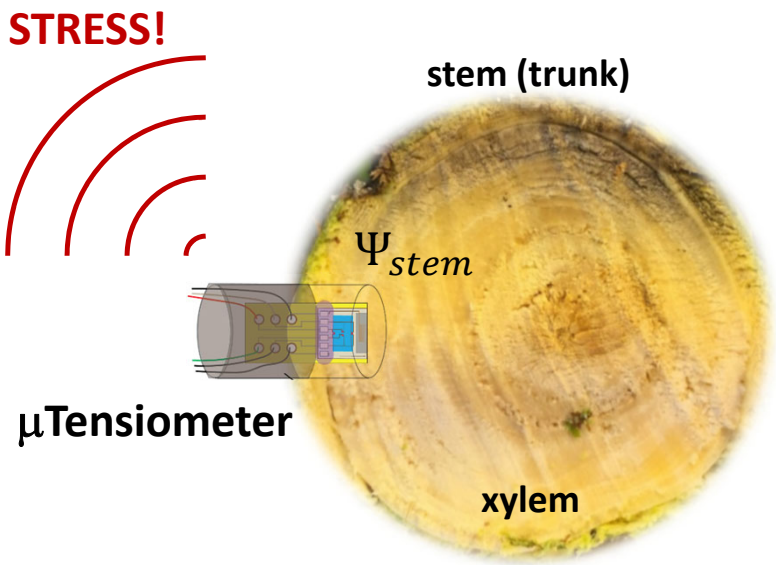
Vinay Pagay


Michael Santiago


Siyu Zhu

Winston Black

synthetic plants ↔ real plants



Grape
(Matchbook Wines; Zamora, CA)

Almond
(Done-Again Farm; Arbuckle, CA)

Apple
(Cornell Orchards; Ithaca, NY)

Corn
(Musgrave Farms; Auburn, NY)

almonds

John Monroe

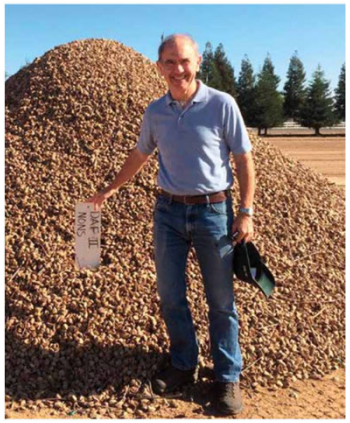
Done Again Farm - Arbuckle, CA

Blue Diamond Growers Board

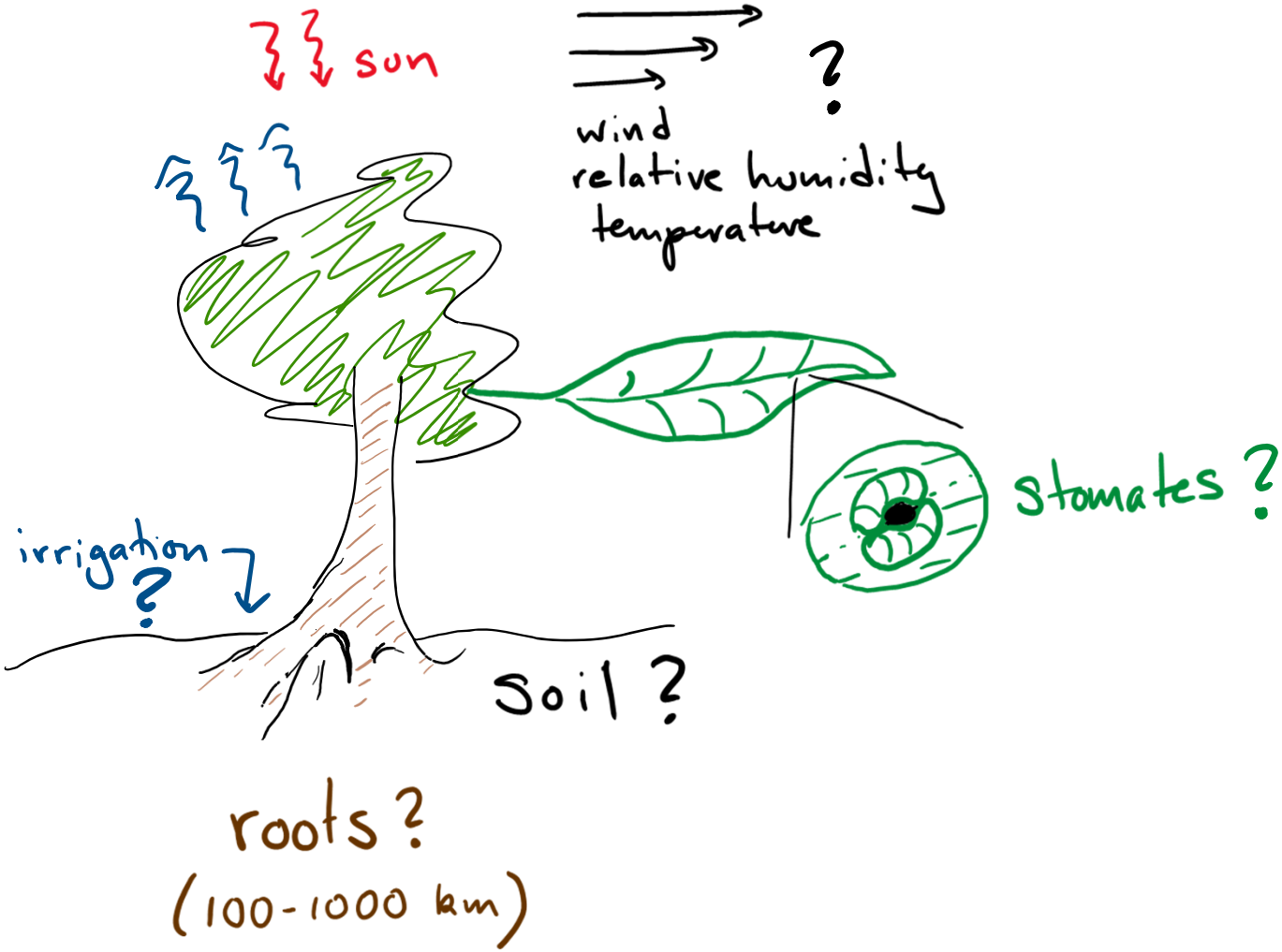
2015

(Lucy Nicholson/Reuters)

almonds – dynamical system



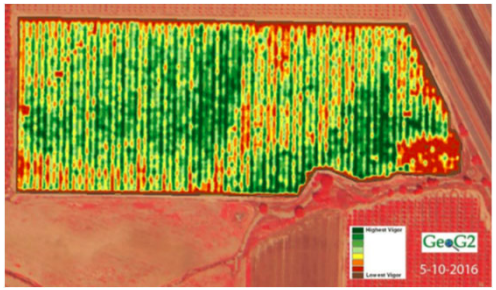
John Monroe



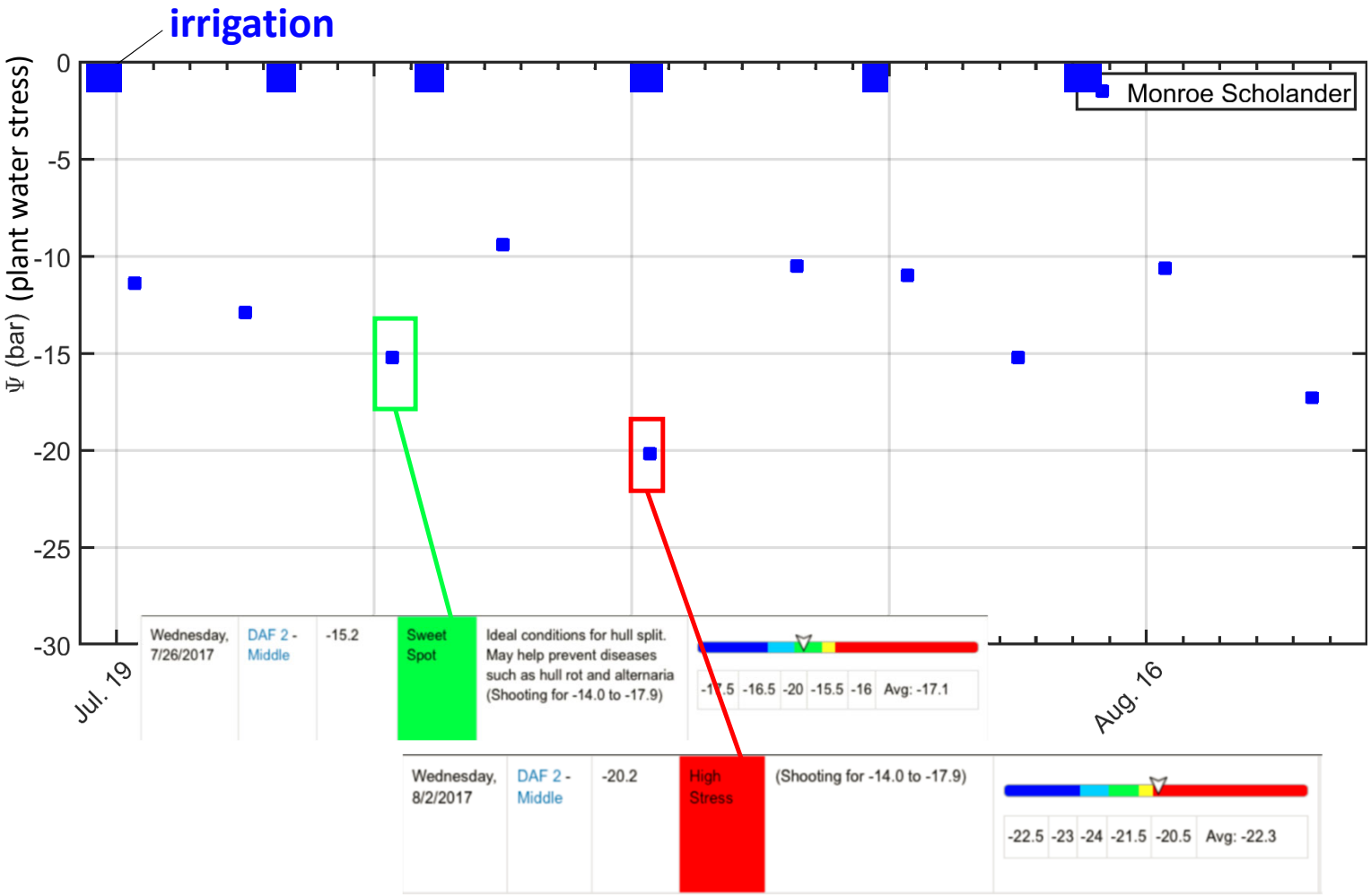
almonds – under sampled

summer 2017

Done-Again Farm, Arbuckle, CA



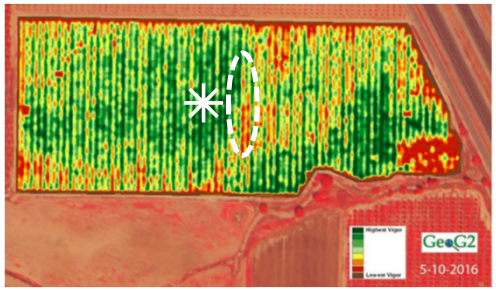
Schölander Bomb



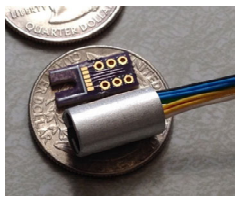
almonds – connecting the dots

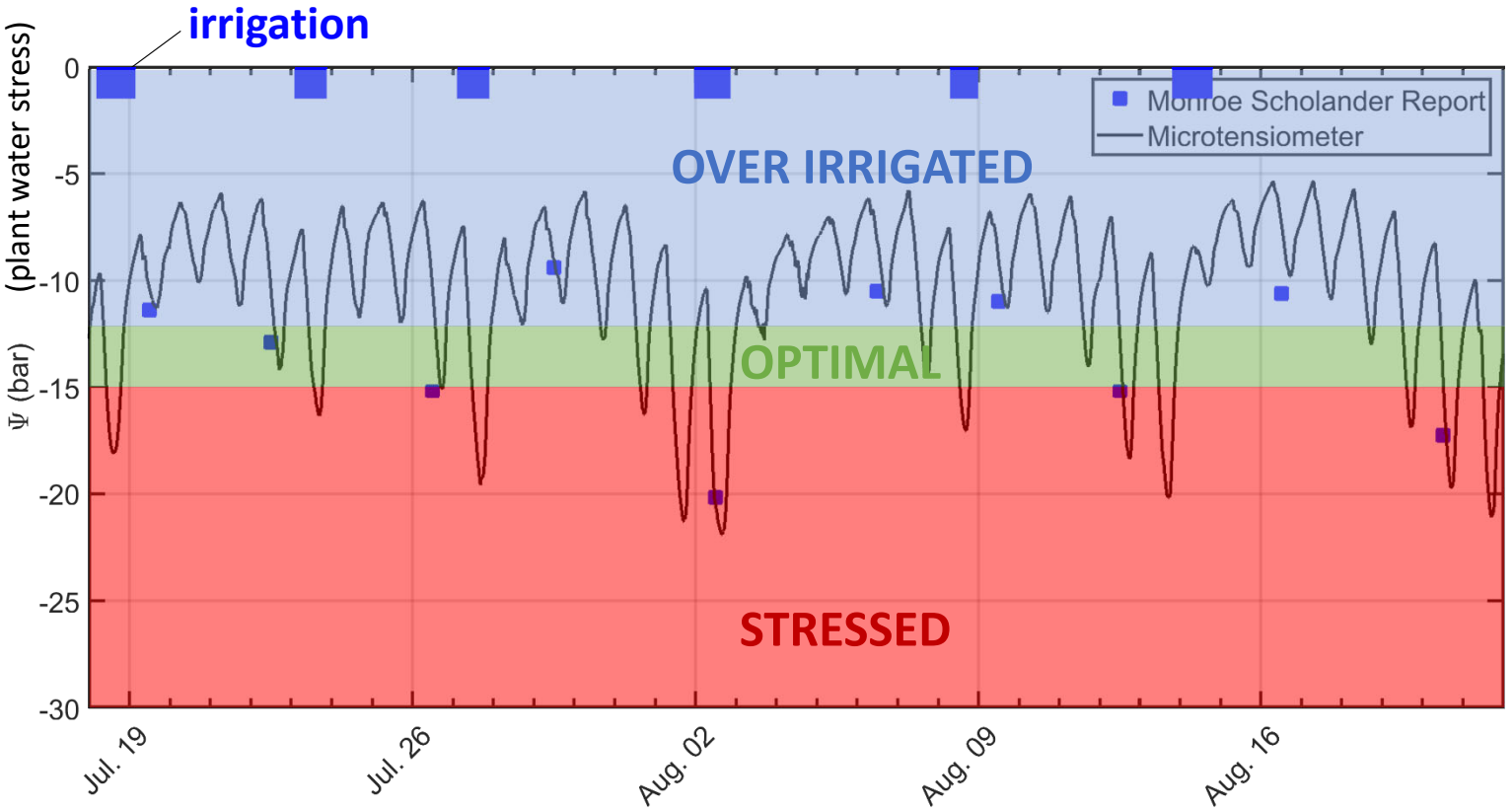
summer 2017

Done-Again Farm, Arbuckle, CA



microTensiometer



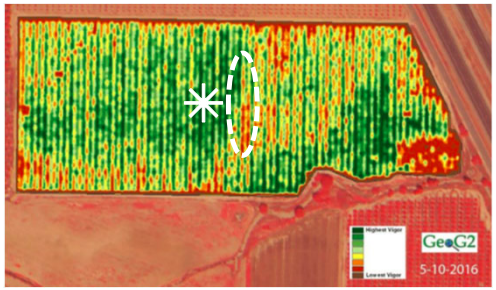


Michael Santiago

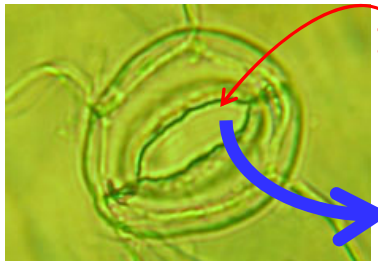
FloraPulse

almonds – connecting the dots

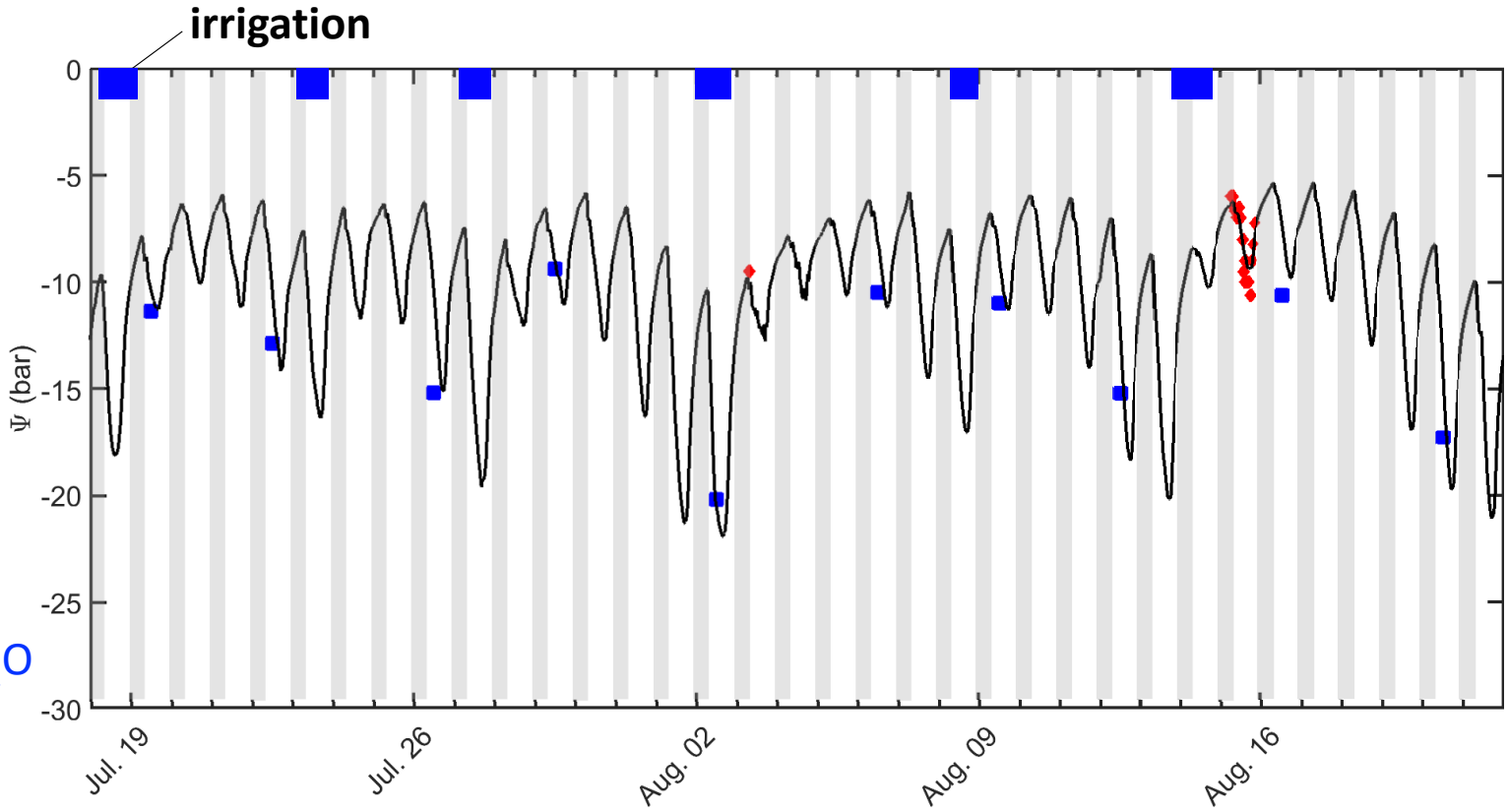
Done-Again Farm, Arbuckle, CA



stomates

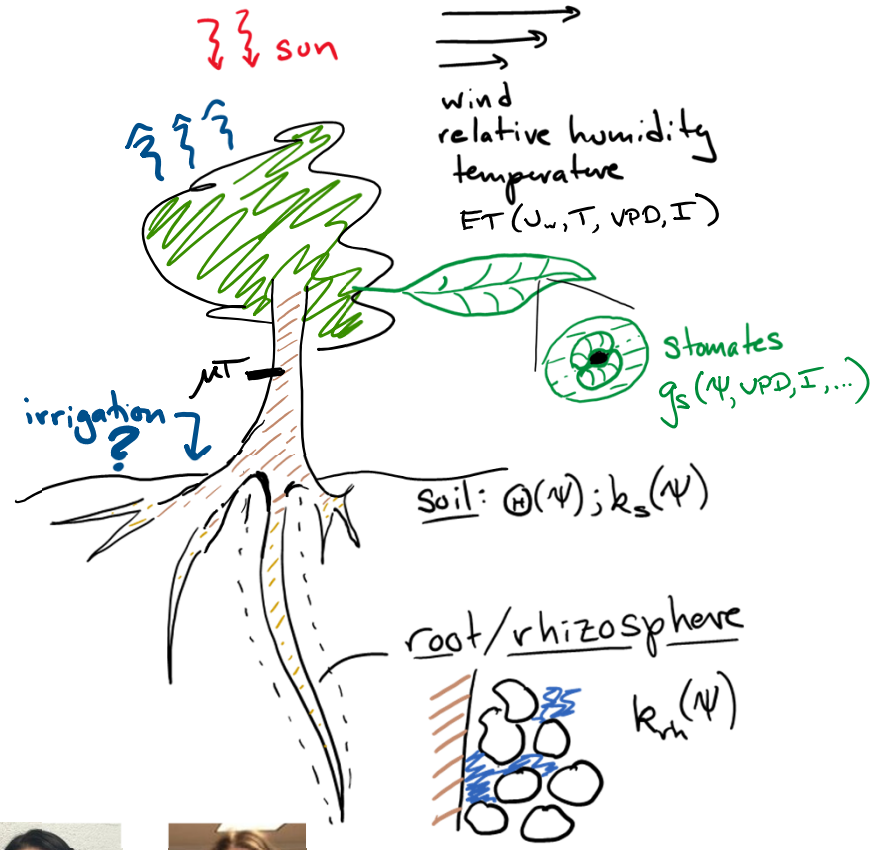


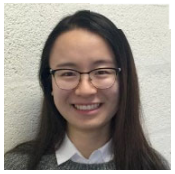
irrigation:



→ properties of soil, roots, trunk, stomates, canopy,…

almonds – resolving the dynamics

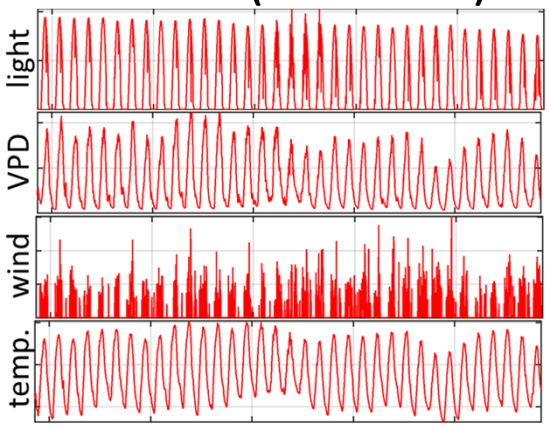




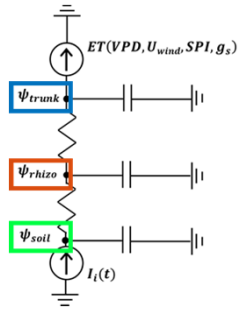
Siyu Zhu

Kathryn Haldeman

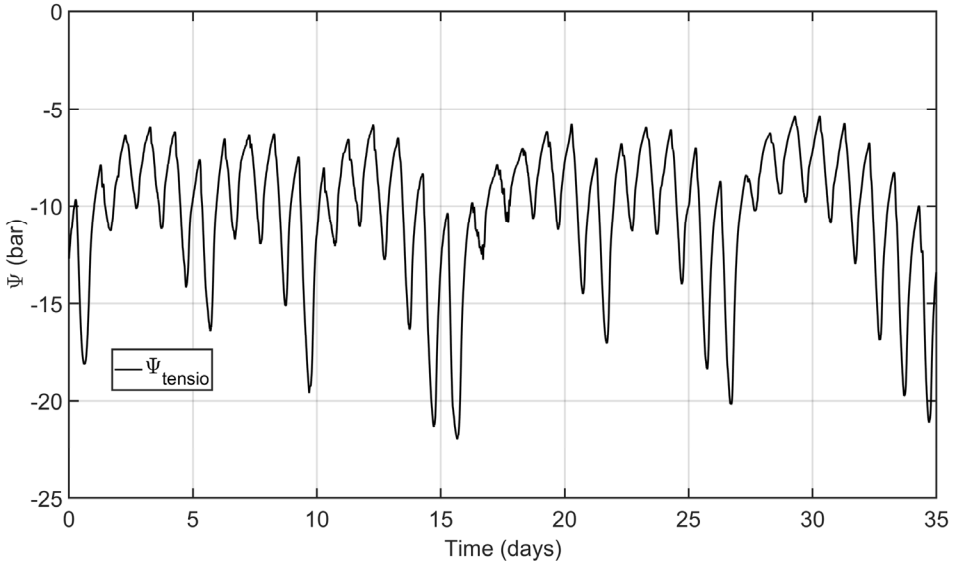
weather (environment)



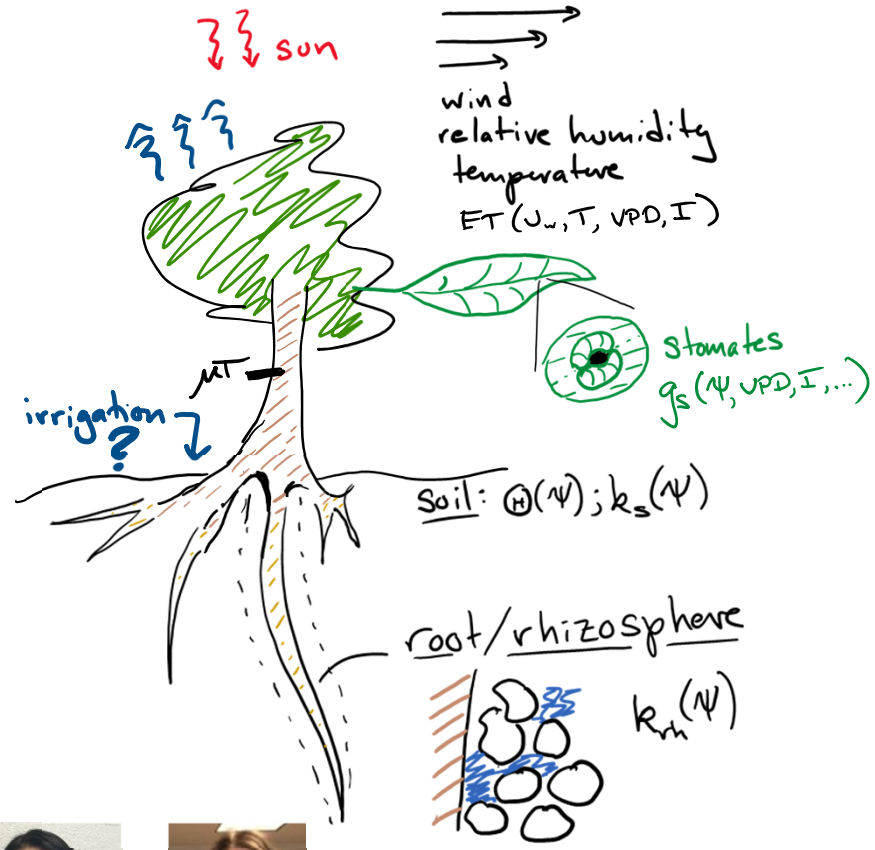
model (physiology)

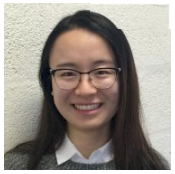


dynamics



almonds – resolving the dynamics





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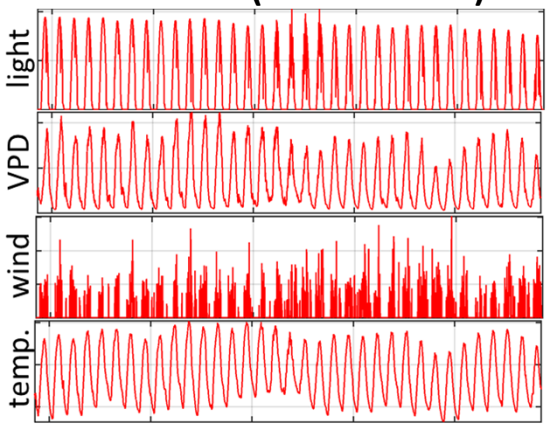

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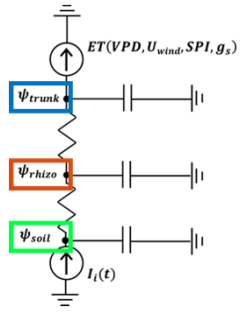
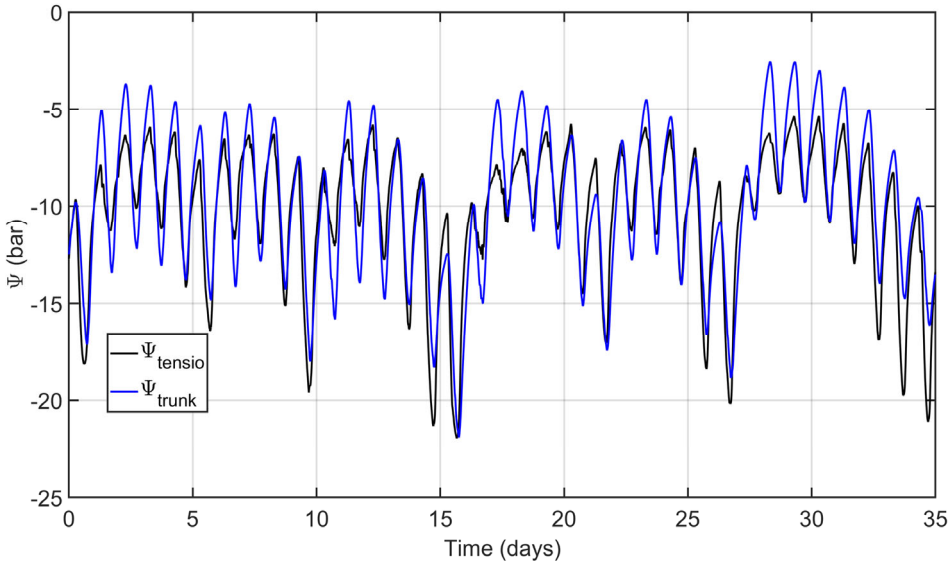
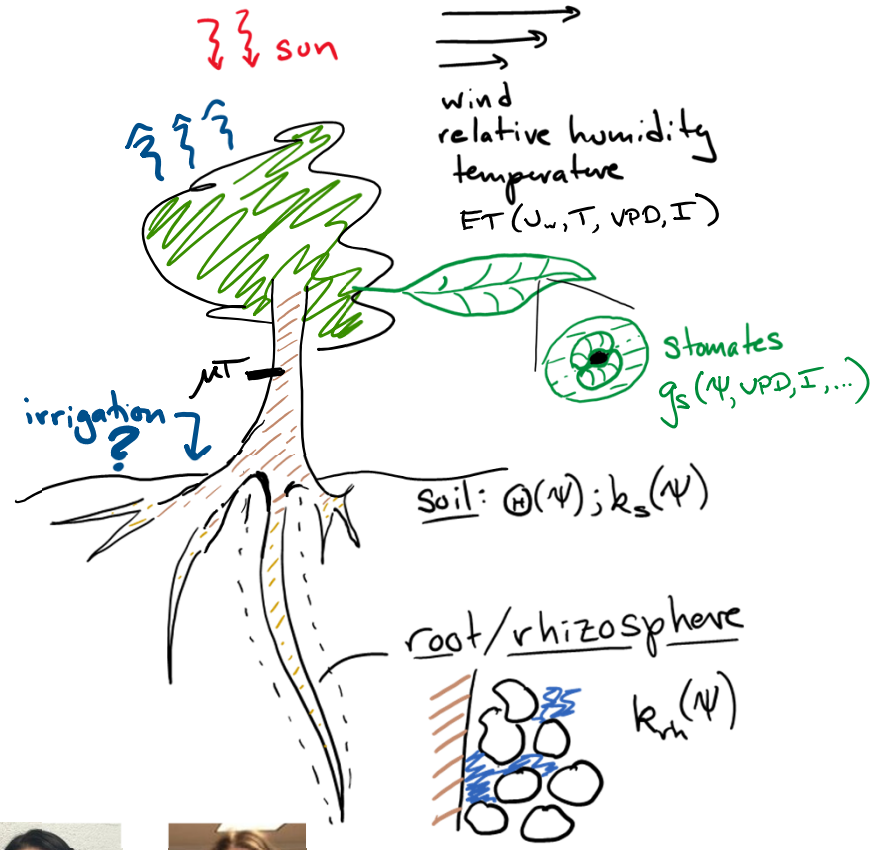
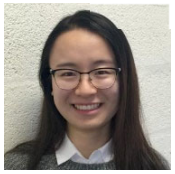


dynamics



almonds – resolving the dynamics





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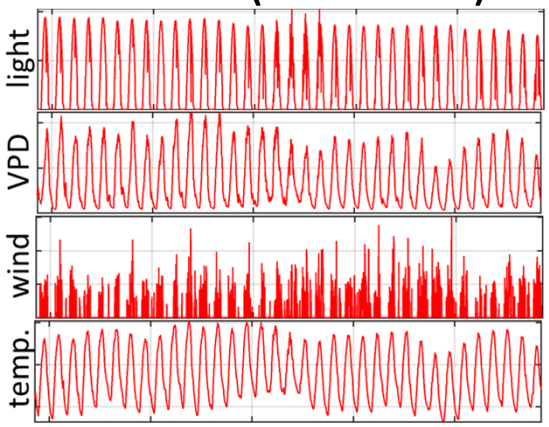
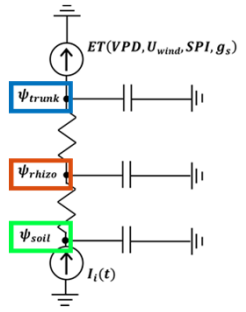
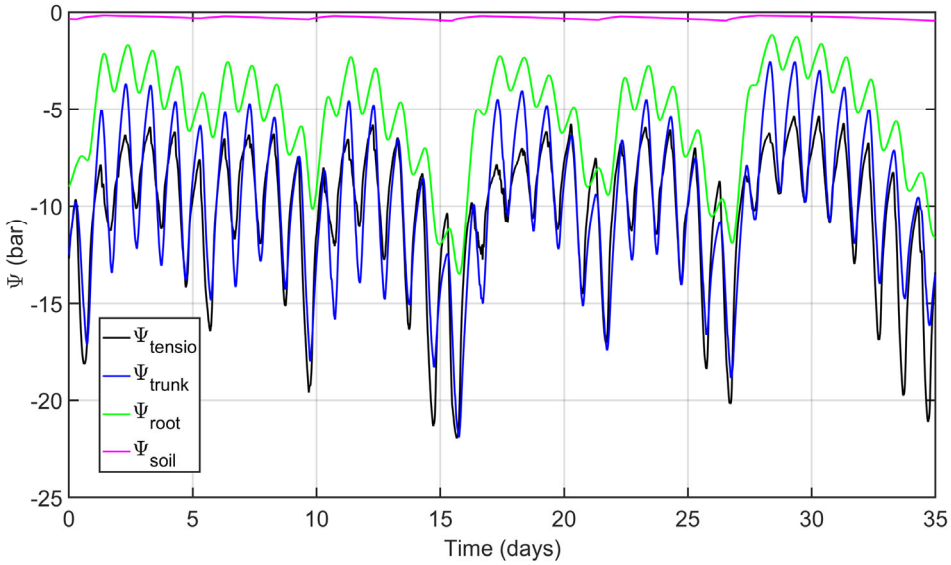


model (physiology)

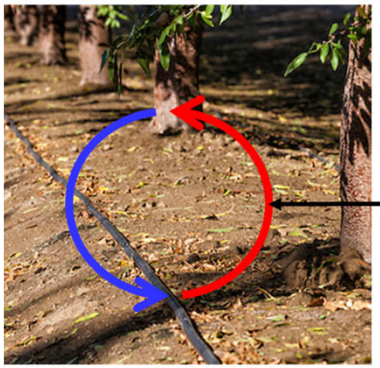


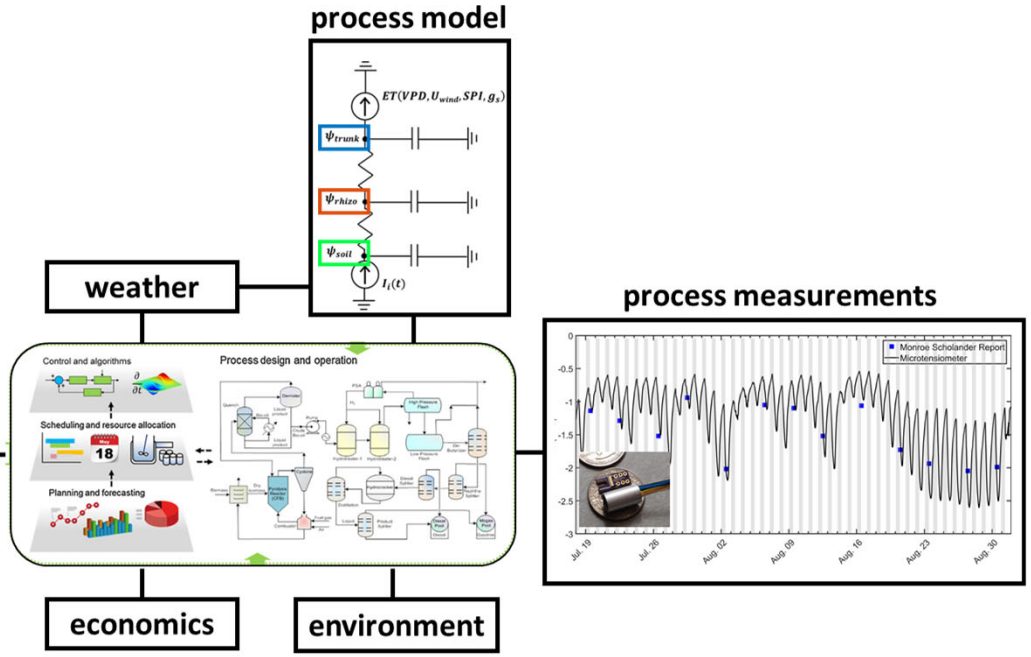
dynamics

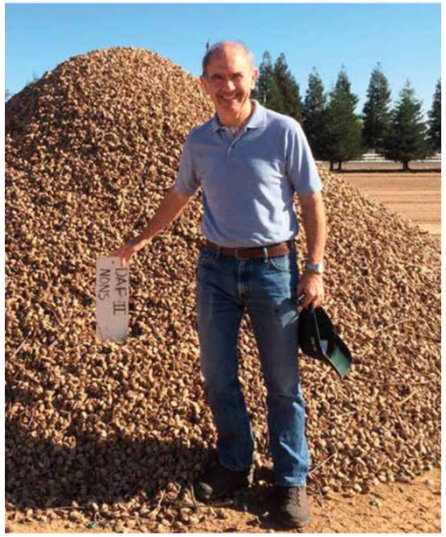


almonds – closing the loop

Prof. Fengqi You





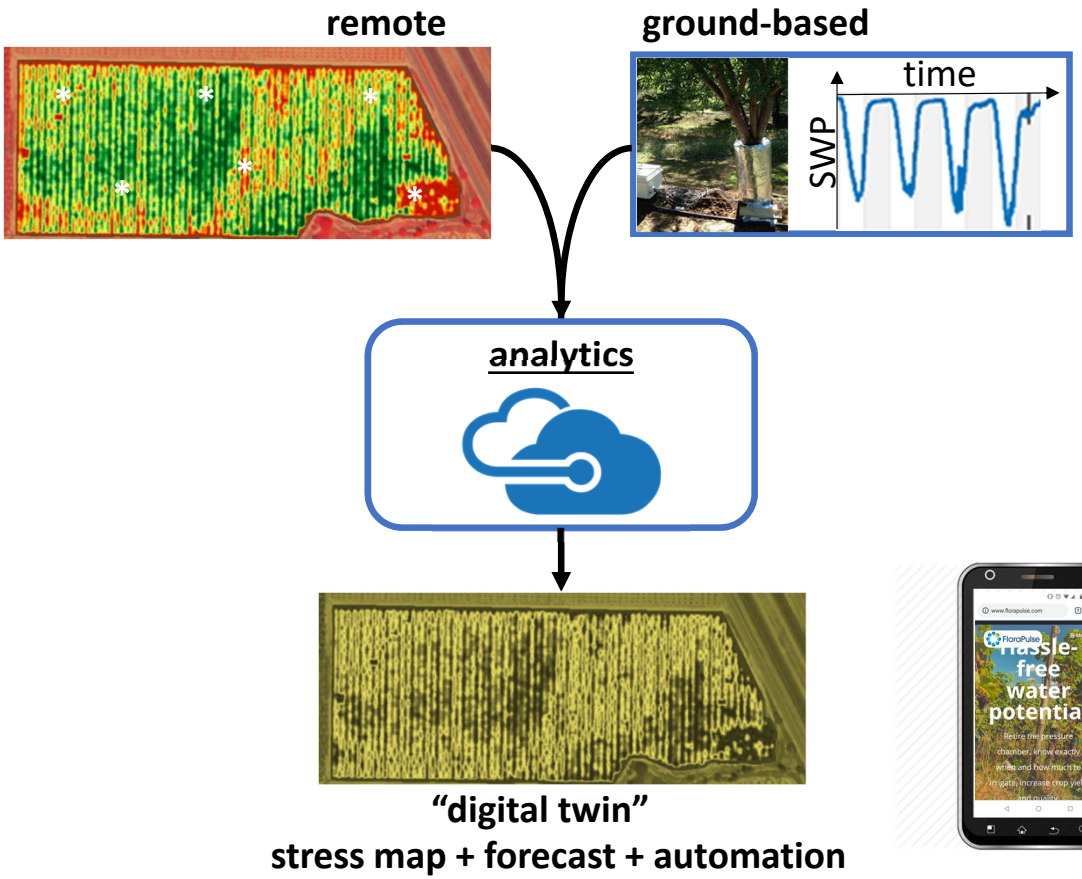


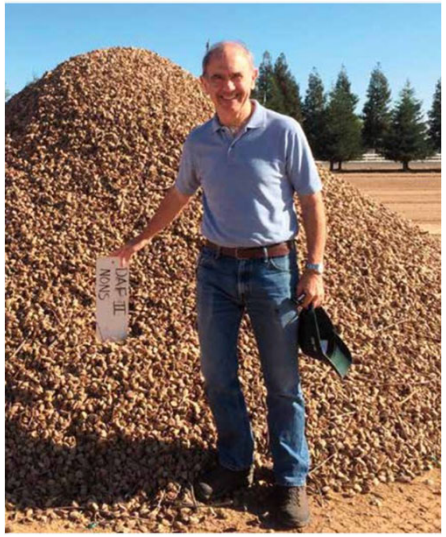
John Monroe

→ Process Optimized Water Management
(efficiency, yield, quality, labor, profit, environment,…)

(Sheng et al., arXiv, 2018)

almonds – supporting good management

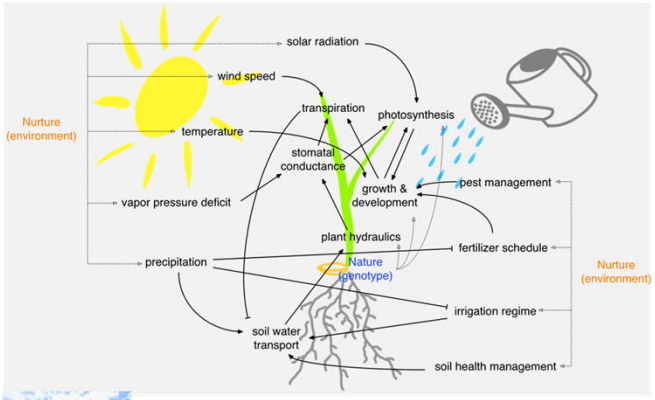




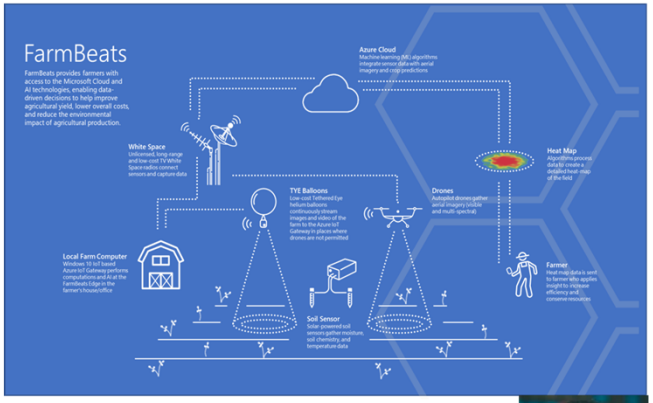
John Monroe

(Cornell/USDA/UC Davis/WSU)

models



systems



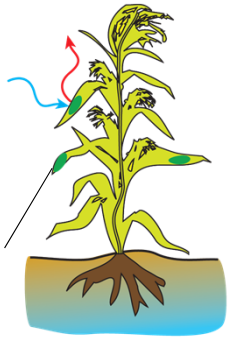
organism-as-sensor

satellite/drone

\+

organism-as-sensor

nano-tech
bio-tech



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cloud

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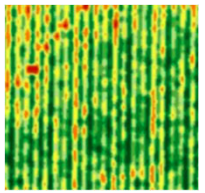
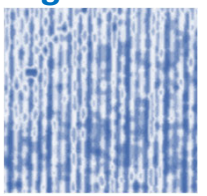
farmer/scientist

data **digital twin**





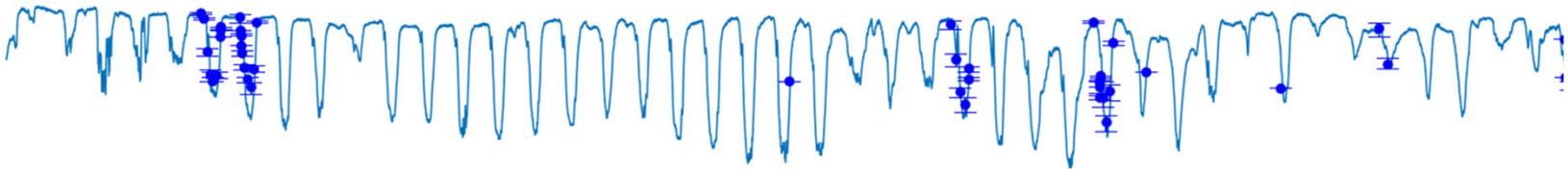
decision support
optimization
discovery

Thank you.

Cornell Initiative for Digital Agriculture

USDA

KIC Kavli Institute at Cornell

CNF Cornell NanoScale Science and Technology Facility

Institute of Biotechnology