THE ALMOND CONFERENCE 2020
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NEW PERSPECTIVES IN IRRIGATION MANAGEMENT

Sebastian Saa, *Almond Board of California*

Kenneth Shackel, *UC Davis*

Andrew Mcelrone, *USDA-UC Davis*

Forrest Melton, *NASA*

Isaya Kisekka, *UC Davis*

california almonds
Almond Board of California

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Sebastian Saa, *Almond Board of California*

Agenda

1. Moderators	Sebastian Saa, Associate Director, ABC Tom Devol, Senior Manager, ABC
2. New Perspectives in Irrigation Management: when to start	Ken Shackel, UC Davis; kashackel@ucdavis.edu
3. ET based irrigation management for almonds: something old and something new	Andrew J. McElrone, USDA; UC Davis; ajmcelrone@ucdavis.edu
4. OPEN ET: Filling the Biggest Data Gap in Water Management	Forrest Melton, NASA Ames & CSU Monterey Bay; forrest.s.melton@nasa.gov
5. Data-Driven Site-specific Irrigation Management	Isaya Kisekka, UC Davis; ikisekka@ucdavis.edu

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NEW PERSPECTIVES IN IRRIGATION MANAGEMENT

Kenneth Shackel, *UC Davis*

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New Perspectives in Irrigation Management: when to start

The ‘Goldilocks’ question:

Am I starting “Too Early,” “Too Late,” Or “Just Right?”

Ken Shackel, UC Davis
Roger Duncan, UCCE
Luke Milliron, UCCE
Bruce Lampinen, UCCE

Concerns about starting too early in walnuts:

Observation (B. Lampinen): Trees that are consistently too wet (above baseline SWP) in the spring can develop numerous symptoms later in the year, often mistaken for other disorders.

Results in Walnut: severe symptoms have not been observed, but at 2 sites (6 years, 3 years) substantial delays (>1 month) have shown no yield effect but a healthier tree appearance.

Concerns about starting too late in almonds/walnuts/prunes/pistachio

The 'Bank Account' Consideration:

"If I wait too long, trees will use up the deep soil moisture and run out of their bank account at harvest (when I can't irrigate)!"

Late season water stress in peach (doubled fruit).

(Handley and Johnson, 2000, ASHS 35:771).

(Severe) post harvest stress and yield reductions in almond.

(Goldhammer and Viveros, 2000, Irrigation Sci. 19:125-131)

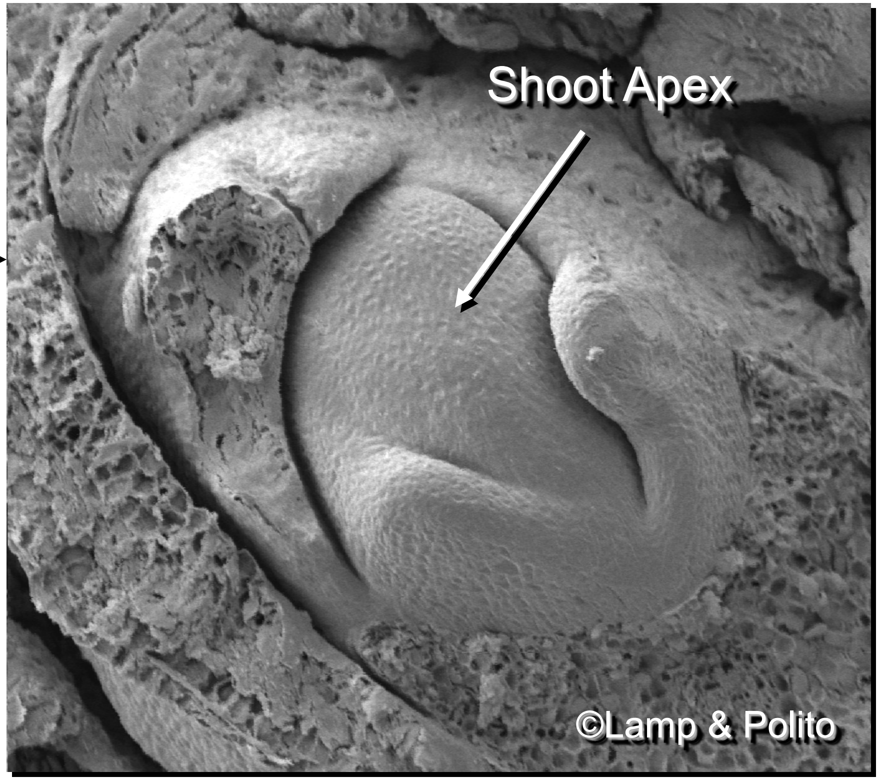
Example: Nonpareil tree and flower bud development in the regional variety trial at Chico, CA, in 1997 (c/o Joe Connell)

Date	Tree	
Feb. 10-22	Bloom	

cv ‘Savana’ (photo: Joe Connell)

Example: Nonpareil tree and flower bud development in the regional variety trial at Chico, CA, in 1997 (c/o Joe Connell)

Date	Tree	Bud (apical meristem)
Feb. 10-22	Bloom	('waking up')
(Spring/Summer)	Growing the crop	(producing leaves and bud scales)



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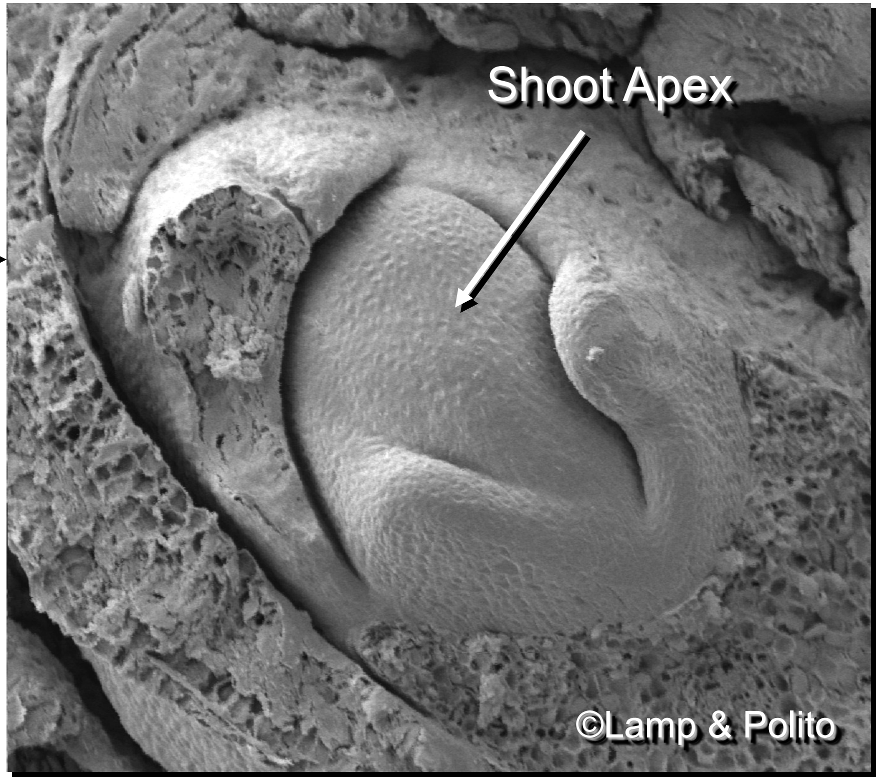

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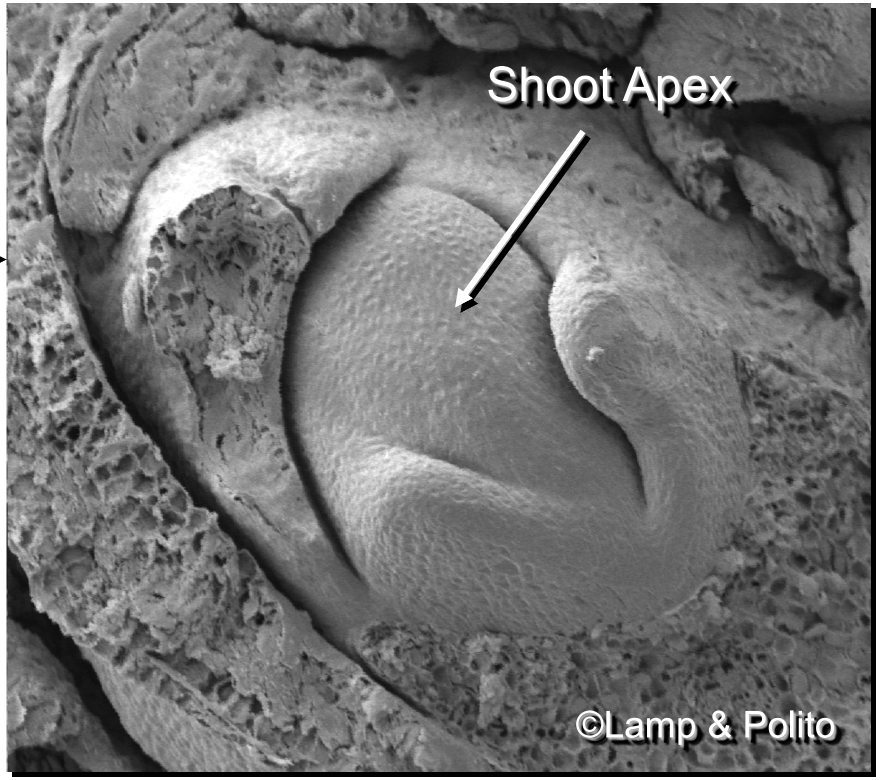

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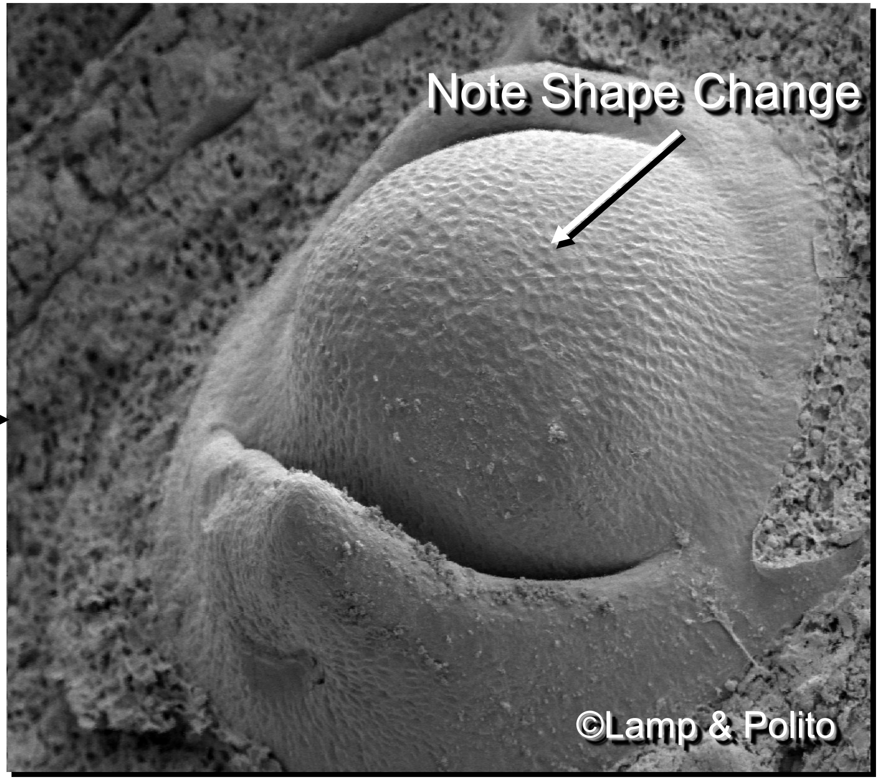
July 28	Splitting…	Flower stage 1



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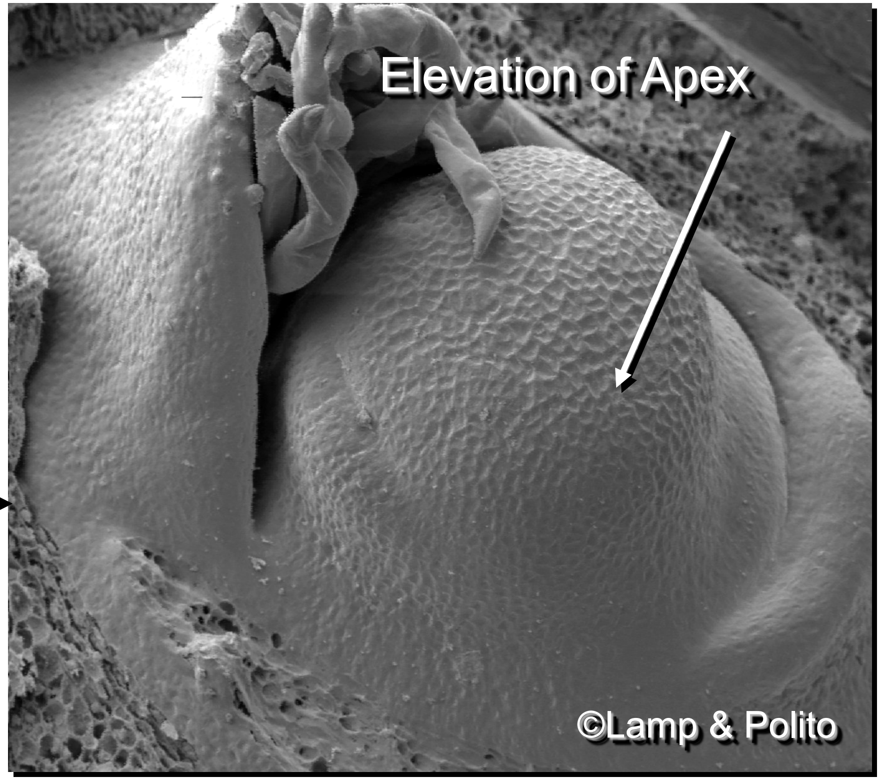
July 28	Splitting…	Flower stage 1
August 11	Split 100%	Flower stage 2



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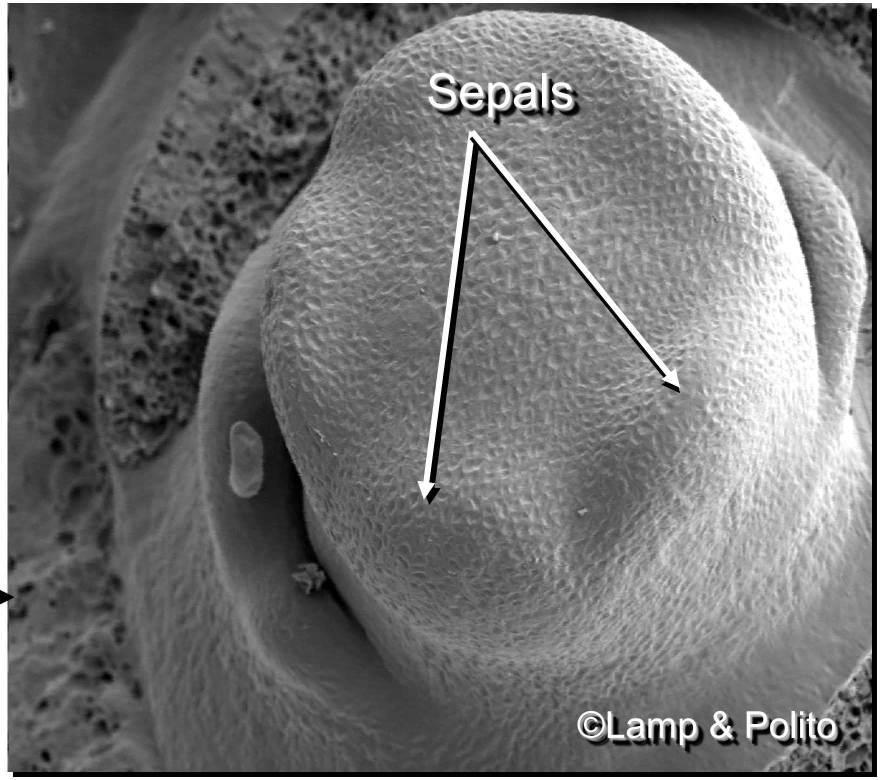
August 18	Shake	Flower stage 3/4



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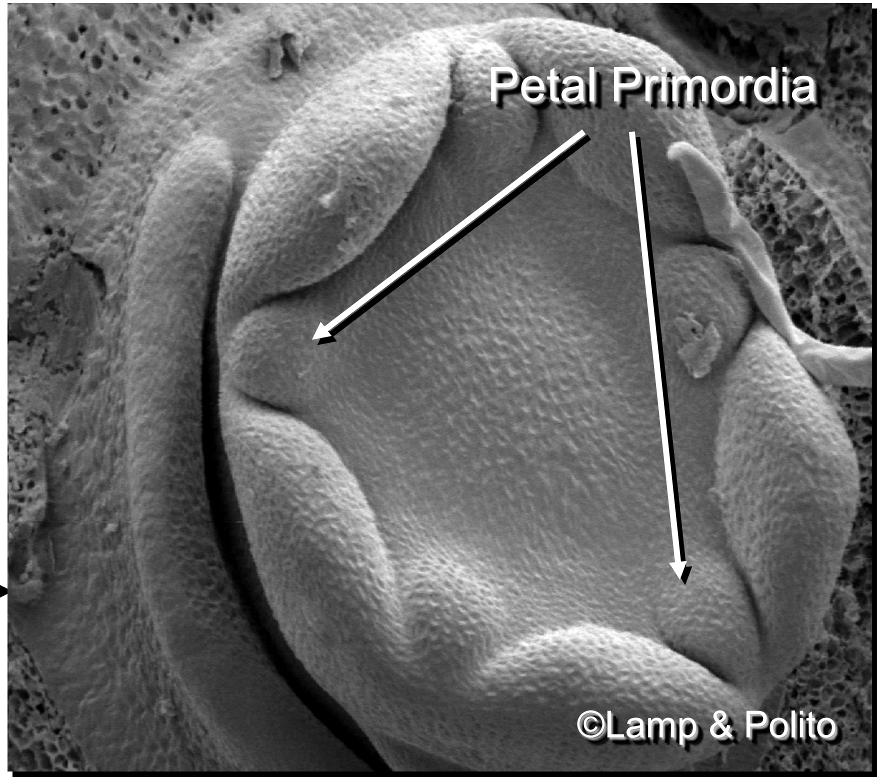

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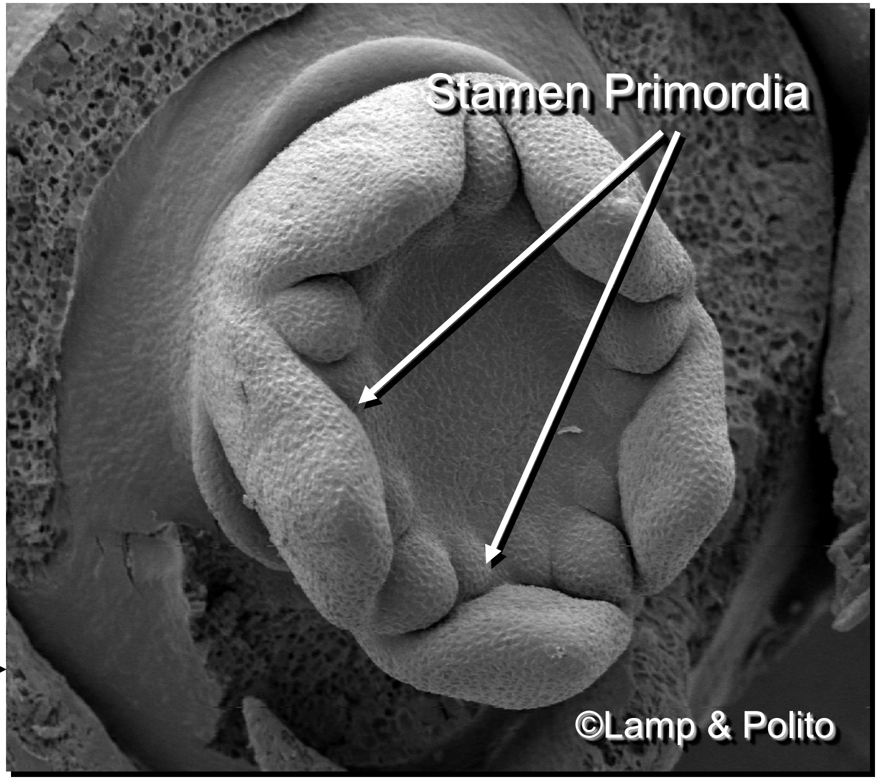
July 28	Splitting…	Flower stage 1
August 11	Split 100%	Flower stage 2
August 18	Shake	Flower stage 3/4
August 26		Flower stage 5



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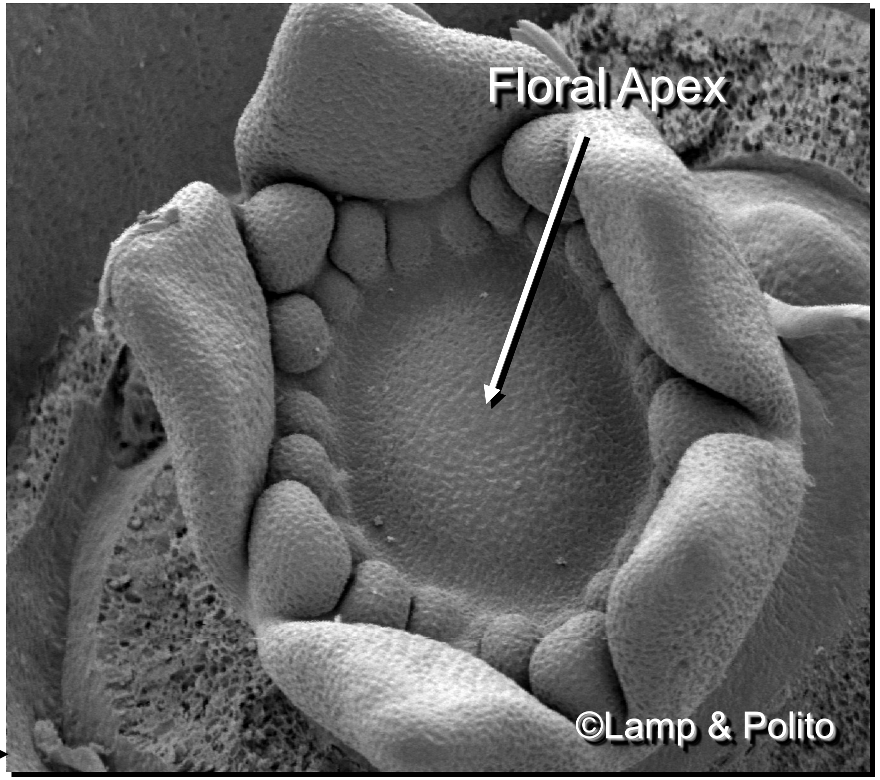
August 18	Shake	Flower stage 3/4
August 26		Flower stage 5
September		Flower stage 6/7



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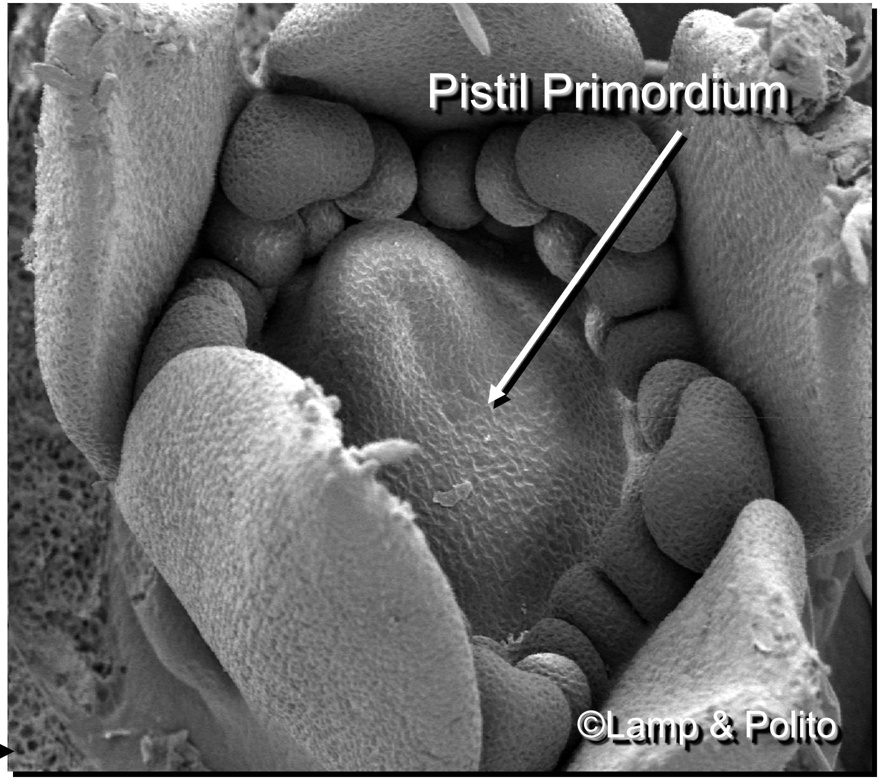
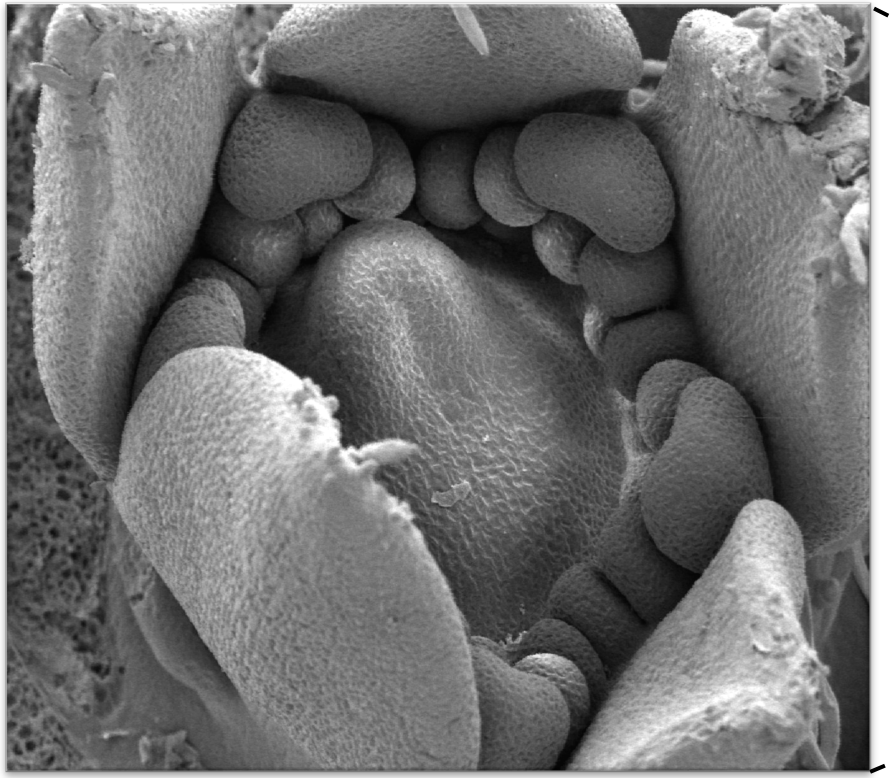


So, the ‘bank account’ concern is a possibility, but in walnuts, long delays did not cause increased water stress at harvest (in fact, delayed trees were somewhat less stressed at harvest).

Size comparison:

Flower bud in late September

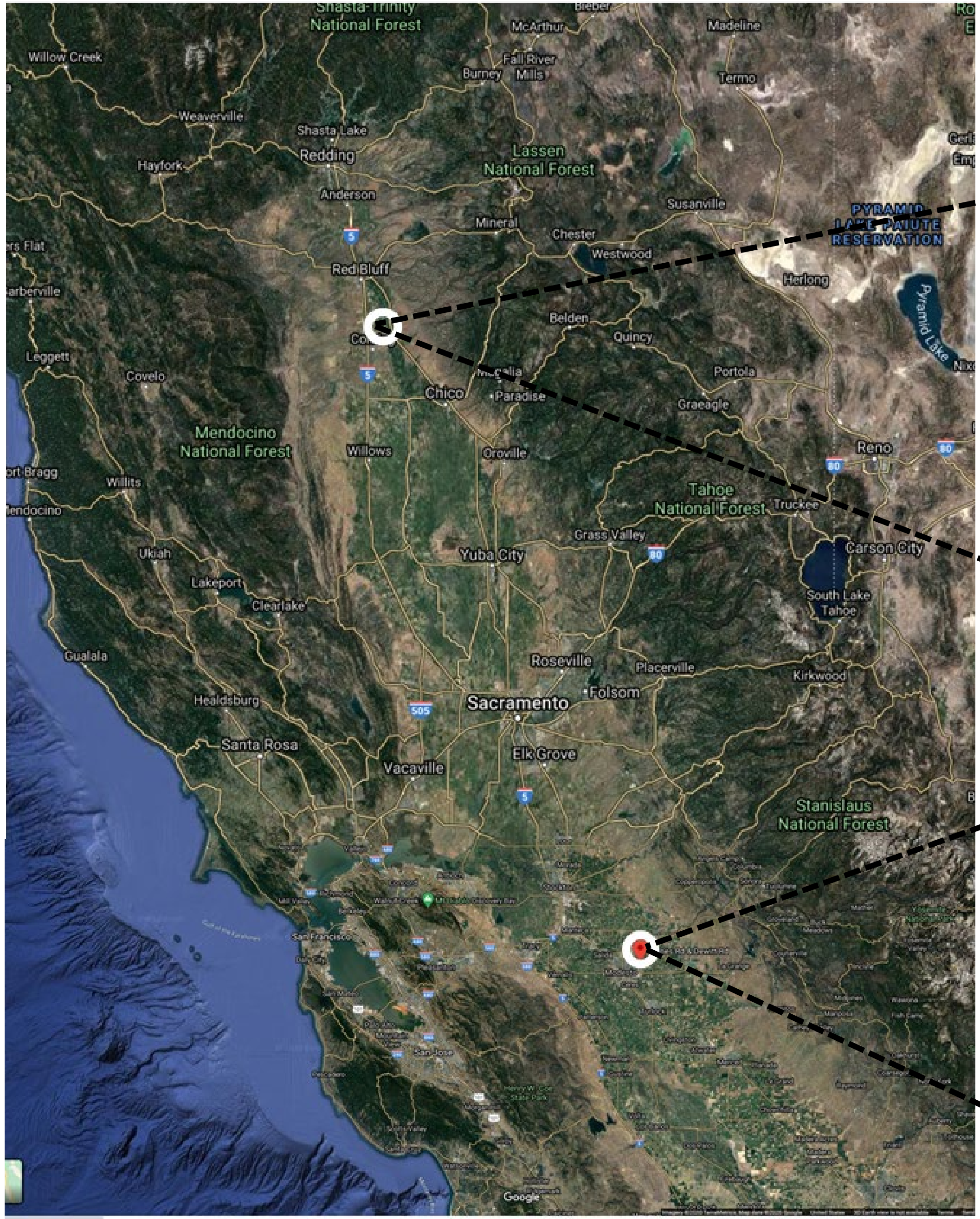


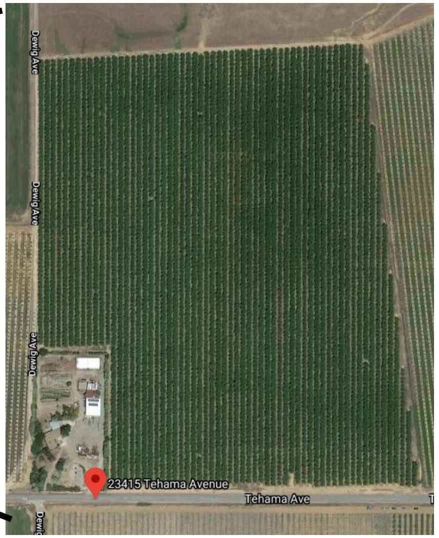
Winter dormant bud in December

(Bud photo: M. Rawls)

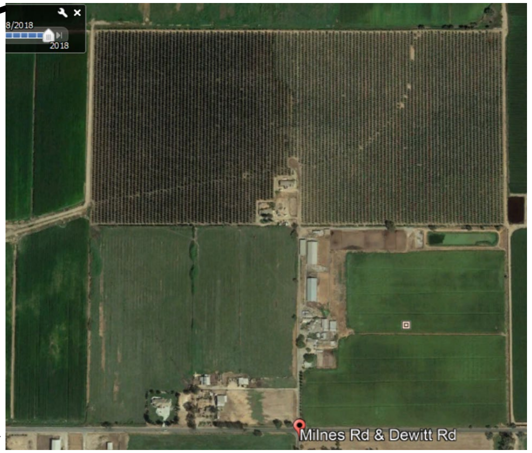
Experiment

2020 delayed irrigation start orchards (FB around 2/22/20).
Control: Irrigate when trees are still ‘wet’ (baseline SWP)
Two levels of delay: wait for 2 or 4 bars below baseline SWP.





Tehama:
11 year old Nonpareil, Price, Peerless orchard, 22’ x 14,’ minisprinkler. Soil: Moda loam/Perkins gravelly loam/Hillgate loam



Stanislaus:
5 year old Independence on Atlas orchard, 21’ x 14,’ microsprinkler.
Soil: San Joaquin sandy loam

"Baseline" values of midday SWP (Bar) under various air temperature and RH conditions for Prune and Almond

Air Temperature (F)	Air RH (%)		
	60	40	20
70	**-5.3**	**-5.9**	**-6.5**
80	**-5.8**	**-6.6**	**-7.5**
90	**-6.4**	**-7.6**	**-8.7**
100	**-7.2**	**-8.8**	**-10.4**
110	**-8.3**	**-10.4**	**-12.6**

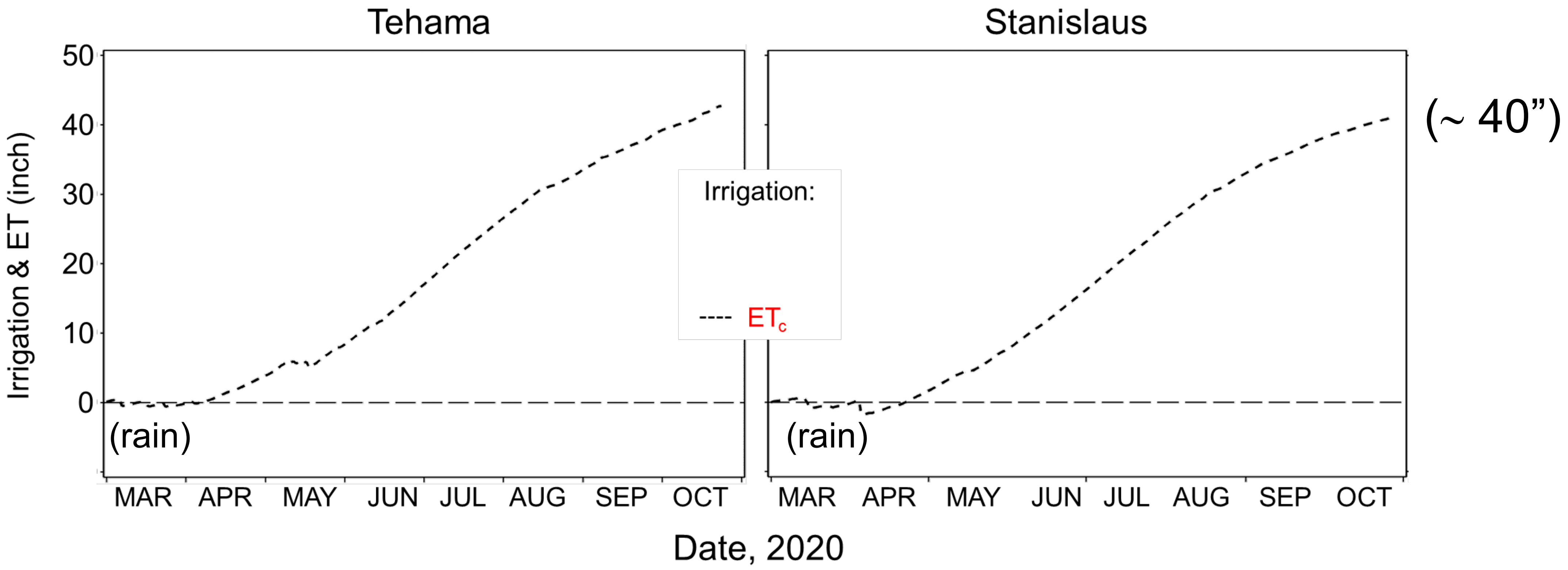
"Baseline" values of midday SWP (Bar) under various air temperature and RH conditions for Prune and Almond

Air Temperature (F)	Air RH (%)		
	60 (humid)	40 →	20 (dry)
70 (cool)	**-5.3**	**-5.9**	**-6.5**
80	**-5.8**	**-6.6**	**-7.5**
90	**-6.4**	**-7.6**	**-8.7**
100	**-7.2**	**-8.8**	**-10.4**
110 (hot)	**-8.3**	**-10.4**	**-12.6**

General levels of almond water stress:

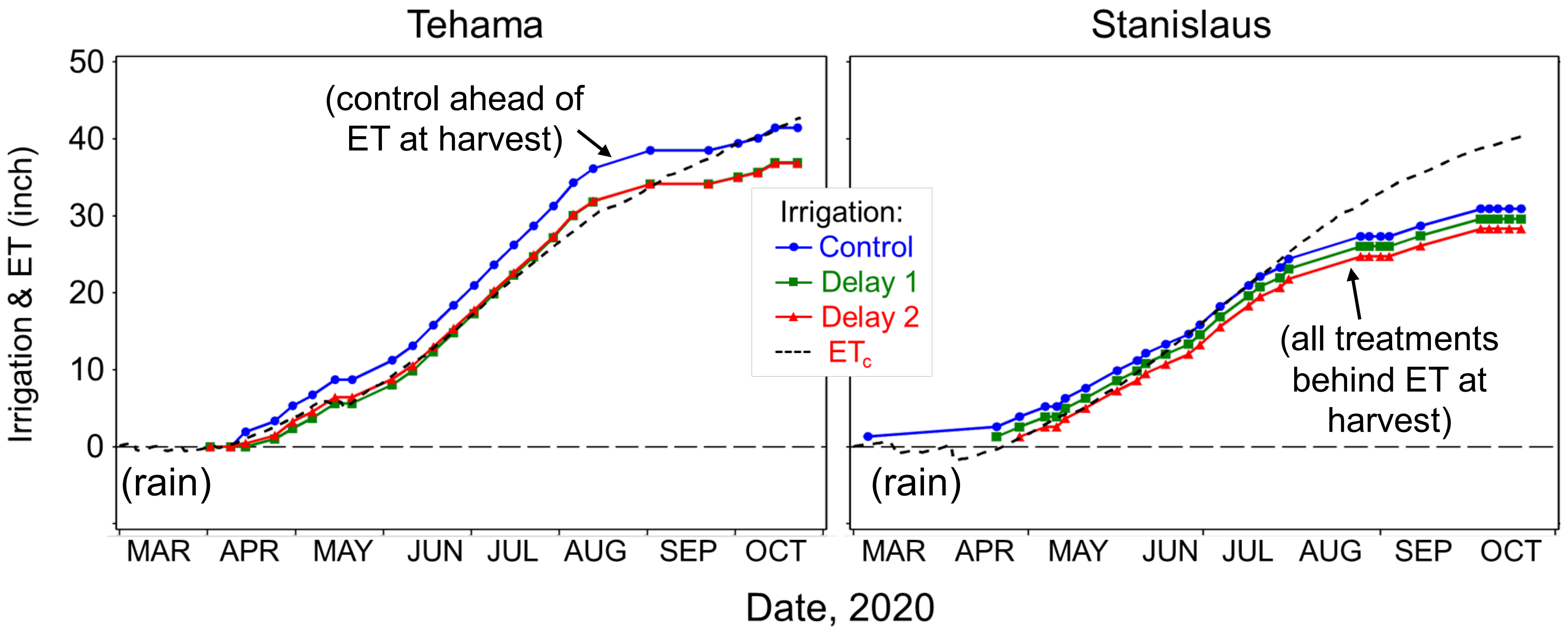
-18 (moderate) → -30 (serious) → → -60 ("I'm not dead yet")

Results



Tehama
Stanislaus
Irrigation & ET (inch)
50
40
30
20
10
0
(rain)
(rain)
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
Date, 2020
Irrigation:
---- ETc
(~ 40”)

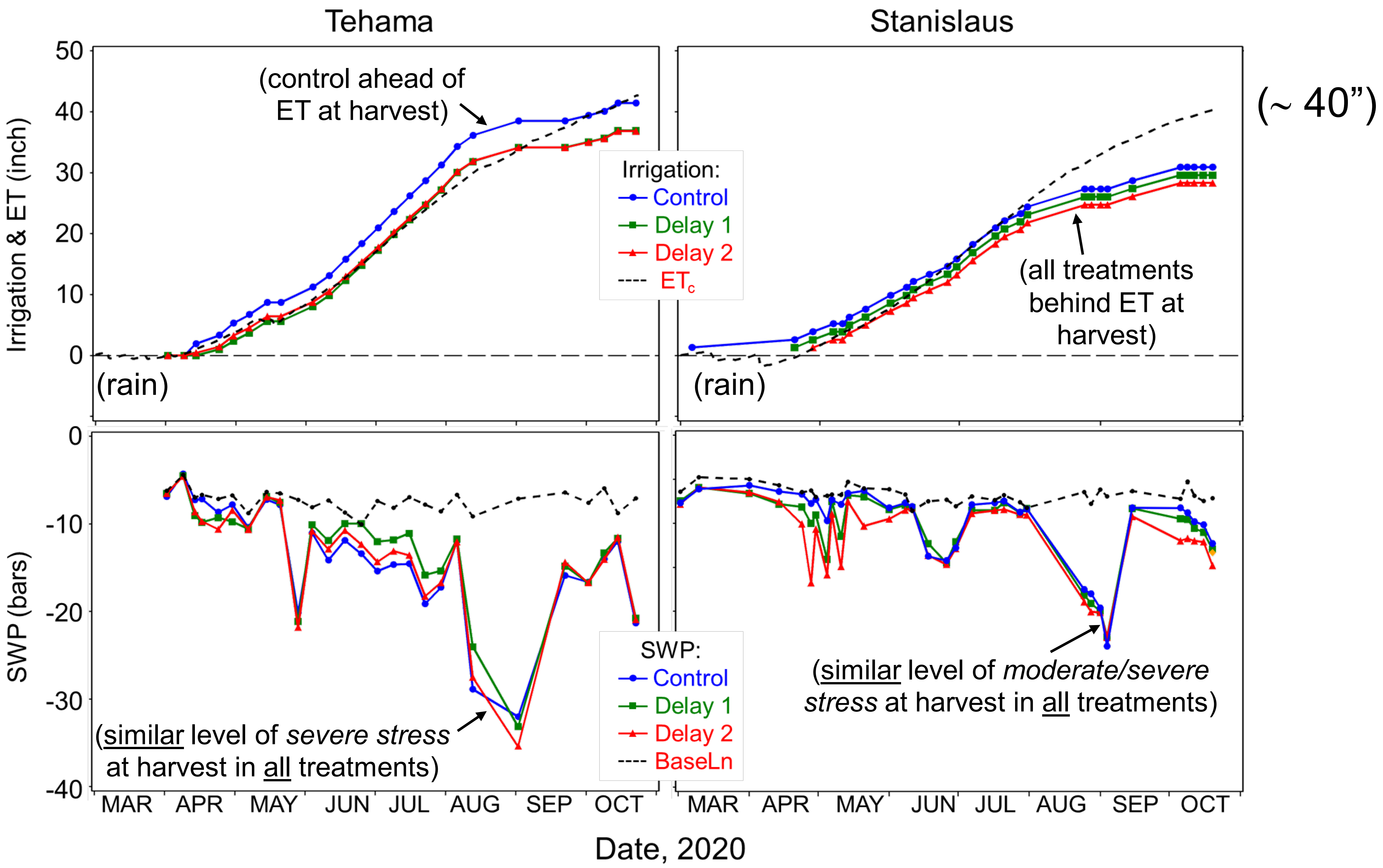
Results



Tehama
Stanislaus
Irrigation & ET (inch)
50
40
30
20
10
0
(control ahead of ET at harvest)
(rain)
(rain)
Irrigation:
Control
Delay 1
Delay 2
ETc
(all treatments behind ET at harvest)
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
Date, 2020

(~ 40")

Results



Tehama
Stanislaus
(~ 40")
Irrigation & ET (inch)
50
40
30
20
10
0
(control ahead of ET at harvest)
(rain)
(rain)
Irrigation:
Control
Delay 1
Delay 2
ET c
(all treatments behind ET at harvest)
SWP (bars)
0
-10
-20
-30
-40
SWP:
Control
Delay 1
Delay 2
BaseLn
(similar level of severe stress at harvest in all treatments)
(similar level of moderate/severe stress at harvest in all treatments)
MAR APR MAY JUN JUL AUG SEP OCT
MAR APR MAY JUN JUL AUG SEP OCT
Date, 2020

Results

No statistical differences between delays, and no trend of difference with increasing delay.

Irrigation Treatment	Yield (kernel #/ac)	
	Tehama (nonpareil)	Stanislaus (Independence)
Control	3750	2530
Delay 1	3230	2270
Delay 2	3690	2540

Irrigation Treatment	Kernel weight (g)		% NOW		% shrivel		% double	
	Tehama	Stanislaus	Tehama	Stanislaus	Tehama	Stanislaus	Tehama	Stanislaus
Control	1.13	1.12	1.8	1.5	2.3	5.5	4	1
Delay 1	1.08	1.18	0	2.5	0.5	1.0	4	0
Delay 2	1.08	1.14	0	2.0	0.8	3.0	7	0

(Tentative) conclusions:

1) As found previously in walnuts, delaying the first irrigation does result in some stress during the delay, but does <u>not</u> result in more stress at harvest.
2) As found previously in everything, different orchards/soils are different: applying full ET may not prevent substantial water stress in one location, and applying a deficit ET may only cause mild to moderate stress in another location.

(Tentative) conclusions:

1) As found previously in walnuts, delaying the first irrigation does result in some stress during the delay, but does not result in more stress at harvest.
2) As found previously in everything, different orchards/soils are different: applying full ET may not prevent substantial water stress in one location, and applying a deficit ET may only cause mild to moderate stress in another location. [More research is needed to find out if this can be predicted based on soil or other orchard conditions].
3) Also as found previously in walnuts, once the first SWP threshold is reached, the next threshold is not far behind. So, waiting for a particular SWP ‘trigger’ may not be as important as just waiting for the trees to ‘start to dry out.’
4) Long term effects (if there are any) should be clear with more years of data.

Thanks for your support and attention!

Ken Shackel, UC Davis
Roger Duncan, UCCE
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Andrew Mcelrone, *USDA-UC Davis*

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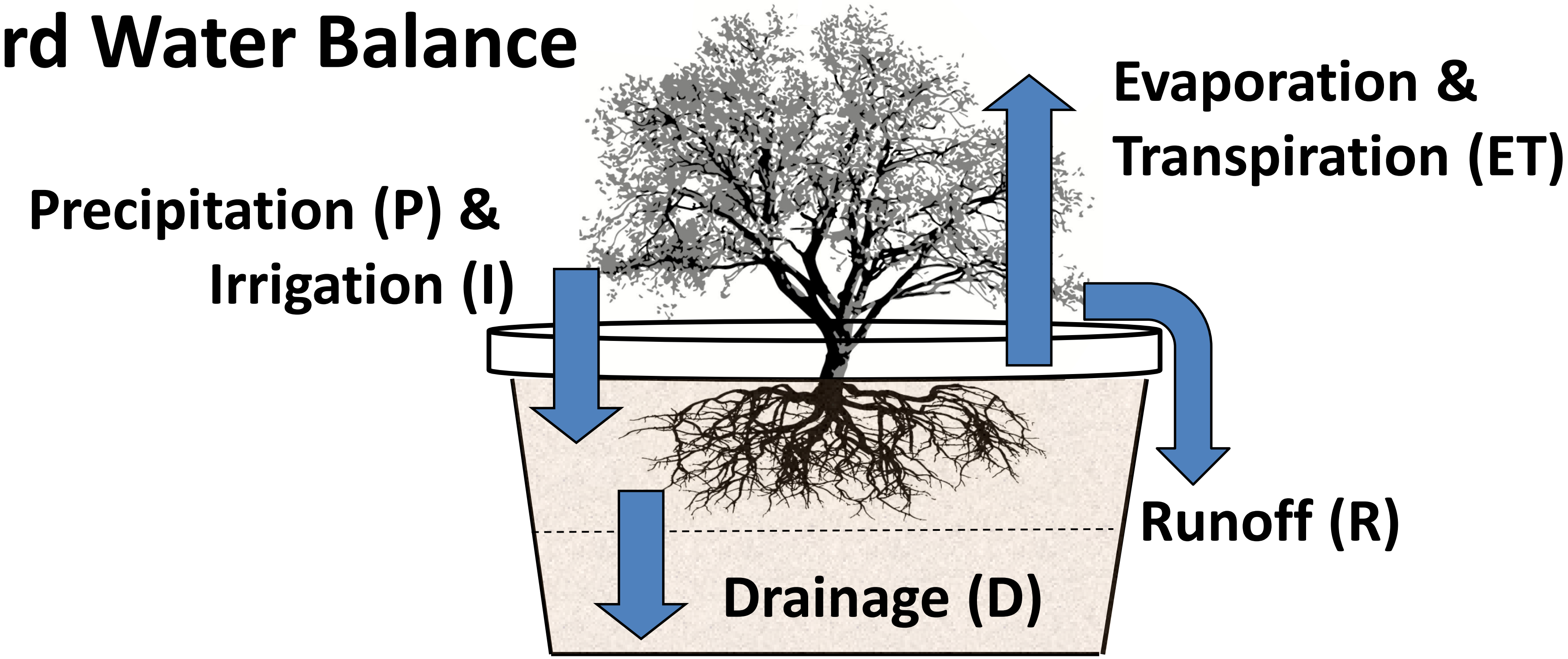
ET based irrigation management for almonds: something old and something new

Andrew J. McElrone; andrew.mcelrone@usda.gov

Orchard Water Balance



Change in soil water = P + I – ET – D – R

Gains (P + I) Losses (ET – D – R)

How much, when, where to irrigate?

tree water use

tree water stress

spatial variability

New tools needed to approach stress thresholds to achieve water savings and production/management goals

California Irrigation Management Information System (CIMIS)

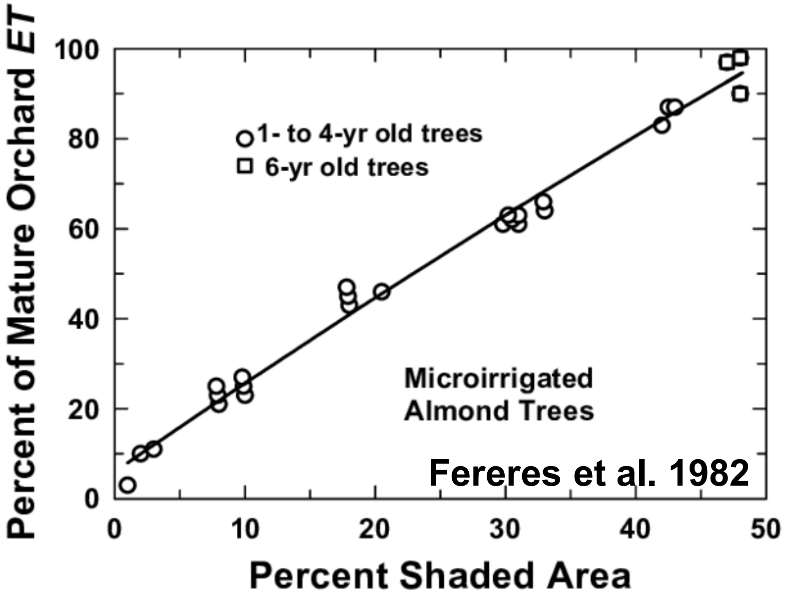
$$ET_c = K_c * ET_o$$

Crop coefficient

Reference ET (well-watered model grass)

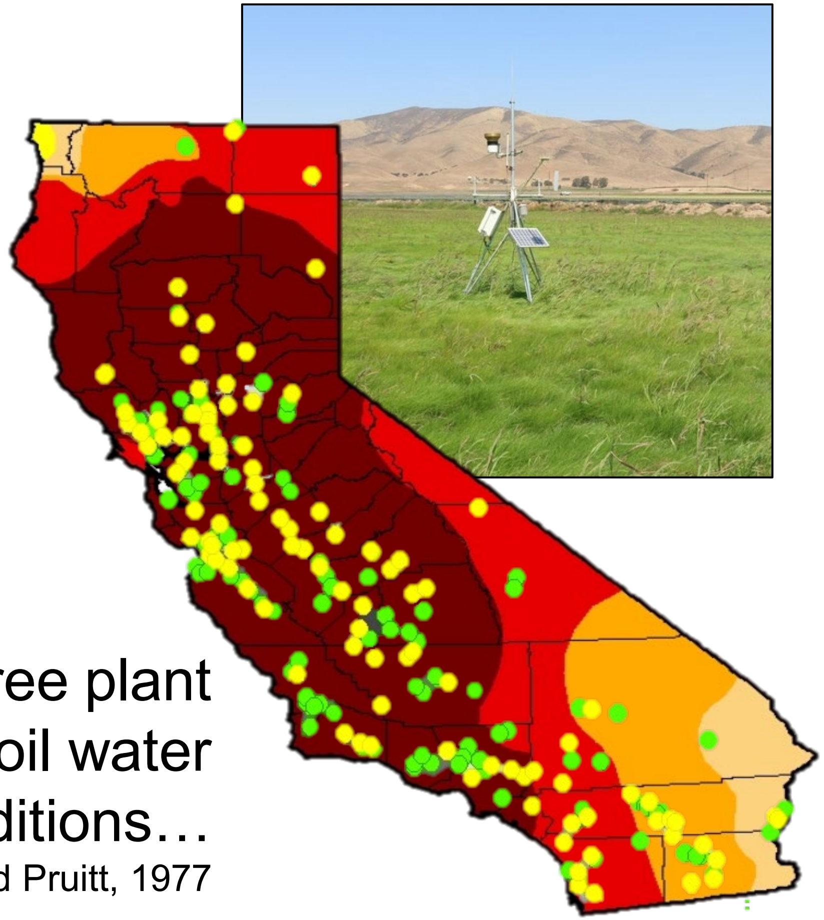
$$K_c = ET_c / ET_o$$

Obtained shaded area below trees

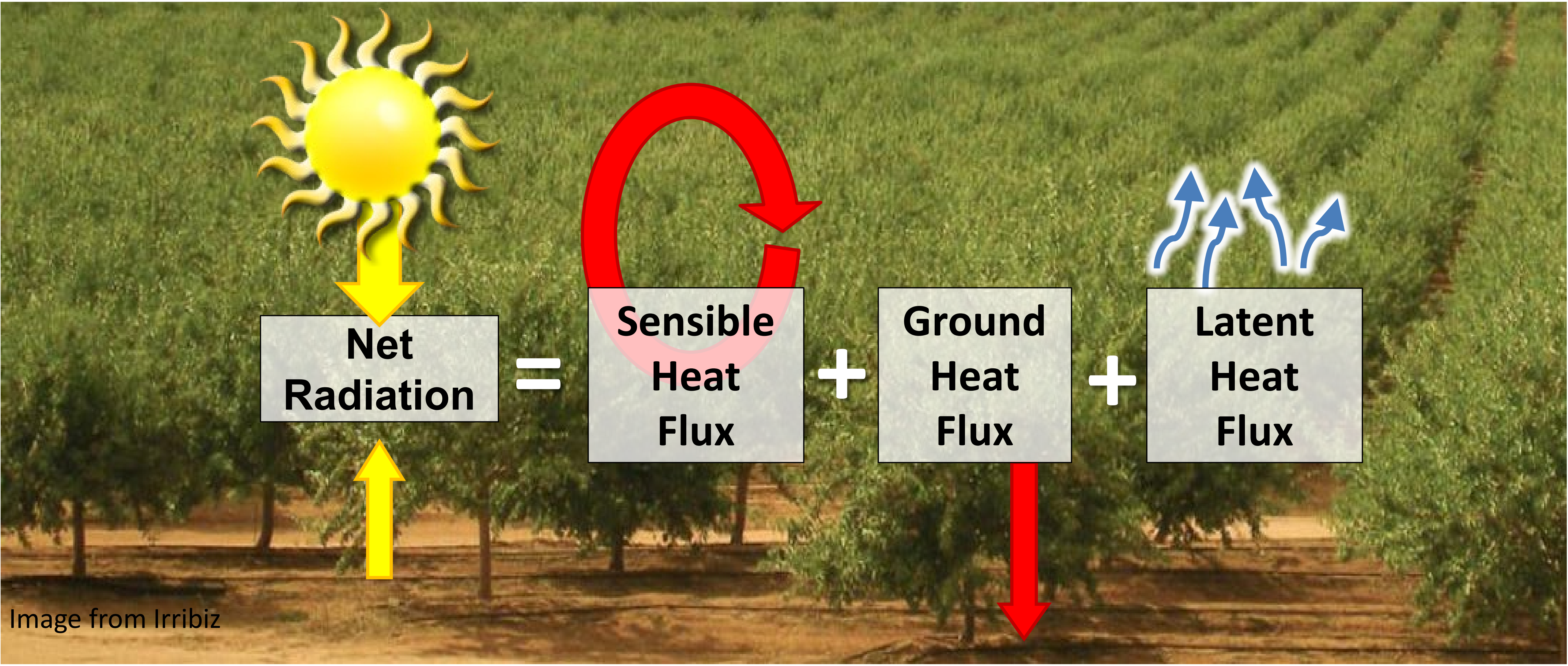


…assumes a disease-free plant grown under optimum soil water and nutrient conditions…

Doorenbos and Pruitt, 1977

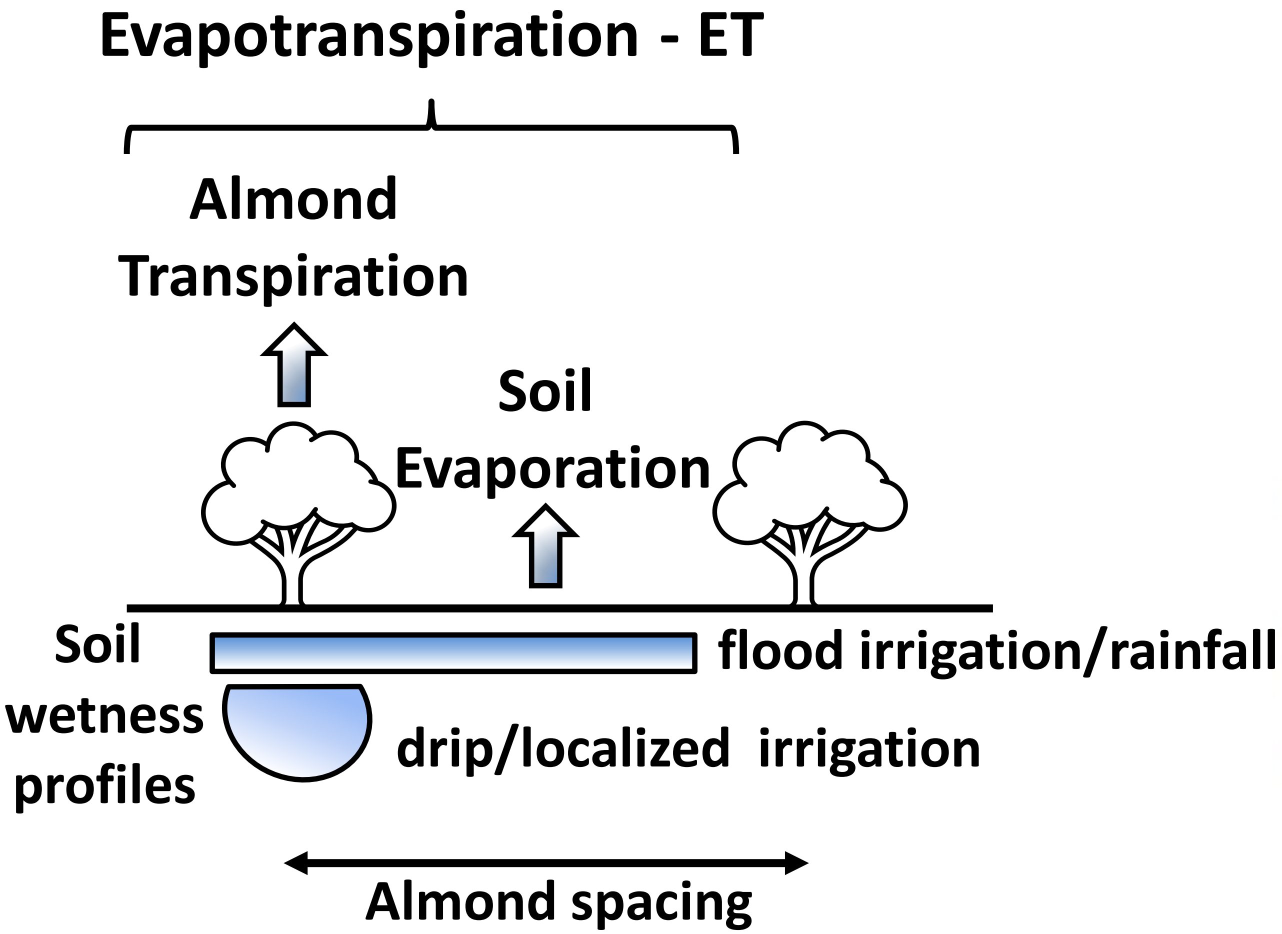


Energy Balance Approaches to Quantify ET

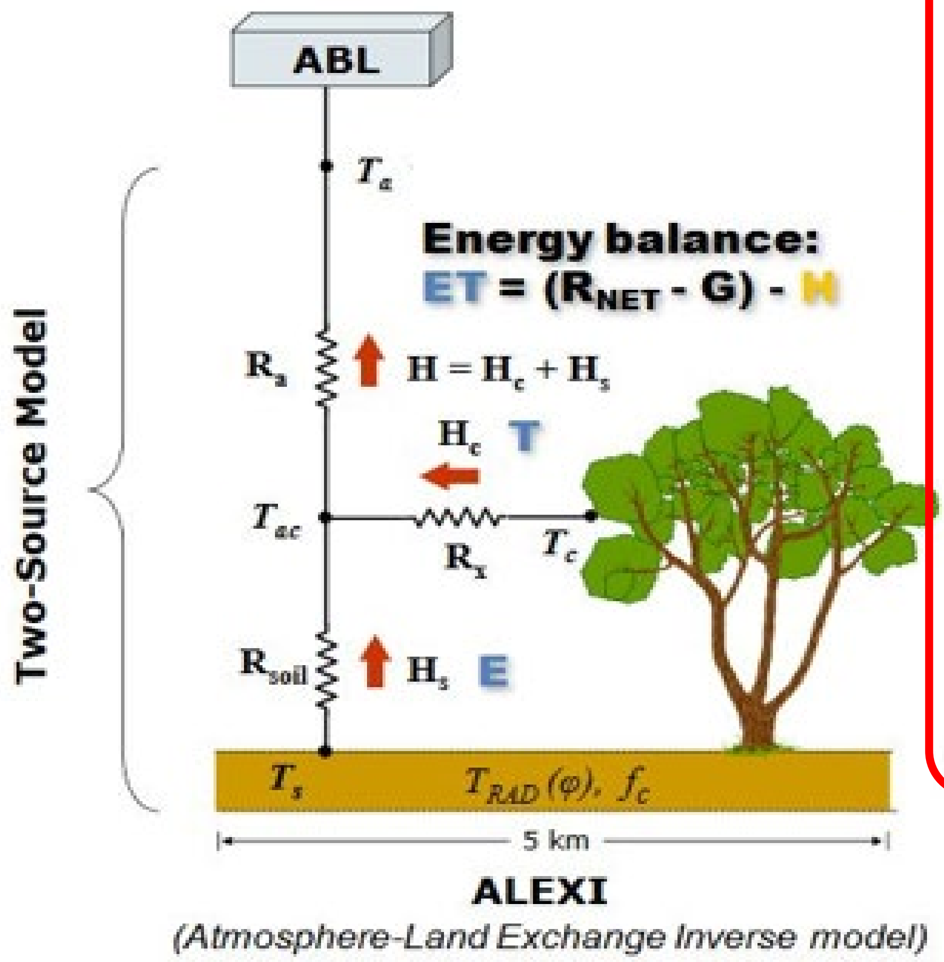


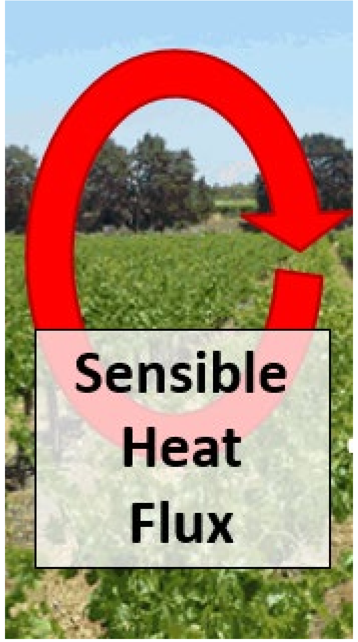
Partitioning the energy at the crop surface

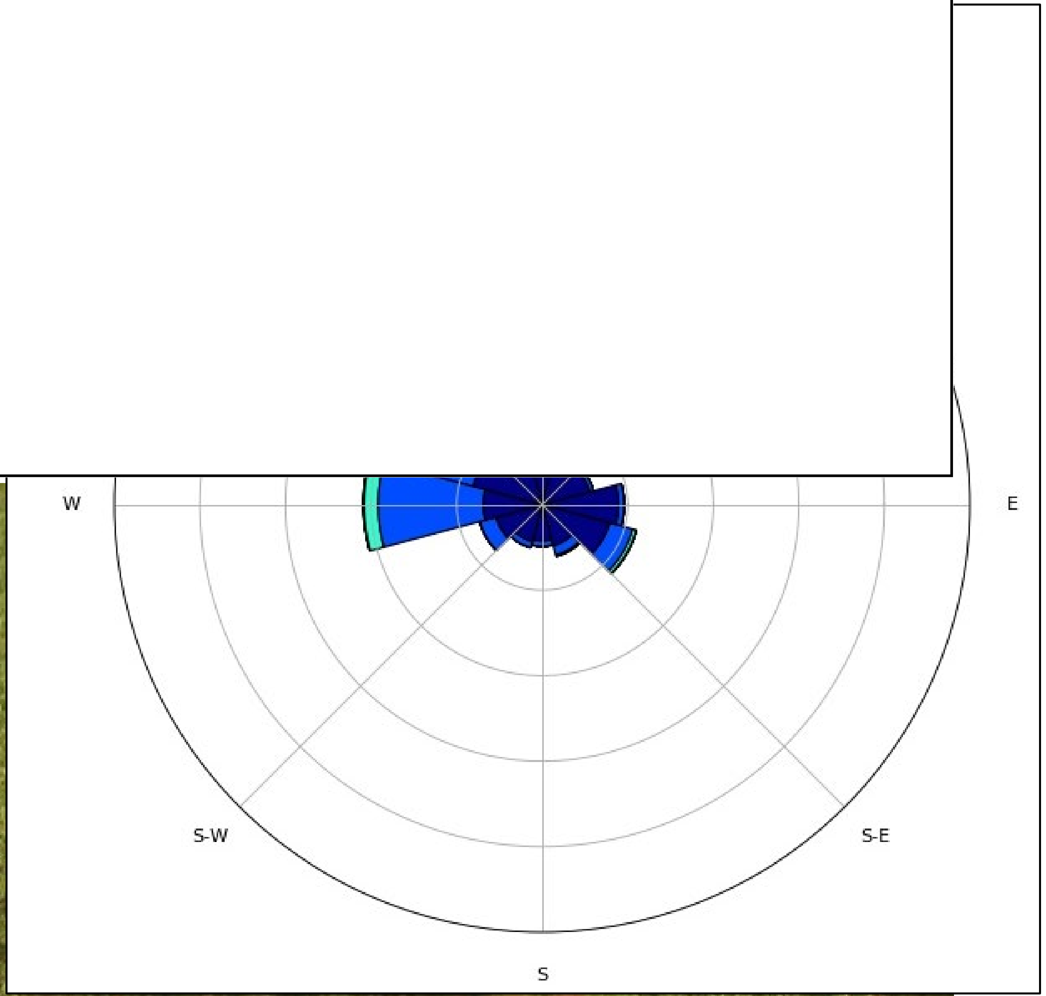
Energy partitioning to determine ET



Two Source Energy Balance







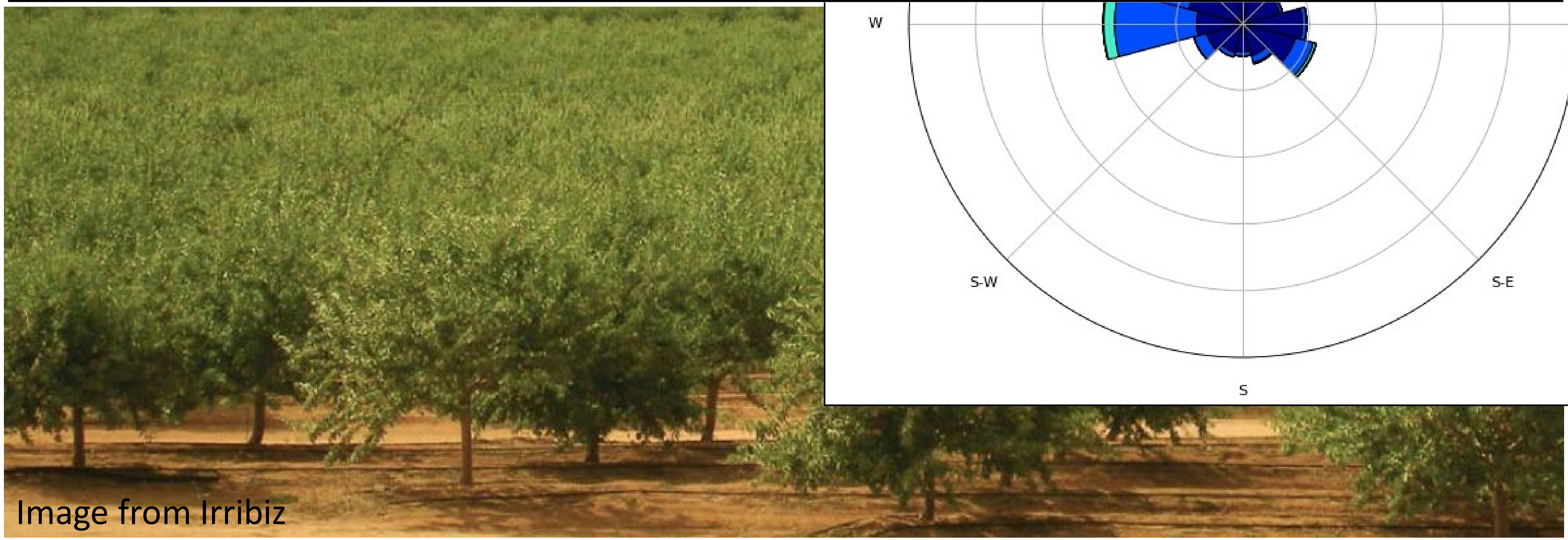
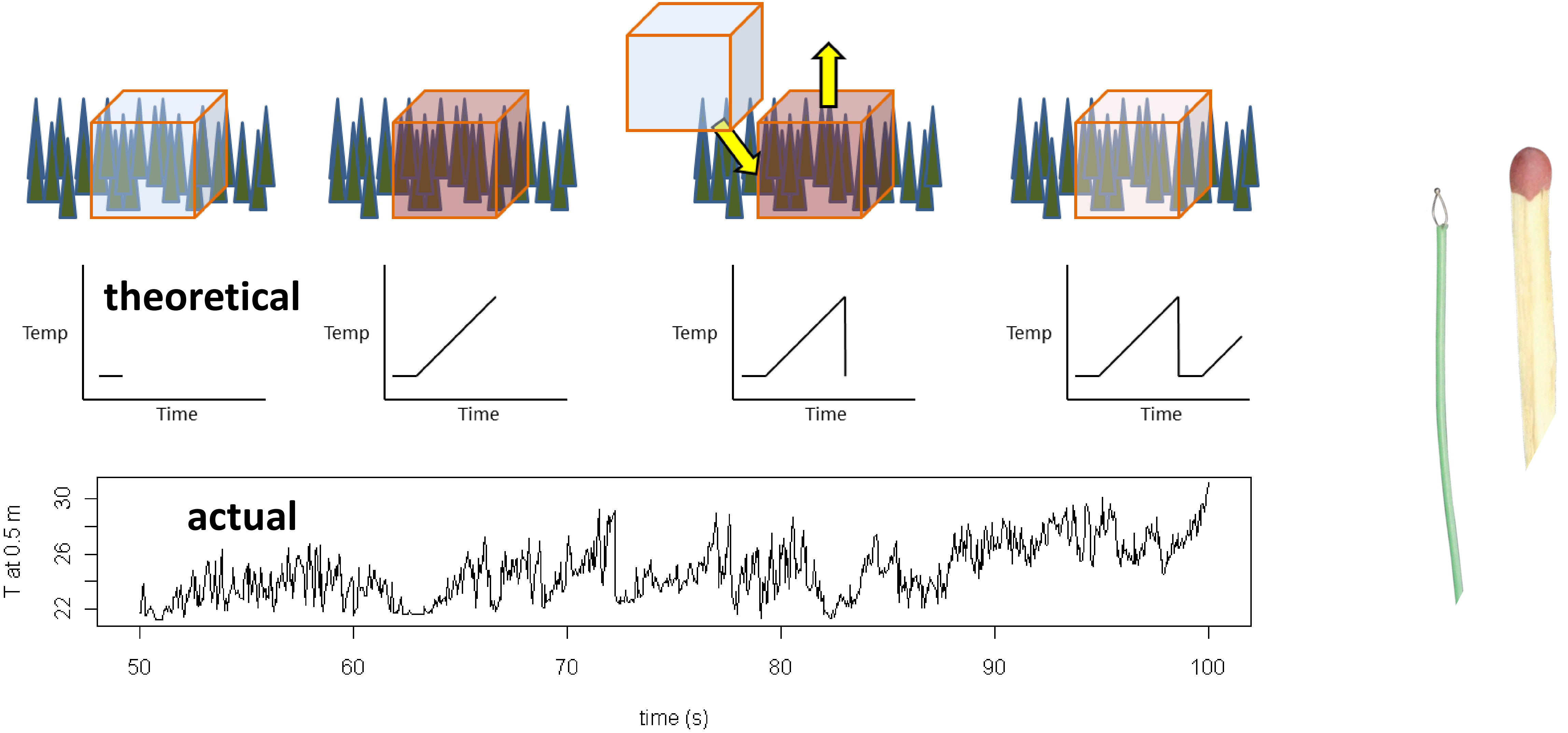


Image from Irribiz

Surface Renewal- Theory vs. Reality



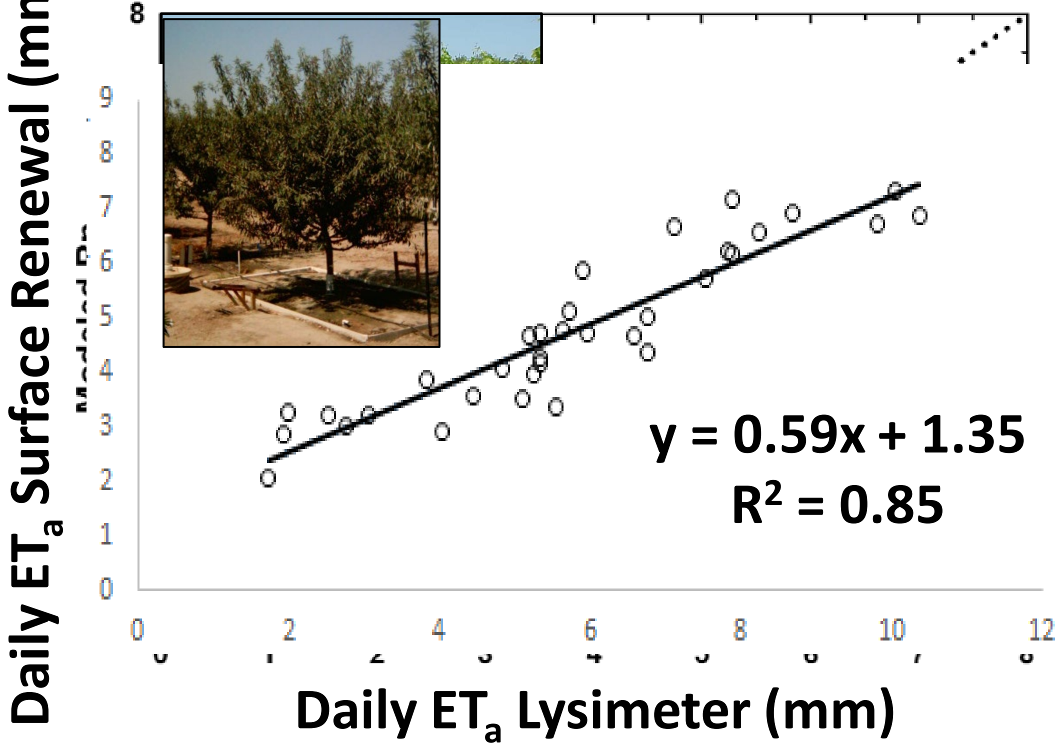
Successfully removed the need to calibrate against expensive research grade system

(Shapland et al. 2012a,b, 2014)

Goal: inexpensive, site-specific measurement of actual crop water use

SR vs. Lysimeter

Surface Renewal

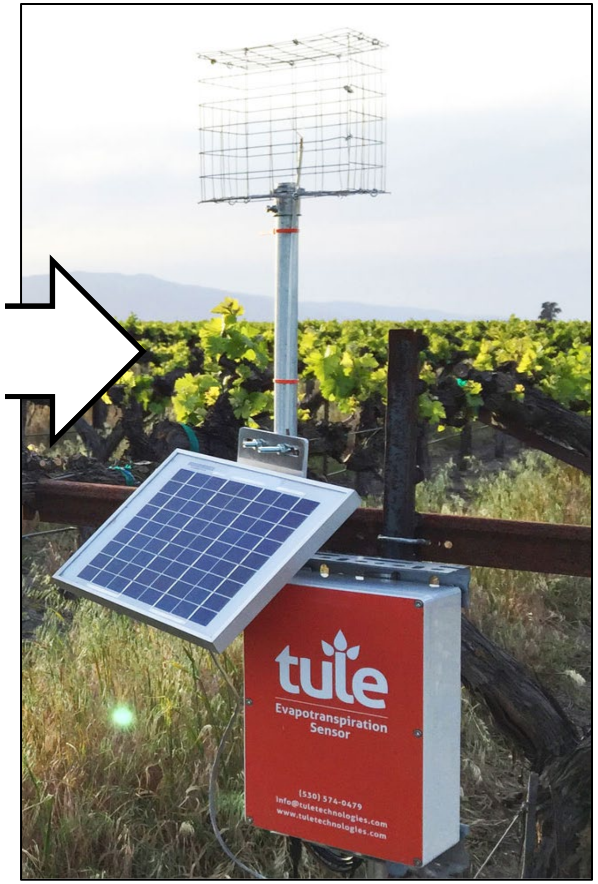


Kearney Agricultural Center

Research Grade System ~$10K

Univ. of California- Parlier CA

Paw U et al. 1989, 1991, 1995



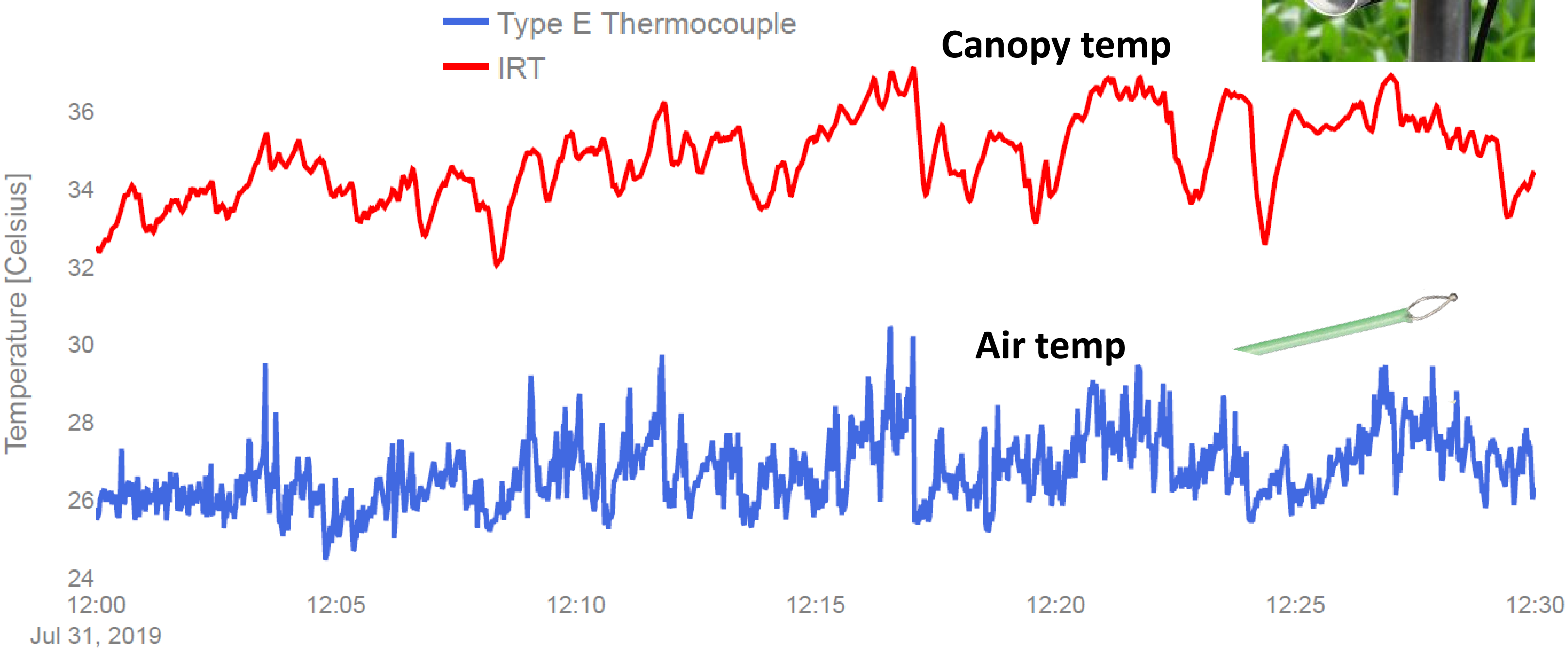
Commercial System

ARABLE

Mark 2

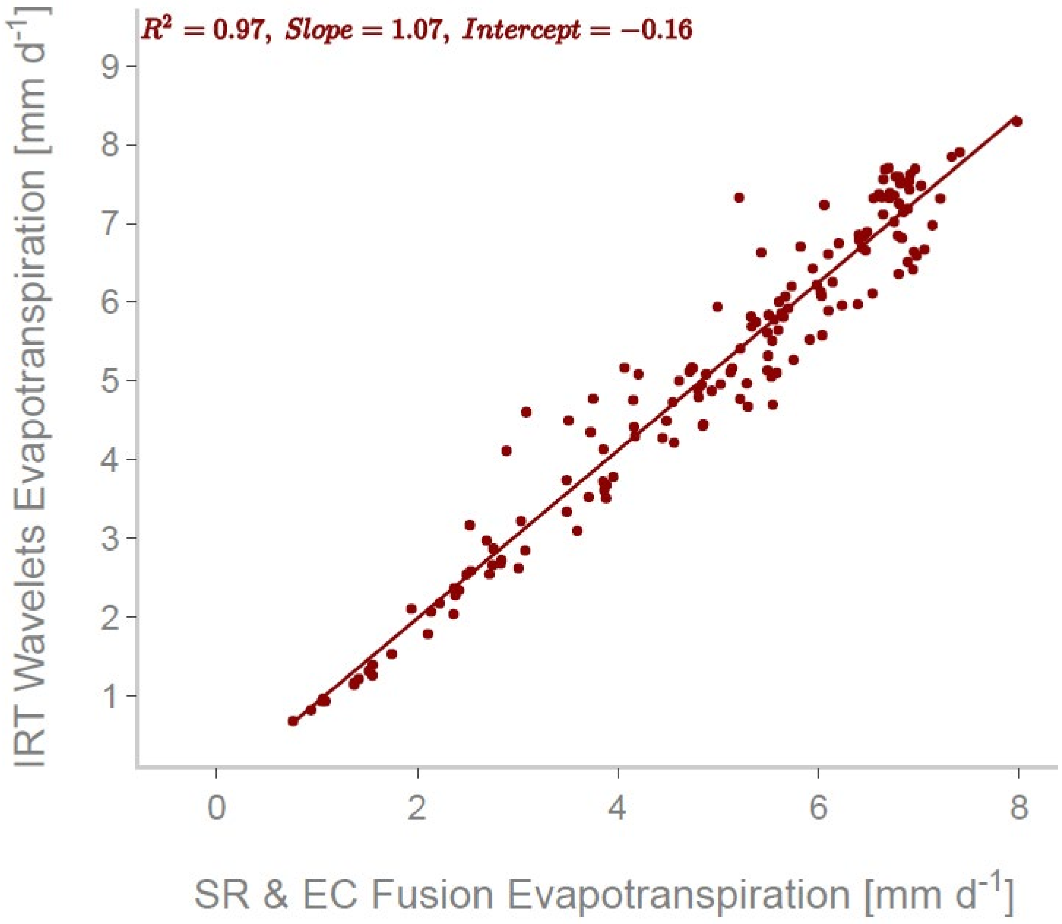
New method with InfraRed Radiometers (IRTs) at 1Hz

Temperature Comparison



Bambach et al. (2019; in prep)

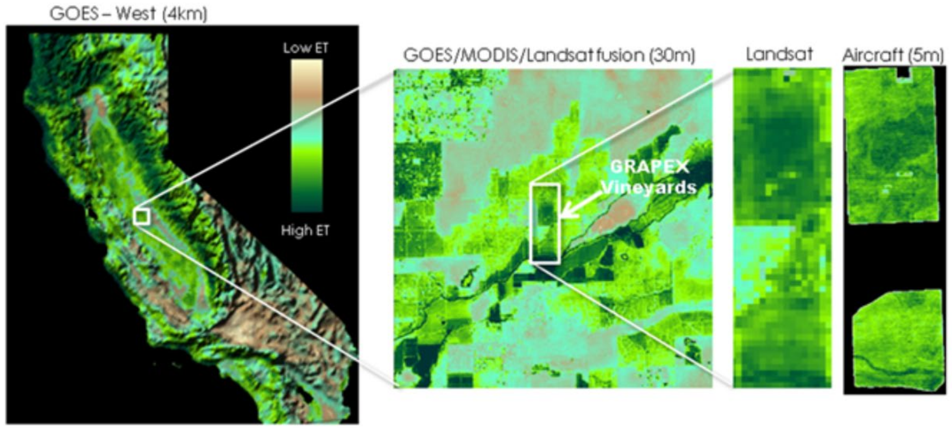
ET from new IRT Method vs. Almond ET from Flux Tower



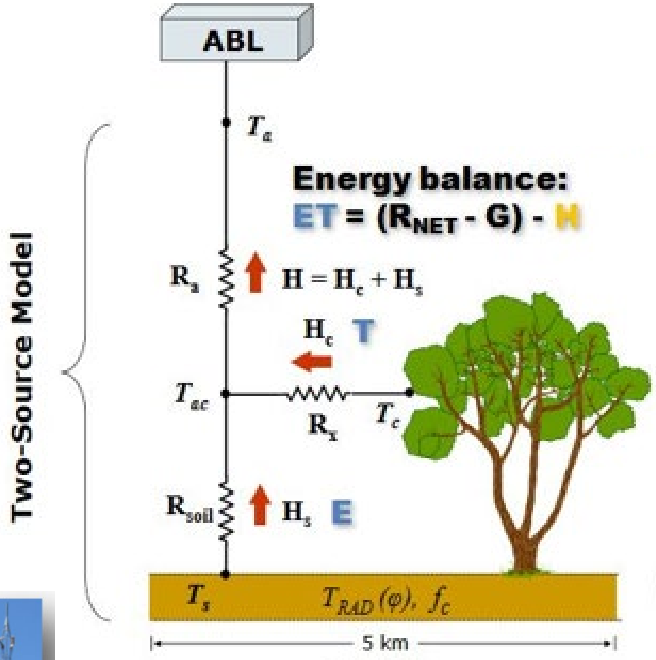
Develop an online tool and instructional videos to facilitate grower adoption of this technique- citizen science model

Grape Remote sensing Atmospheric Profile & Evapotranspiration eXperiment

Refine and apply a multi-scale remote sensing ET toolkit for mapping crop water use and stress for improved irrigation management in CA



Two Source Energy Balance

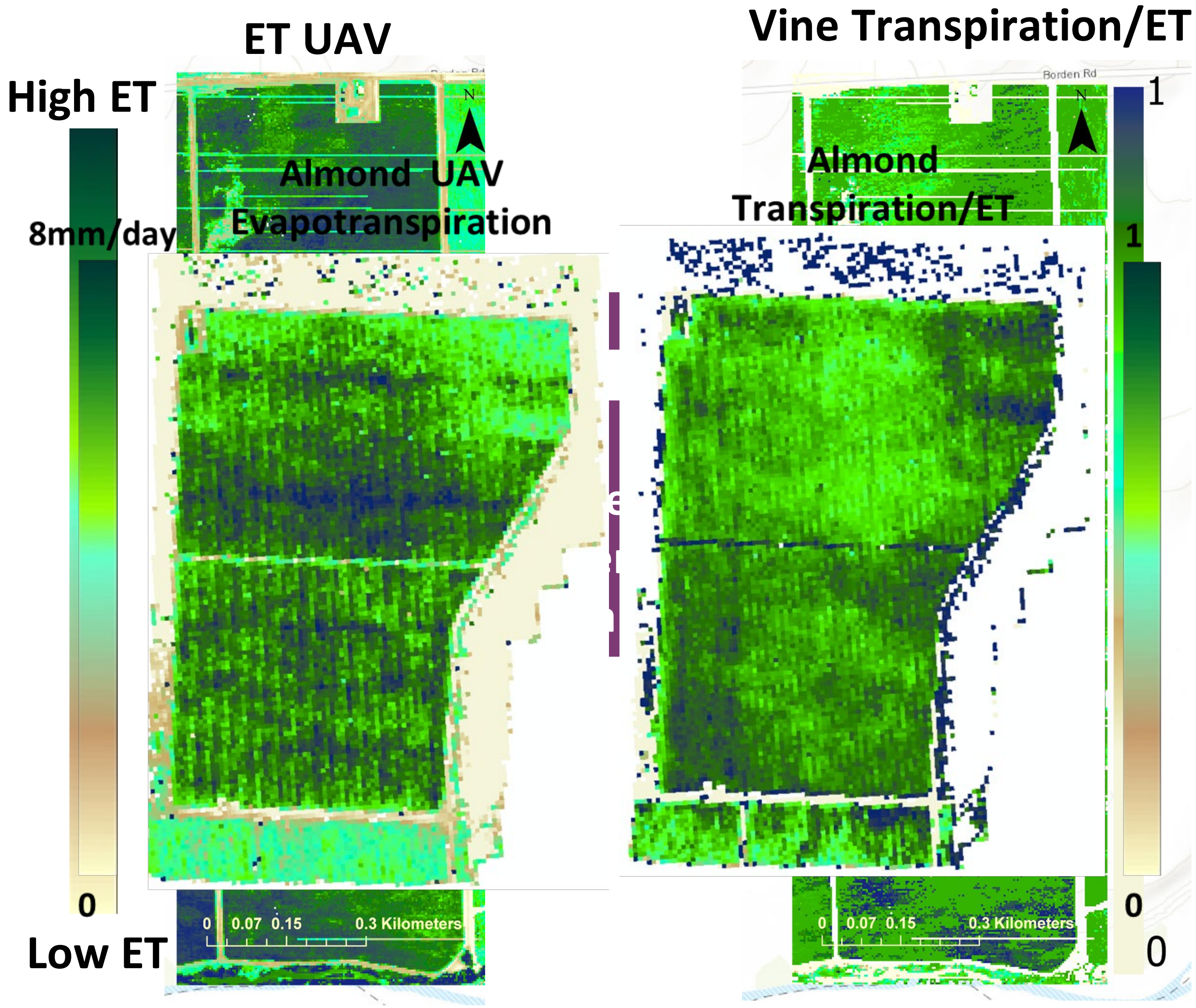


ALEXI

(Atmosphere-Land Exchange Inverse model)

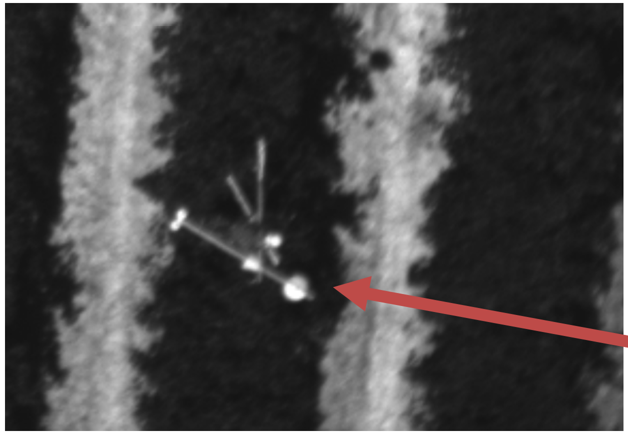
Parsing Transpiration from ET

Utah State- Aggie Air- Alfonso Torres and team

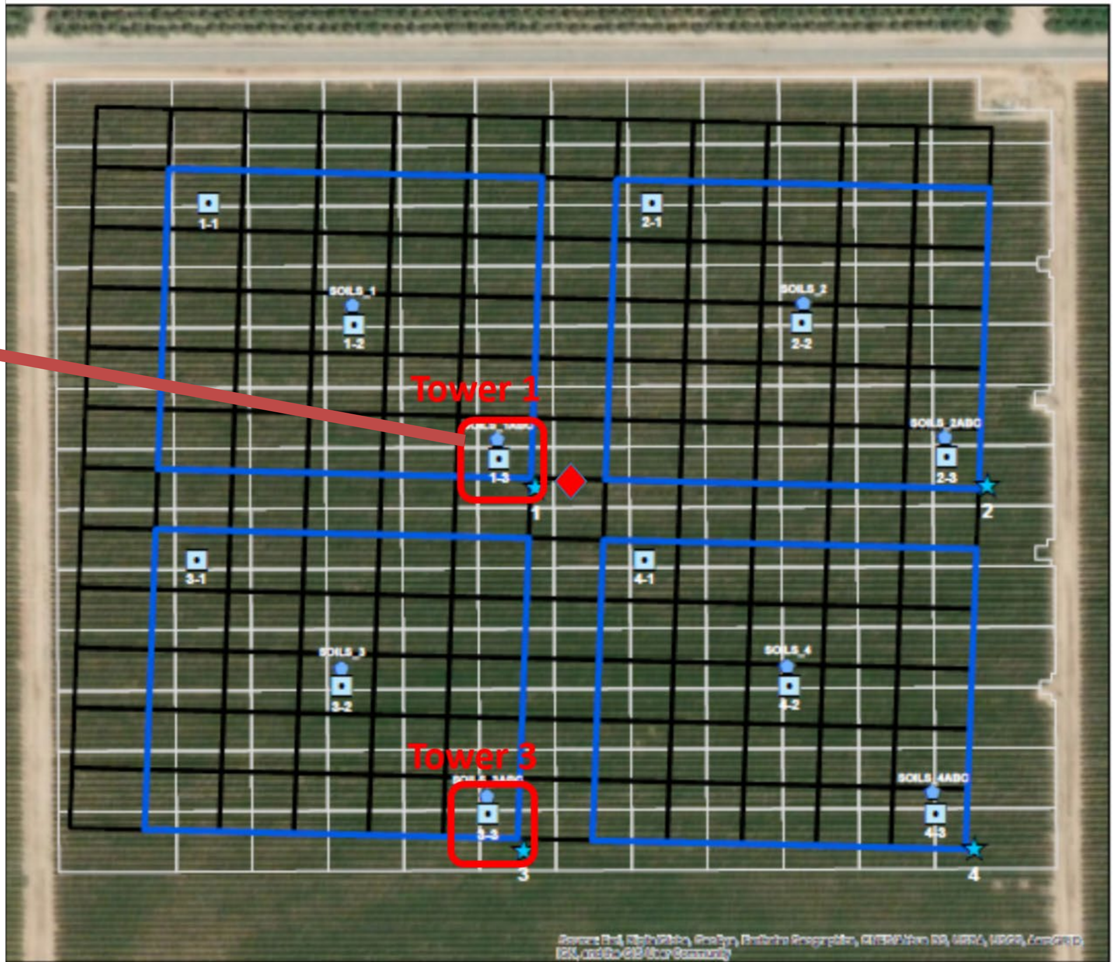


Hovering UAV 1Hz data capture- Aggie Air

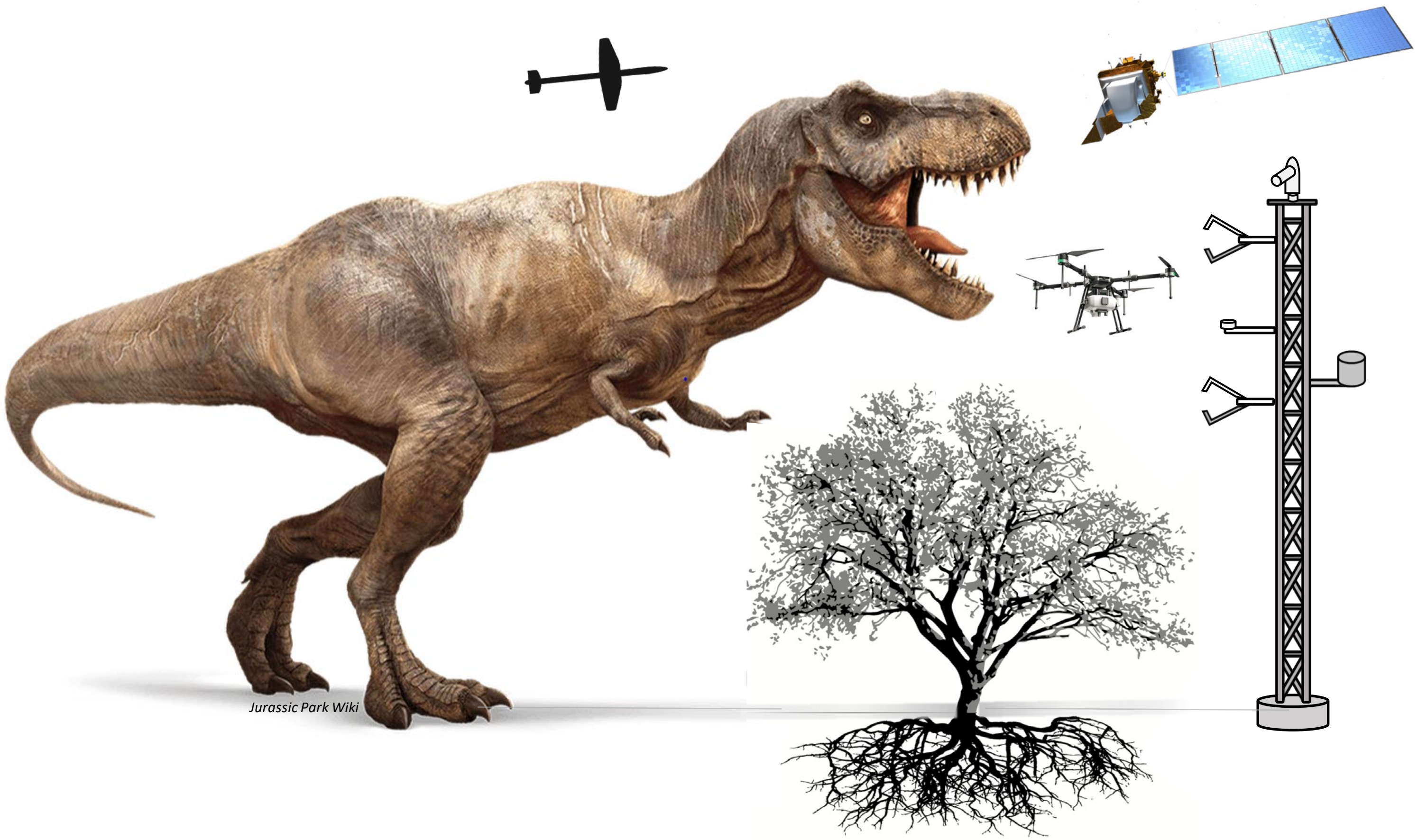
TSEB at 1Hz comparison with Eddy flux tower and new IRT method



Actual image of Tower from hover flight (1inch/pixel)



T-REX: Tree crop Remote sensing of Evapotranspiration eXperiment



CDFA-Specialty Crop Block Grant

Development of Low-Cost and Accessible Irrigation Management Tools for Almonds…

Partners: ABC, Bergwerff (Winters Farming), Lak Brar, Melton (OpenET), Magney

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NEW PERSPECTIVES IN IRRIGATION MANAGEMENT

Forrest Melton, *NASA*

california almonds
Almond Board of California

OPENET

Filling the Biggest Data Gap in Water Management

Forrest Melton, NASA Ames & CSU Monterey Bay
Robyn Grimm, Environmental Defense Fund
Justin Huntington, Desert Research Institute

EDF ENVIRONMENTAL DEFENSE FUND® Finding the ways that work
DRI Desert Research Institute
NASA
Google Earth Engine

The OPENET Team

Environmental Defense Fund Robyn Grimm, Dana Rollison, Maurice Hall

DRI, NASA Ames, Habitat Seven (Multimodel Development, Integration, API, UI) Justin Huntington, Forrest Melton, Jamie Herring, Charles Morton, Britta Daudert, Alberto Guzman, Jody Hansen, Jordan Harding, Matt Bromley

USDA, NASA Marshall Space Flight Center, U. Maryland, U. Wisconsin (ALEXI/DisALEXI) Martha Anderson, Yun Yang, Christopher Hain, Mitch Schull, Mutlu Ozdogan

U. of Nebraska, U. of Idaho, DRI (EE METRIC) Ayse Kilic, Rick Allen, Peter Revelle, Samuel Ortega

NASA JPL (PT JPL) Josh Fisher, Gregory Halverson

NASA Ames, CSUMB, Stanford University (SIMS) Forrest Melton, Alberto Guzman, Lee Johnson, Tianxin Wang, Conor Doherty

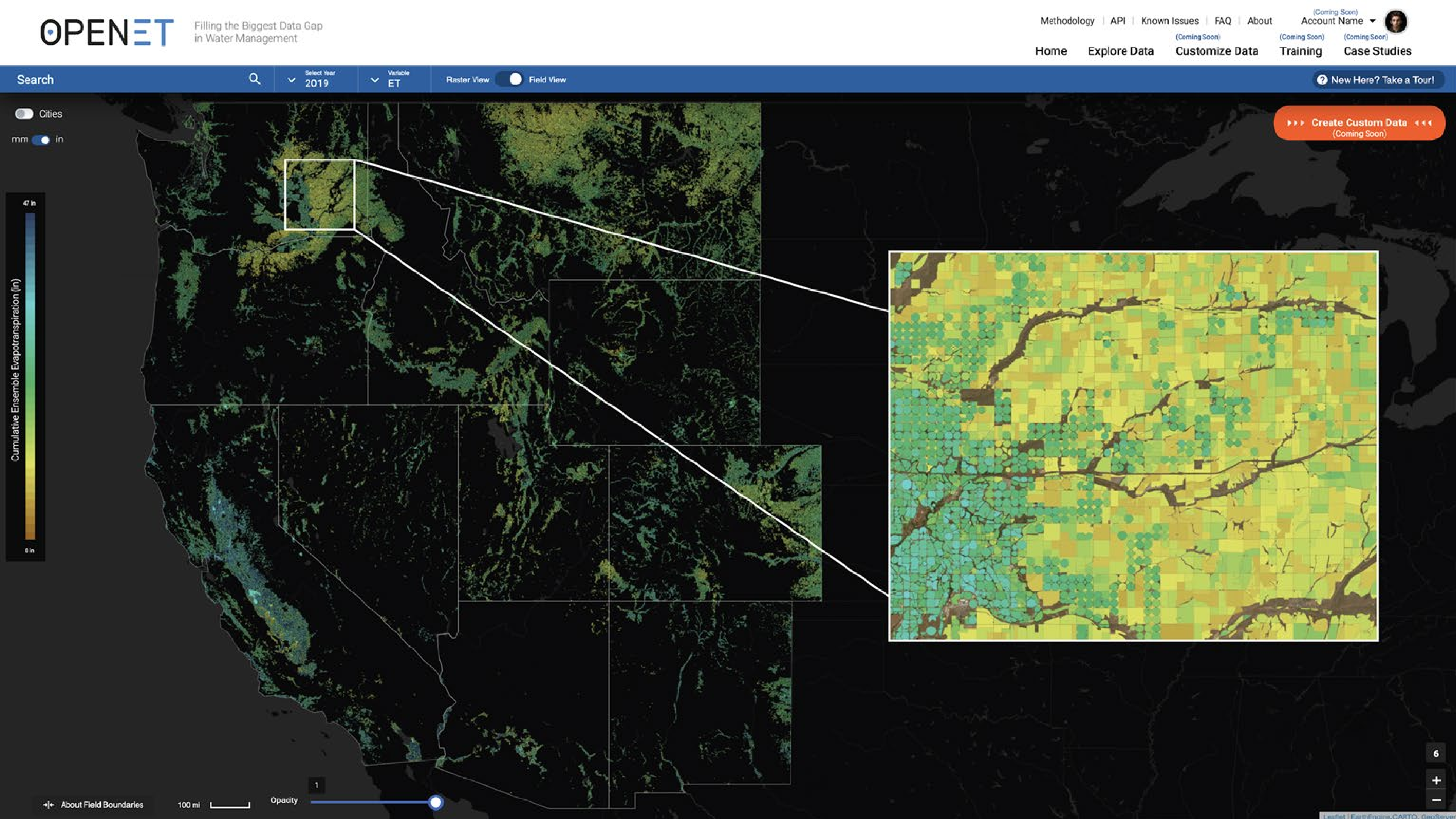
USGS (SSEBop) Gabriel Senay, MacKenzie Friedrichs

Google Earth Engine Tyler Erickson

Evapotranspiration and Consumptive Use

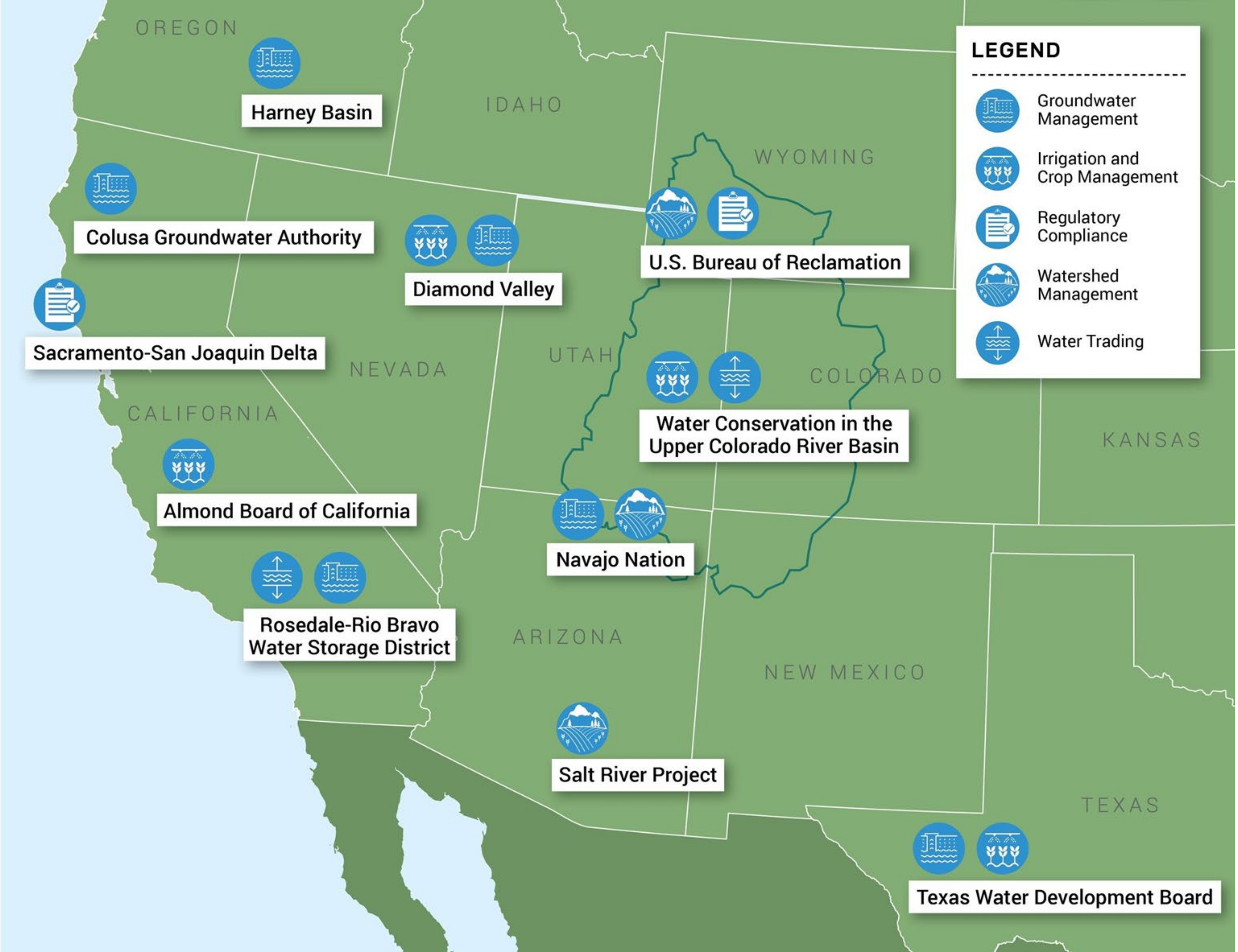
Water applied to a field ultimately:

- Evaporates
- Transpires (after being used by plants to grow)
- Recharges underlying groundwater
- Runs off and returns to a local canal or river


OPENET
Filling the Biggest Data Gap in Water Management
Methodology | API | Known Issues | FAQ | About
(Coming Soon)
Account Name
Home
Explore Data
(Coming Soon)
Customize Data
(Coming Soon)
Training
(Coming Soon)
Case Studies
Search
Select Year
2019
Variable
ET
Raster View
Field View
New Here? Take a Tour!
Cities
mm
in
Create Custom Data
(Coming Soon)
47 in
Cumulative Ensemble Evapotranspiration (in)
0 in
About Field Boundaries
100 mi
Opacity
1
6
+
−

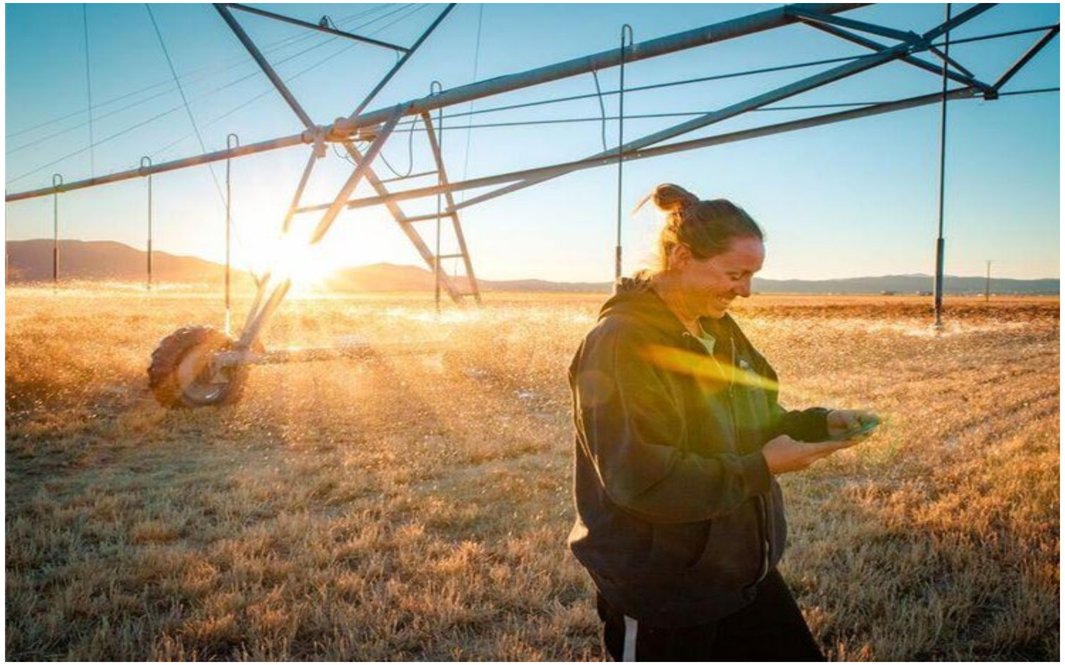
Measuring ET enables:

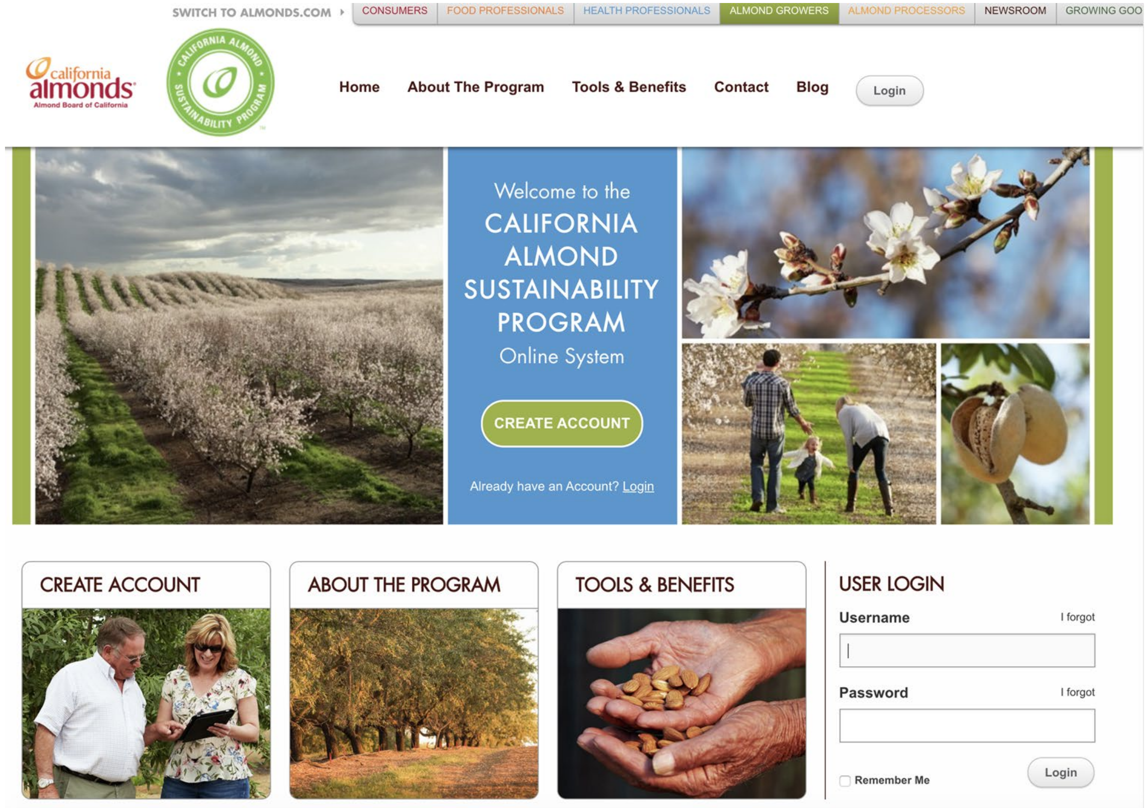
- Development of realistic water budgets
- Incentives for conservation and innovation
- Proper credit for reduced use
- Reduced transaction costs for water trading programs
- Increased on-farm efficiencies


OREGON
IDAHO
WYOMING
NEVADA
UTAH
COLORADO
CALIFORNIA
KANSAS
ARIZONA
NEW MEXICO
TEXAS
Harney Basin
Colusa Groundwater Authority
Diamond Valley
U.S. Bureau of Reclamation
Sacramento-San Joaquin Delta
Water Conservation in the Upper Colorado River Basin
Almond Board of California
Navajo Nation
Rosedale-Rio Bravo Water Storage District
Salt River Project
Texas Water Development Board
LEGEND
Groundwater Management
Irrigation and Crop Management
Regulatory Compliance
Watershed Management
Water Trading

Working with Farmers and Improving Irrigation Scheduling Tools

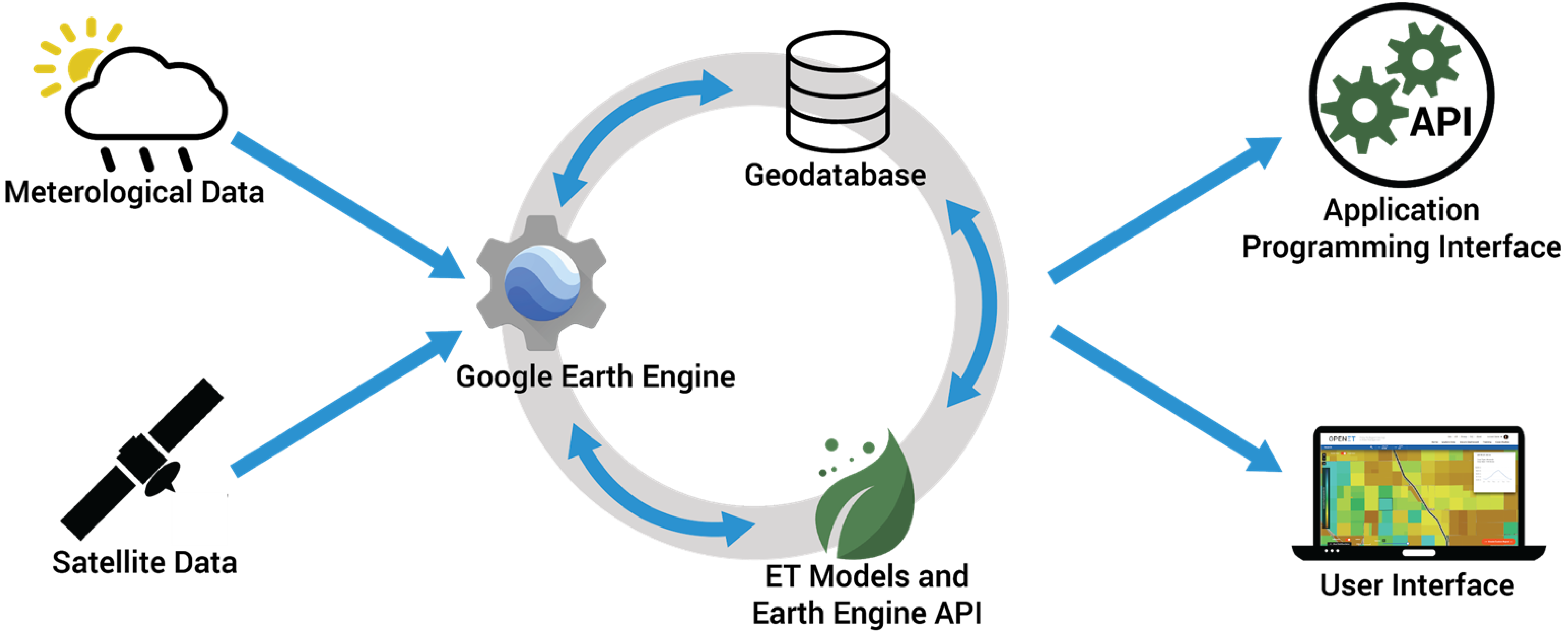
Current challenge: accurate estimation of national scale near real-time crop ET with satellite data



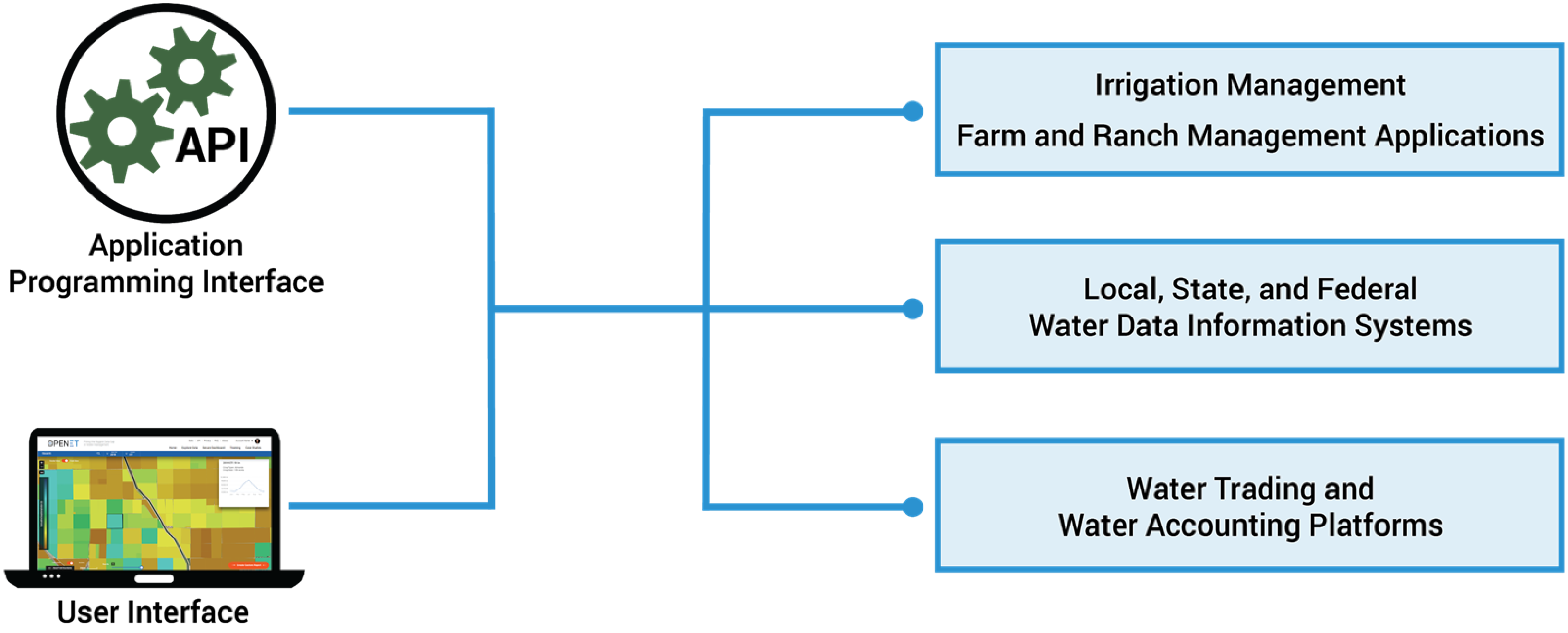


"If you give farmers better information on when they should and shouldn't have their water on, you're going to save water. I think that's the greatest asset of OpenET" - Denise Moyle, Diamond Valley Nevada

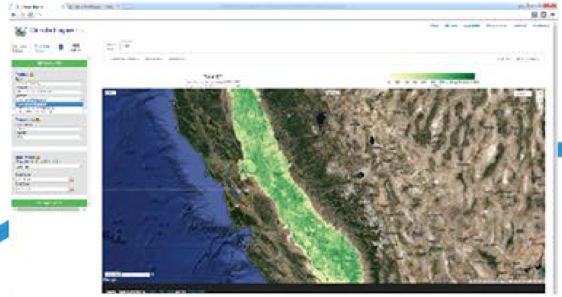
How OpenET Works



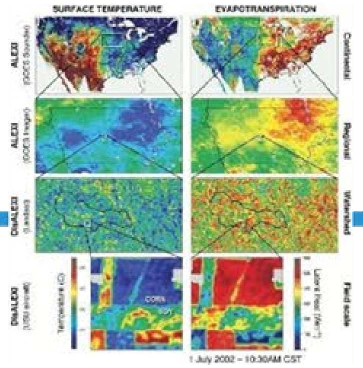
OpenET API for Integration with Other Software



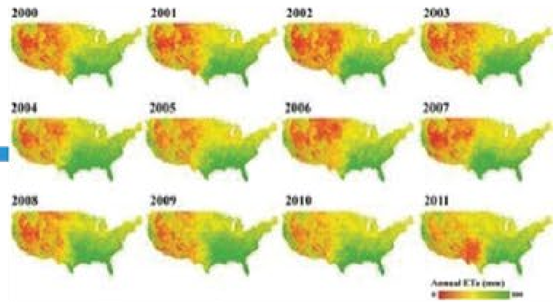
OpenET Uses Well-Established Methods



EE METRIC
University of Nebraska,
University of Idaho

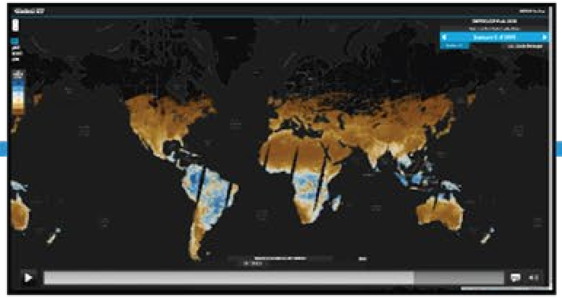


ALEXI/DisALEXI
USDA, NASA, University of Maryland,
University of Wisconsin

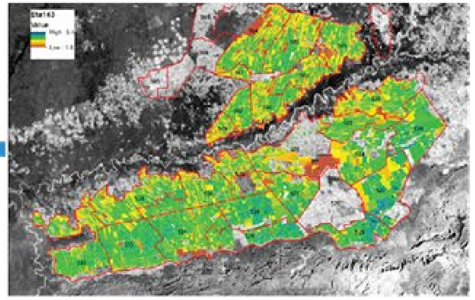


SSEBop
USGS

SIMS
NASA, CSUMB, Stanford University



PT-JPL
NASA



SEBAL

OpenET Uses Data from a Constellation of Satellites

Image credit: NASA/Goddard Space Flight Center Conceptual Image Lab

USGS-NASA Landsat 5/7/8
(TM / ETM+ / OLI)
30m/0.22 acres | overpass every 8-16 days

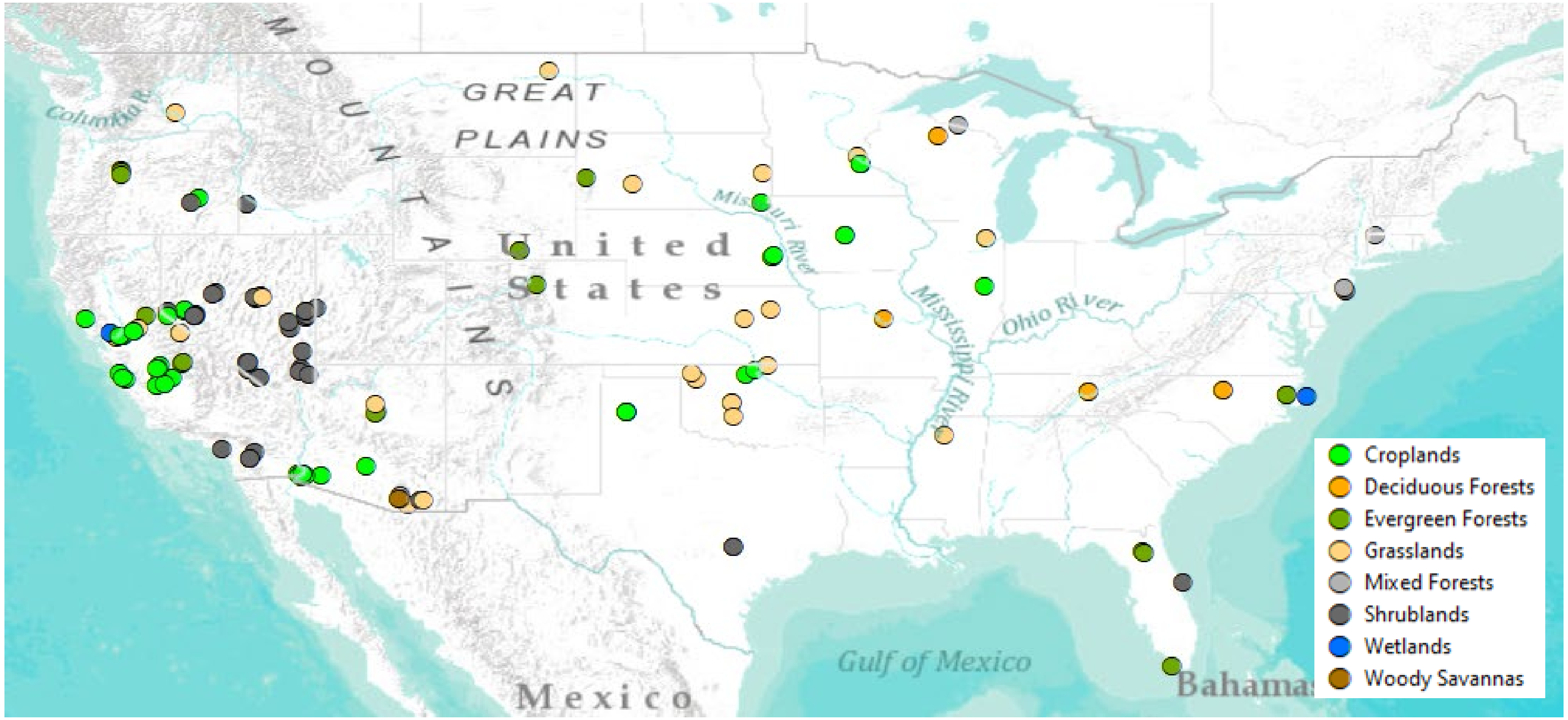
NASA Terra / Aqua
1 km | daily overpass

NASA-NOAA Suomi NPP
~300-375m | daily overpass

NOAA GOES-15/16/17
0.5-4 km | < hourly

ESA Sentinel-2A, 2B
20m/0.1 acres | overpass every 5-10 days

ET Intercomparison and Accuracy Assessment

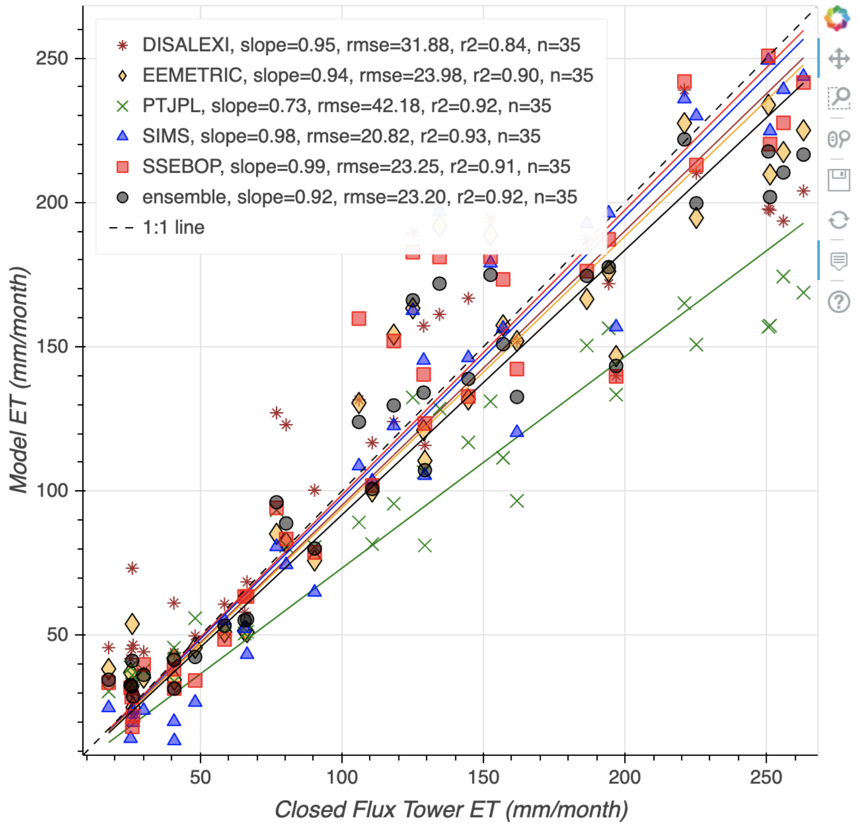


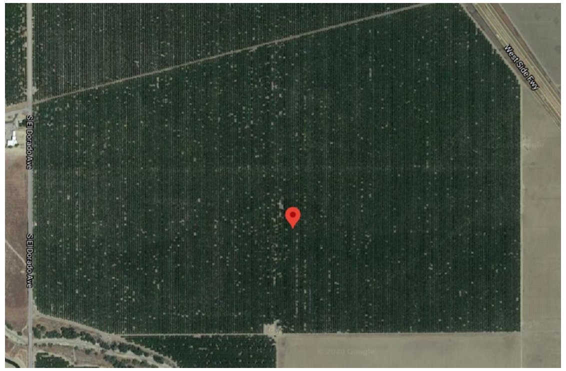
Examples of Initial Results for Almonds

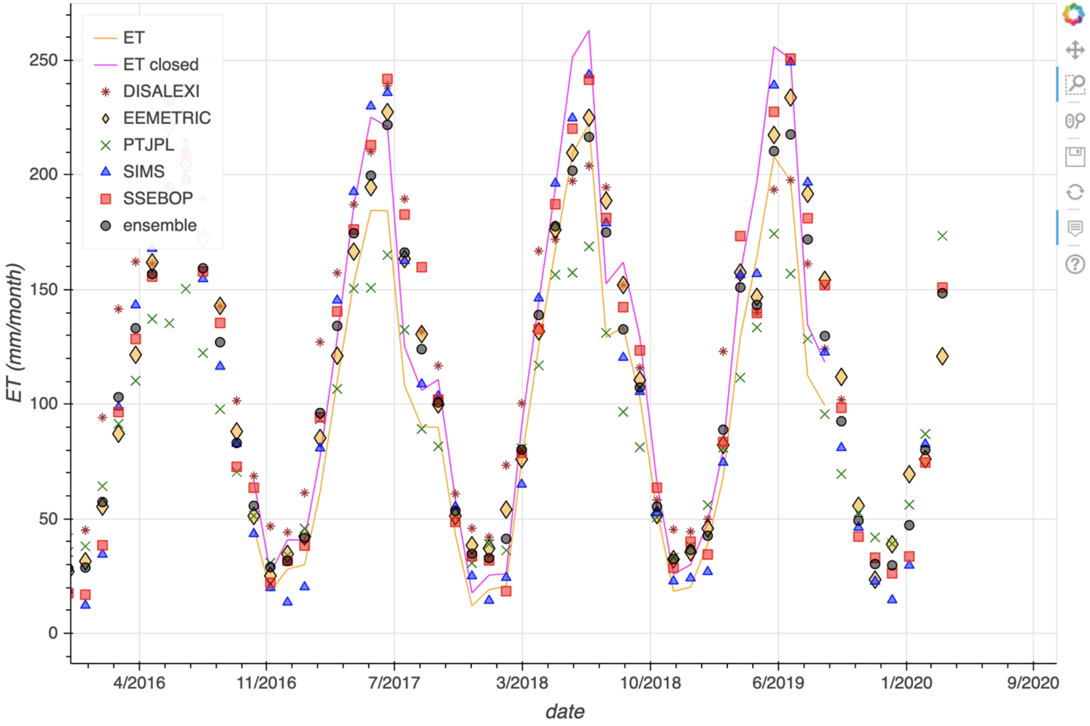
Almond Orchard | South Central Valley, CA

Site: Almond High; **State:** CA
Land Cover: Croplands, *Almond*
EBC: 0.83; **EBC_GS:** 0.83; **EBC_NGS:** 0.82; **Correction:** 1.26
Monthly ET Comparison, cimis

3x3 pixel grid, full period



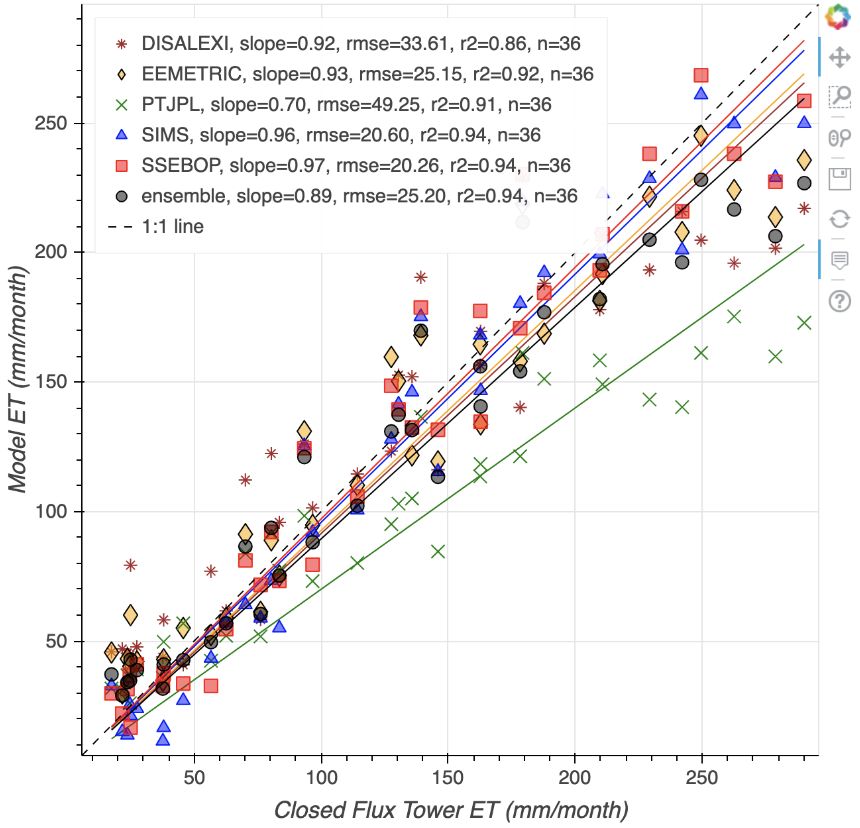


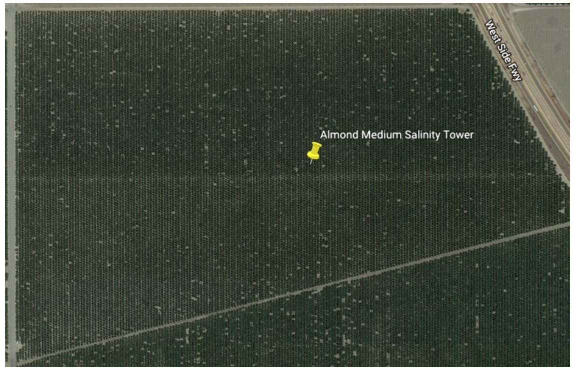


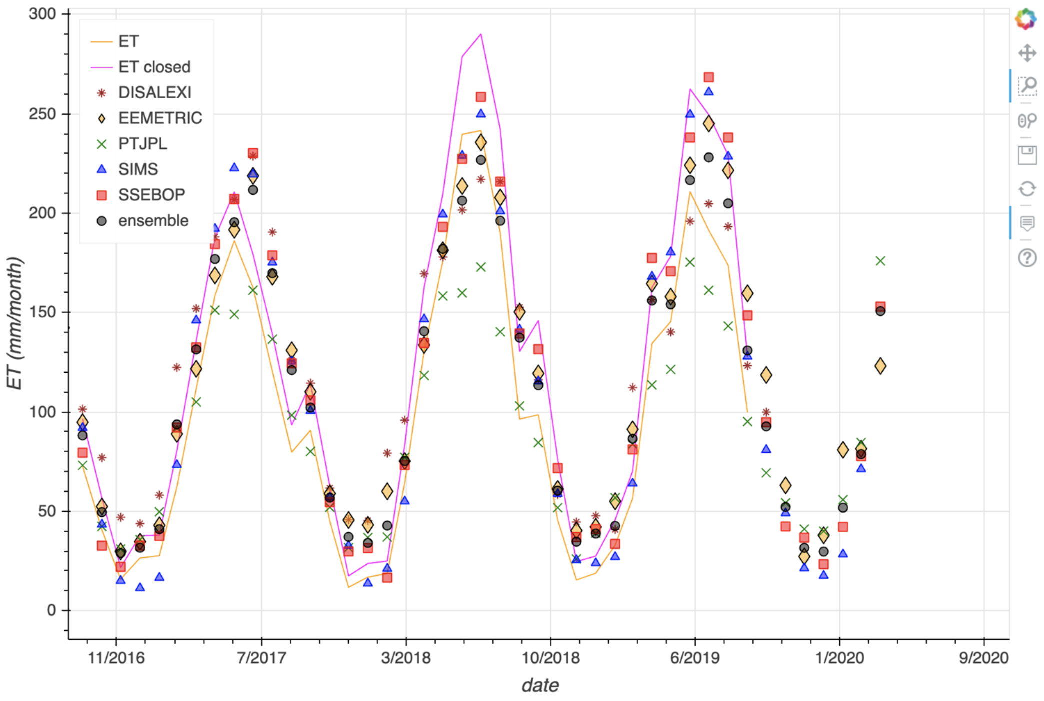
Examples of Initial Results for Almonds

Almond Orchard | South Central Valley, CA

Site: Almond Med; **State:** CA
Land Cover: Croplands, *Almond*
EBC: 0.82; **EBC_GS:** 0.83; **EBC_NGS:** 0.79; **Correction:** 1.31
Monthly ET Comparison, cimis







OPENET

Filling the Biggest Data Gap in Water Management

OpenET will go live in 2021

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NEW PERSPECTIVES IN IRRIGATION MANAGEMENT

Isaya Kisekka, *UC Davis*

Data-Driven Smart Irrigation Management in Almonds

Isaya Kisekka

Associate Professor

Departments: Land Air Water Resources | Biological and Agricultural Engineering

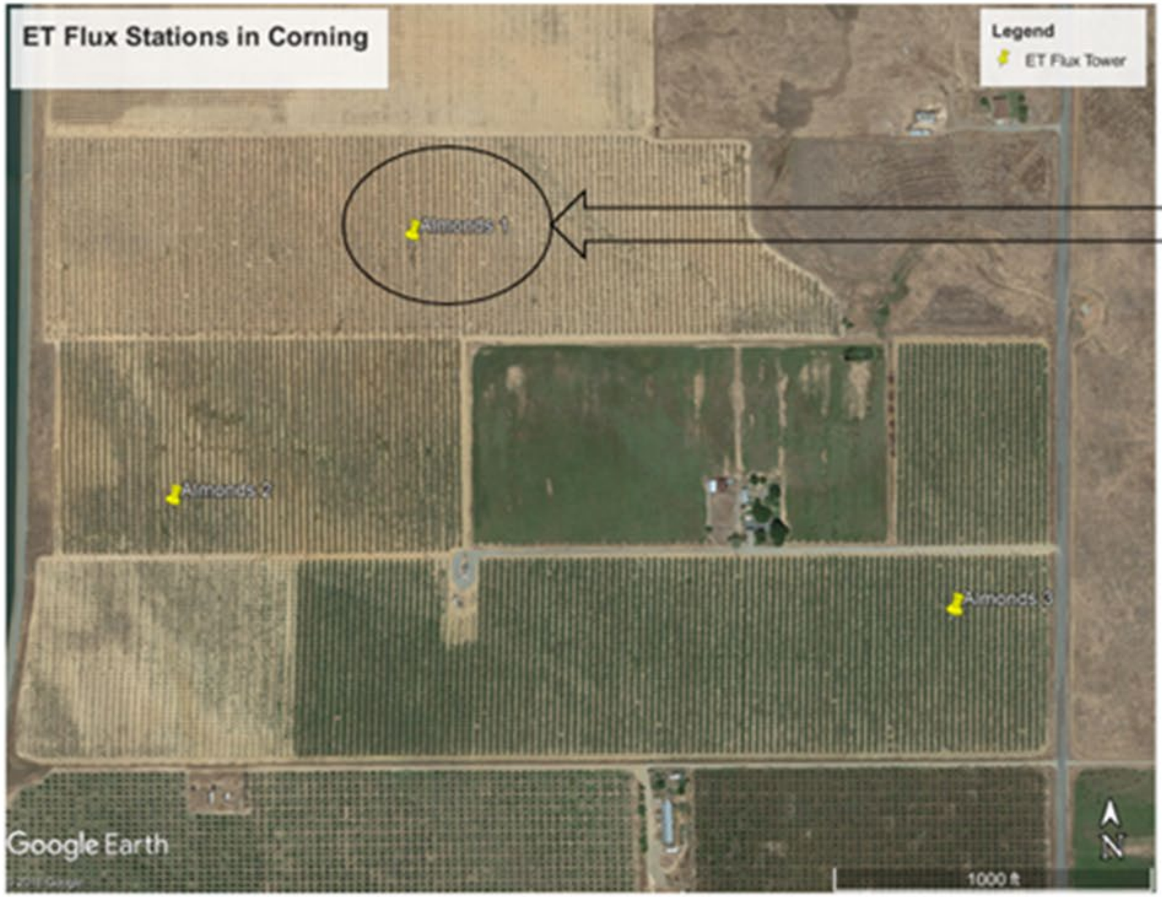
Understanding Water Use of Young Almond Orchards

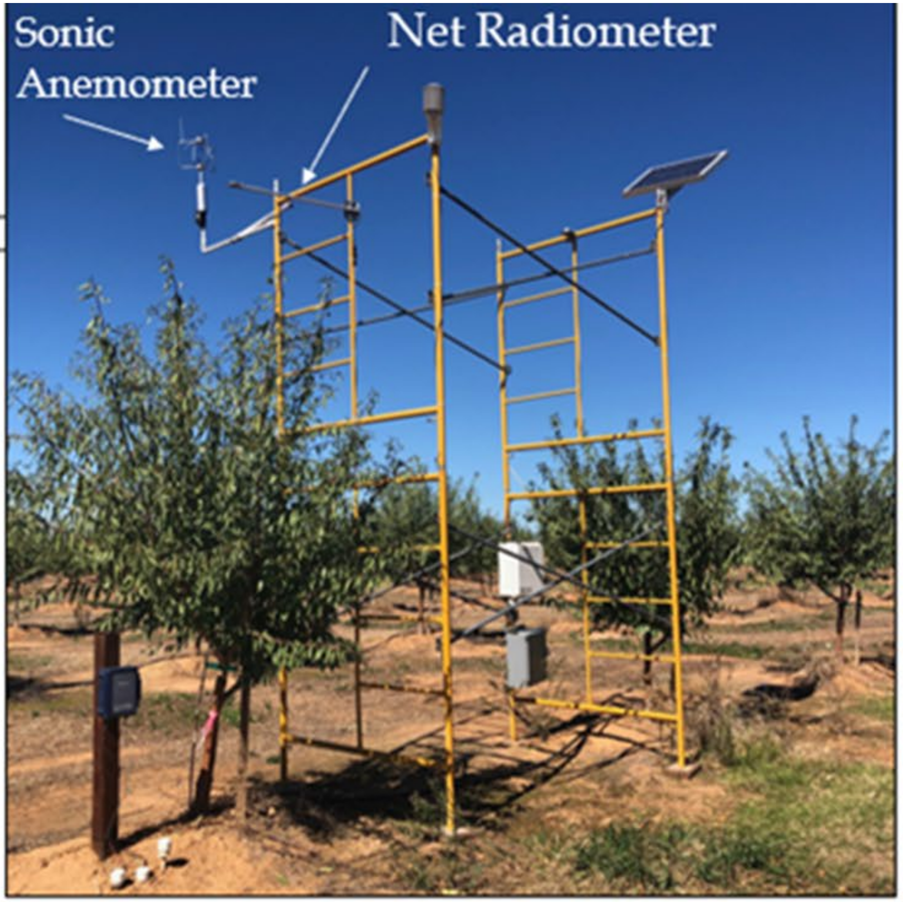
Quantifying water use of young almond orchards

1st Leaf Orchard

2nd Leaf Orchard

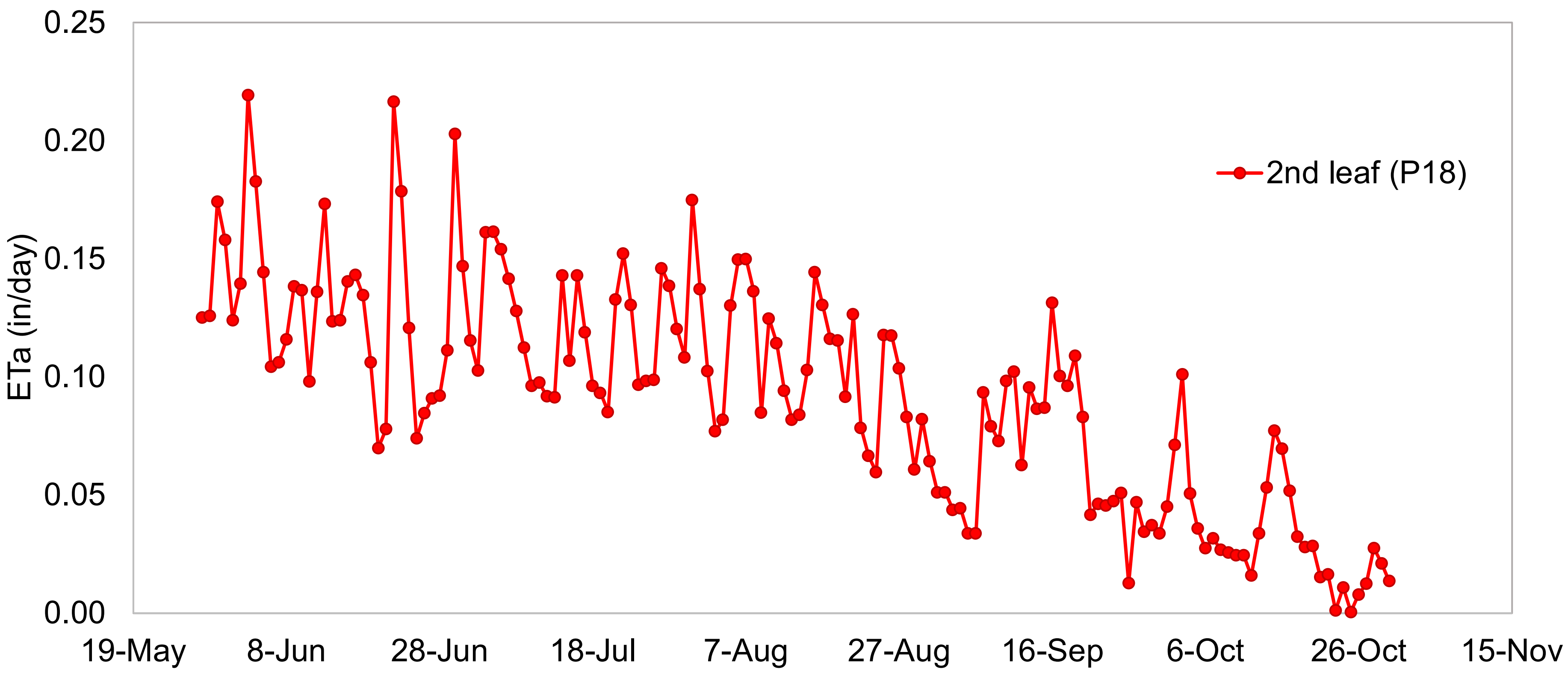
Field Site: Corning, CA



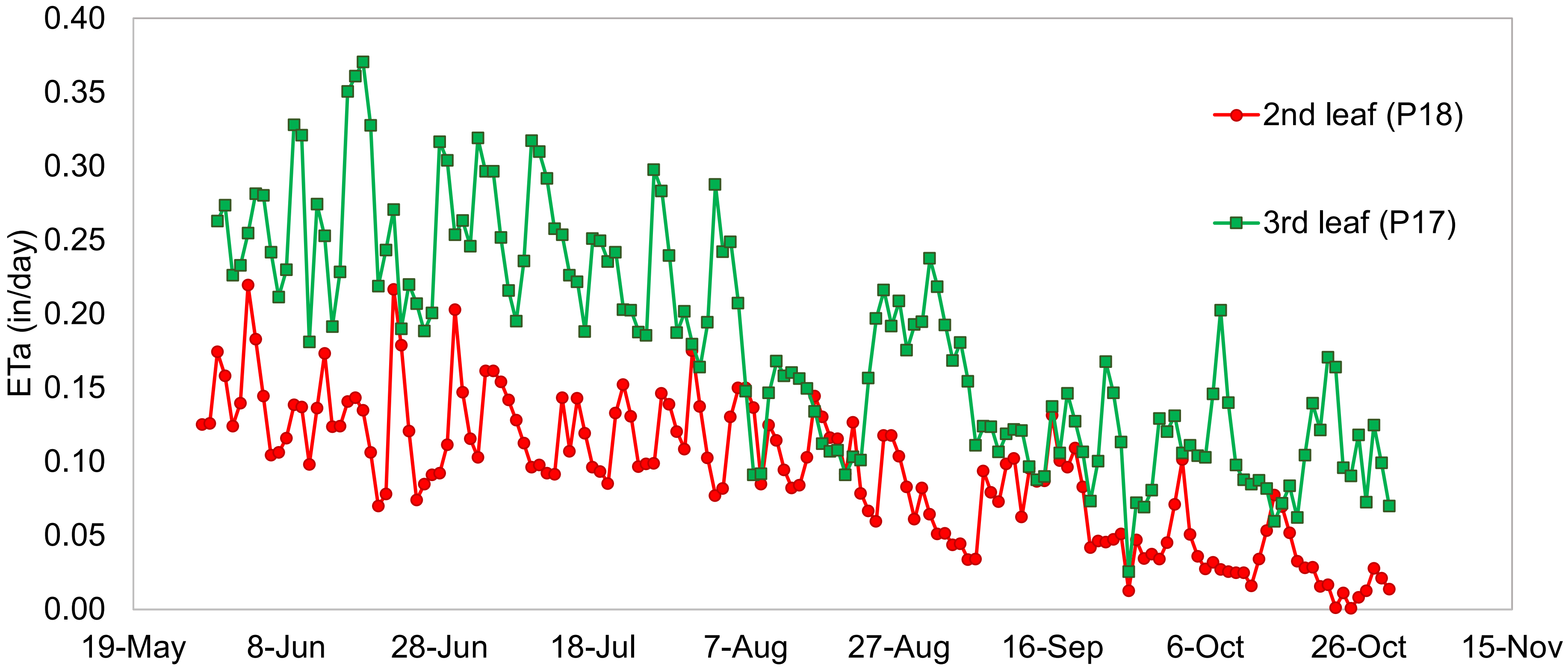


LE = Rn – H - G

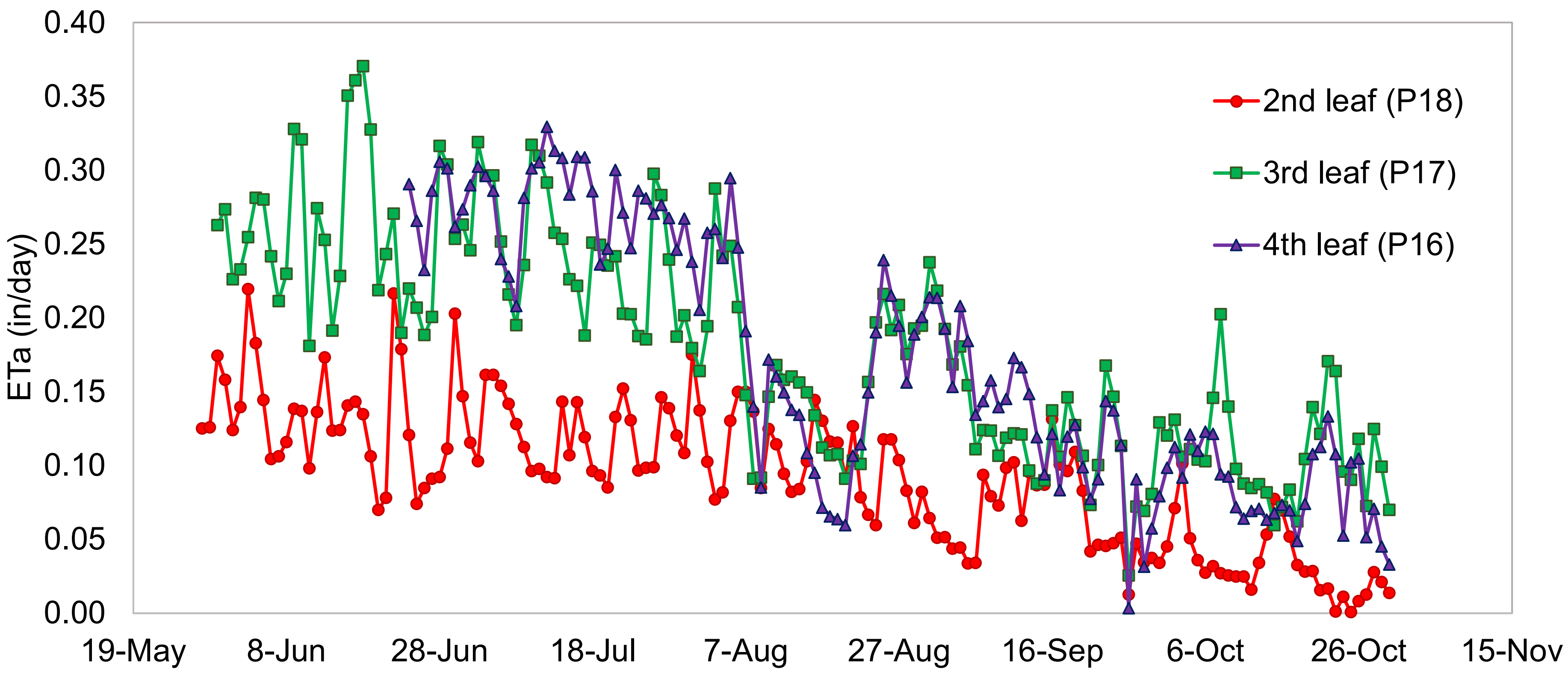
2019: Actual evapotranspiration in young almond orchards



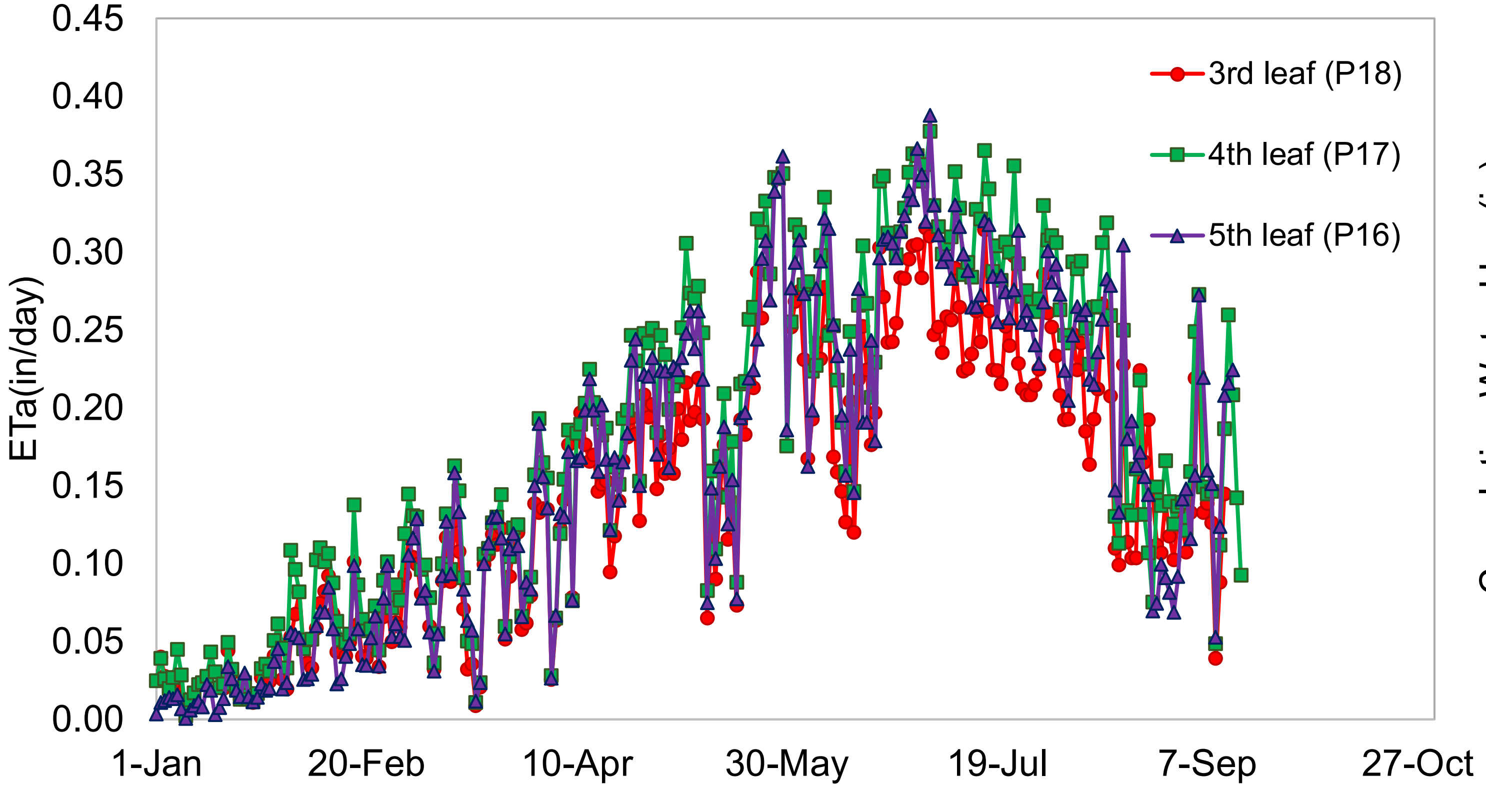
2019: Actual evapotranspiration in young almond orchards

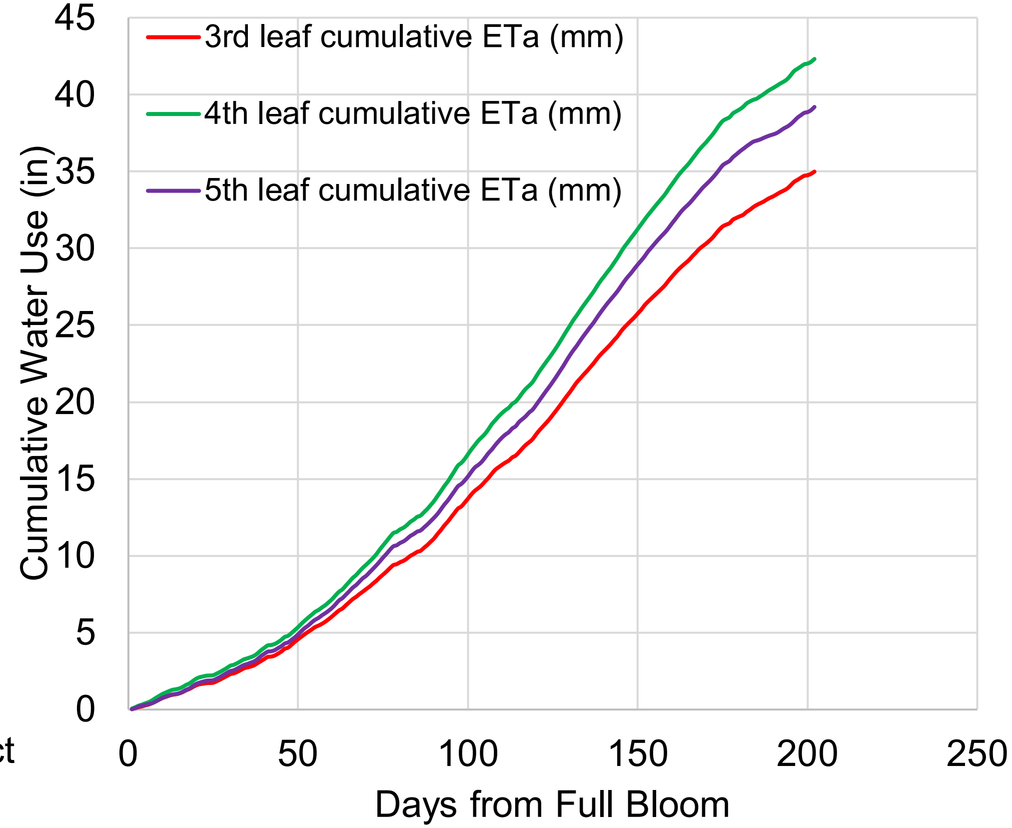


2019: Actual evapotranspiration in young almond orchards



2020: Actual evapotranspiration in young almond orchards





Most of the increase in evapotranspiration occurred during the first four years of plant growth

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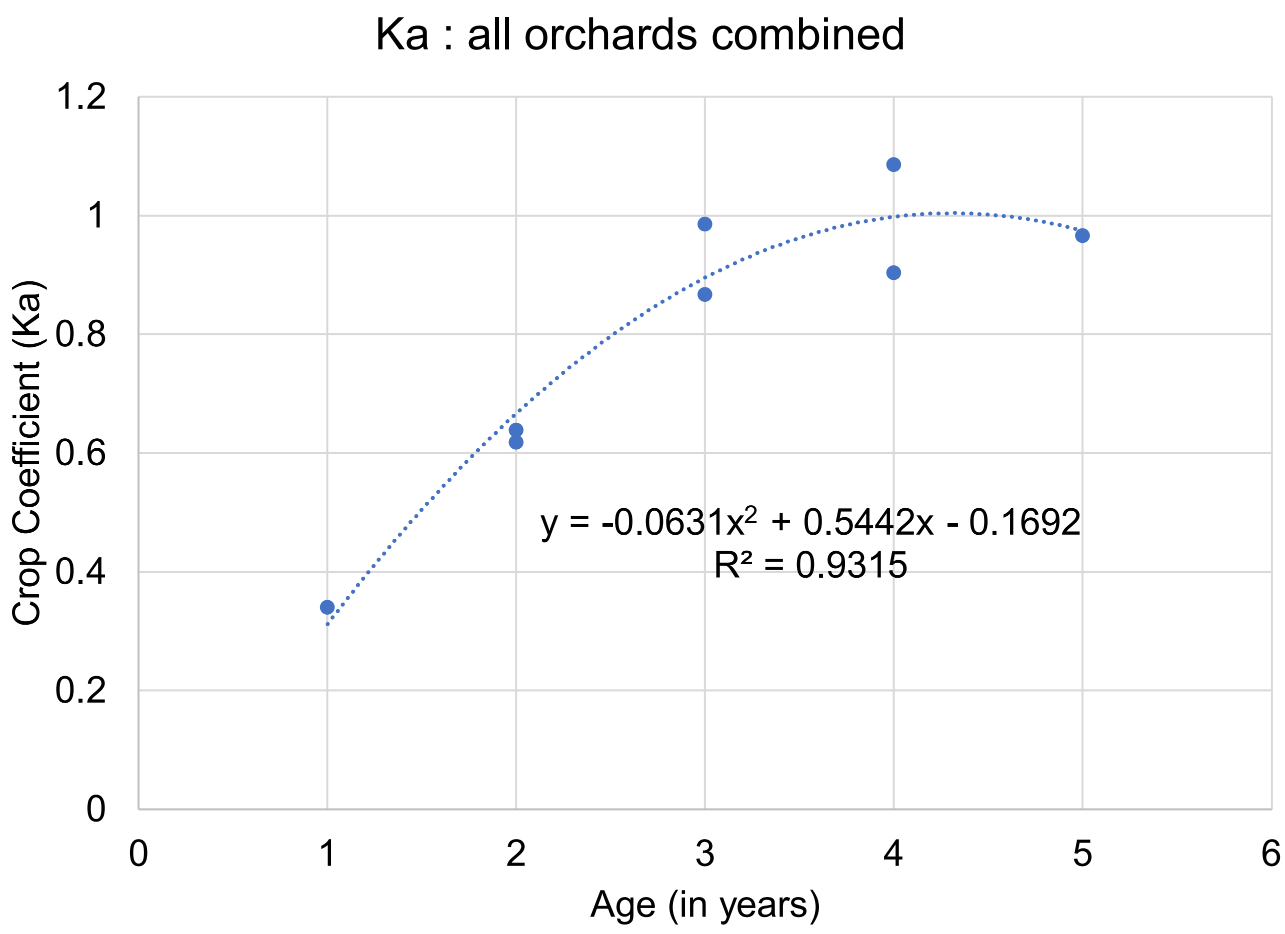
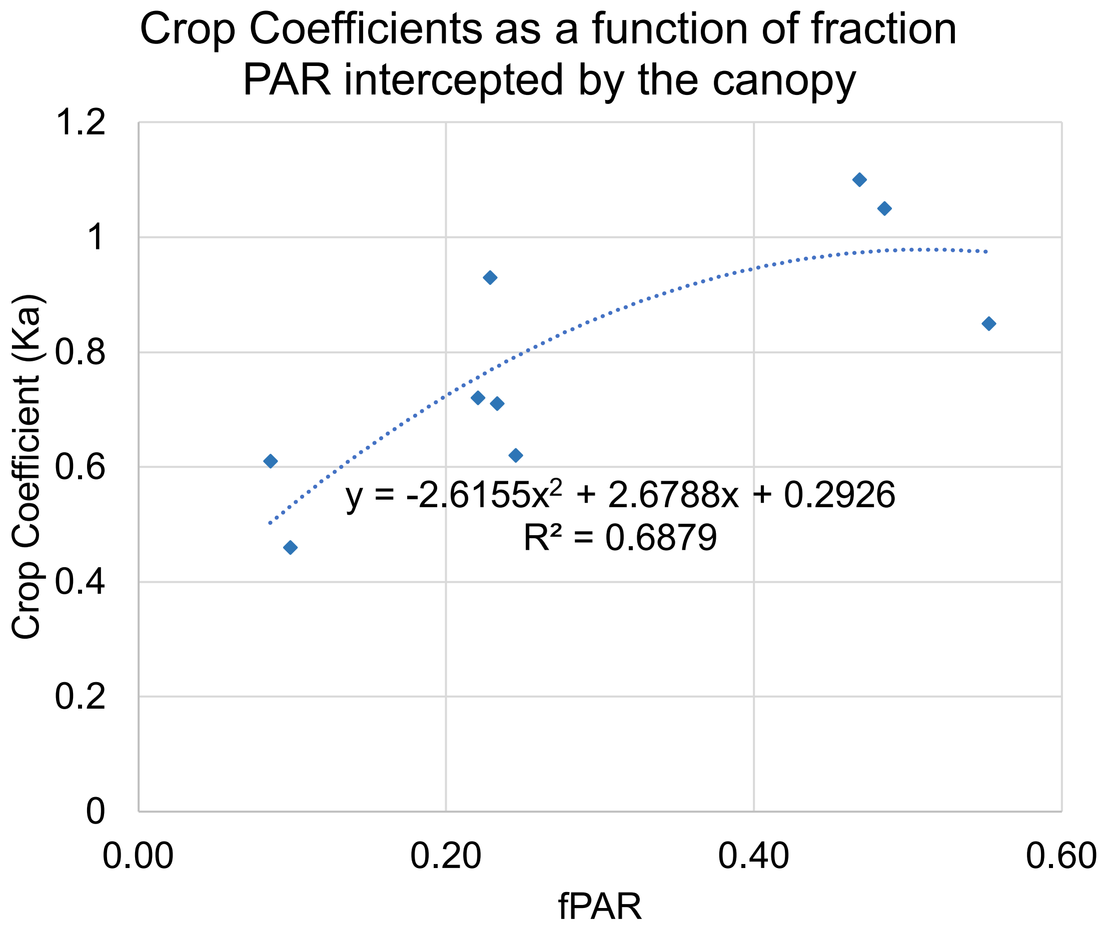
Young almond orchard crop coefficients

$$K_c = \frac{ET_c}{ET_o} = \frac{R_{n,c} - G_c - H_c}{\frac{\Delta(R_{nr} - G_r) + \rho c_p(e_z^0 - e_z)/r_{ar}}{\Delta + \gamma(1 + r_{sr}/r_{ar})}}$$

Symbol	Description
ET_c	Actual evapotranspiration of almond
ET_o	Reference evapotranspiration of a grass crop
K_c	Crop coefficient
H_c	Sensible heat flux density to the air of almond crop
$R_{n,c}$ and R_{nr}	Net incoming radiation of the almond crop and grass reference, respectively
G_c and G_r	Ground heat flux density of the almond crop and grass reference, respectively
r_{ar}	Aerodynamic resistance for reference grass crop
r_{sr}	Surface resistance for reference grass crop
Δ	Slope of the saturation vapor pressure/temperature curve
e_z^0	Saturation vapor pressure of air at height z
e_z	Vapor pressure of air at height z
γ	Psychometric constant
ρ	Density of air
c_p	Specific heat at constant pressure

Young almond orchard crop coefficients





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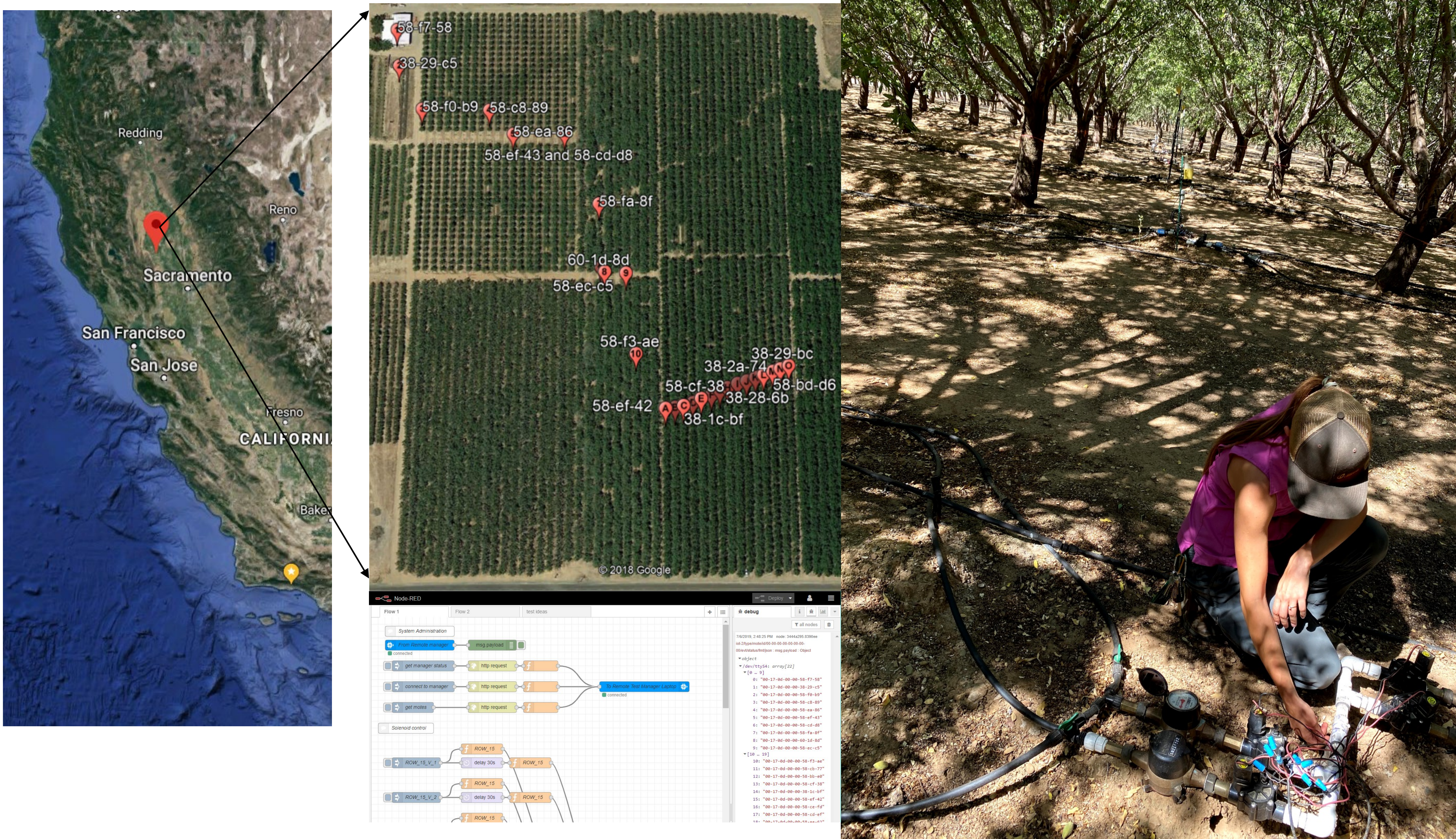
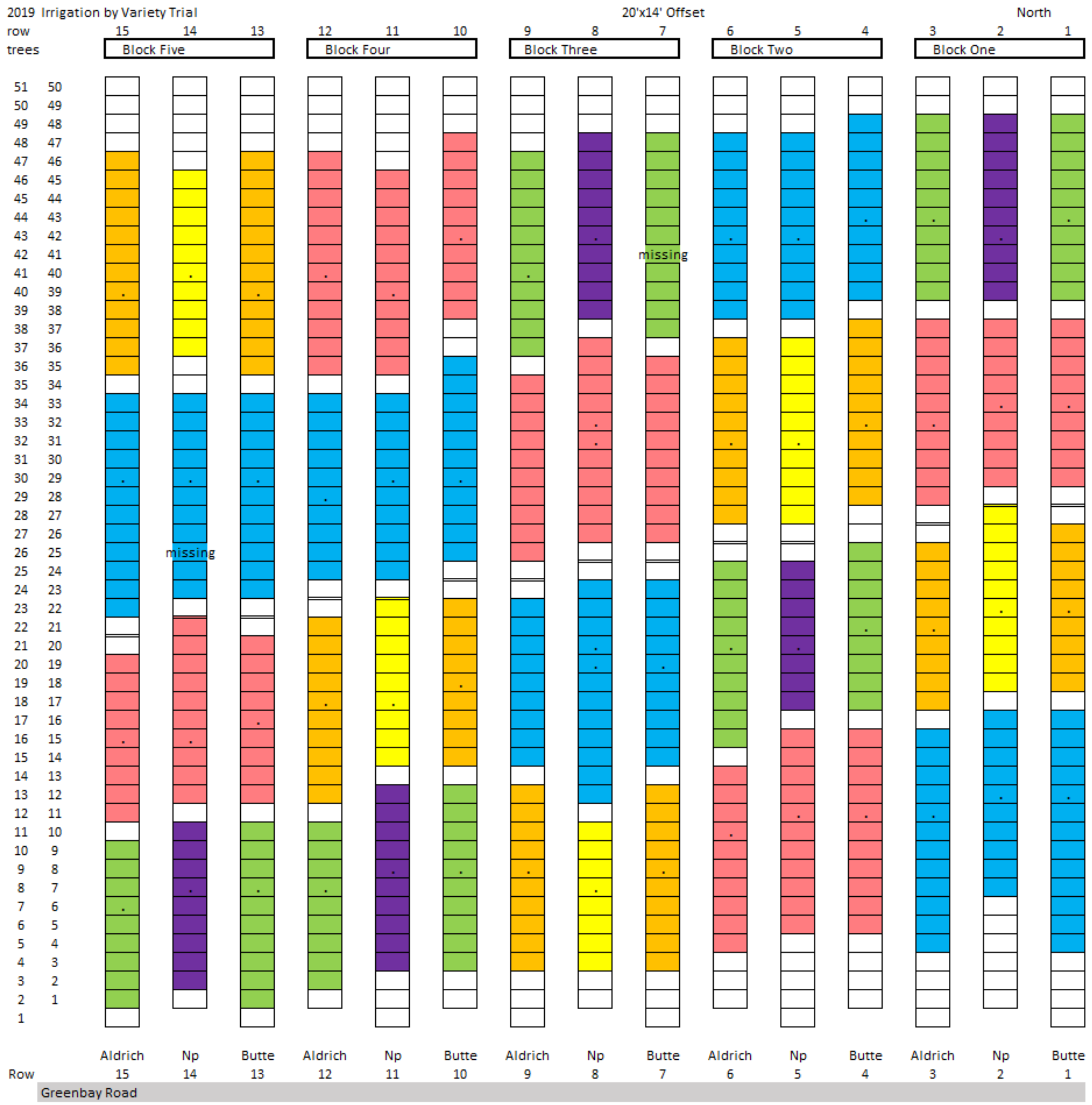
Site-specific Irrigation Management by Variety


Redding
Reno
Sacramento
San Francisco
San Jose
Fresno
CALIFORNI
Bake
58-f7-58
38-29-c5
58-f0-b9
58-c8-89
58-ea-86
58-ef-43 and 58-cd-d8
58-fa-8f
60-1d-8d
58-ec-c5
58-f3-ae
38-29-bc
38-2a-74
58-bd-d6
58-cf-38
38-28-6b
58-ef-42
38-1c-bf
© 2018 Google
Node-RED
Deploy
Flow 1
Flow 2
test ideas
debug
System Administration
From Remote manager
msg.payload
get manager status
http request
connect to manager
To Remote Test Manager Laptop
get motes
Solenoid control
ROW_15
delay 30s
ROW_15_V_1
ROW_15_V_2

Experimental Design

2019	Overall Treatment
S1	100-75-100% ET based on nonpareil growth stages (in all varieties)
S1	100-75-100% ET based on variety-specific growth stages (in all varieties)
S3	100-50-100% ET based on nonpareil growth stages (in all varieties)
S4	100-50-100% ET based on variety-specific growth stages (in all varieties)
S5	100-100-100% ET based on nonpareil growth stages (in nonpareil only) with single dripline during harvest season
S6	100-100-100% ET based on nonpareil growth stages (in nonpareil only) with double dripline during harvest season

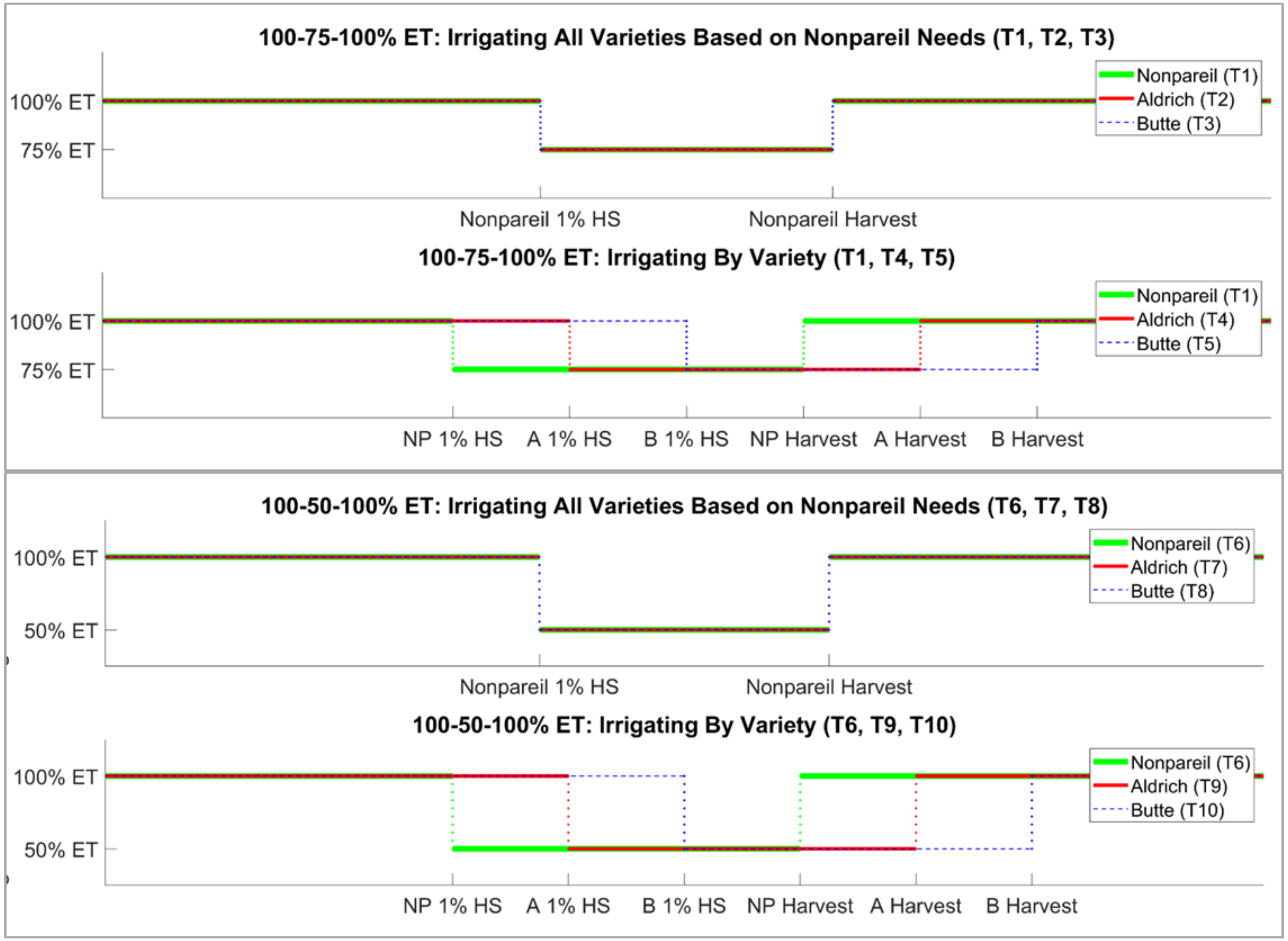


Site-specific irrigation management by variety

Compare the effects of:

(1) irrigating according to Nonpareil hull-split timing

(2) irrigating according to variety specific hull-split timing



Site-specific irrigation management by variety

Total Yield Per Acre									
Year	**Variety**	**Overall Treatment**	**Number of Observations**	**Mean**	**Standard Deviation**	**N**			
2019	A	S1	5	1503	376	5	a		
		S2	5	1433	358	5	a		
		S3	5	1352	338	5	a		
		S4	5	1419	355	5	a		
	B	S1	5	2677	669	5		b	c
		S2	5	2482	620	5		b	
		S3	5	2431	608	5		b	
		S4	5	2373	593	5		b	
	N	S1	5	2820	705	5		b	c
		S2	5	2820	705	5		b	c
		S3	5	2687	672	5		b	c
		S4	5	2687	672	5		b	c
		S5	5	3048	762	5			c
		S6	5	2844	711	5		b	c

- A: Aldrich
- B: Butte
- N: Nonpareil

Treatments with the same letters are not significantly different

Site-specific irrigation management by variety

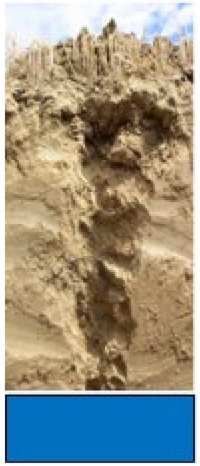
Total Yield Per Acre										
Year	**Variety**	**Overall Treatment**	**Number of Observations**	**Mean**	**Standard Deviation**	**N**				
2020	A	S1	5	3122	780	5	d		f	g
		S2	5	3126	782	5	d		f	g
		S3	5	2954	739	5	d			g
		S4	5	3233	808	5	d		f	
	B	S1	5	2617	654	4		e		g
		S2	5	2394	598	5		e		
		S3	5	2355	589	5		e		
		S4	5	2238	559	4		e		
	N	S1	5	3477	869	5	d		f	
		S2	5	3477	869	5	d		f	
		S3	5	3335	834	5	d		f	
		S4	5	3335	834	5	d		f	
		S5	5	3512	878	5			f	
		S6	5	3506	877	5			f	

- A: Aldrich
- B: Butte
- N: Nonpareil

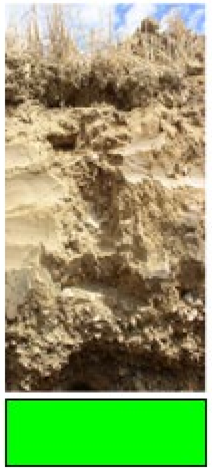
Treatments with the same letters are not significantly different

Zone Irrigation Management based on Soil Type

Site-specific irrigation management by soil type

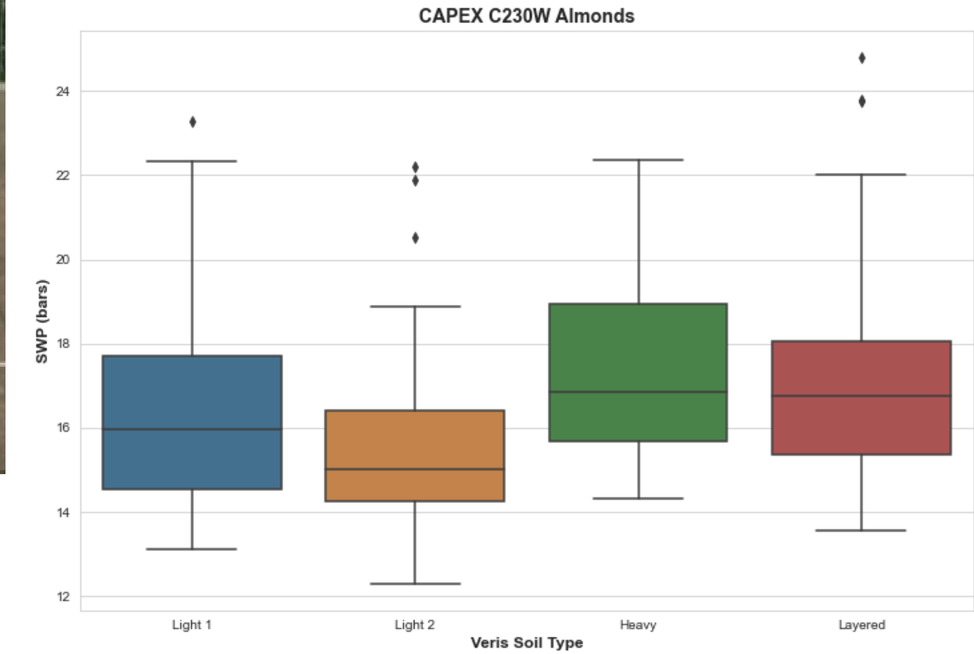


Heavy soil irrigation zone

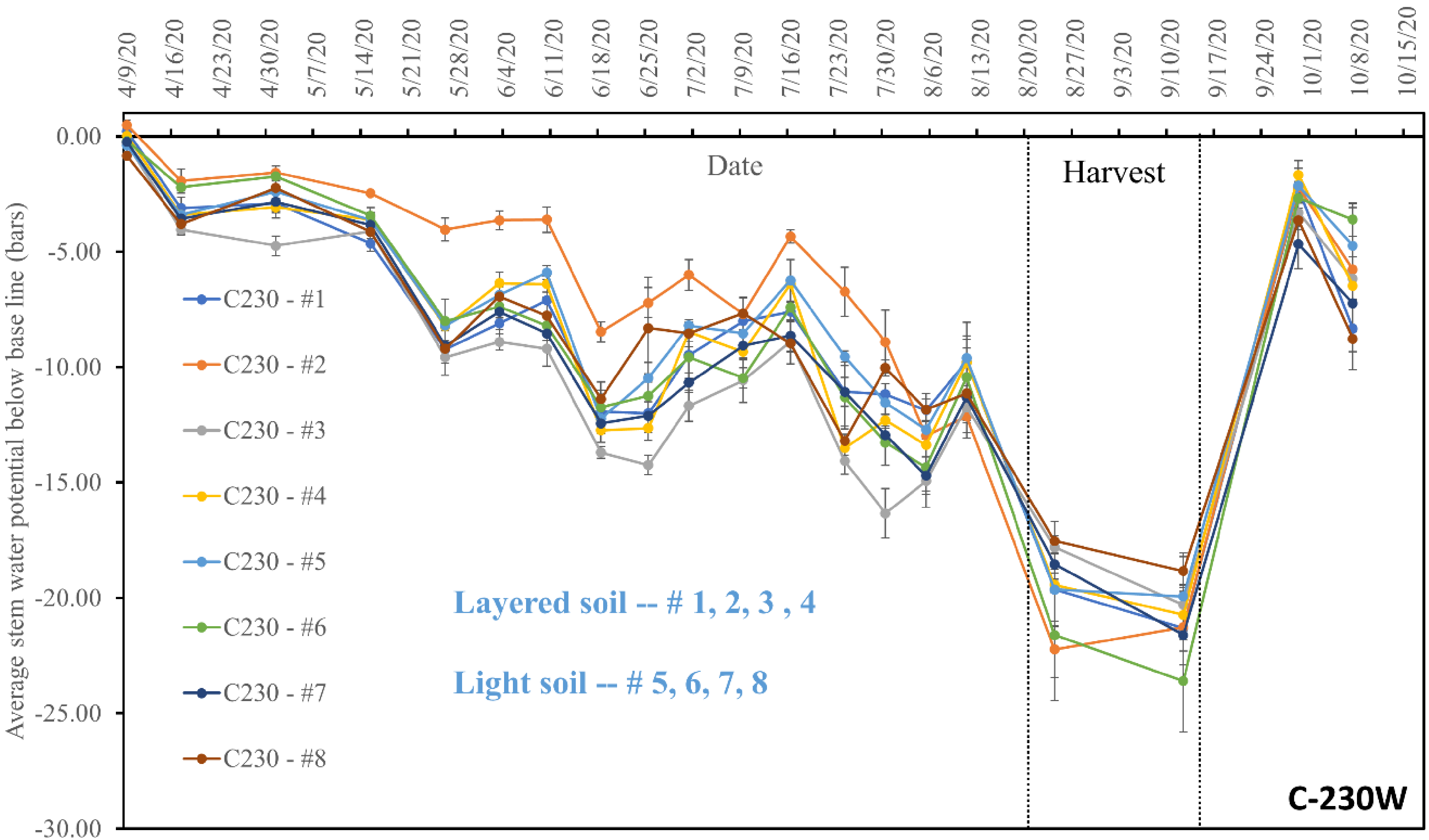


Layered soil irrigation zone

Light soil irrigation zone



Effect of soil type on tree stem water potential in block C-230 at CAPEX



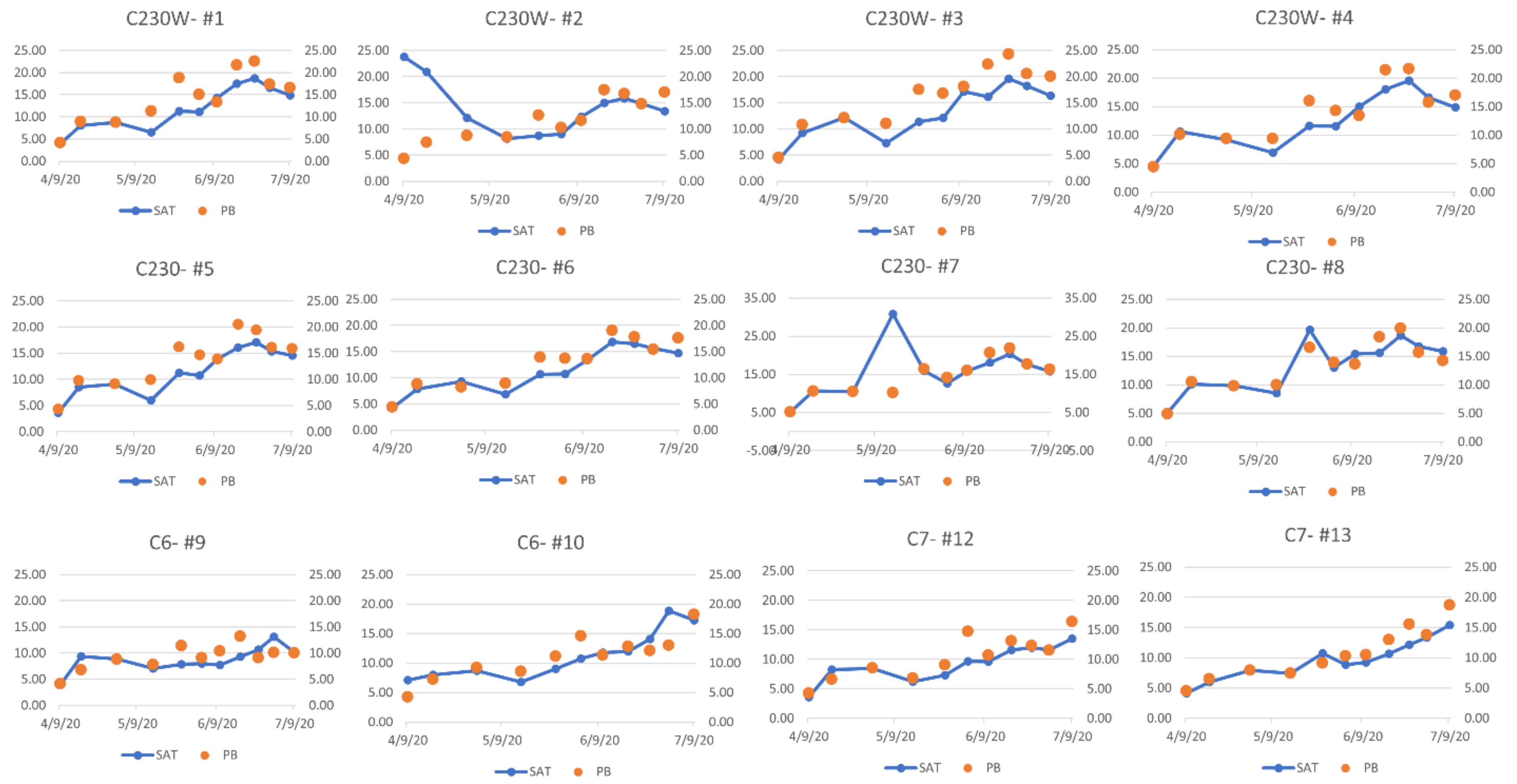
Emerging Soil and Plant Water Status Sensing Technologies for Data-driven Smart Irrigation Management in Almonds

Promising irrigation scheduling technologies in almonds

Large area cosmic ray soil moisture sensing

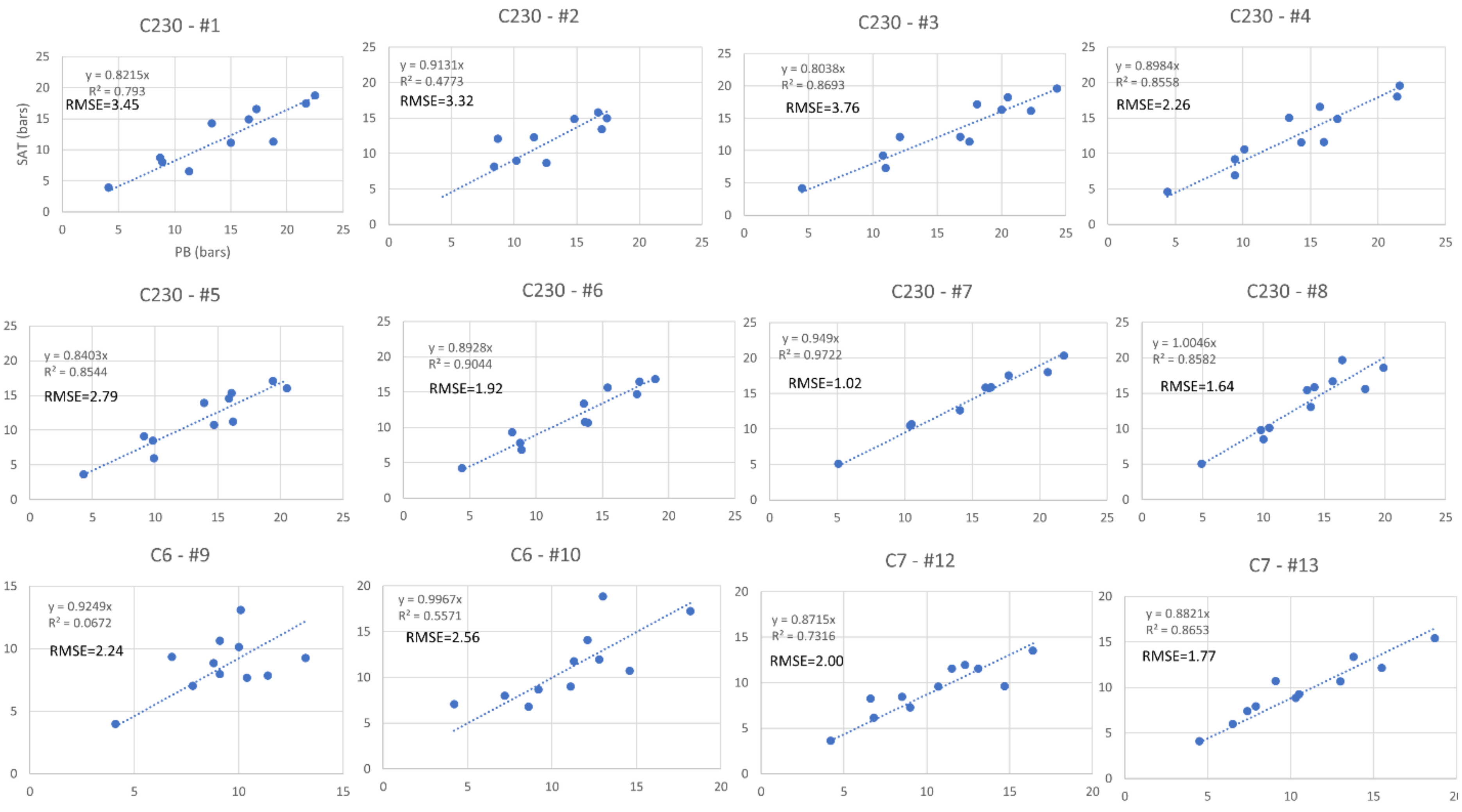
Automated micro-tensiometer for measuring stem water potential

Automated stem water potential monitoring



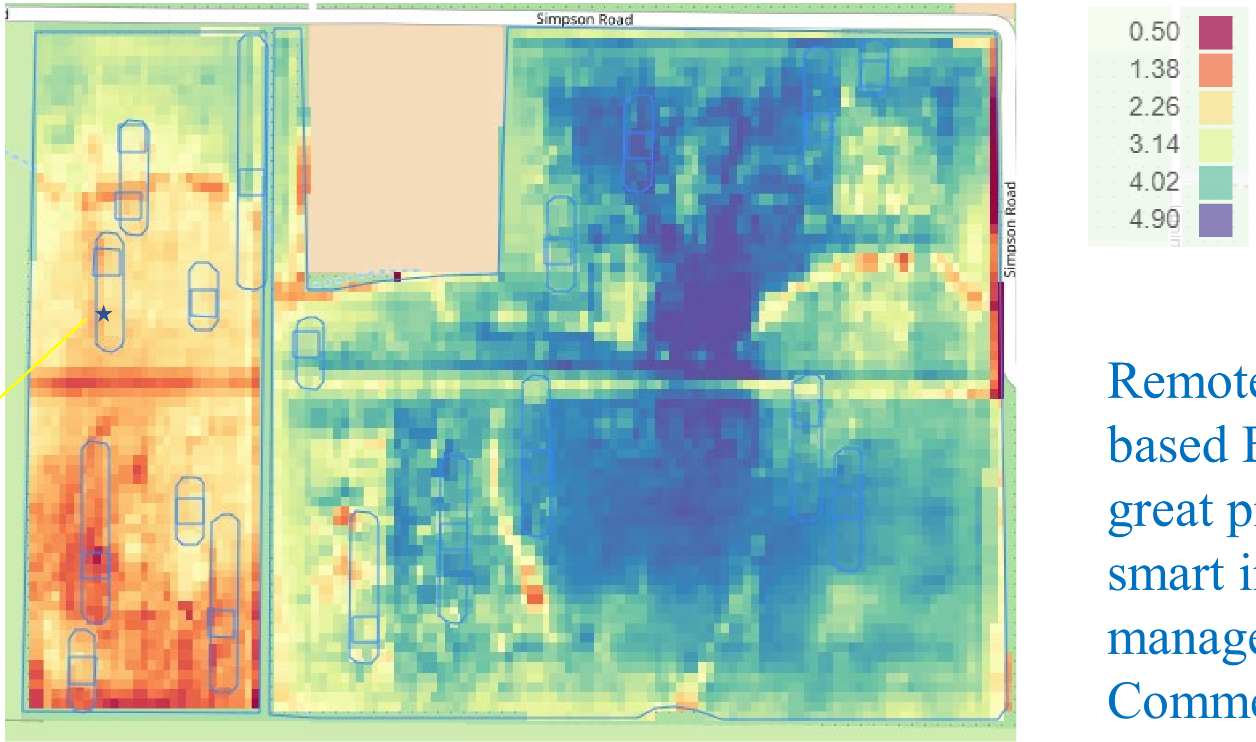
Comparing pressure bomb versus calibrated Saturas micro-tensiometer

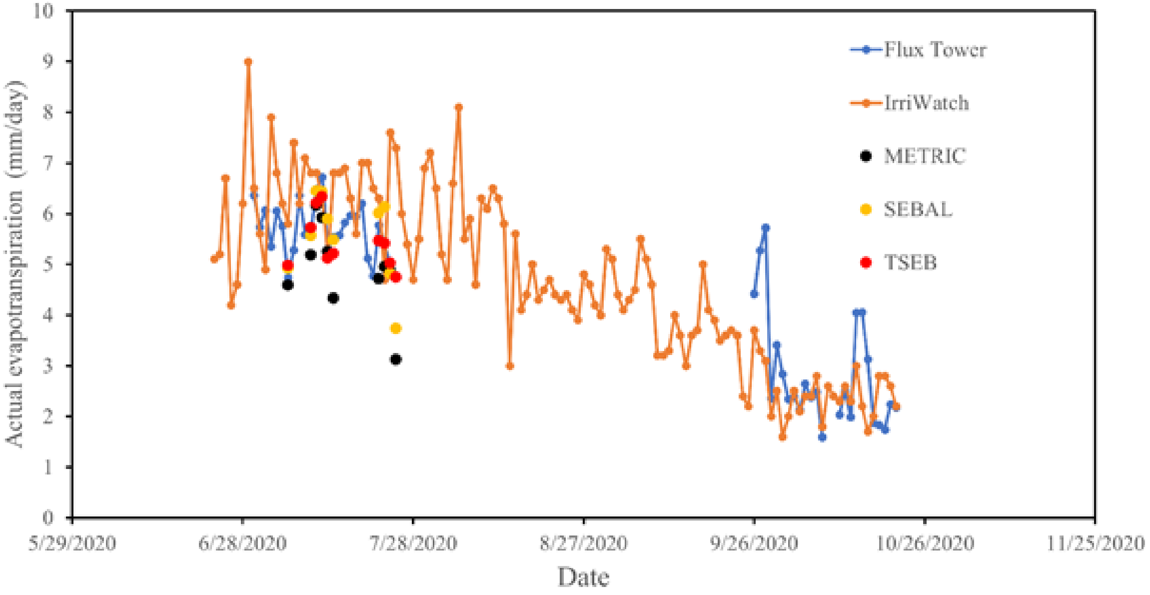
Evaluating performance of micro-tensiometers against pressure chamber



After calibration micro-tensiometers show good correlation with pressure chamber

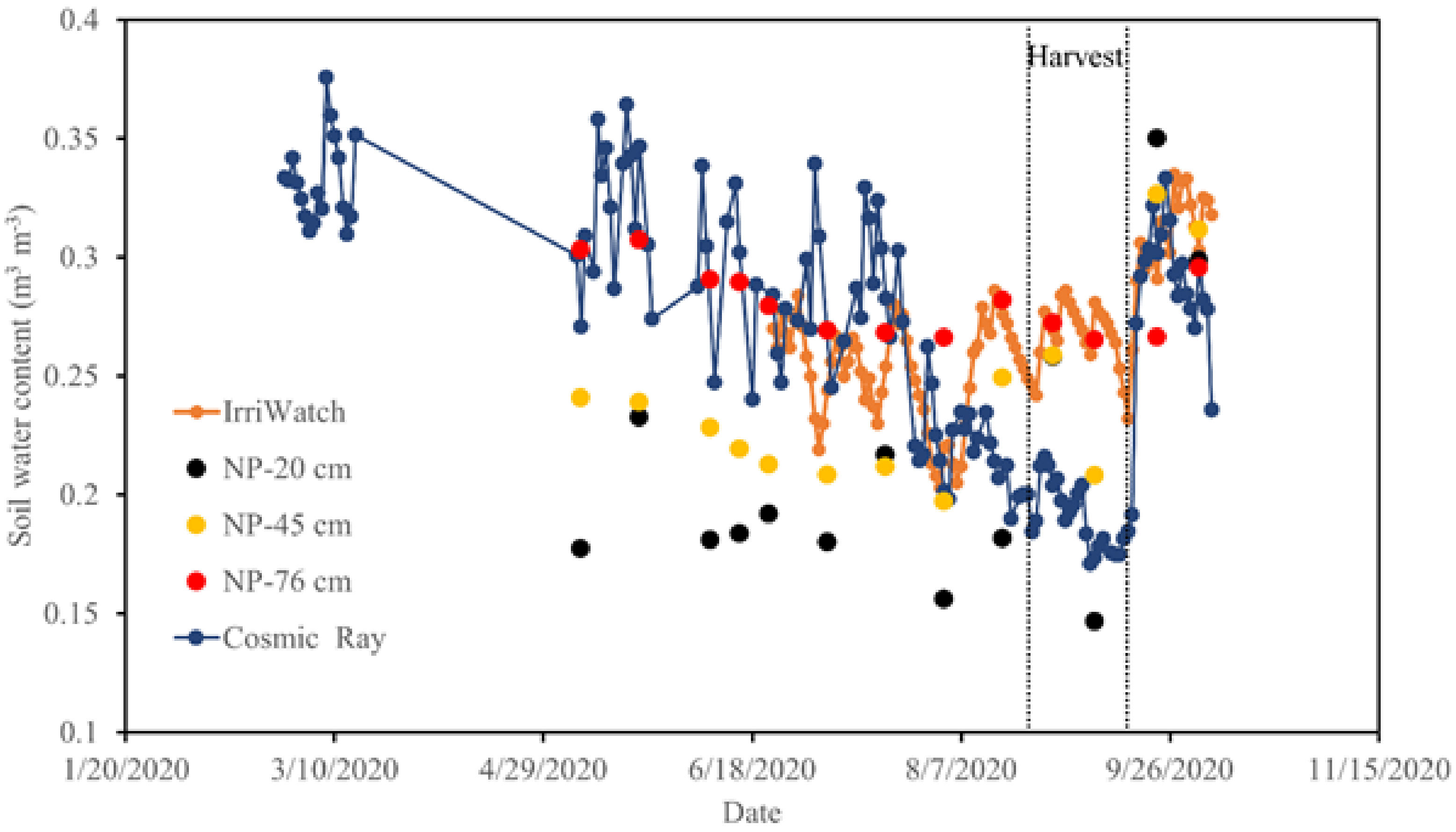
Eddy Covariance flux tower for validation of remote sensing ET





Remote sensing based ET shows great promise for smart irrigation management. Commercially available (e.g., https://www.irriwatch.com/en/ , https://jainsusa.com/monitoring-control/jain-logic/agralogics/)

Orchard scale proximal soil moisture sensing using cosmic ray neutron probe



Cosmic ray neutron probe provides areal averaged soil moisture in the top 2 to 3 ft of the soil profile for an area ~ 30 to 50 acres.

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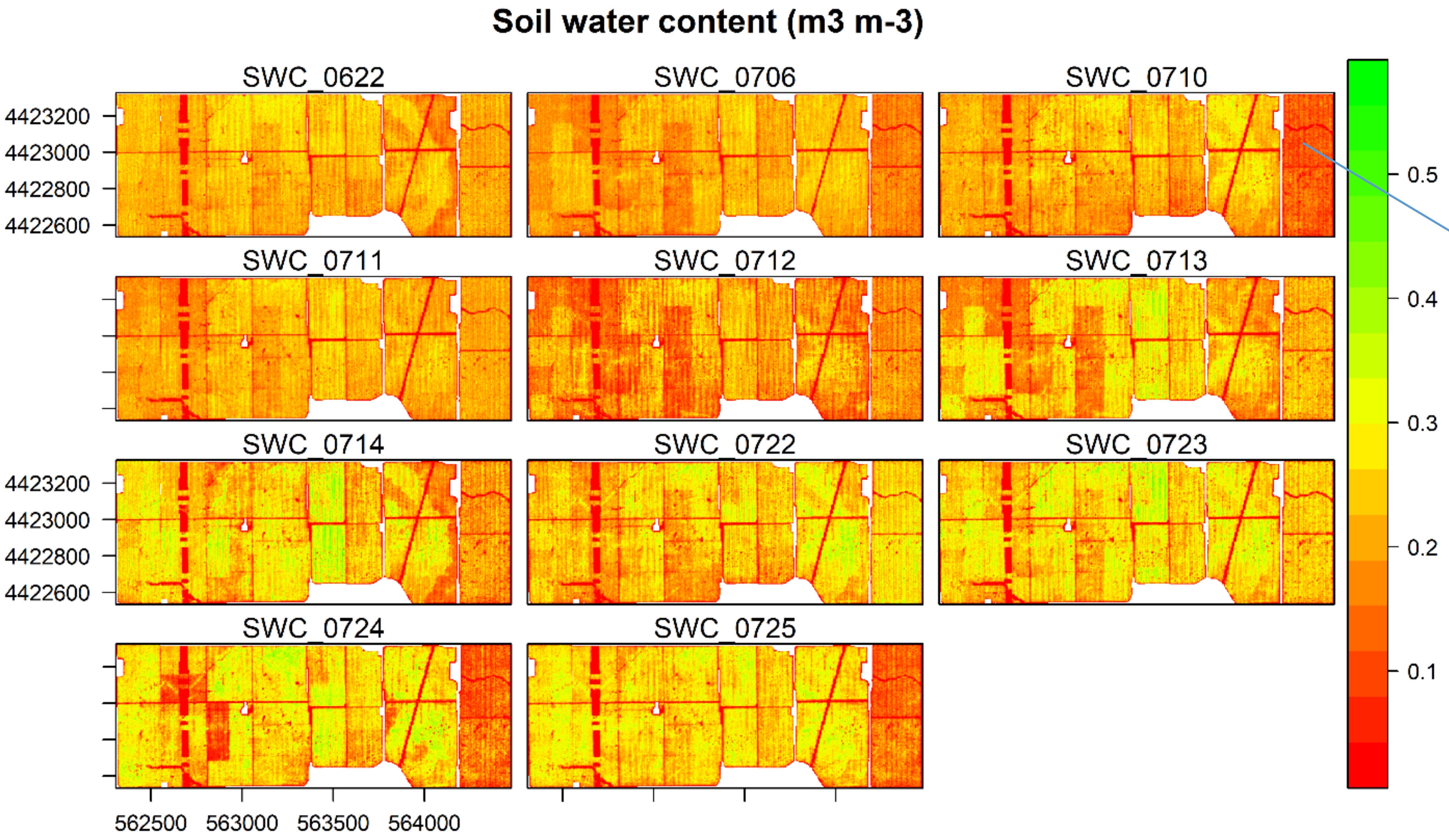
Combining high resolution soil water maps (derived from ceres images) with ground based wireless soil water sensing



Wireless soil water sensing

Thank You

Acknowledgements

- Kelley Marie Drechsler
- Srinivasa Rao Peddinti
- Allan Fulton
- Iael Hoffman
- Franz Niederholzer
- Umair Gull
- Ryan Fulton
- Floyid Nicolas
- Usama Al-Dughaishi
- Samuel Metcalf
- Esteve Ranch
- Nickels Soil Lab

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