The NASA Satellite Irrigation Management Support (SIMS) System:

Applications of satellite data to support improvements in irrigation management in California

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Overview

Why is NASA involved in ET mapping?

What is the Satellite Irrigation Management Support (SIMS) system?

How does SIMS work?

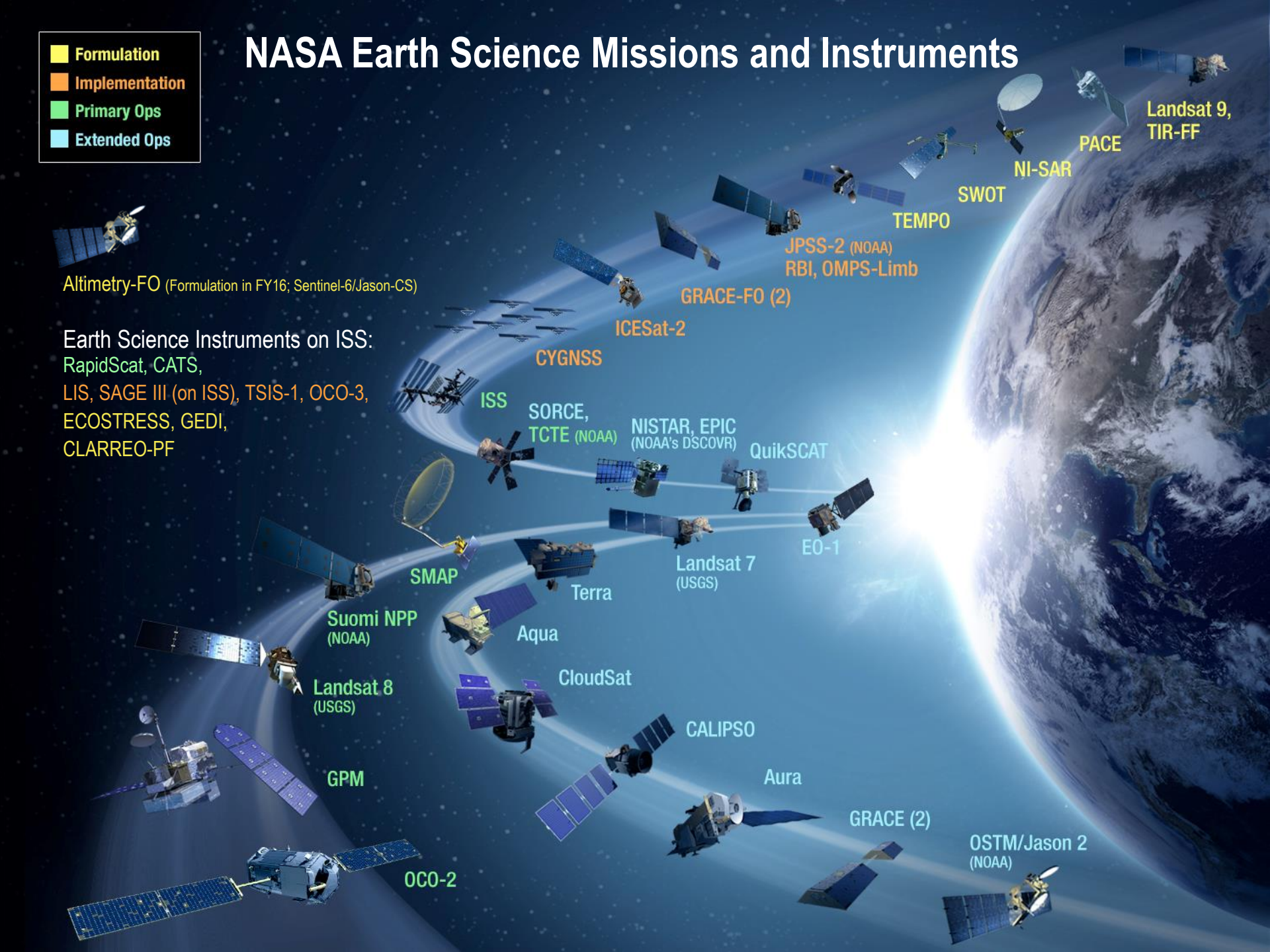
How accurate is SIMS?

Accessing Data from SIMS

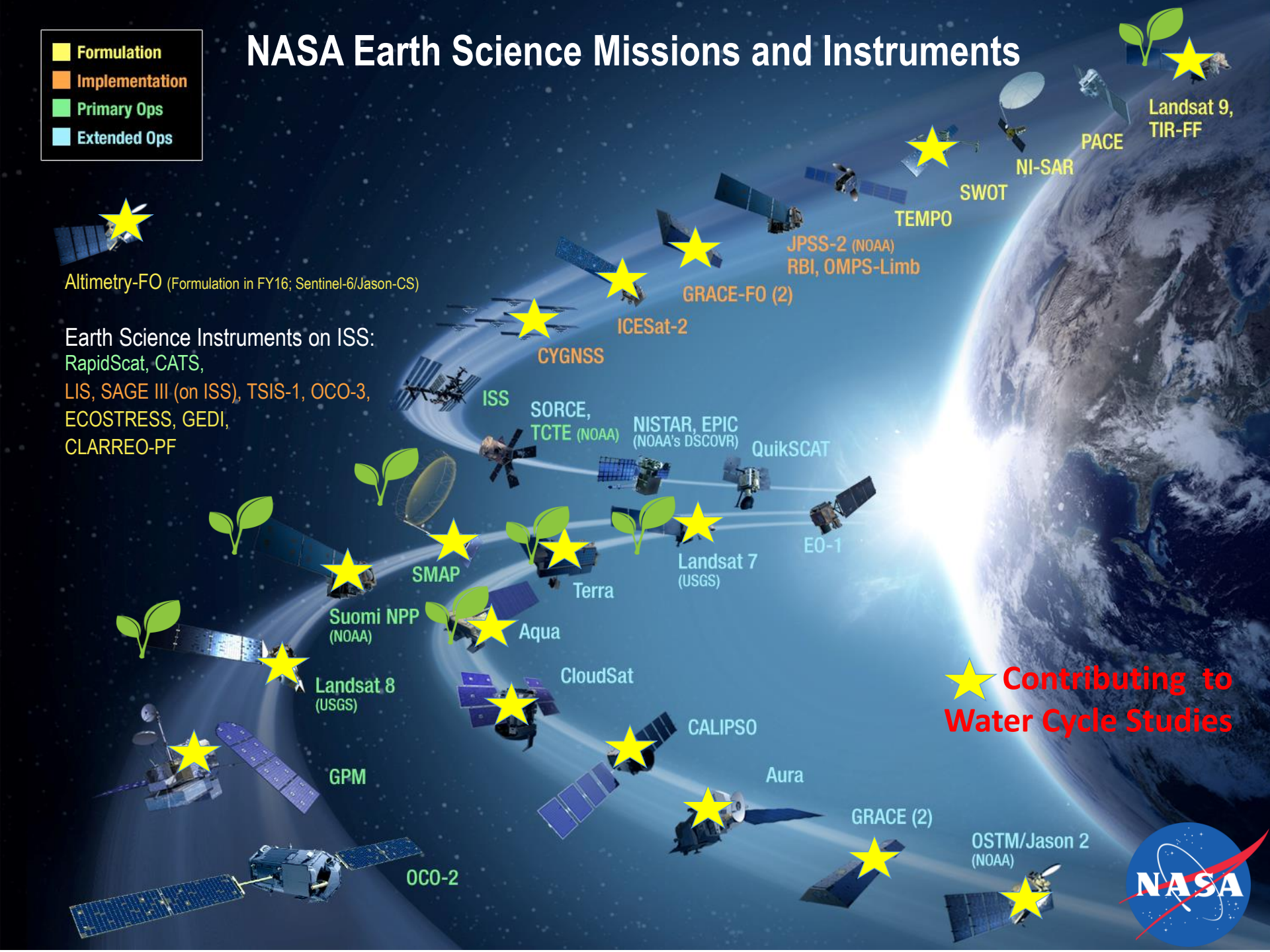
SIMS 2.0

OpenET

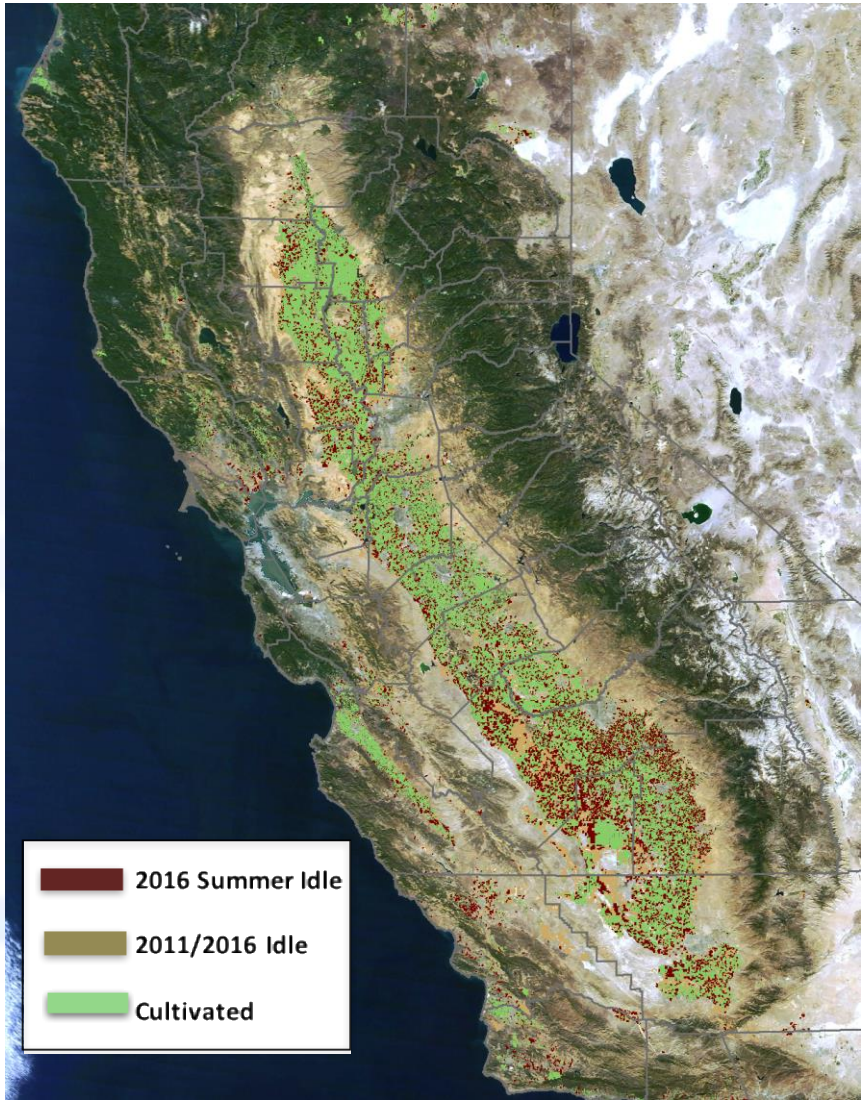
NASA Earth Science Missions and Instruments



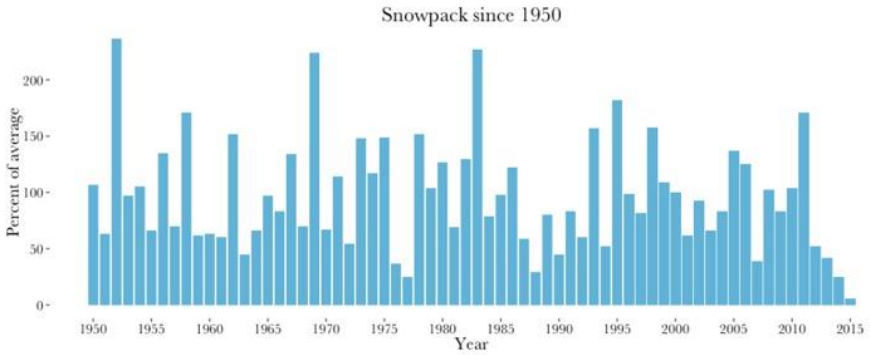
NASA Earth Science Missions and Instruments



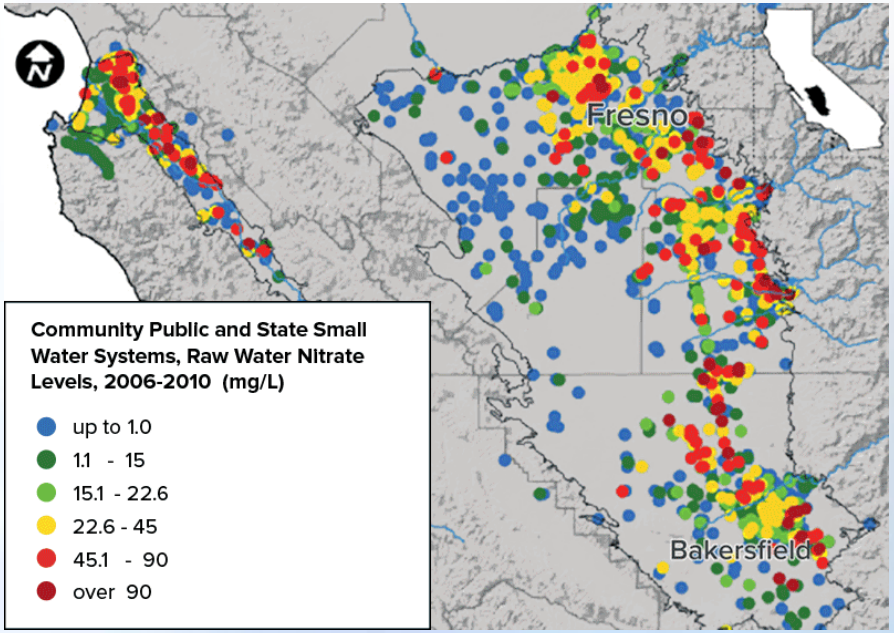
Threats to Water Supplies and Water Quality in California



Source: CDWR



Source: CDWR



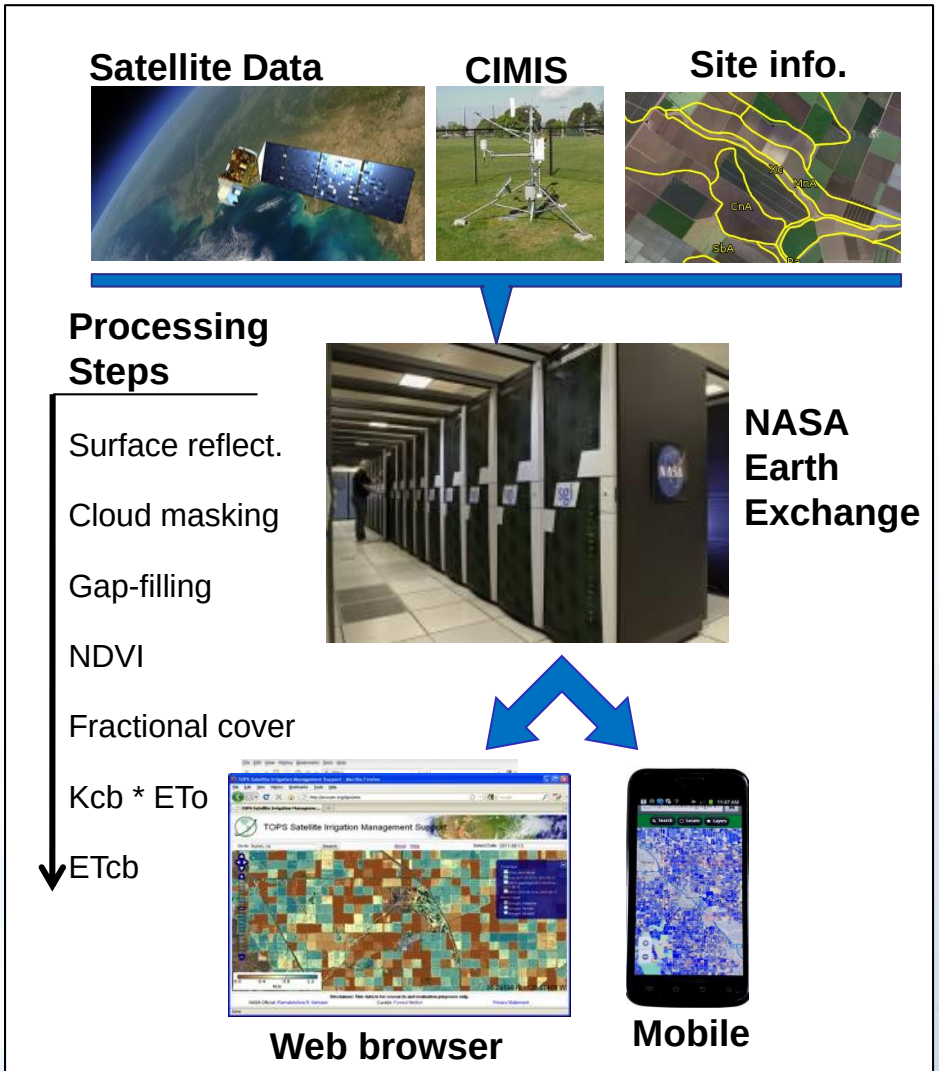
Source: UC Davis

Satellite Irrigation Management Support (SIMS)

Objective: *Increase the utility of satellite data for irrigation scheduling and evaluation of on-farm water use efficiency by growers/irrigators.*

Requirements:

- Field scale
- Cost effective
- 10+ year baseline
- Known accuracy
- Timely
- Open data
- Data continuity is critical



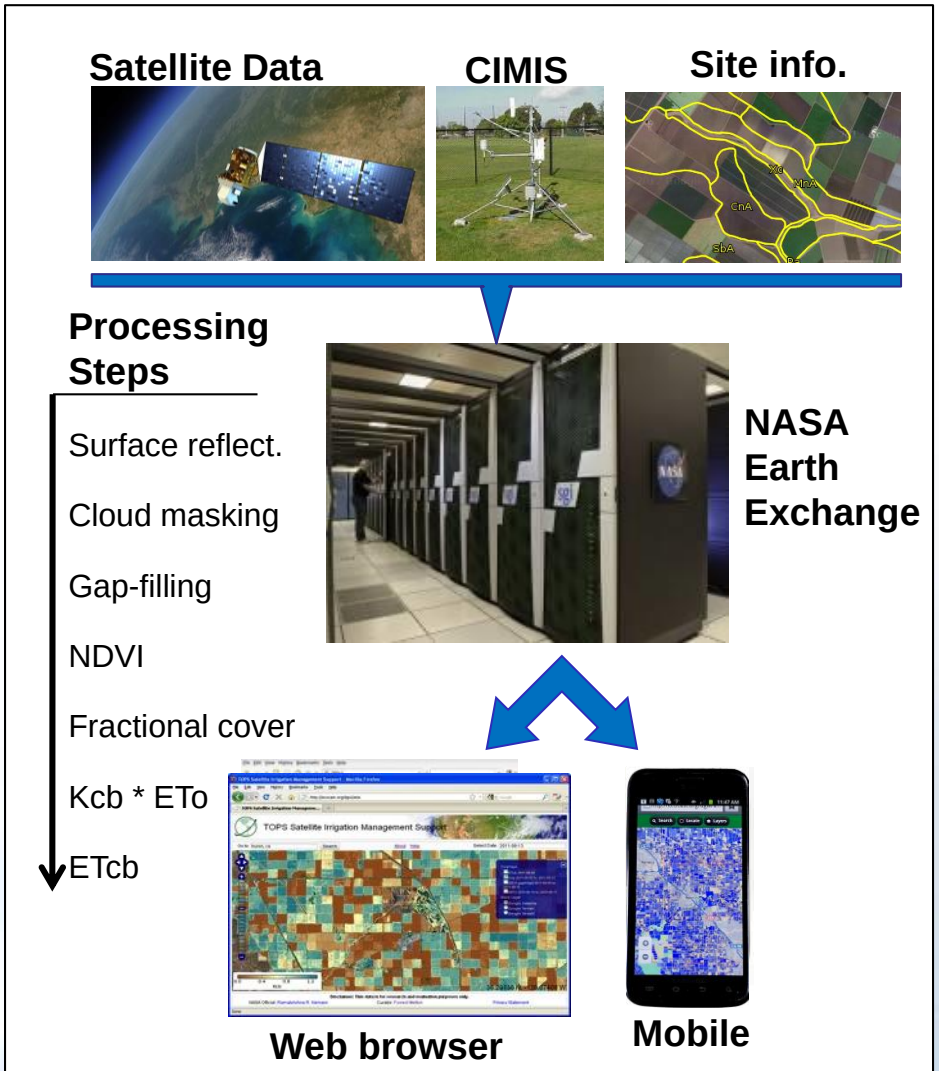
Melton et al., 2012, IEEE JSTARS

Satellite Irrigation Management Support (SIMS)

Objective: *Increase the utility of satellite data for irrigation scheduling and evaluation of on-farm water use efficiency by growers/irrigators.*

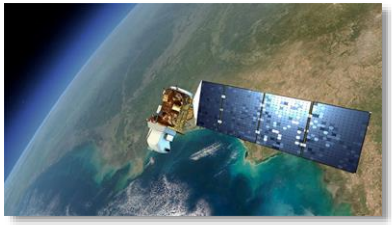
Applications:

- Irrigation scheduling and management
- Calculation of water use efficiency metrics
- Compliance monitoring for water transfer agreements
- ET mapping



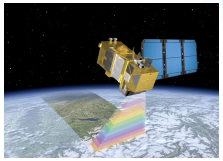
Melton et al., 2012, IEEE JSTARS

California Irrigation Management Information System

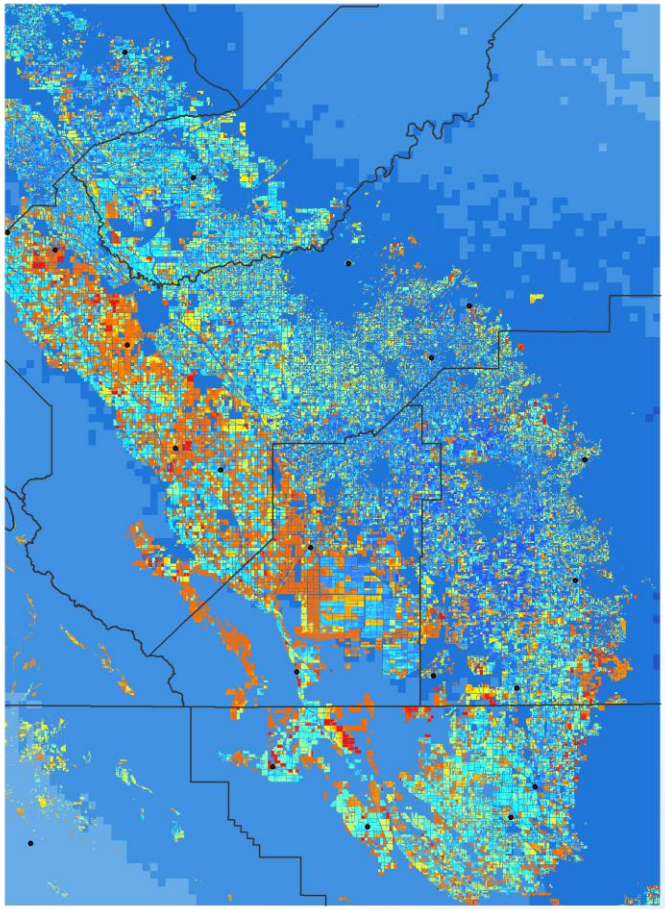


Landsat 5/7/8

MODIS,Terra & Aqua



ESA Sentinel-2A/2B



CIMIS Station

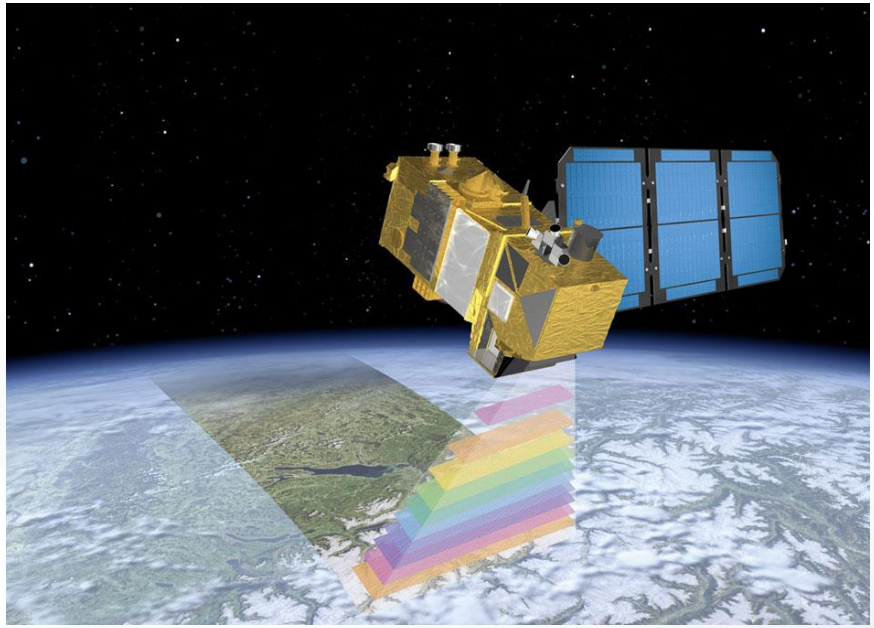
Spatial CIMIS ET_0 (mm)

0 14

SIMS ET_{cb} (mm)

0 10

Satellite Data



Landsat 5/7/8 (TM / ETM+ / OLI)
30m / 0.25 acres
Overpass every 8-16 days

Sentinel-2A and 2B
20m / 0.1 acres
Overpass every 5-10 days

Approach: Combining CIMIS and Satellite Data

$$ET_{cb} = ET_o * K_{cb}$$

CIMIS (CoAgMet, AgriMet, AZMET)

satellite

Standard K_c Profile (manual)

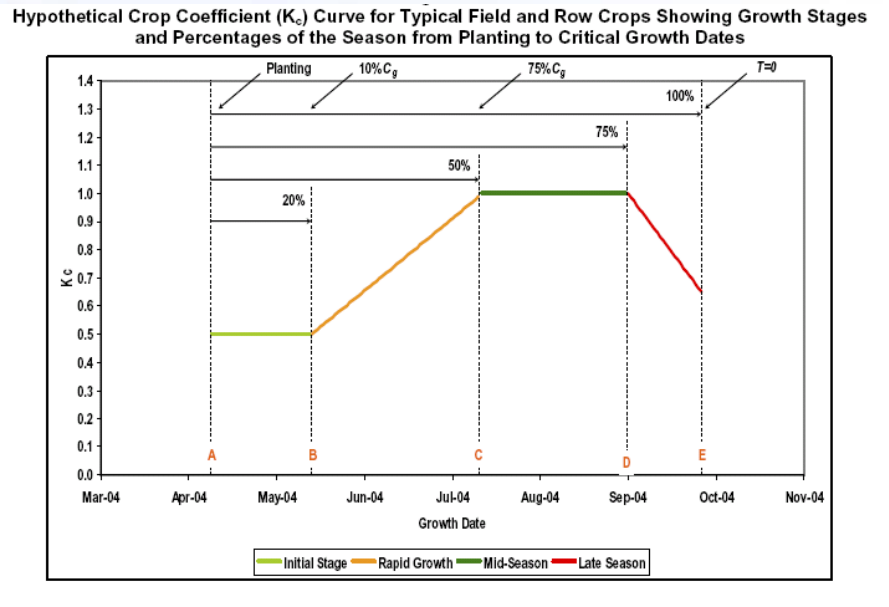
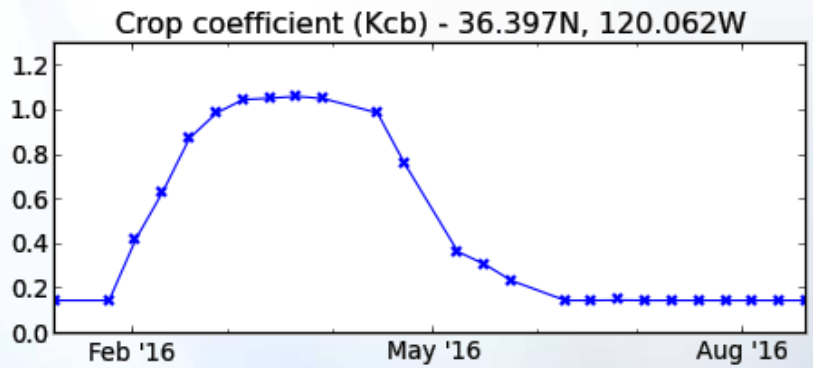


Figure credit: 2005 California Water Plan Update

SIMS K_{cb} Profile (Automated, Satellite-derived)



K_c profiles via reflectance based algorithms (K_{cb})

SIMS Approach

Step 1:
NDVI → Fractional Cover (F_c)

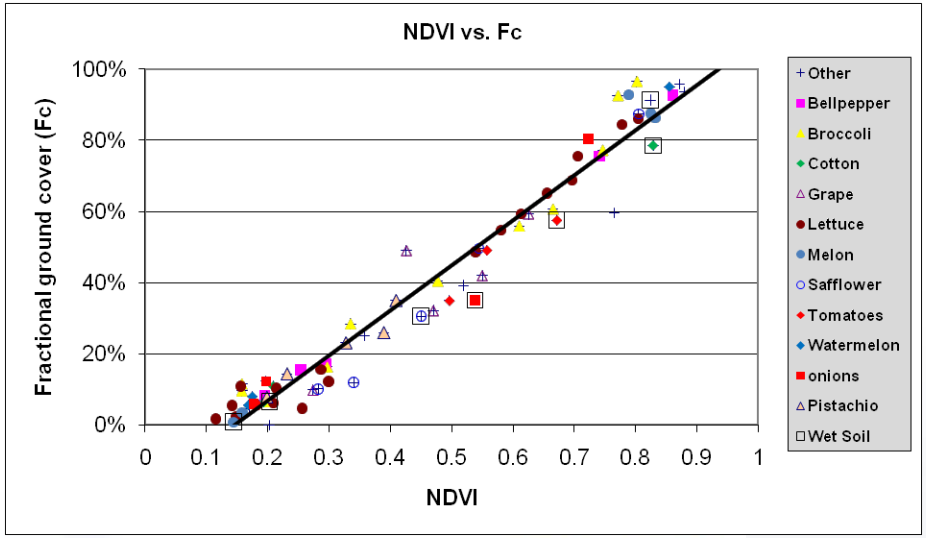
- Based on studies by Trout et al., 2008; Johnson et al., 2012

Step 2:
F_c → K_d → K_{cb}

- Allen and Pereira, 2009 / ASCE Manual 70; (also Bryla et al., 2010; Grattan et al., 1998; Hanson & May, 2006; Lopez-Urrea et al., 2009 . . .)

Step 3:
$ET_{cb} = ET_0 * K_{cb}$

- Follows FAO-56 approach
- ET_0 from CIMIS
- Calculation of soil evaporation and crop stress via soil water balance



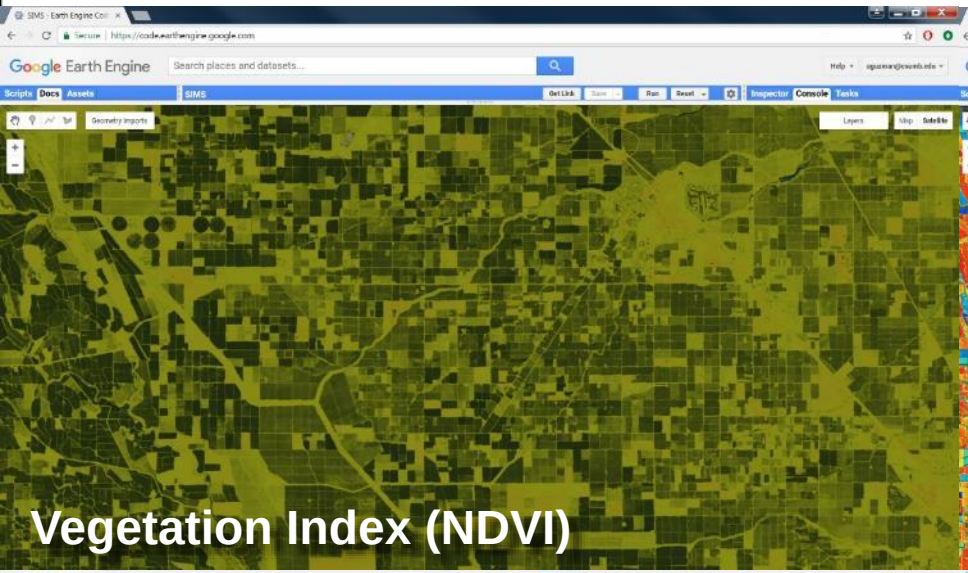
Jonnson et al., 2012

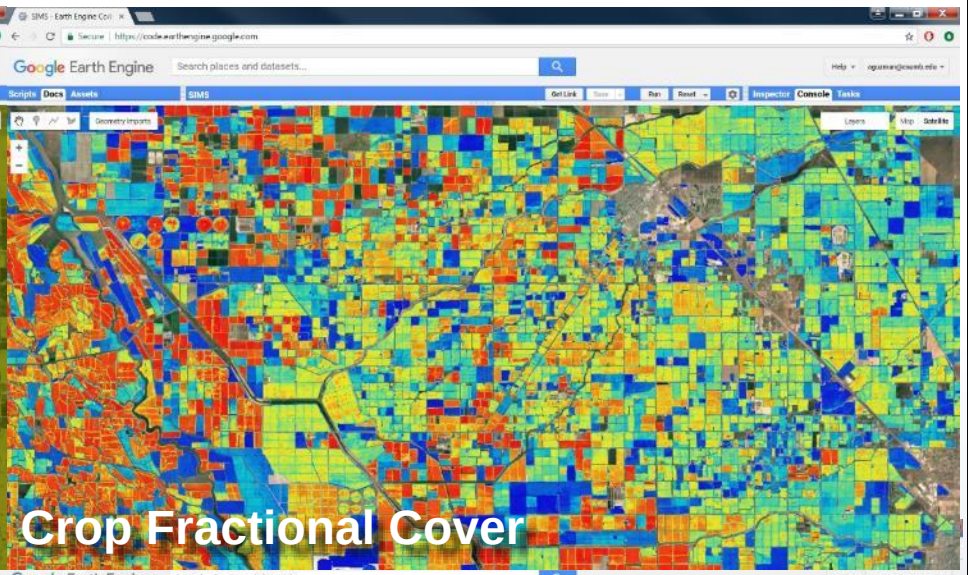
$K_d = \min(1, M_L * Fc\_eff, Fc\_eff^{1/(1+h)})$

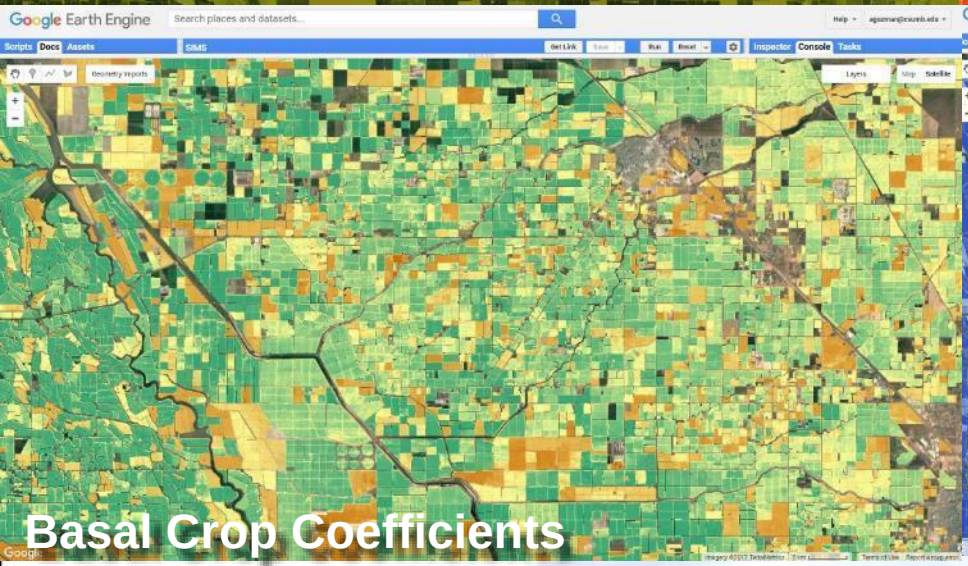
M_L : effect of canopy density on shading / max relative ET
K_d : density coefficient
Fc_eff : effective fractional cover
h : crop height

Allen and Pereira, 2009

Remote Sensing of Evapotranspiration: Reflectance-based Approach







SIMS Approach: Strengths and Limitations

Limitations of the SIMS Approach

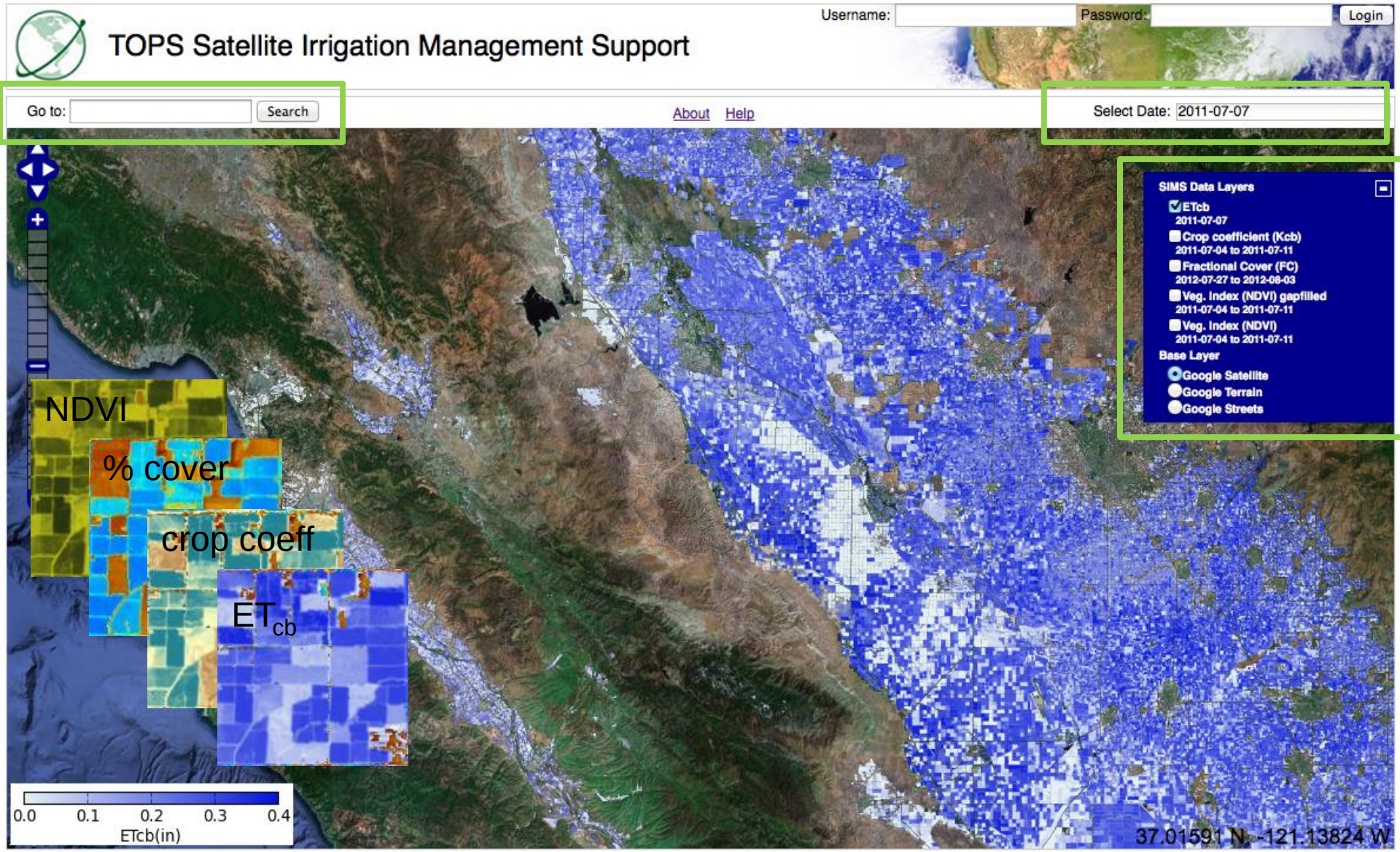
- Additional corrections needed for soil evaporation and crop stress (e.g., via METRIC or soil water balance)
- At present, only applicable for ag land cover types, but could be extended

Strengths of the SIMS Approach

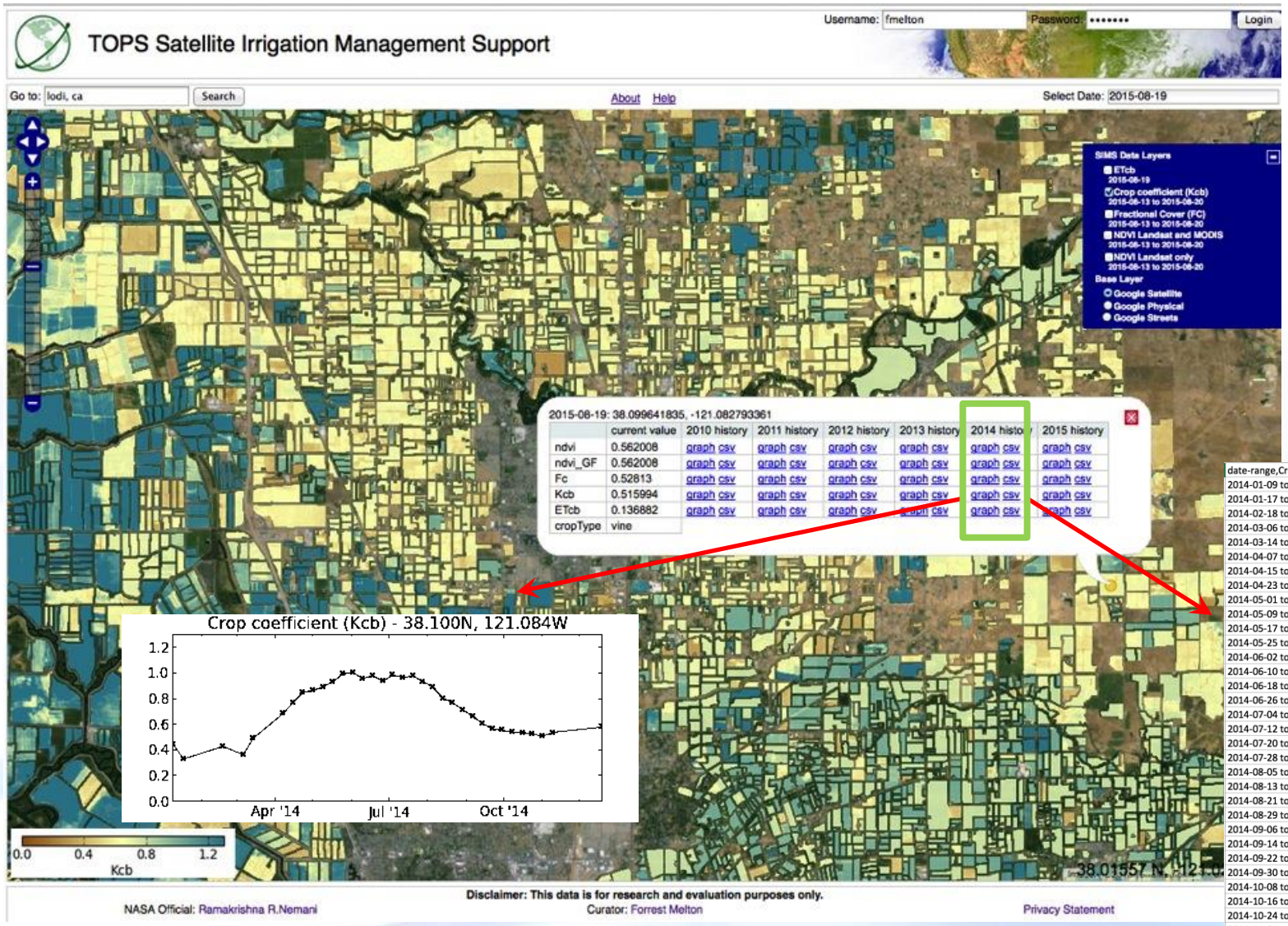
- Extensible framework for satellite data processing
- ET_{cb} represents biological demand for water by the plant
- Fully automated estimates at field scale
- NDVI data freely available from multiple satellites (e.g., Landsat 7, Landsat 8 and Sentinel-2A)
- Field scale estimates that account for weather conditions and observed crop canopy conditions
- Increasingly well-known uncertainty; small bias error

SIMS Web Interface

http://ecocast.arc.nasa.gov/dgw/sims/

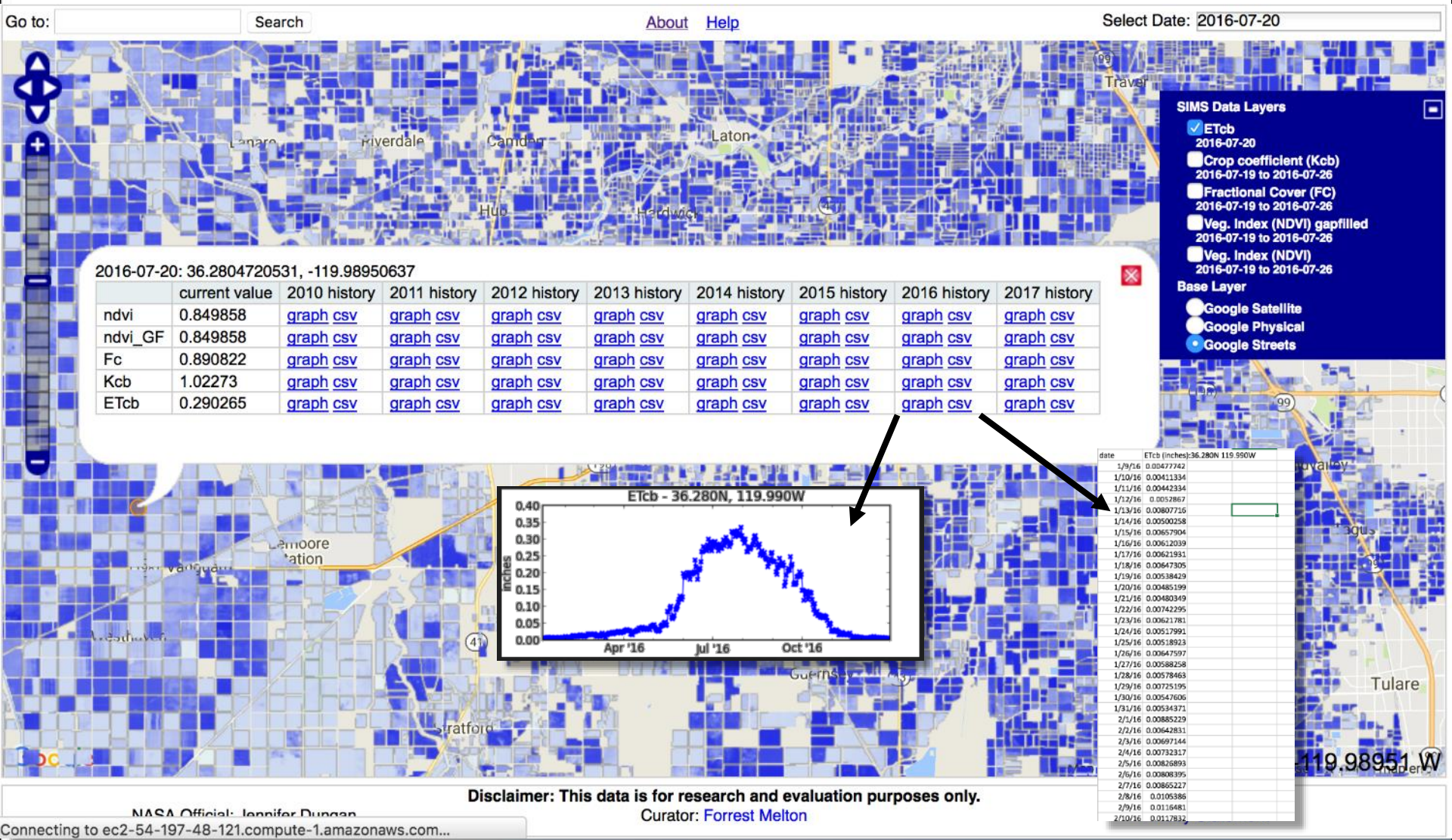


SIMS Crop Coefficients (K_{cb})



date-range,Crop coefficient (Kcb):38.100N 121.084W
2014-01-09 to 2014-01-16,0.447528
2014-01-17 to 2014-01-24,0.332215
2014-02-18 to 2014-02-25,0.430964
2014-03-06 to 2014-03-13,0.365221
2014-03-14 to 2014-03-21,0.493125
2014-04-07 to 2014-04-14,0.687888
2014-04-15 to 2014-04-22,0.772487
2014-04-23 to 2014-04-30,0.854694
2014-05-01 to 2014-05-08,0.867175
2014-05-09 to 2014-05-16,0.895801
2014-05-17 to 2014-05-24,0.936026
2014-05-25 to 2014-06-01,0.996763
2014-06-02 to 2014-06-09,1.00815
2014-06-10 to 2014-06-17,0.959359
2014-06-18 to 2014-06-25,0.983789
2014-06-26 to 2014-07-03,0.939171
2014-07-04 to 2014-07-11,0.989387
2014-07-12 to 2014-07-19,0.967774
2014-07-20 to 2014-07-27,0.982006
2014-07-28 to 2014-08-04,0.937237
2014-08-05 to 2014-08-12,0.895458
2014-08-13 to 2014-08-20,0.805912
2014-08-21 to 2014-08-28,0.772752
2014-08-29 to 2014-09-05,0.718169
2014-09-06 to 2014-09-13,0.664749
2014-09-14 to 2014-09-21,0.608851
2014-09-22 to 2014-09-29,0.566576
2014-09-30 to 2014-10-07,0.557143
2014-10-08 to 2014-10-15,0.540485
2014-10-16 to 2014-10-23,0.539659
2014-10-24 to 2014-10-31,0.528475
2014-11-01 to 2014-11-08,0.510469

SIMS Basal Crop Evapotranspiration (ET_{cb})



Accuracy Assessment Field Campaign

1) Surface Energy Balance

Eddy covariance / surface energy balance residual flux towers

2) Soil Water Balance

Volumetric water content / capacitance probes

Flow meters

Capillary lysimeters

Field Sites

Crop Type	Crop	Location
Grain	Corn*	CSU Fresno
Grain	Wheat	San Joaquin Valley
Row	Garlic	San Joaquin Valley
Row	Lettuce*	SJ & Salinas Valley
Row	Broccoli*	Salinas Valley
Row	Cauliflower	San Joaquin Valley
Row	Tomato(2)*	San Joaquin Valley
Row	Cotton (drip)*	San Joaquin Valley
Vine	Melon	San Joaquin Valley
Vine	Wine grapes*	Salinas Valley
Vine	Raisins*	San Joaquin Valley
Tree	Peach*	San Joaquin Valley
Tree	Almond*	San Joaquin Valley
Tree	Orange*	San Joaquin Valley

***Eddy covariance / SEBR instrumentation.**

Accuracy Assessment Summary

Seasonal Accuracies

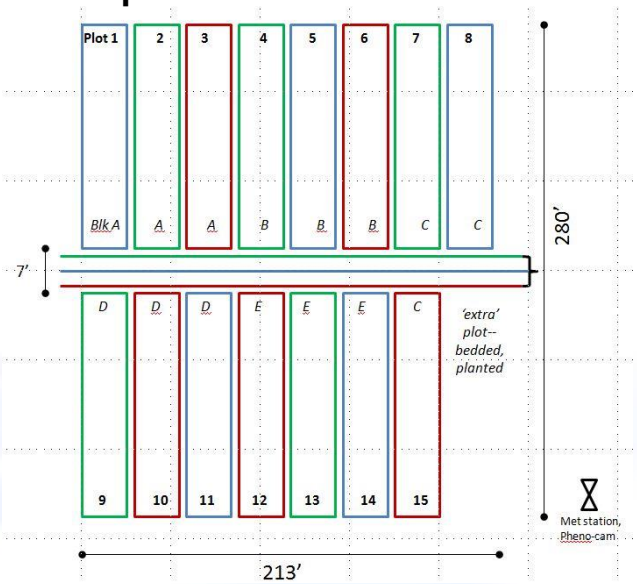
- SIMS ET_{cb} MAE is +/- 15% with ~12% positive bias error across all crops studied
- For well irrigated crops, SIMS ET_{cb} MAE is less than 9% with 6% positive bias error
- For individual fields, SIMS ET_{cb} + IrriQuest soil water balance model reduces MAE to less than 8% across with less than 2% bias error for all crop types studied → highly accurate for field-scale evaluation of on-farm water use efficiency
- Accuracies relative to ground measurements; approaching accuracy of ground measurements (weighing lysimeter 5%, eddy covariance ~10%)

Daily Accuracies

- MAE of 0.4 to 0.75 mm for well watered crops for SIMS ET_{cb}
- MAE of 0.5 to 1.25 mm for deficit irrigated crops for SIMS ET_{cb}
- Bias errors are positive for almost all sites

Benefits of ET-based Irrigation Scheduling

Randomized block design with replicated treatments



Treatments:

- Standard practice
- SIMS
- CropManage

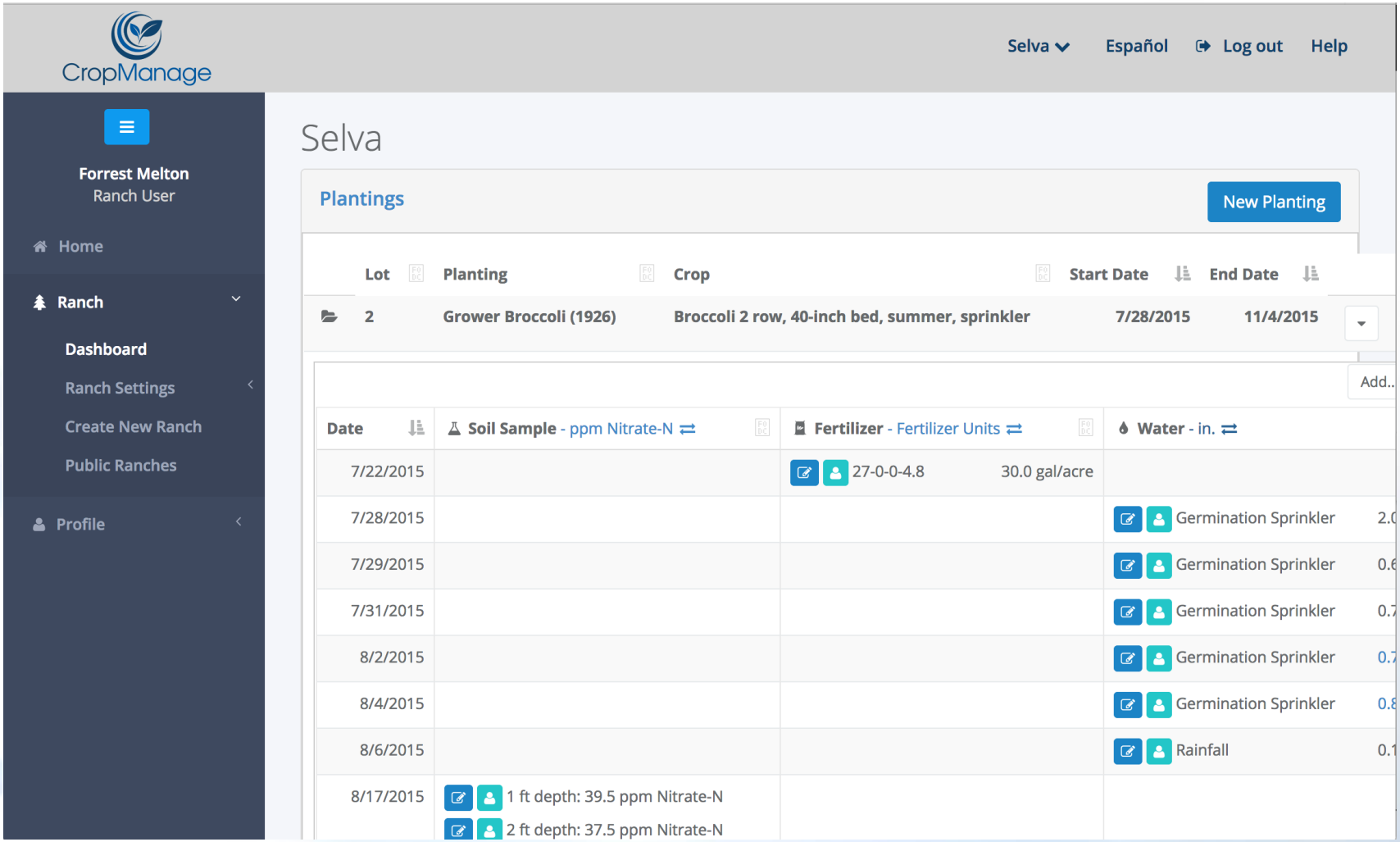
Results to date for reductions in applied water from field trials:

- Lettuce (Iceberg & Romaine): 21-29%
- Broccoli: 30-40%
- Cabbage: 21-22%
- Strawberries: 28%

No statistically significant differences in yield/quality

Johnson et al., 2016, Hort Sci 51.7
Zaragoza et al., in prep.

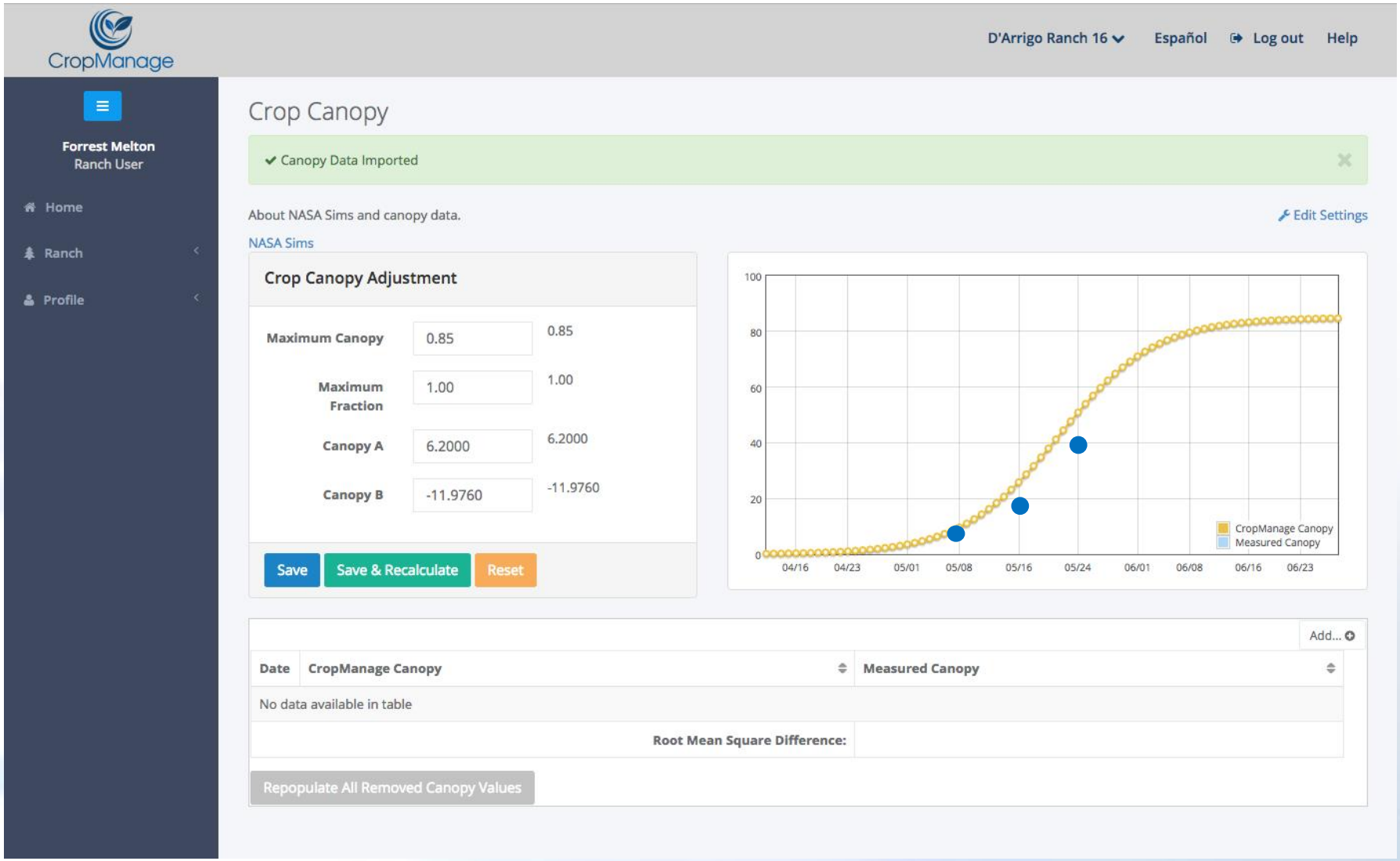
SIMS Web Data Services for Integration with Irrigation & Nutrient Management Software



https://cropmanage.ucanr.edu/

Michael Cahn, UCCE

Crop Manage – SIMS API



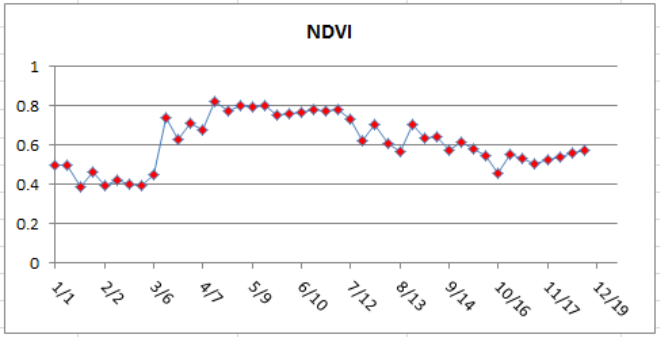
https://cropmanage.ucanr.edu/

Michael Cahn, UCCE

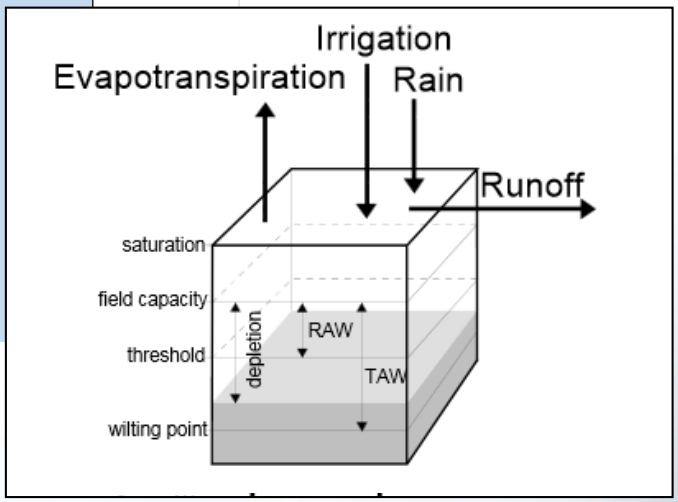
Irri*Quest*
On-farm Water Use Efficiency Calculator

Example for almond in San Joaquin Valley, 2013

	A	B	C	D	E	F	G	H	I	J	K	L
1	sims update	[1.1] ndvi	goto SIMS	[1.2] crop type:	[1.3] region:	[1.4] mid-season period:		date	[1.5] precip (in.):	[1.6] ETo (in.):	view default ETo	
2	1-Jan	0.495388		almond	San Joaquin Valley	spring/summer		1-Jan	0.00	0.03	goto CIMIS	
3	9-Jan	0.493614						2-Jan	0.00	0.03		
4	17-Jan	0.388297						3-Jan	0.01	0.03		
5	25-Jan	0.463374						4-Jan	0.02	0.02		
6	2-Feb	0.391162						5-Jan	0.01			
7	10-Feb	0.42256						6-Jan	0.33			
8	18-Feb	0.397599						7-Jan	0.28			
9	26-Feb	0.391901						8-Jan	0.02			
10	6-Mar	0.448919						9-Jan	0.01			
11	14-Mar	0.737658						10-Jan	0.01			
12	22-Mar	0.628556						11-Jan	0.00			
13	30-Mar	0.713049						12-Jan	0.00			
14	7-Apr	0.675355						13-Jan	0.00			
15	15-Apr	0.822237						14-Jan	0.00			
16	23-Apr	0.770835						15-Jan	0.00			
17	1-May	0.797692						16-Jan	0.00			



FAO-56 Soil water balance model:

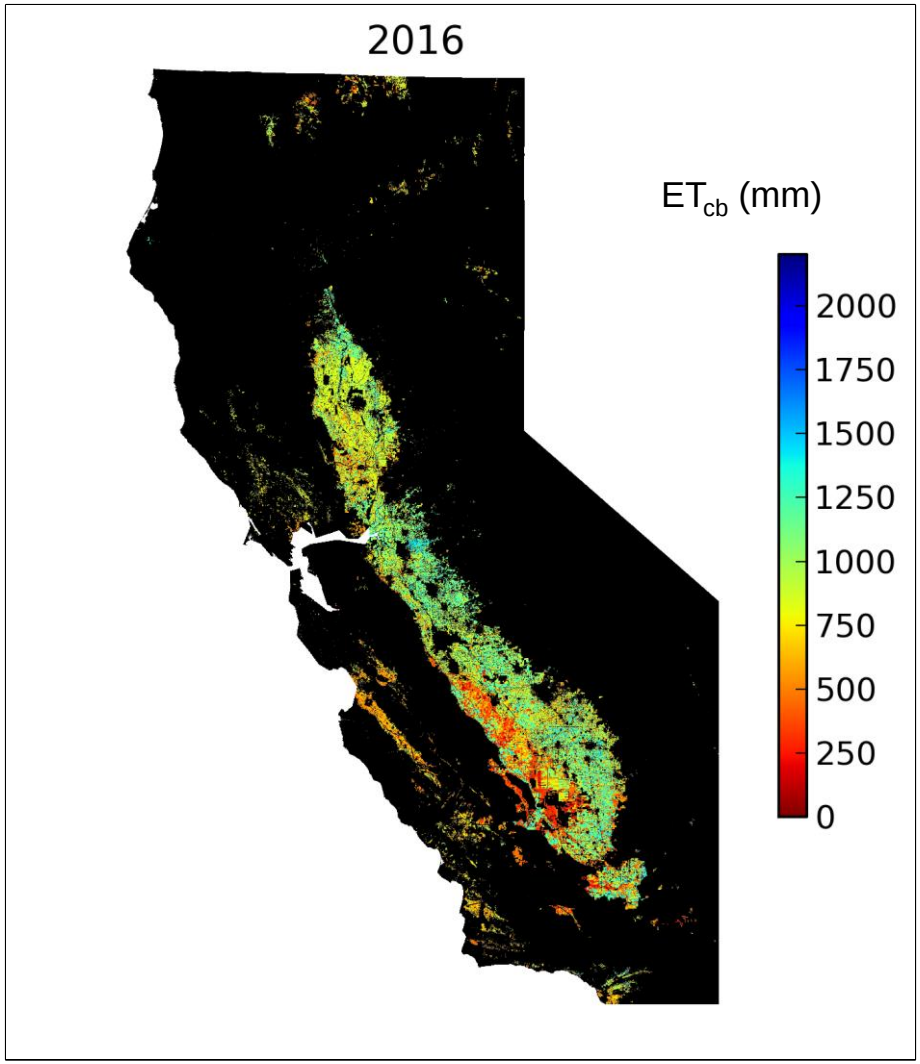


Outputs:
- Crop ET (daily, seasonal)
- Crop Consumptive Use Fraction
- Agronomic Water Use Fraction

- Derives stress & evaporation coefficients: Ks, Ke
- Calculates adjusted ET as: $ET_c = (K_s * K_{cb} + K_e) * ET_o$

Lee Johnson, NASA Ames / CSUMB
https://ecocast.arc.nasa.gov/simsi/irriquest/

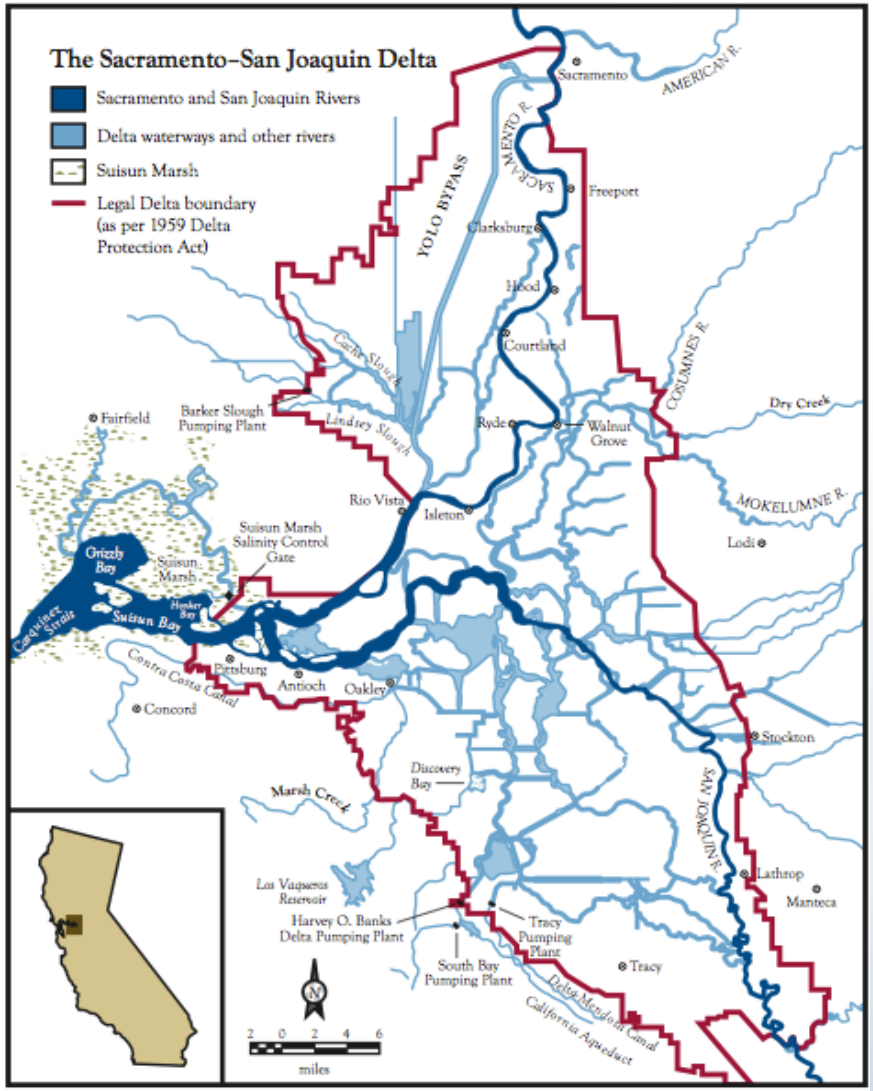
SGMA Applications
SIMS Annual ET_{cb}, 2010-2017



ET Intercomparison Study for the SF Bay Delta

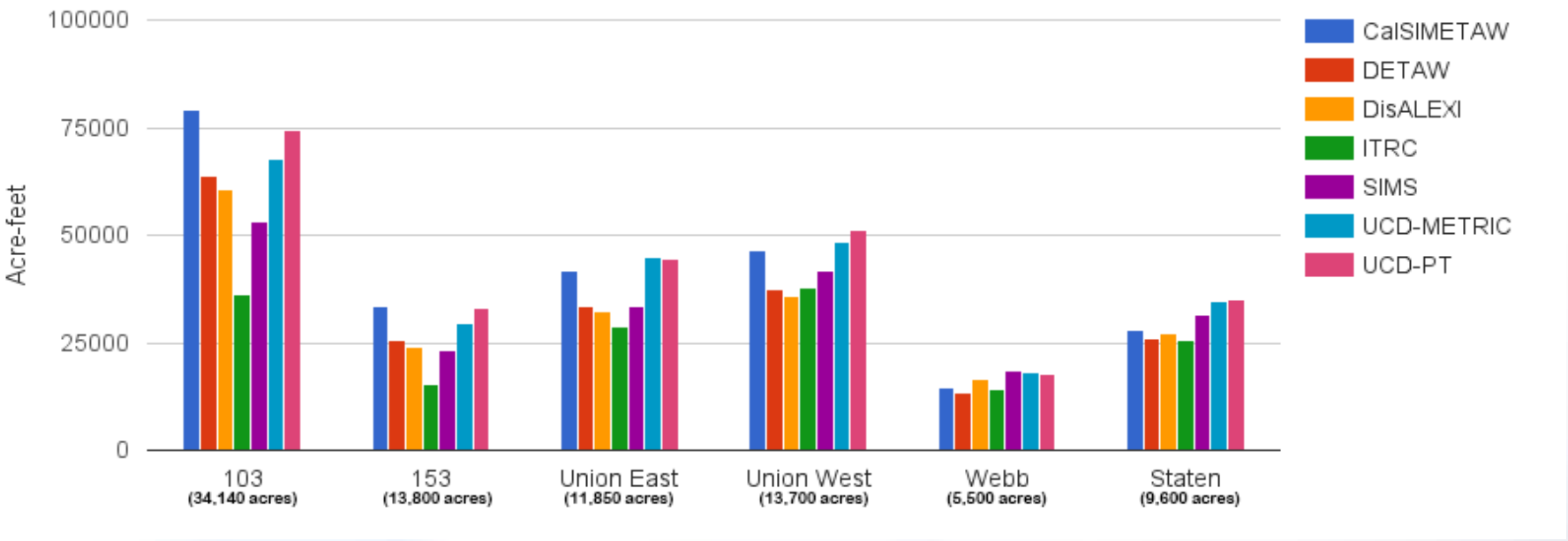
Methods compared:

- CalSIMETAW (DWR)
- DETAW (DWR)
- DisALEXI (USDA-ARS)
- ITRC-METRIC (ITRC Cal Poly SLO)
- UCD-METRIC (UC Davis)
- UCD-PT (UC Davis)
- SIMS (NASA-ARC)



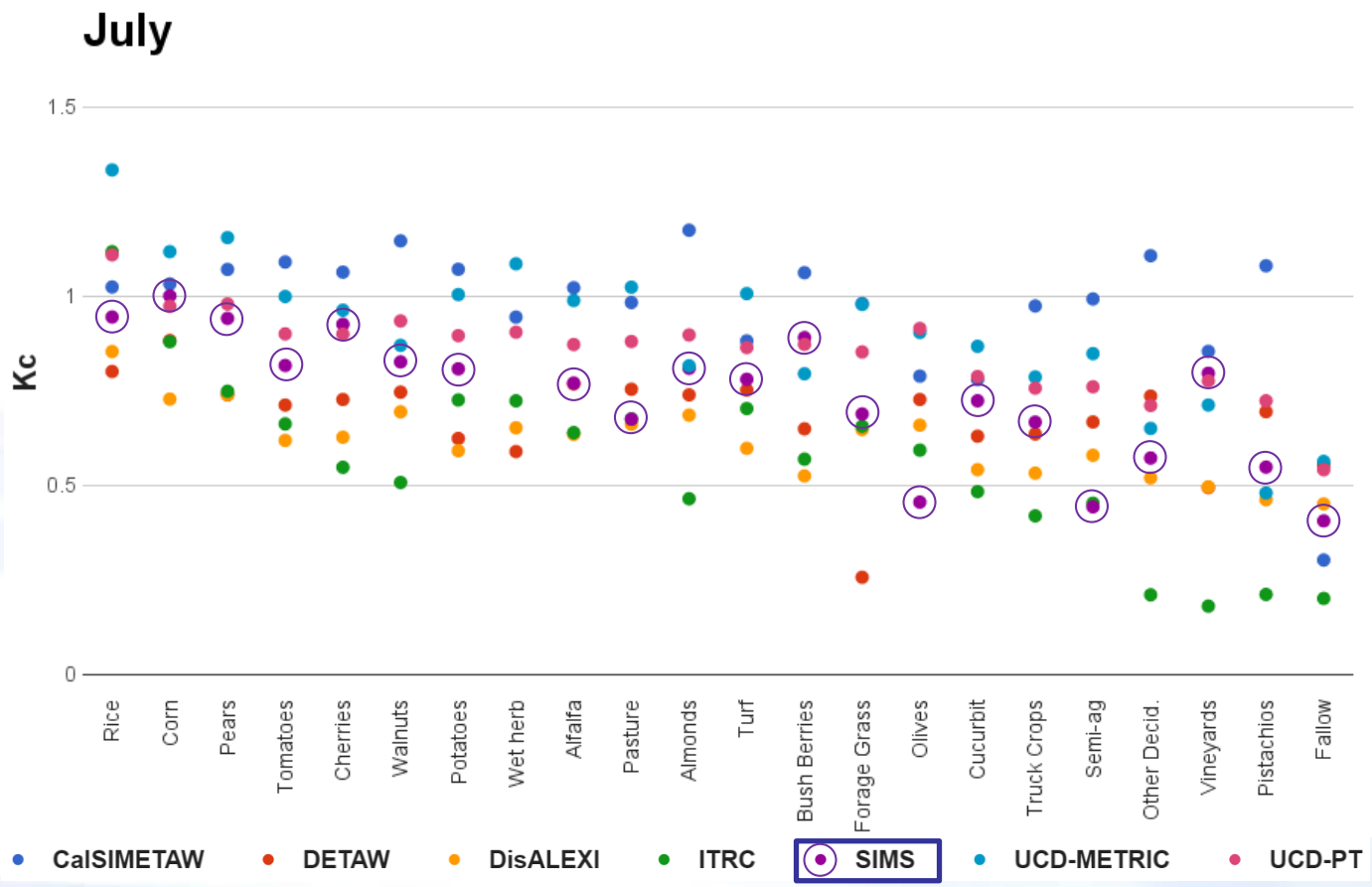
Josue Medellin, Yufang Jin, UC Davis
Medellin et al., 2016

Total Annual ET by CA Delta Subregion



Preliminary results from 1st year of 2-year study
Medellin et al., 2016

Average Observed ET_{rf} (K_c) by Crop Type for CA Delta



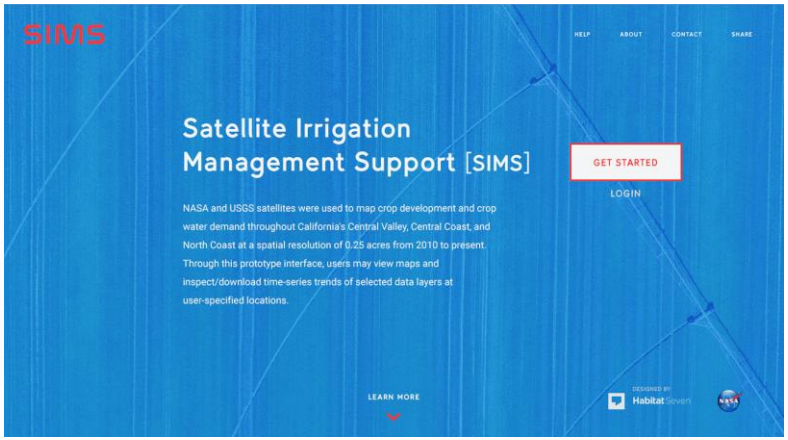
- **SIMS close to median of ET model ensemble for most crop types**

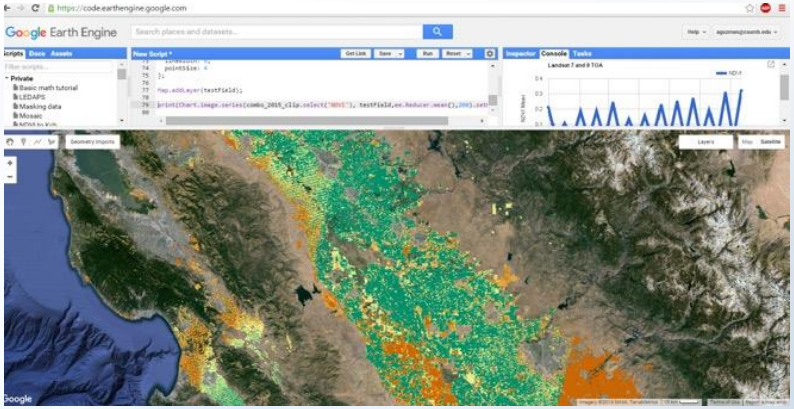
Preliminary results from first year of two-year study

Medillin et al., 2016; https://watershed.ucdavis.edu/project/delta-et

SIMS 2.0: Moving SIMS to the Cloud

- Currently porting SIMS from the NASA Earth Exchange to Google Earth Engine
  - Reduced costs for satellite data management / sustained operations
  - Easier to scale to other regions
  - Ability to create automated reports
- With support from CA DWR, work beginning to implement IrriQuest prototype as a desktop application





SIMS Application Programming Interface

- **Designed for machine to machine queries**
- **Contact forrest.s.melton@nasa.gov for a user API key and API documentation**

Data Service:
http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1

Query example for a single day:
http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1?
apikey=*userkey*&**date**=2016-04-14&**lon**=-120.46428&**lat**=36.69523&**croptype**=75

Query example for a timeseries for full year or current year-to-date:
http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1?
apikey=*userkey*&**year**=2016&**lon**=-120.46428&**lat**=36.69523&**croptype**=75

http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1?
varname=Fc&**apikey**=*userkey*&**year**=2016&**croptype**=75&**geom**=POLYGON+((-
120.9710708296299941+37.4955228156940024,
-120.9765639936899930+37.4573781184929970,
-120.9133926069799969+37.4475663354349990,
-120.9216323530699952+37.4955228156940024,
-120.9710708296299941+37.4955228156940024))

February 2018

OpenET

A Water Community Focused Open Source ET Project

Towards Filling the Biggest Gap in Water Information

Justin Huntington, Charles Morton – Desert Research Institute
Forrest Melton, Lee Johnson, Alberto Guzman, NASA Ames / CSUMB
Robyn Grimm & Maurice Hall, EDF, Josh Fisher, JPL, Martha Anderson, USDA ARS,
Chris Hain, NASA MSFC, Wim Bastiaanssen, IHE-DELFT . . . and many others . . .

EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

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DRI Desert Research Institute

California State University MONTEREY BAY

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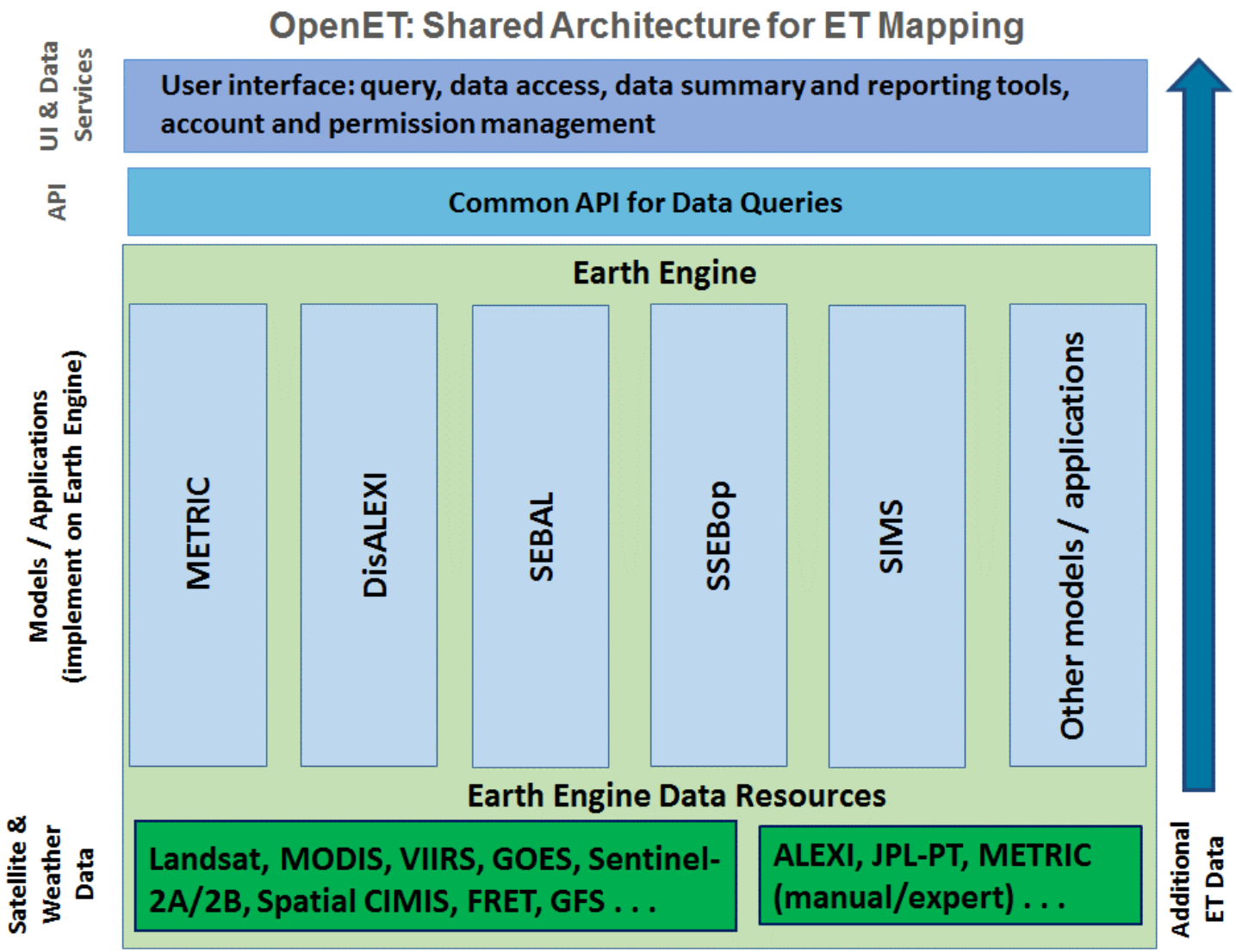
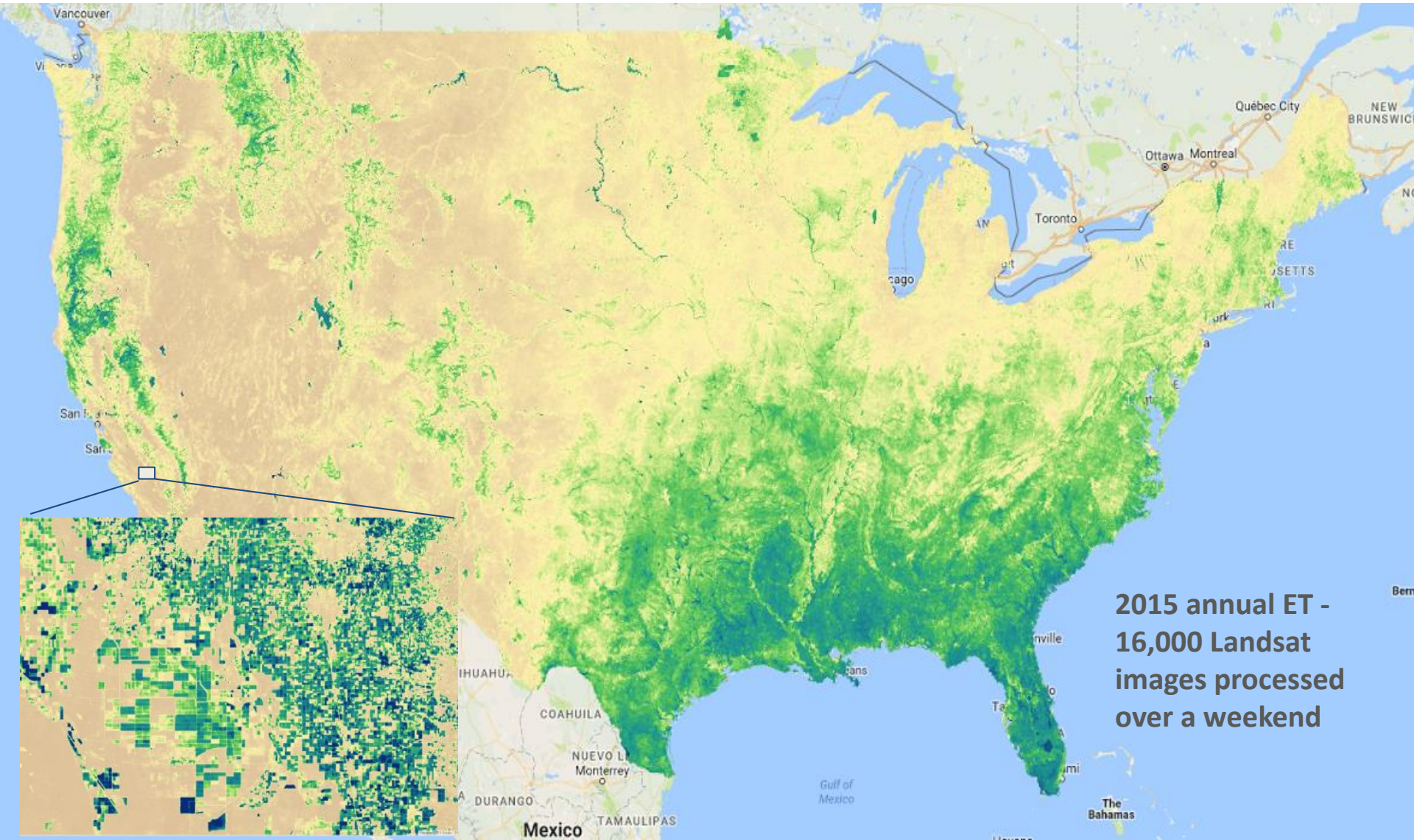
One Platform, Multiple Operational Models



Our First Test

- Regional scale field level ET mapping on Google Earth Engine
- Justin Huntington & Charles Morton (DRI), Gabriel Senay & MacKenzie Friedrichs (USGS)



2015 annual ET - 16,000 Landsat images processed over a weekend

Questions?

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Lessons Learned

1) Field validation and quantification of accuracy is critical, but also challenging in commercial agriculture settings

2) Partnership with growers / ag community is key, but requires sustained investment of time

3) For agricultural applications, data continuity is essential → Landsat 8 TIRS data interruptions have been challenging

4) Needs for APIs to integrate with other tools → Collaboration creates success; competition creates confusion for stakeholders

5) Transition to operations always takes longer than planned → start planning on Day 1 of a new effort

A Few Definitions

- **Potential ET (PET):** The evapotranspiration that would occur if a sufficient water source were available

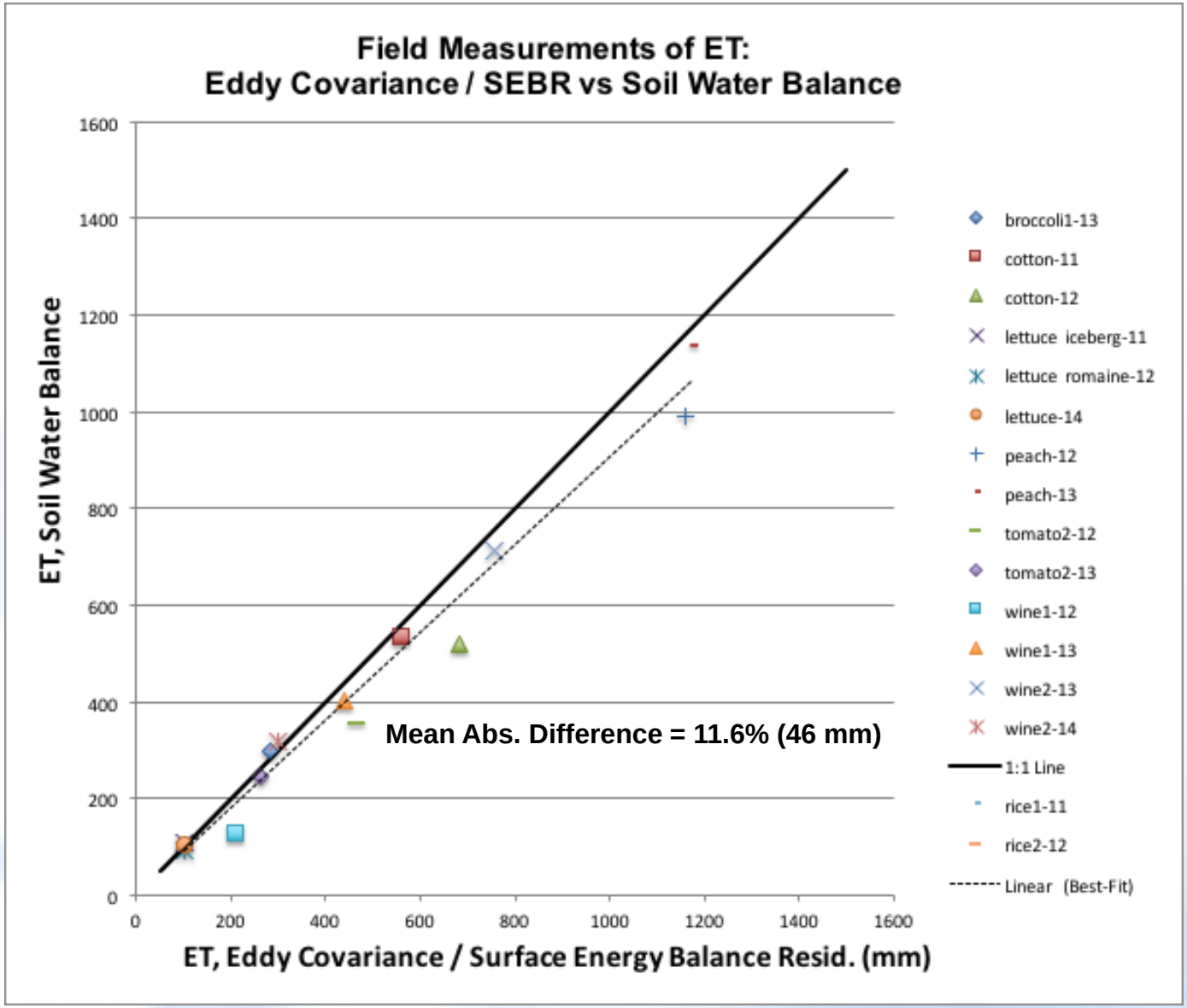
- **Reference ET (ET_o or ET_r):** The PET from a well-watered reference surface (usually a 1 m alfalfa crop or a grass surface)

- **Basal crop evapotranspiration (ET_{cb}):** The evapotranspiration from a well-watered crop on a dry soil surface (i.e., transpiration + diffusive soil evaporation)

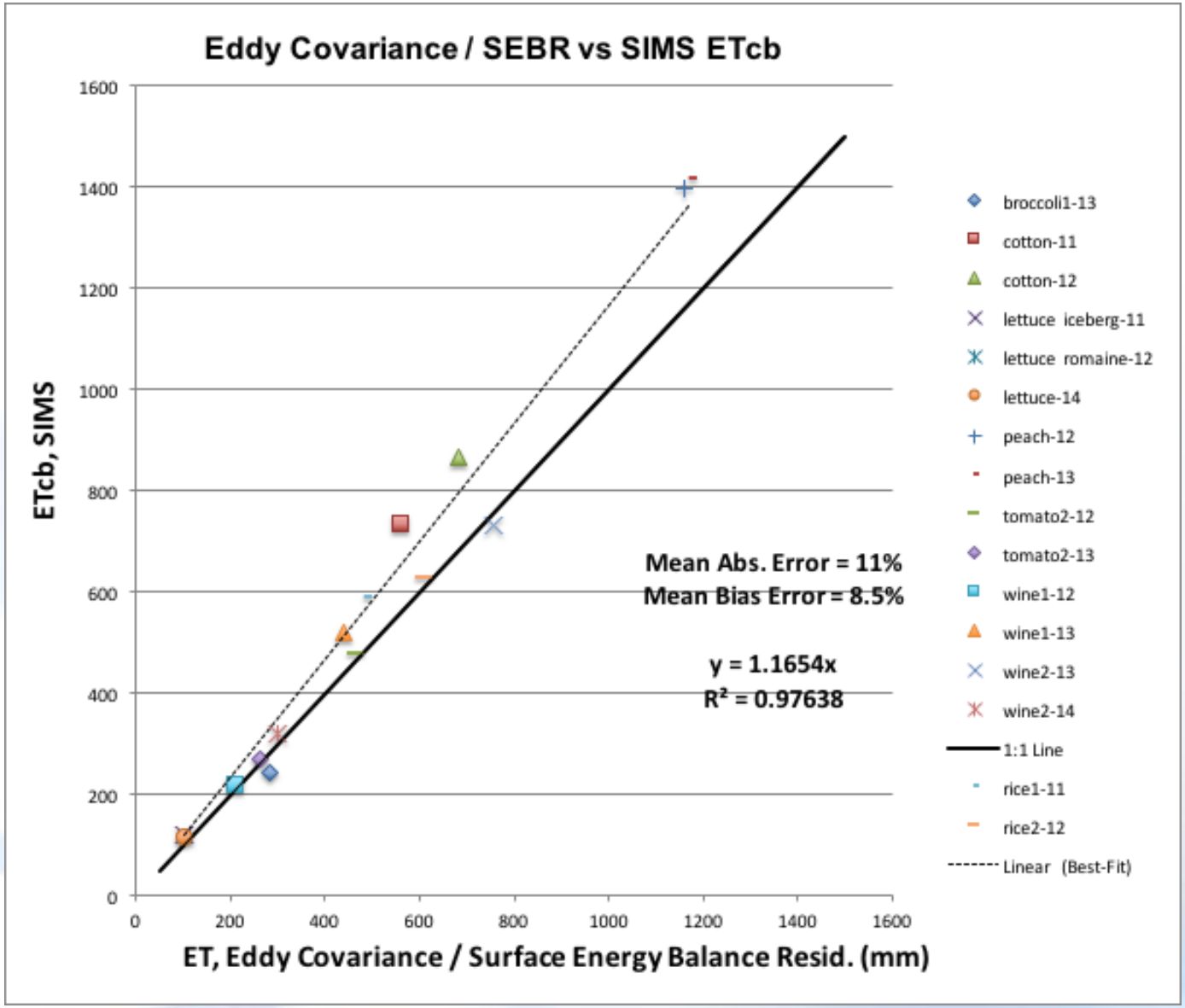
- **Actual basal crop evapotranspiration ($ET_{cb\text{-}a}$):** $ET_{cb\text{-}a}$ adjusts ET_{cb} to account for the observed canopy extent and crop growth stage, incorporating crop-specific corrections for stomatal resistance at different stages (SIMS provides $ET_{cb\text{-}a}$)

- **Actual crop evapotranspiration (ET_a):** Total crop evapotranspiration, including soil evaporation and crop stress

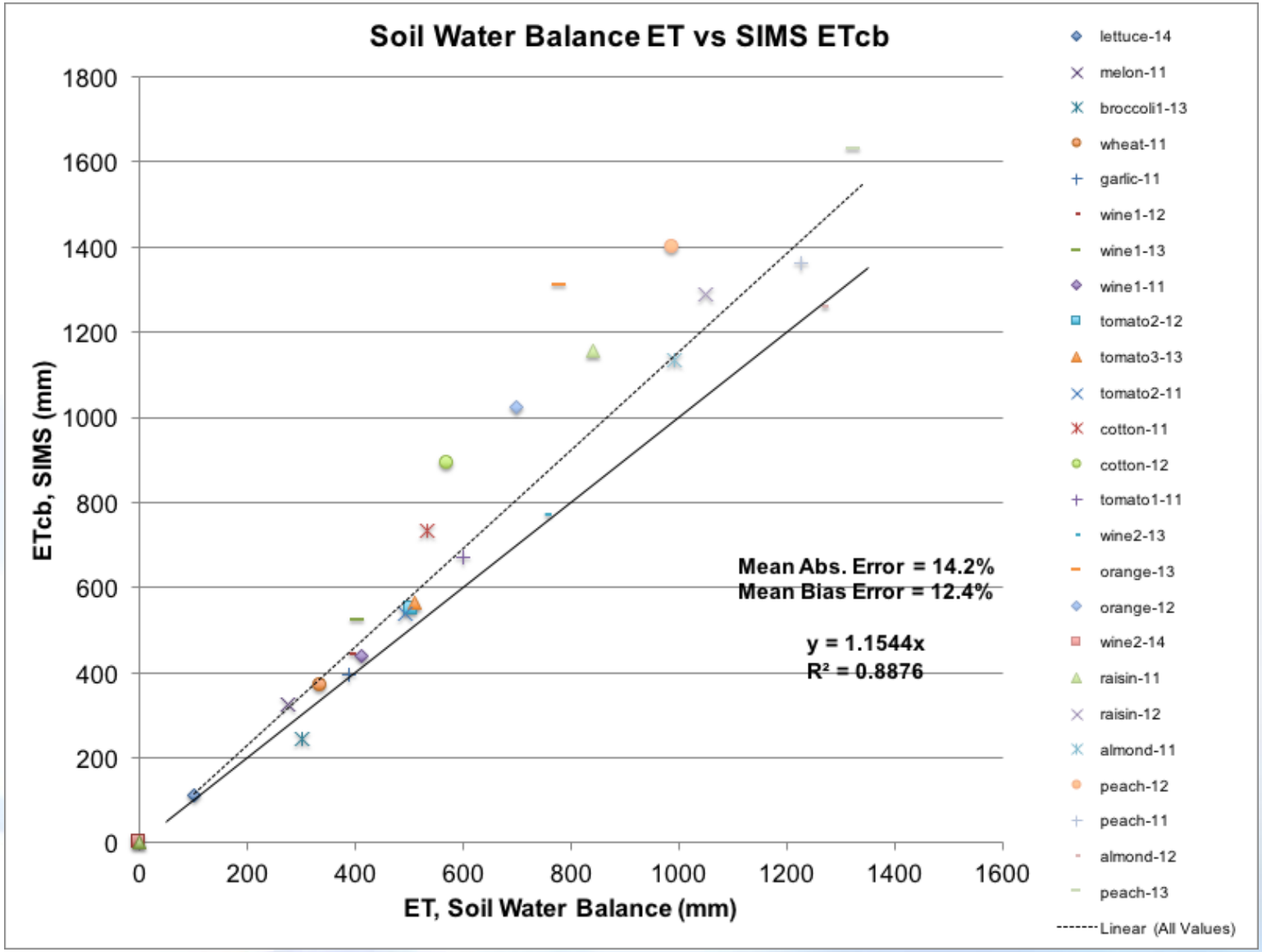
Results: Ground Measurements



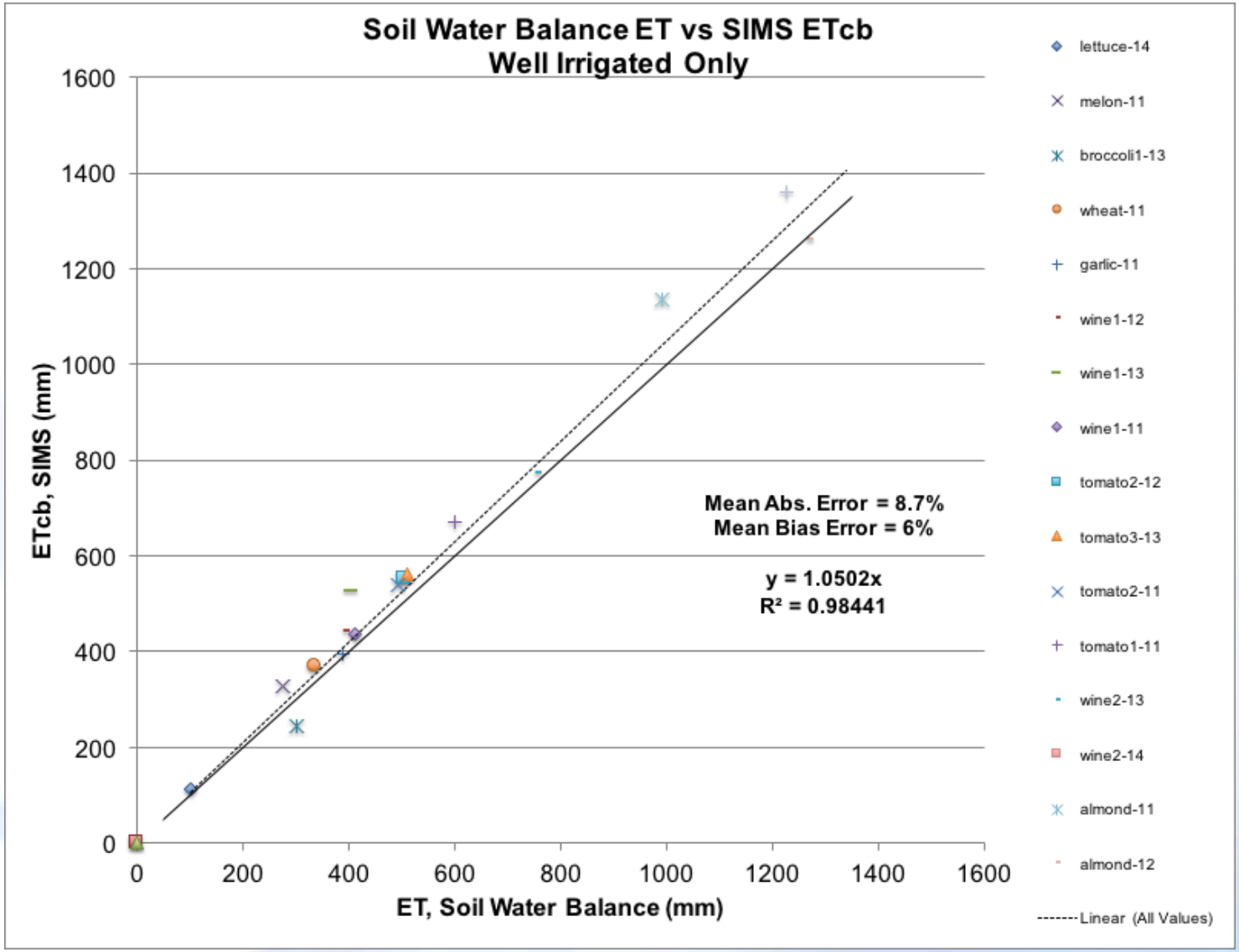
Results: Eddy Covariance vs SIMS ET_{cb}



Results: Field Soil Water Balance vs SIMS ET_{cb}

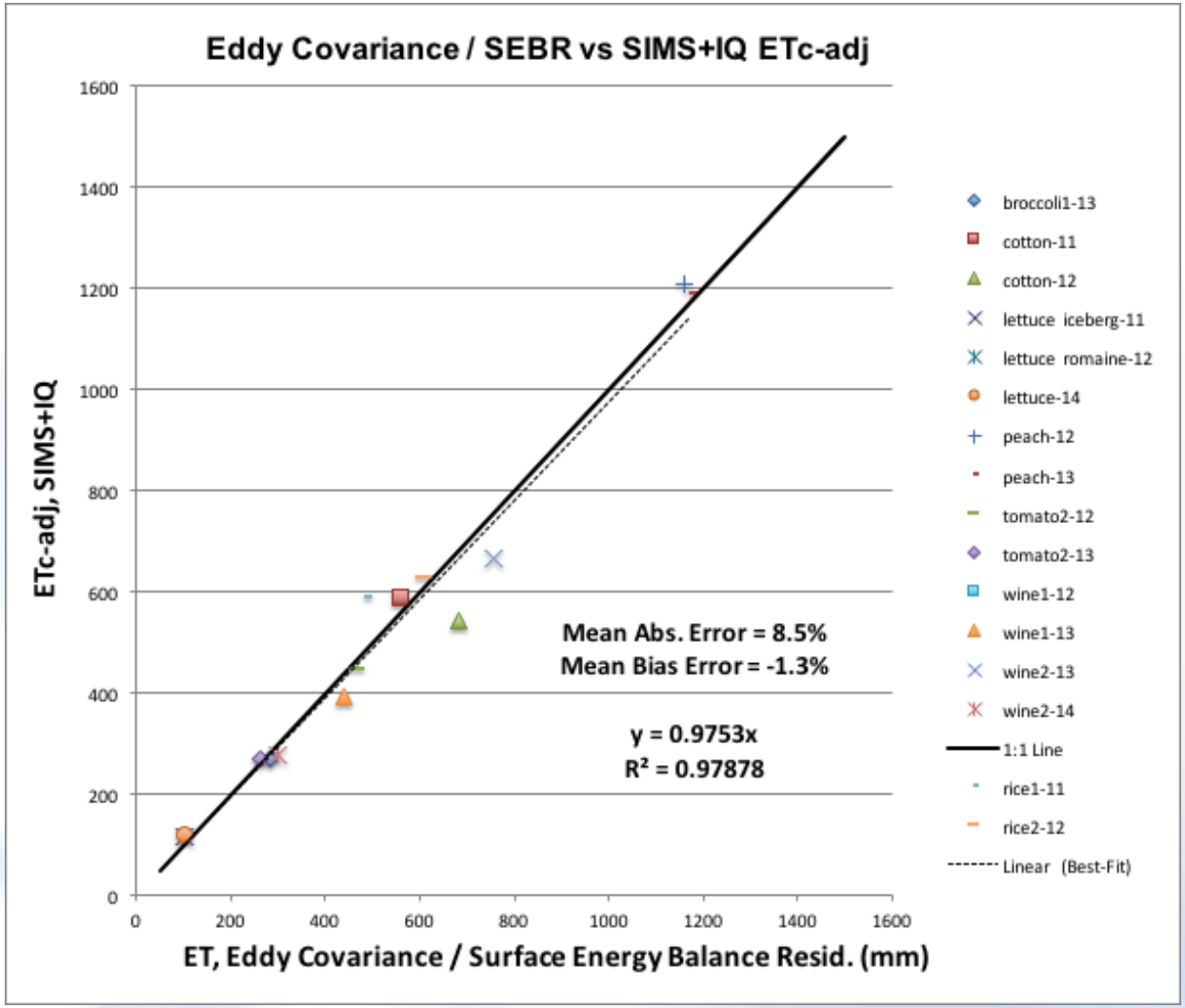


Results: Field Soil Water Balance vs SIMS ET_{cb}



Results: Eddy Covariance vs SIMS $ET_{c\text{-}adj}$

SIMS + IrriQuest



Results: Field Soil Water Balance vs $ET_{c\text{-}adj}$

SIMS + IrriQuest