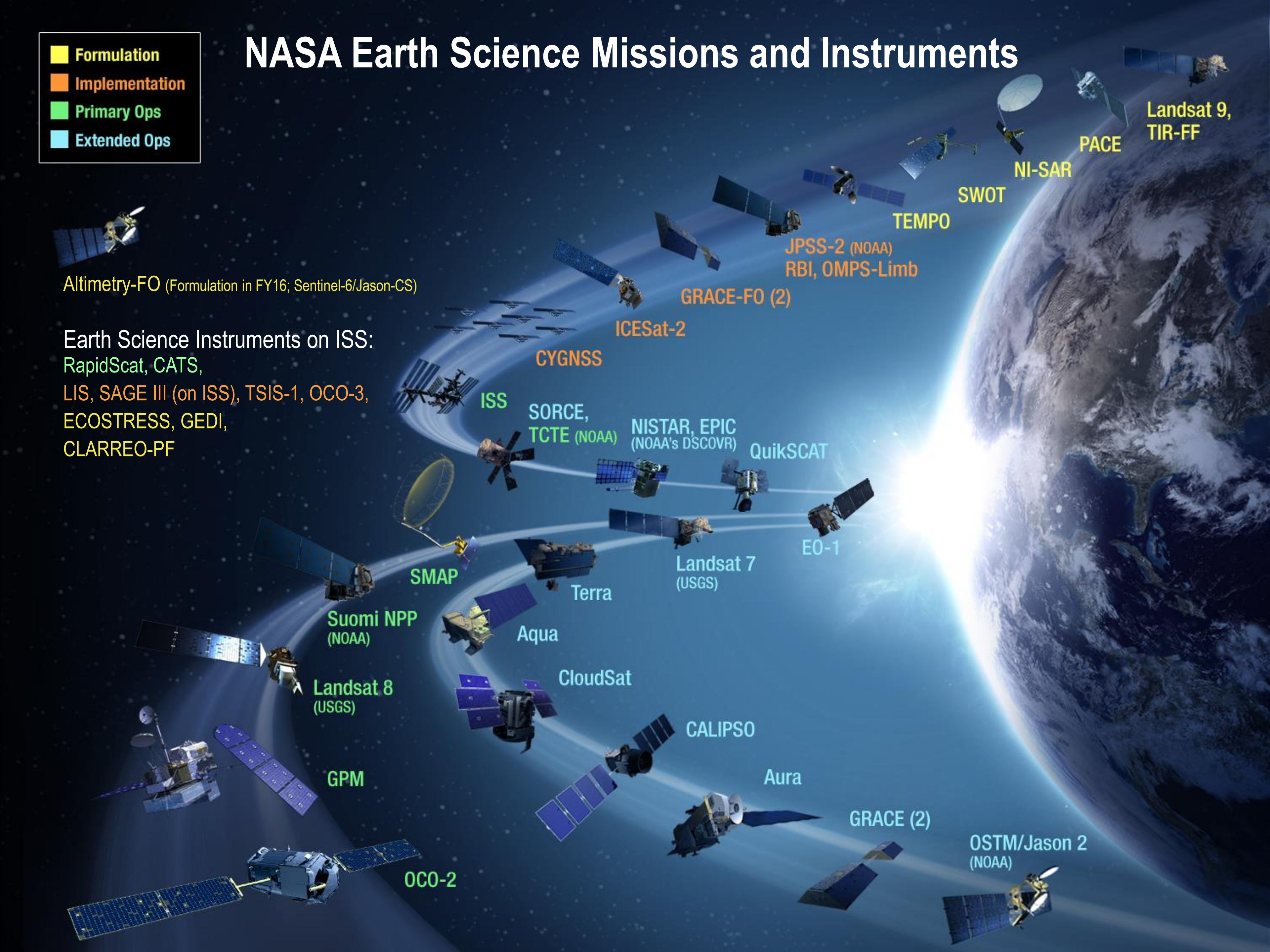
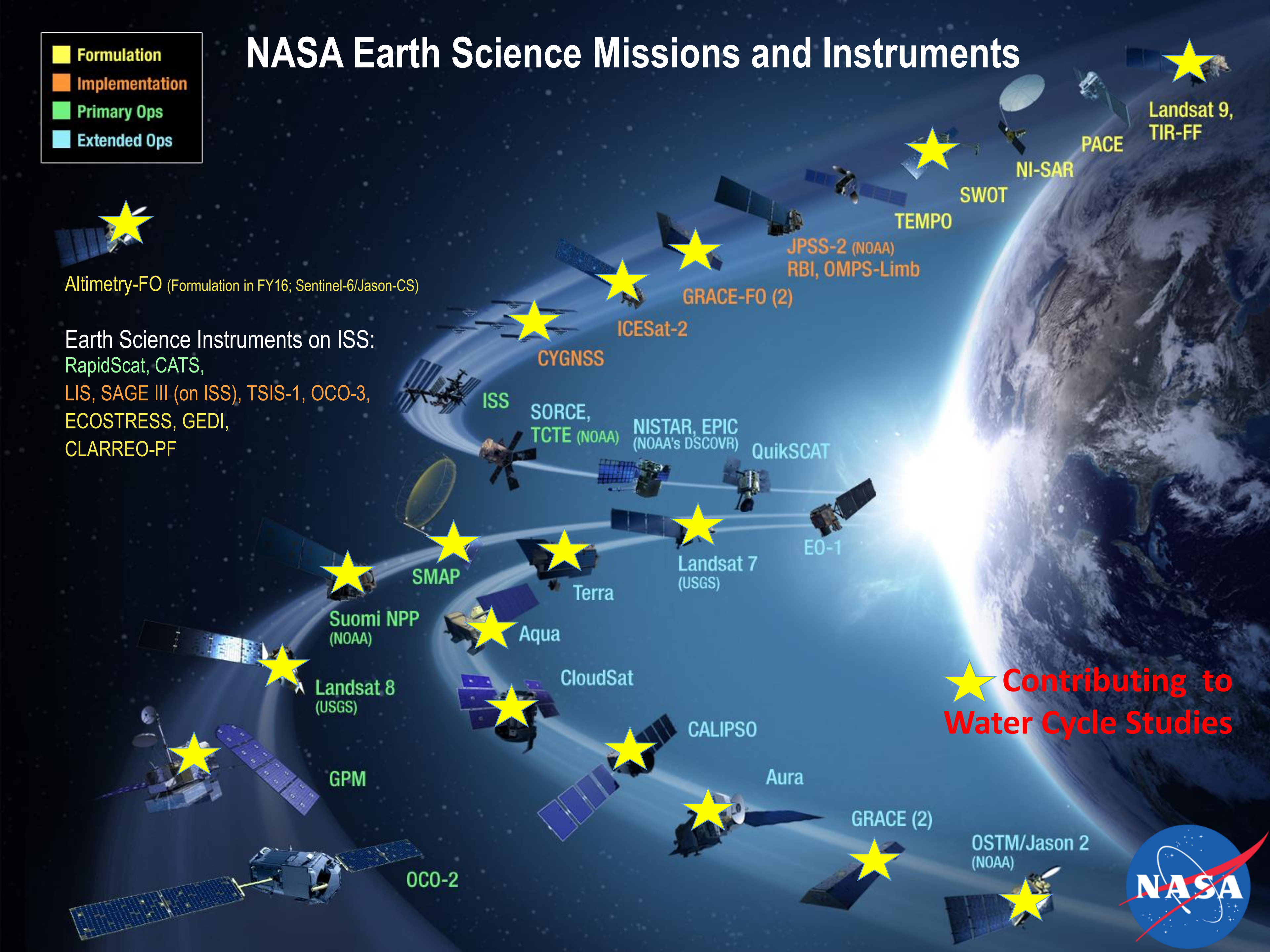

NASA Earth Science Missions and Instruments
Formulation
Implementation
Primary Ops
Extended Ops
Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS, GEDI,
CLARREO-PF
Landsat 9, TIR-FF
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA) RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE, TCTE (NOAA)
NISTAR, EPIC (NOAA's DSCOVR)
QuikSCAT
EO-1
Landsat 7 (USGS)
Terra
SMAP
Suomi NPP (NOAA)
Aqua
Landsat 8 (USGS)
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2 (NOAA)
OCO-2



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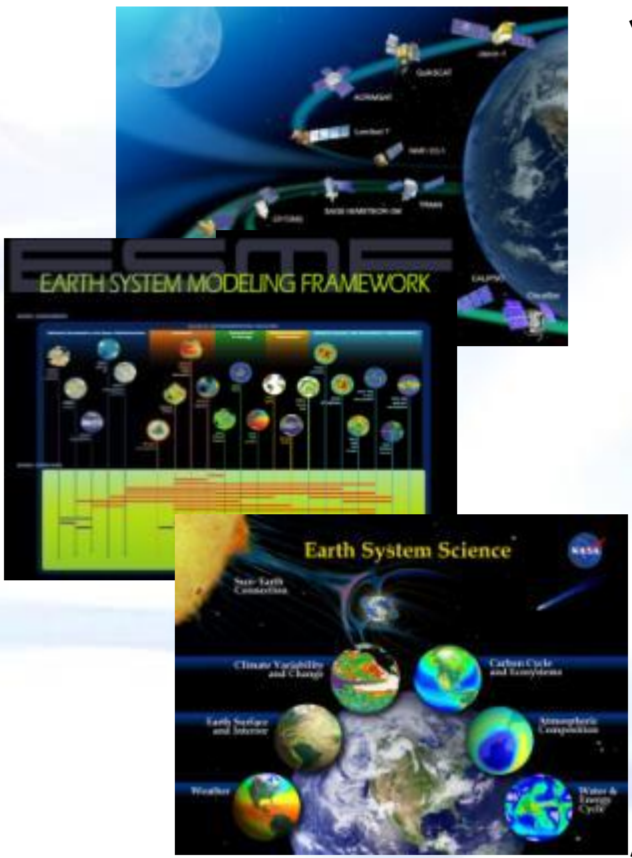
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2
Contributing to
Water Cycle Studies
NASA

NASA Applied Sciences Program
A Pathway Between Earth Science & Society

Results of NASA Earth Science Research

Uses by Partners and Stakeholder Communities



NASA Applied Science Program

GEOSS Societal Benefit Areas

CIMIS and NASA's Satellite Irrigation Management Support System:

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

Forrest Melton
Senior Research Scientist

Cooperative for Research in Earth Science and Technology
NASA Ames Research Center
&
California State University, Monterey Bay
Seaside, CA

Water Information Management Systems Workshop
Pasadena, CA
17 January 2018

Project Team

Project Team:
Forrest Melton, Lee Johnson, Alberto Guzman, Jason Dexter, Isabel Zaragosa, Carolyn Rosevelt, Carlos Xian, Michael Hang
NASA ARC-CREST / CSU Monterey Bay

Bekele Temesgen, Ricardo Trezza, Simon Eching, Kent Frame
CA Dept. of Water Resources

Michael Cahn, Richard Smith
UC Cooperative Extension

Project Collaborators:
Western Growers Association, Booth Ranches, Chiquita, Constellation Brands, Del Monte Produce, D'Arrigo Bros., Driscoll's Dole, Inc., E & J. Gallo, Farming D, Fresh Express, Huntington Farms, Pereira Farms, Ryan Palm Farms, Tanimura & Antle, CDFA

Overview

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

Why is NASA involved in ET mapping?

How does SIMS work?

How accurate is SIMS?

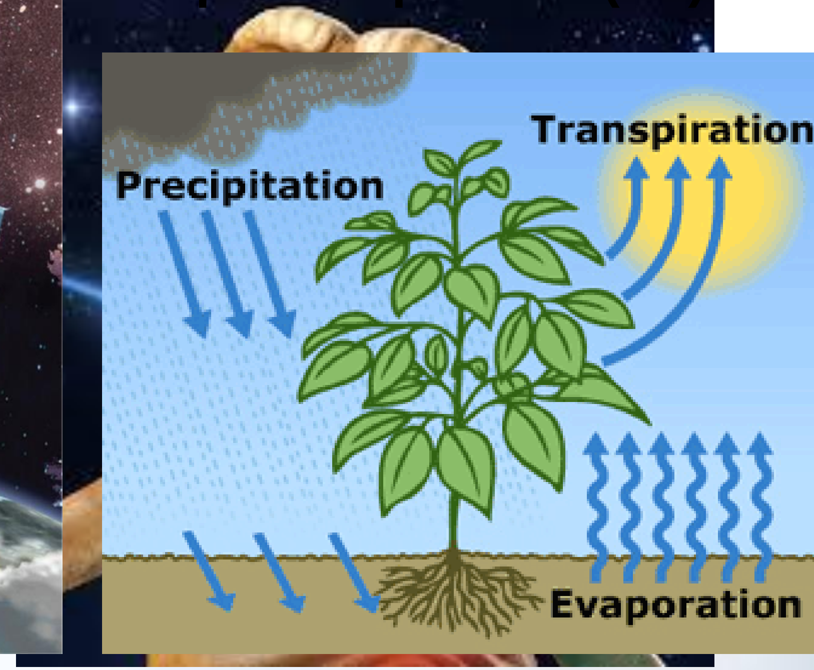
Accessing Data from SIMS

- Using the web
- Using the web API
- CropManage
- Irriquest

SIMS 2.0

NASA + ET?

Evapotranspiration (ET)

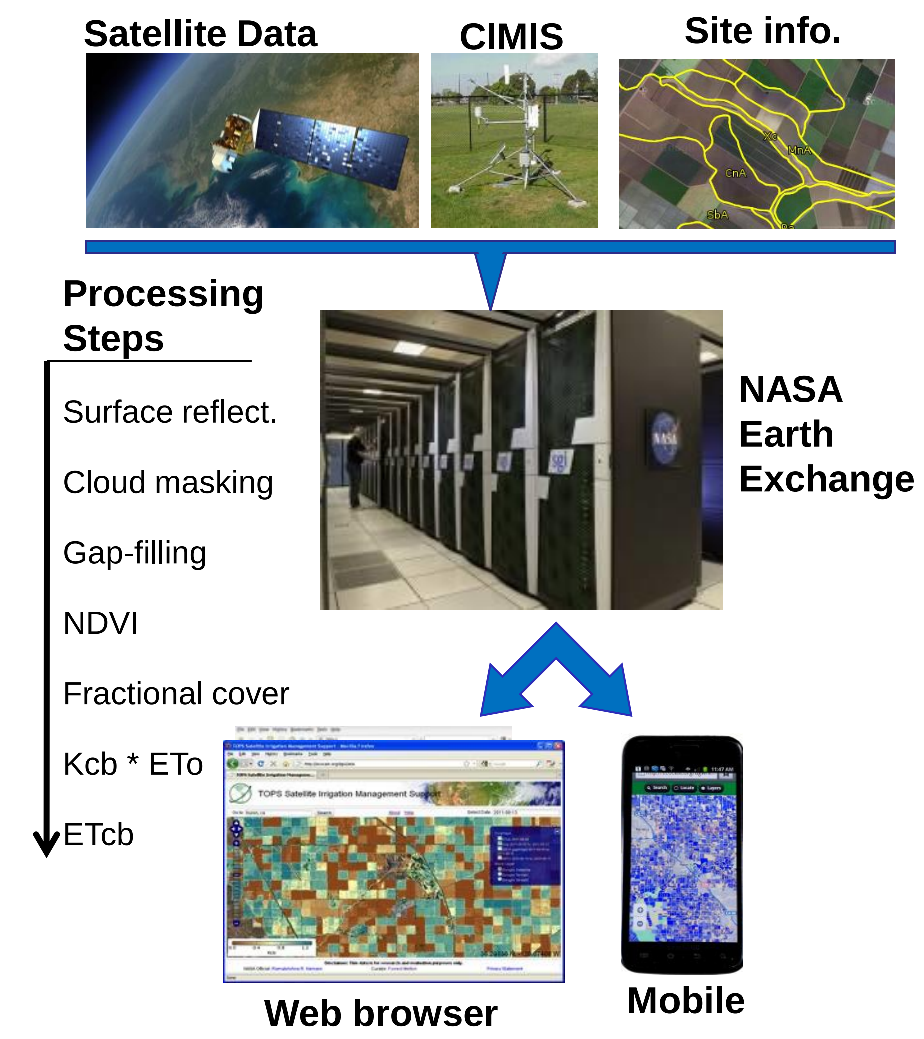


Satellite Irrigation Management Support (SIMS)

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



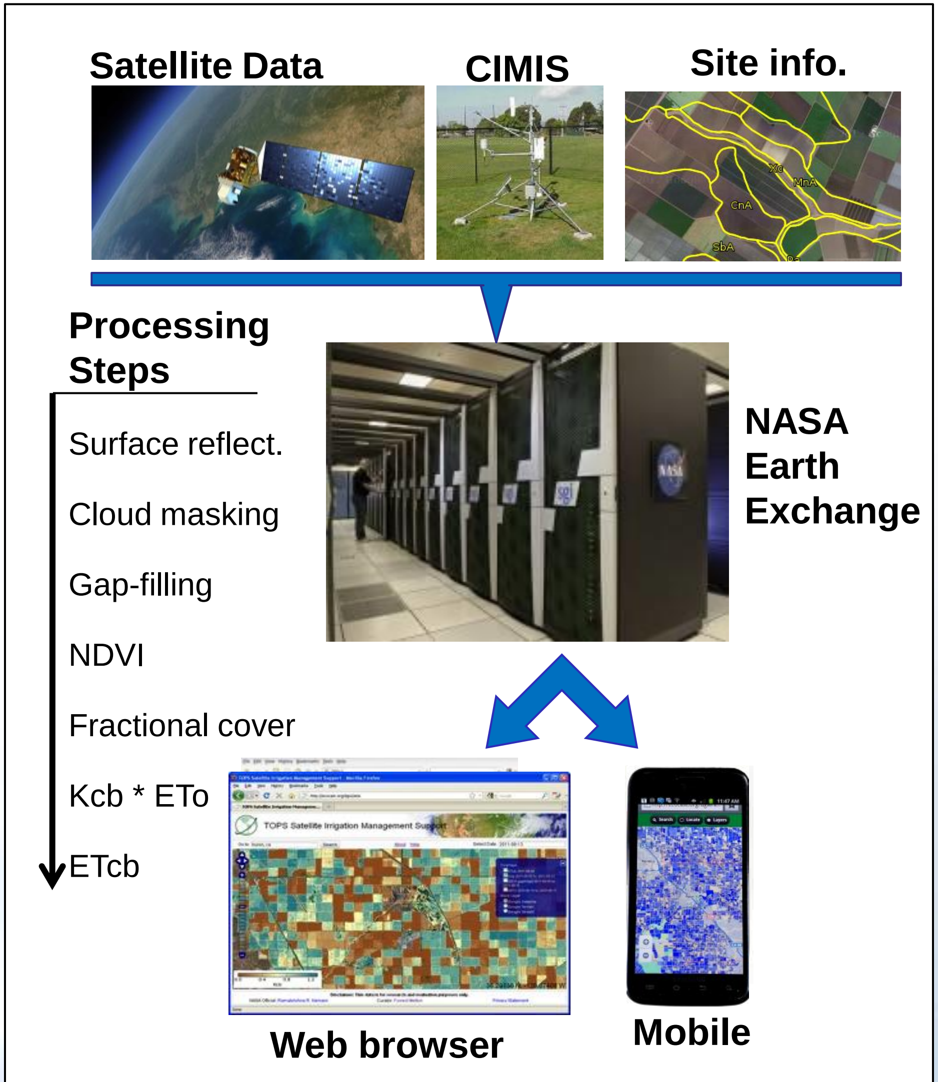
Melton et al., 2012, IEEE JSTARS

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.*

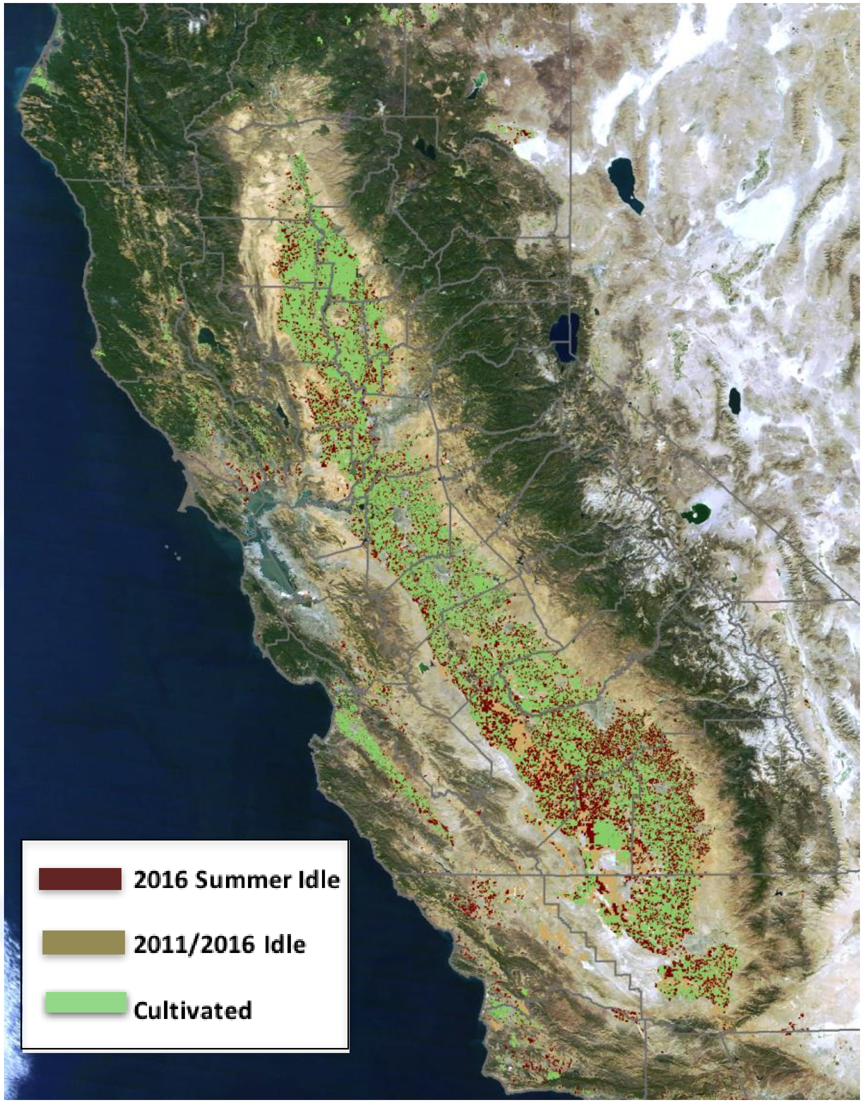
Applications:

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

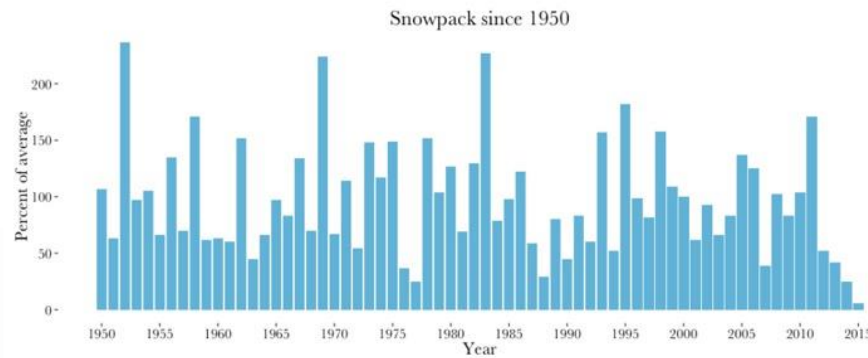


Melton et al., 2012, IEEE JSTARS

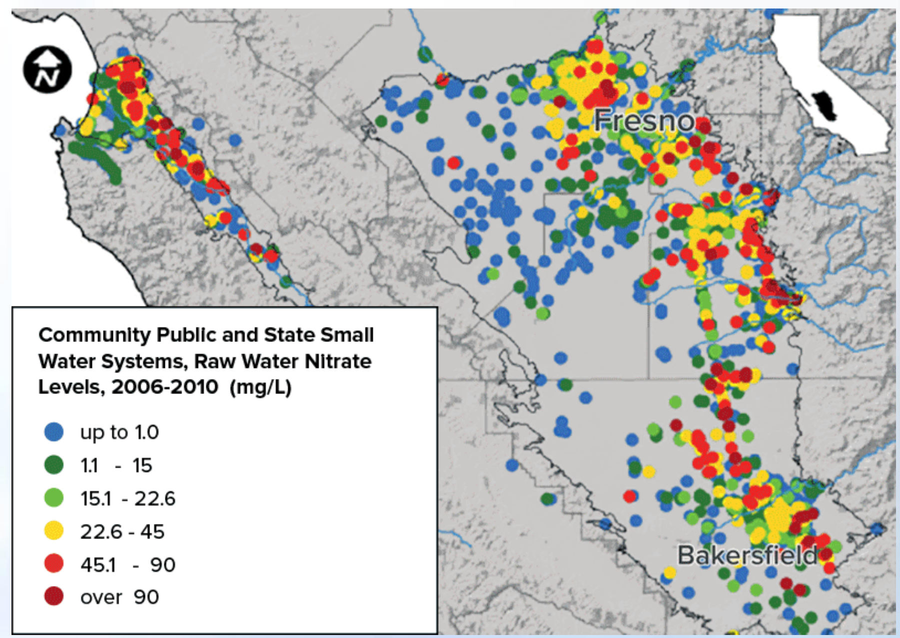
Threats to Water Supplies and Water Quality in California



Source: CDWR



Source: CDWR

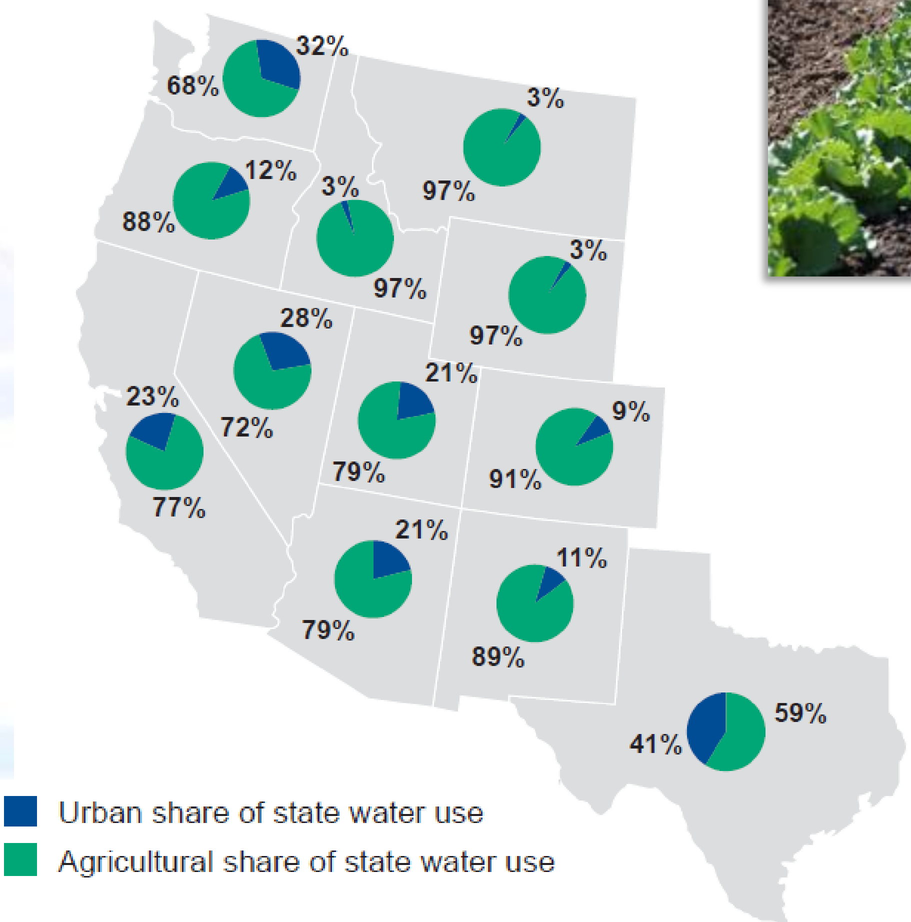


Source: UC Davis

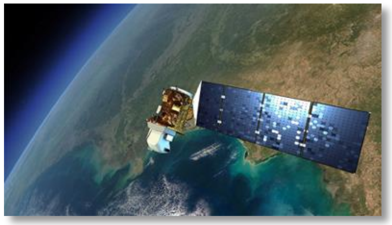
Precision Agriculture: Optimizing Irrigation

$$P + I = E + \overset{\sim 0}{\cancel{\Delta S_{sw}}} + \overset{\sim 0}{\cancel{D}} + \overset{0}{\cancel{R}}$$

(Precip + Irrigation = Evapotranspiration + Change in Soil Moisture + Drainage + Runoff)

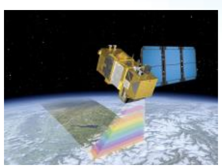


California Irrigation Management Information System

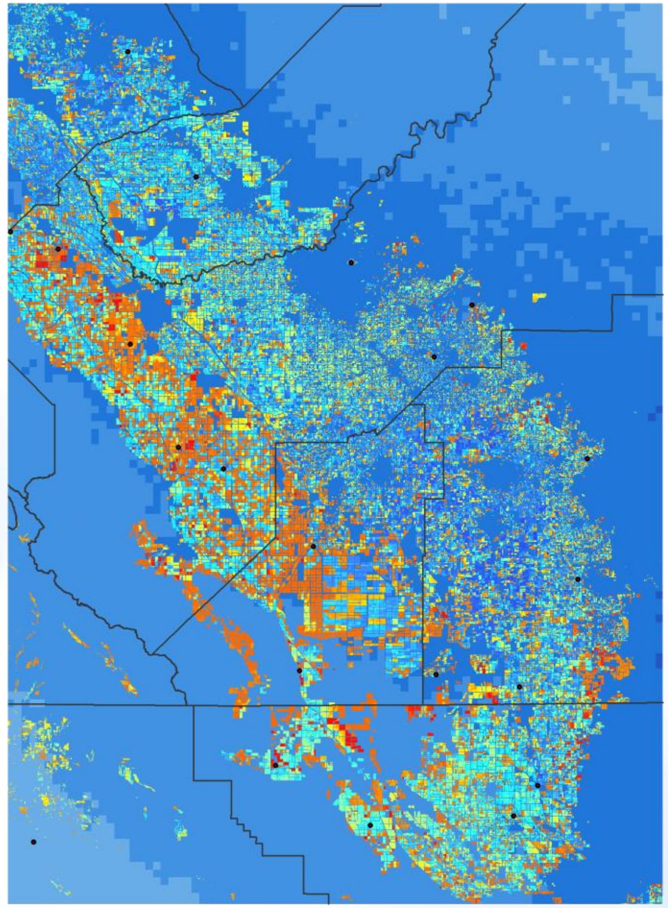


Landsat 5/7/8

MODIS,Terra & Aqua



Sentinel-2A/2B



CIMIS Station

Spatial CIMIS ET_0 (mm)

0 14

SIMS ET_{cb} (mm)

0 10

Approach: Combining CIMIS and Satellite Data

$$ET_{cb\text{-}a} = ET_o * K_{cb}$$

<u>CIMIS</u>

(CoAgMet, AgriMet, AZMET)

<u>satellite</u>

Standard K_c Profile (manual)

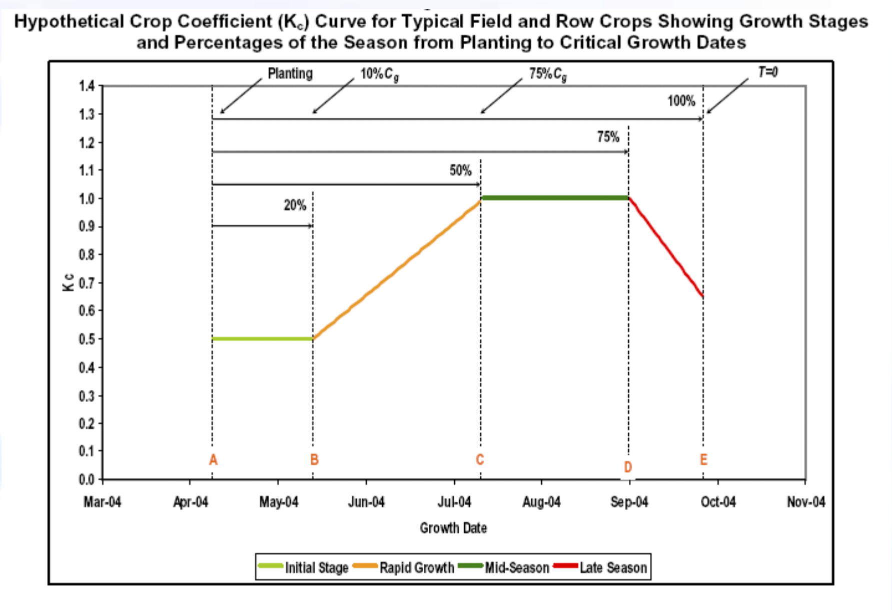
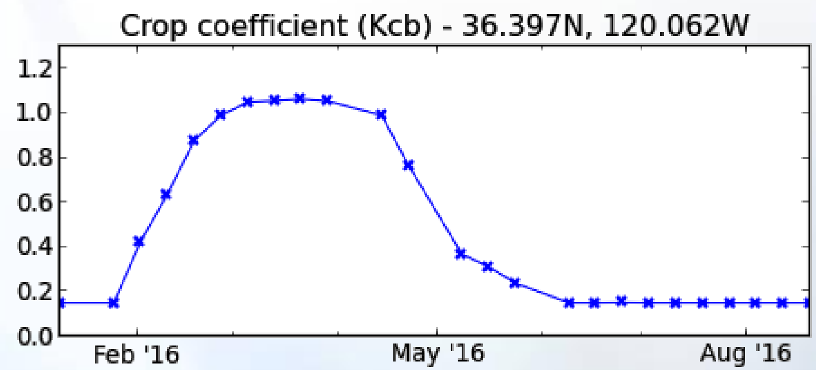


Figure credit: 2005 California Water Plan Update

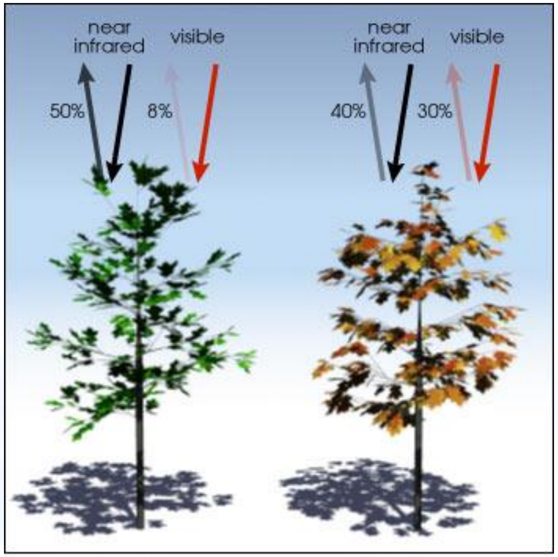
SIMS $K_{cb\text{-}a}$ Profile
(Automated, Satellite-derived)



K_c profiles via reflectance based algorithms ($K_{cb\text{-}a}$)

Remote Sensing of Evapotranspiration: Reflectance-based Approach

Normalized Difference Vegetation Index (NDVI)



$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$ $\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$

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

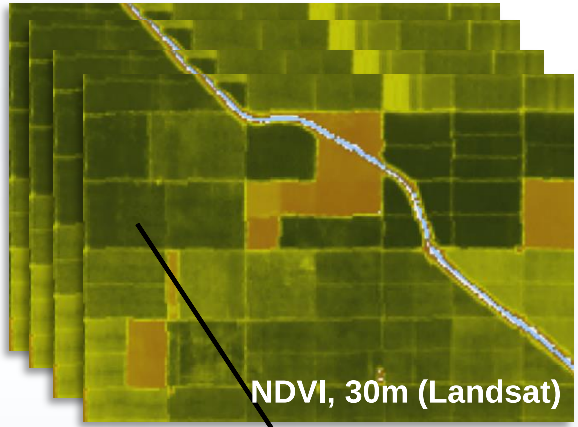
M_L : effect of canopy density on shading / max relative evapotranspiration
K_d : density coefficient
Fc_eff : effective fractional cover
h : crop height

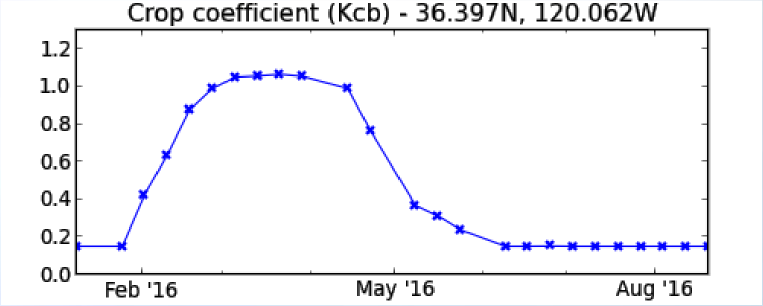
Allen & Pereira, 2009

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

Ag weather network
Allen et al., 1998

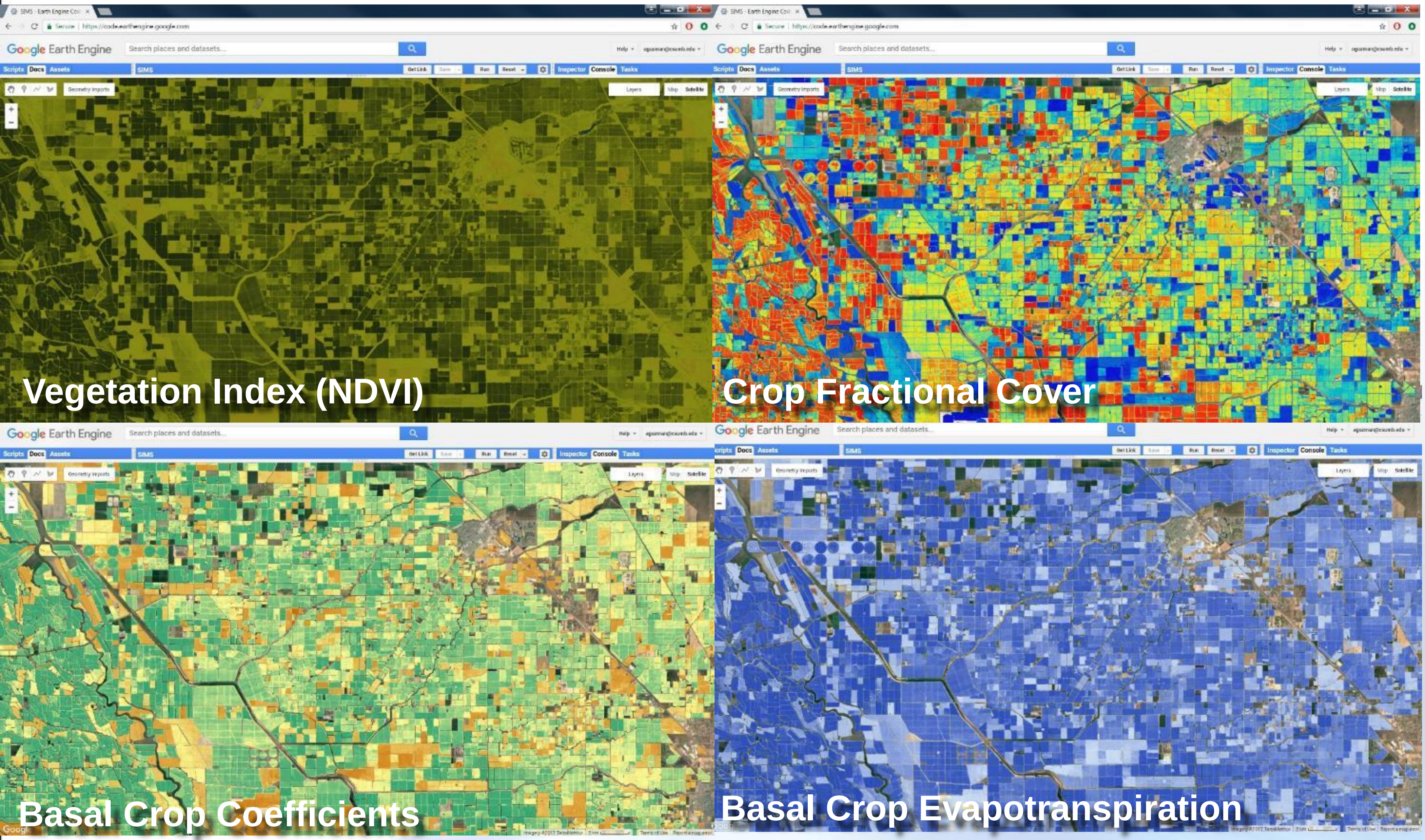
Satellite data





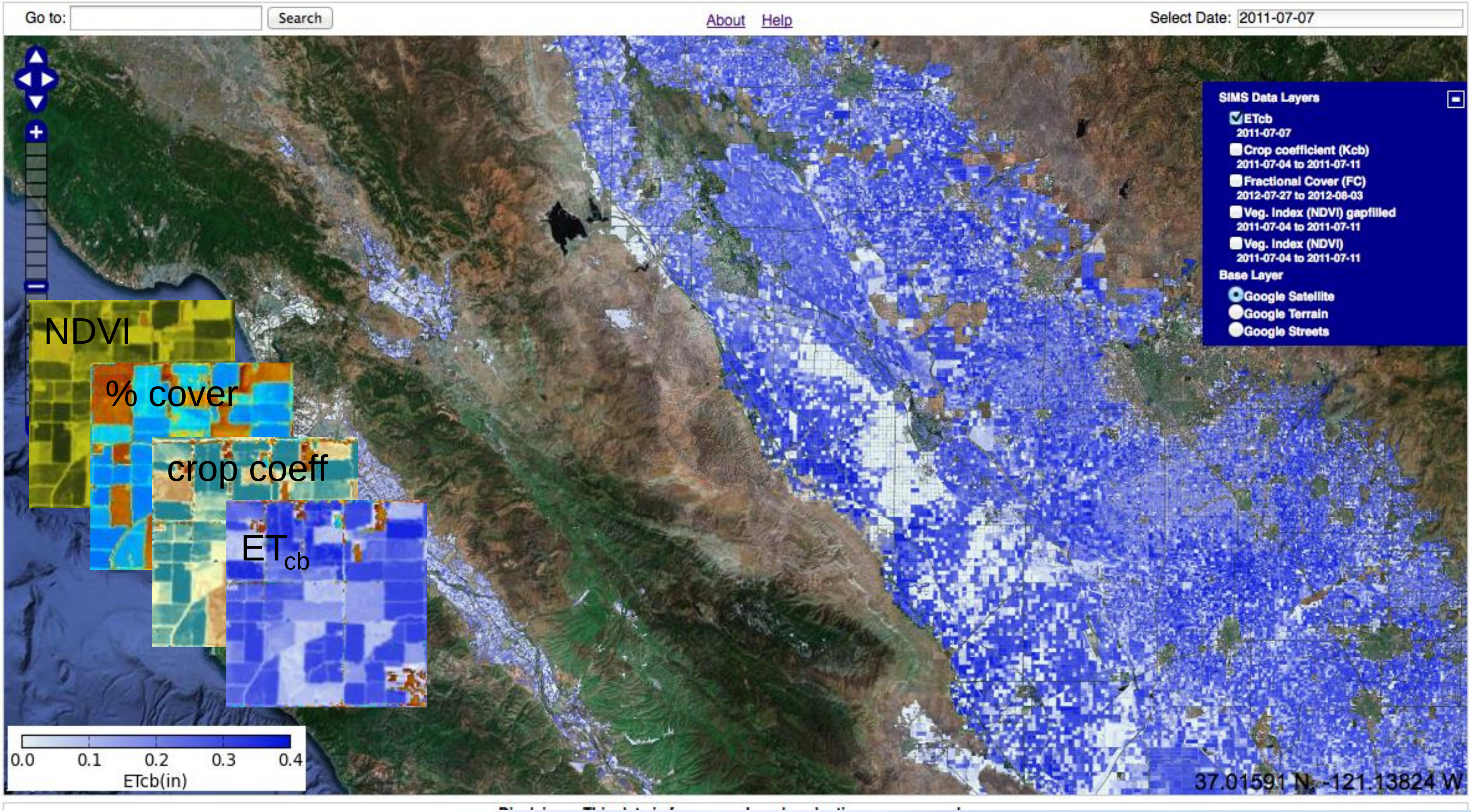
Trout et al., 2008
Johnson and Trout, 2012

Remote Sensing of Evapotranspiration: Reflectance-based Approach

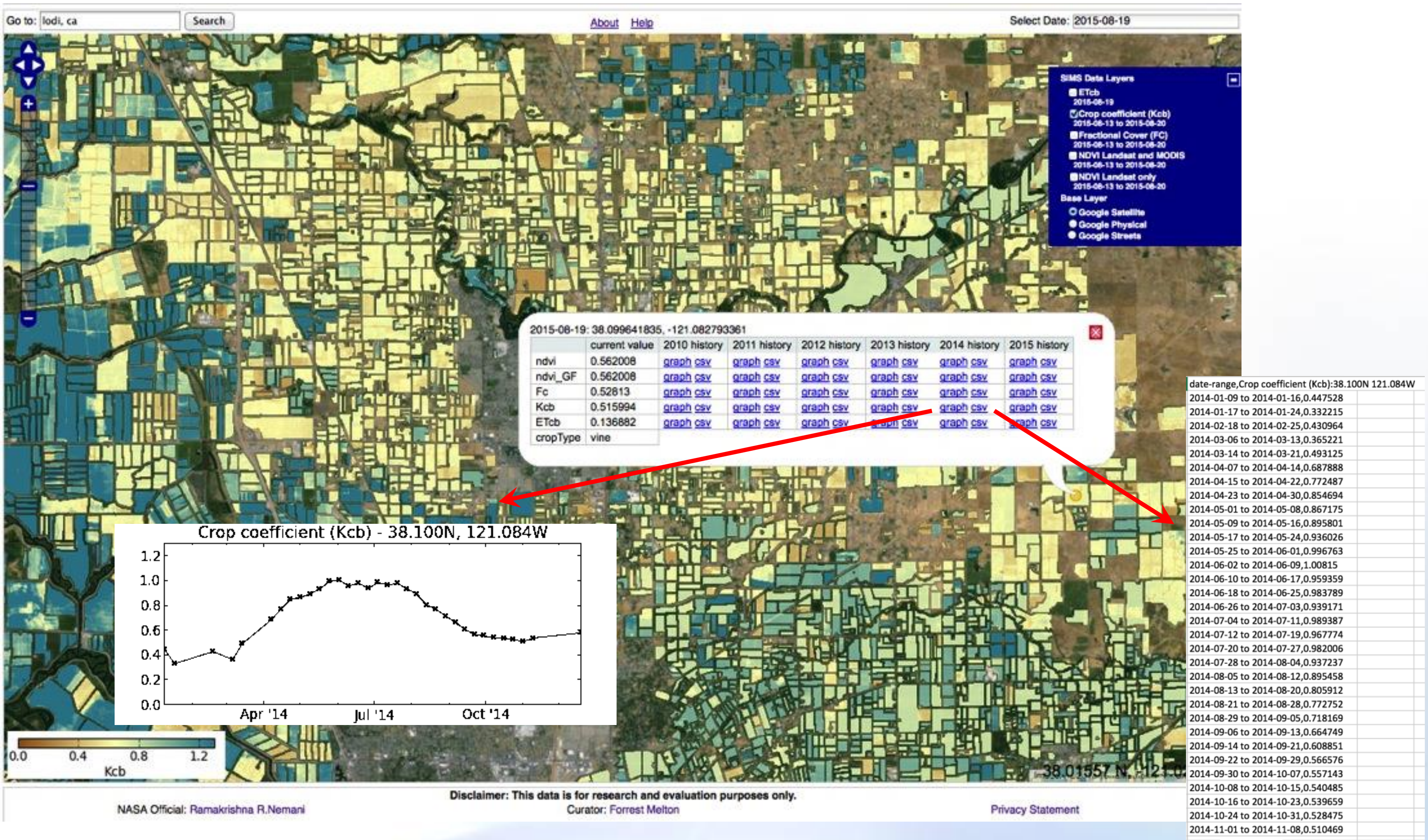


Satellite Irrigation Management Support (SIMS)

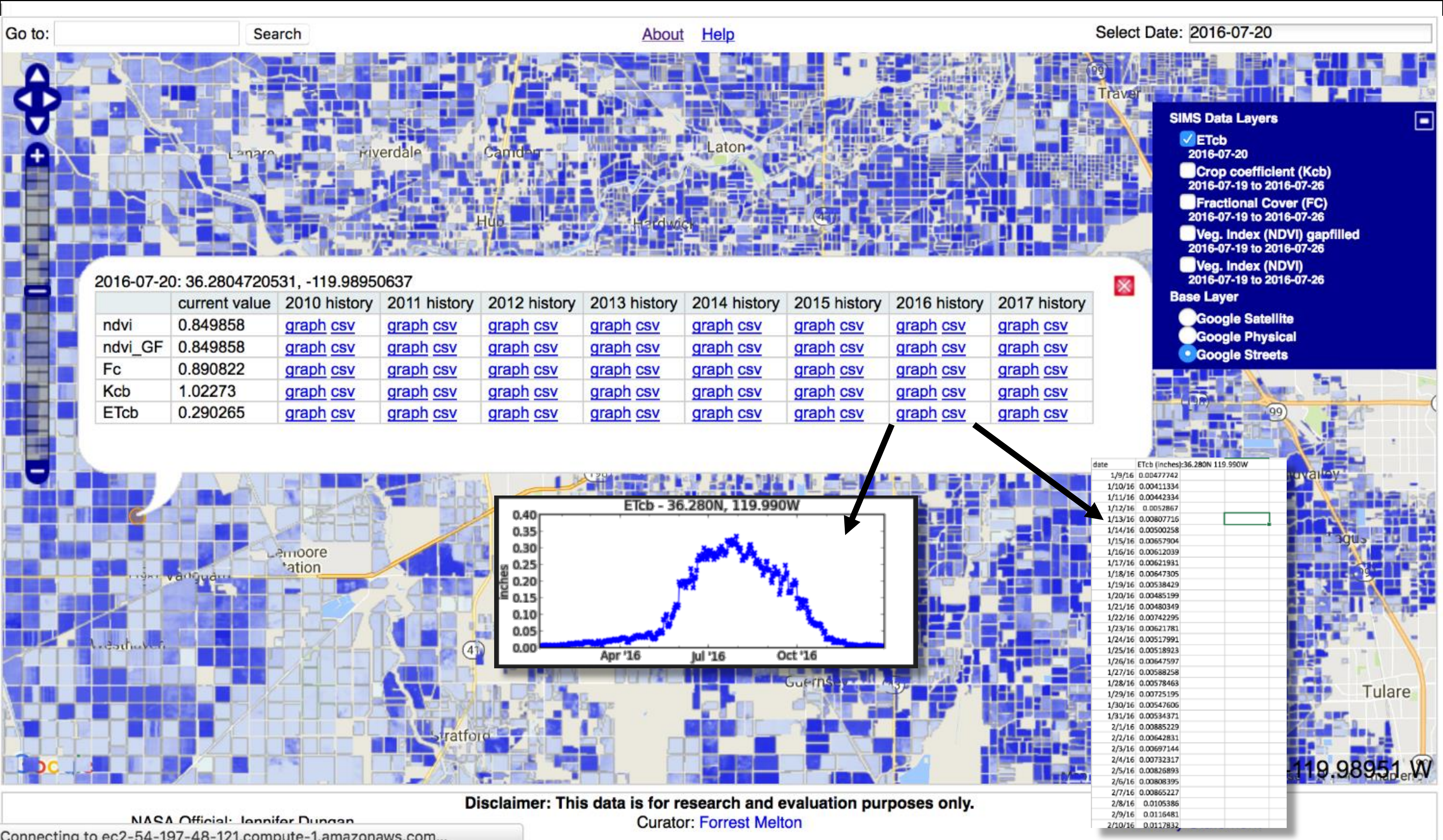
http://ecocast.arc.nasa.gov/dgw/sims/



SIMS Crop Coefficients (K_{cb})



SIMS Daily Crop ET_{cb}



	current value	2010 history	2011 history	2012 history	2013 history	2014 history	2015 history	2016 history	2017 history
ndvi	0.849858	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv
ndvi_GF	0.849858	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv
Fc	0.890822	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv
Kcb	1.02273	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv
ETcb	0.290265	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv	graph csv

date	ETcb (inches):36.280N 119.990W
1/9/16	0.00477742
1/10/16	0.00411334
1/11/16	0.00442334
1/12/16	0.0052867
1/13/16	0.00807716
1/14/16	0.00500258
1/15/16	0.00657904
1/16/16	0.00612039
1/17/16	0.00621931
1/18/16	0.00647305
1/19/16	0.00538429
1/20/16	0.00485199
1/21/16	0.00480349
1/22/16	0.00742295
1/23/16	0.00621781
1/24/16	0.00517991
1/25/16	0.00518923
1/26/16	0.00647597
1/27/16	0.00588258
1/28/16	0.00578463
1/29/16	0.00725195
1/30/16	0.00547606
1/31/16	0.00534371
2/1/16	0.00885229
2/2/16	0.00642831
2/3/16	0.00697144
2/4/16	0.00732317
2/5/16	0.00826893
2/6/16	0.00808395
2/7/16	0.00865227
2/8/16	0.0105386
2/9/16	0.0116481
2/10/16	0.0117832

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

Accuracy Assessment Summary

Seasonal Accuracies

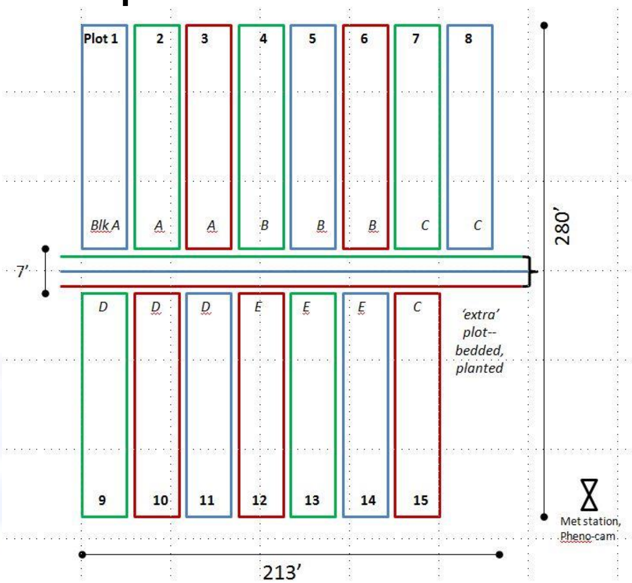
- Accuracies relative to ground measurements; approaching accuracy of ground measurements (lysimeter 5%, eddy covariance ~10%)
- SIMS seasonal ET_{cb} mean absolute error (MAE) is less than +/- 15% with ~12% positive bias error across 14 crops studied to date
- For well-irrigated crops, SIMS ET_{cb} MAE is less than 10% with 6% positive bias error
- For individual fields, combining SIMS ET_{cb} with IrriQuest soil water balance model reduces MAE to less than 8% across with less than 2% bias error all crop types studied → highly accurate for field-scale evaluation of on-farm water use efficiency

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



<u>Treatments:</u>

- Standard practice
- SIMS
- CropManage

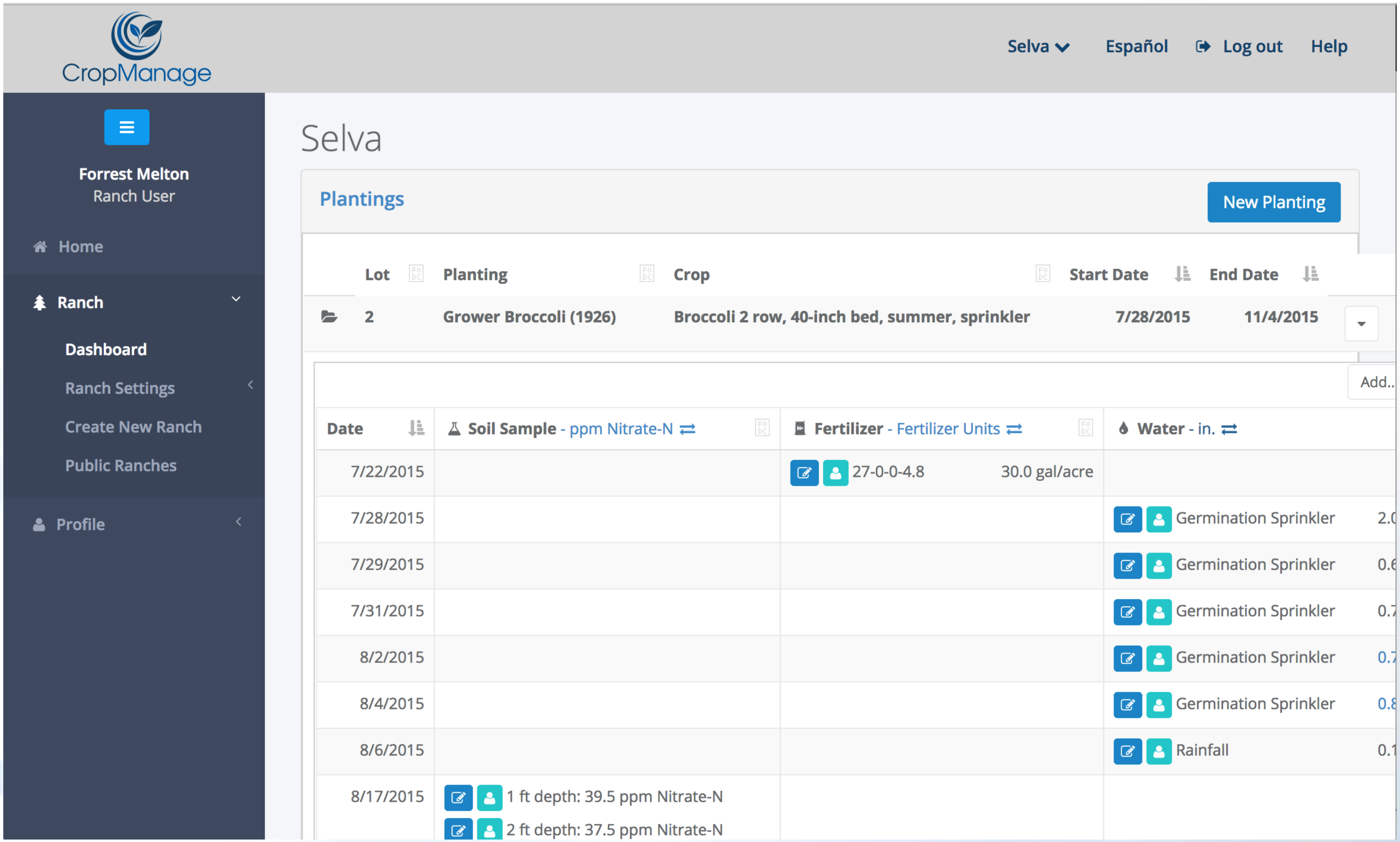
Results to date for reductions in applied water:

- 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.

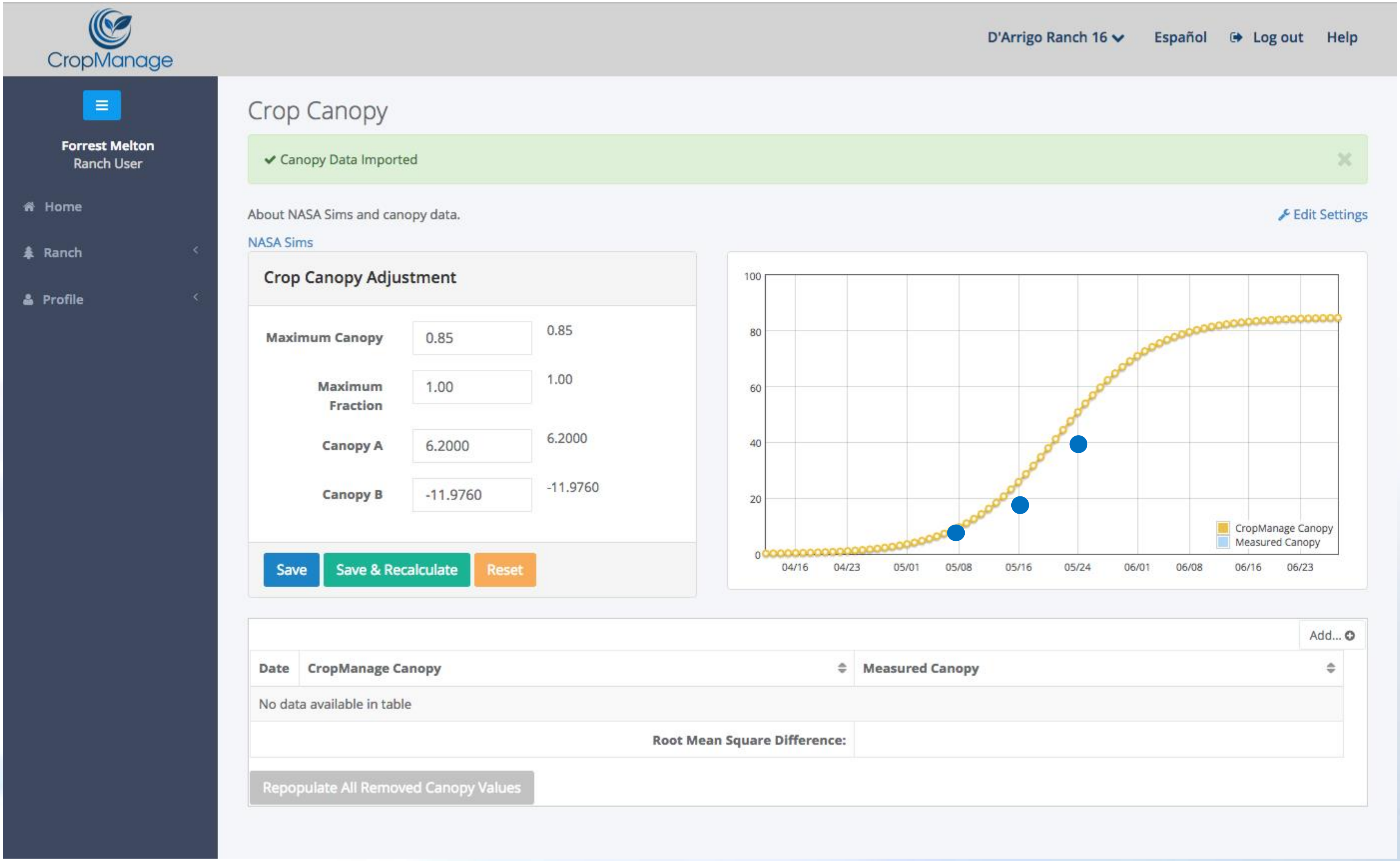
Web Data Services for Integration with Irrigation & Nutrient Management Software



https://cropmanage.ucanr.edu/

Michael Cahn, UCCE

Crop Manage – SIMS API

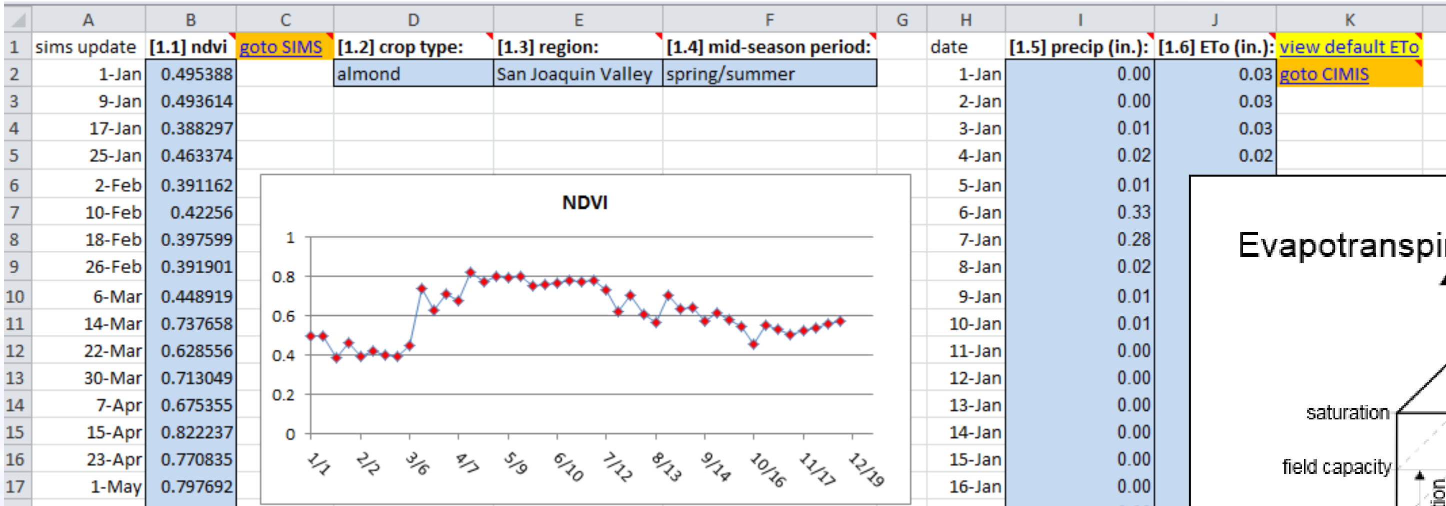


https://cropmanage.ucanr.edu/

Michael Cahn, UCCE

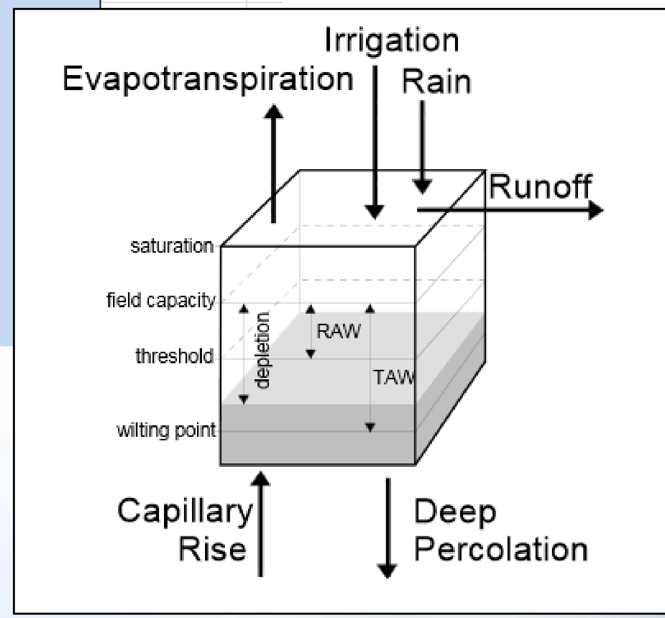
Irri*Quest*
On-farm Water Use Efficiency Calculator

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			

Soil water balance model:



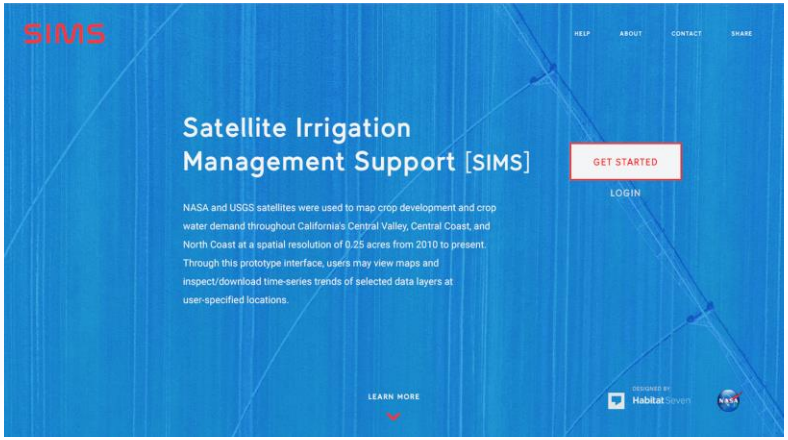
Outputs:
- Crop ET (daily, seasonal)
- Crop Consumptive Use Fraction
- Agronomic Water Use Fraction

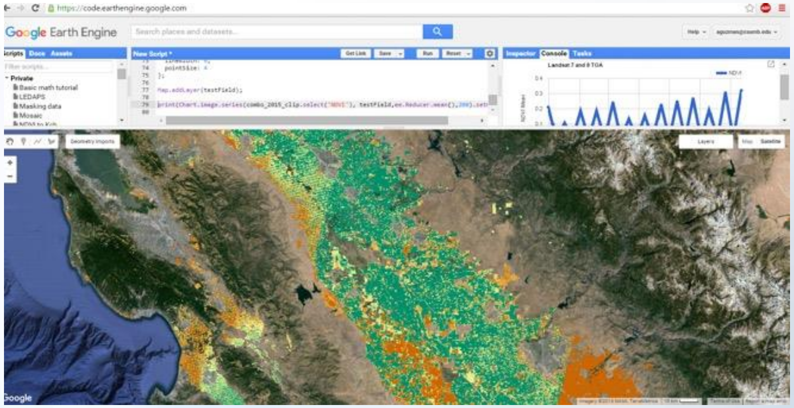
- Derives stress & evaporation coefficients: Ks, Ke
- Calculates adjusted ET as: $ET_c = (K_s*K_{cb} + K_e)*ET_o$

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

SIMS 2.0: Moving SIMS to the Cloud

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





Questions?

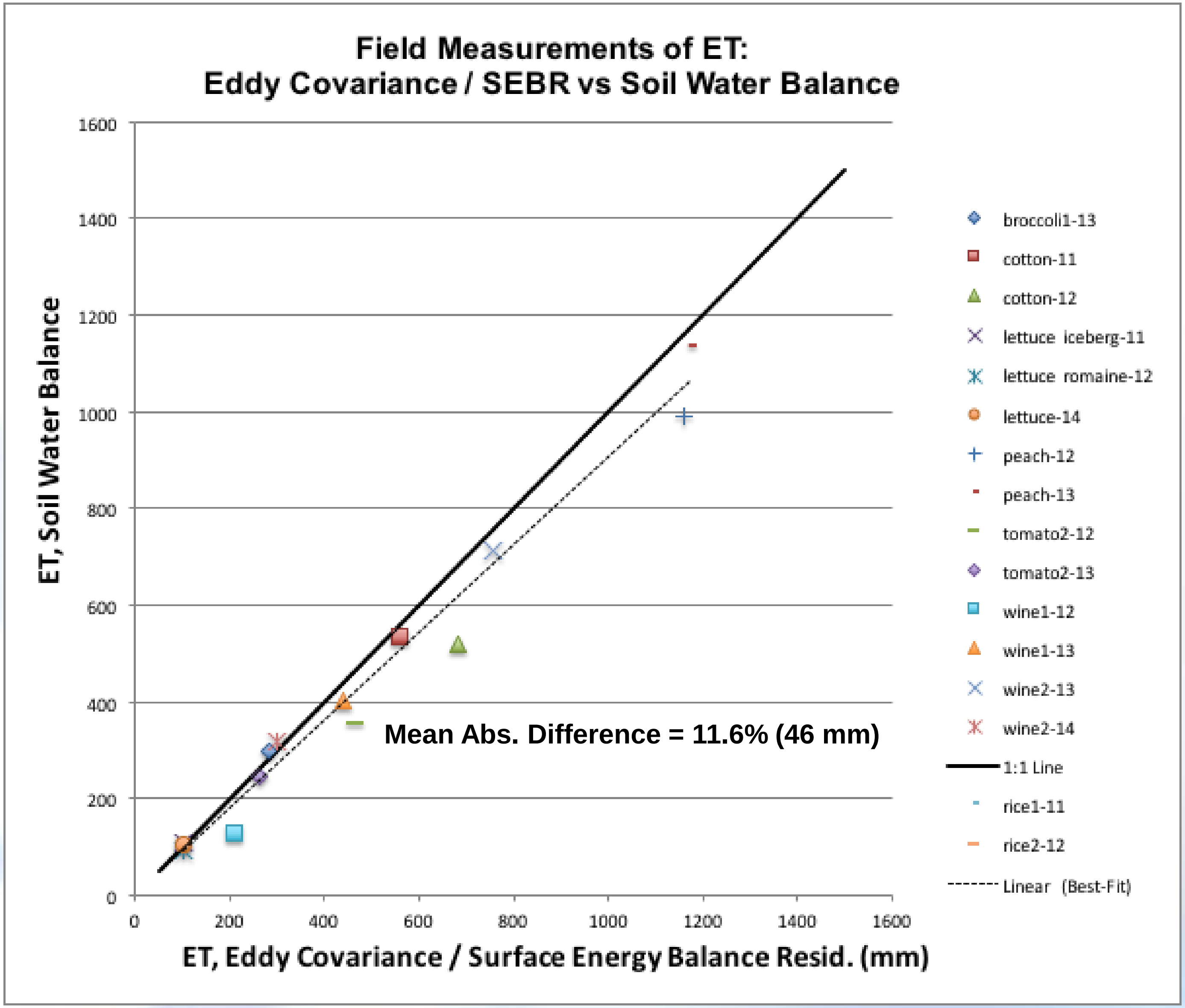
For more information:
forrest.s.melton@nasa.gov
http://appliedsciences.nasa.gov/

Support from the NASA Applied Sciences Program, WWAO, the California Department of Water Resources, CDFA, and the CSU Agricultural Research Institute

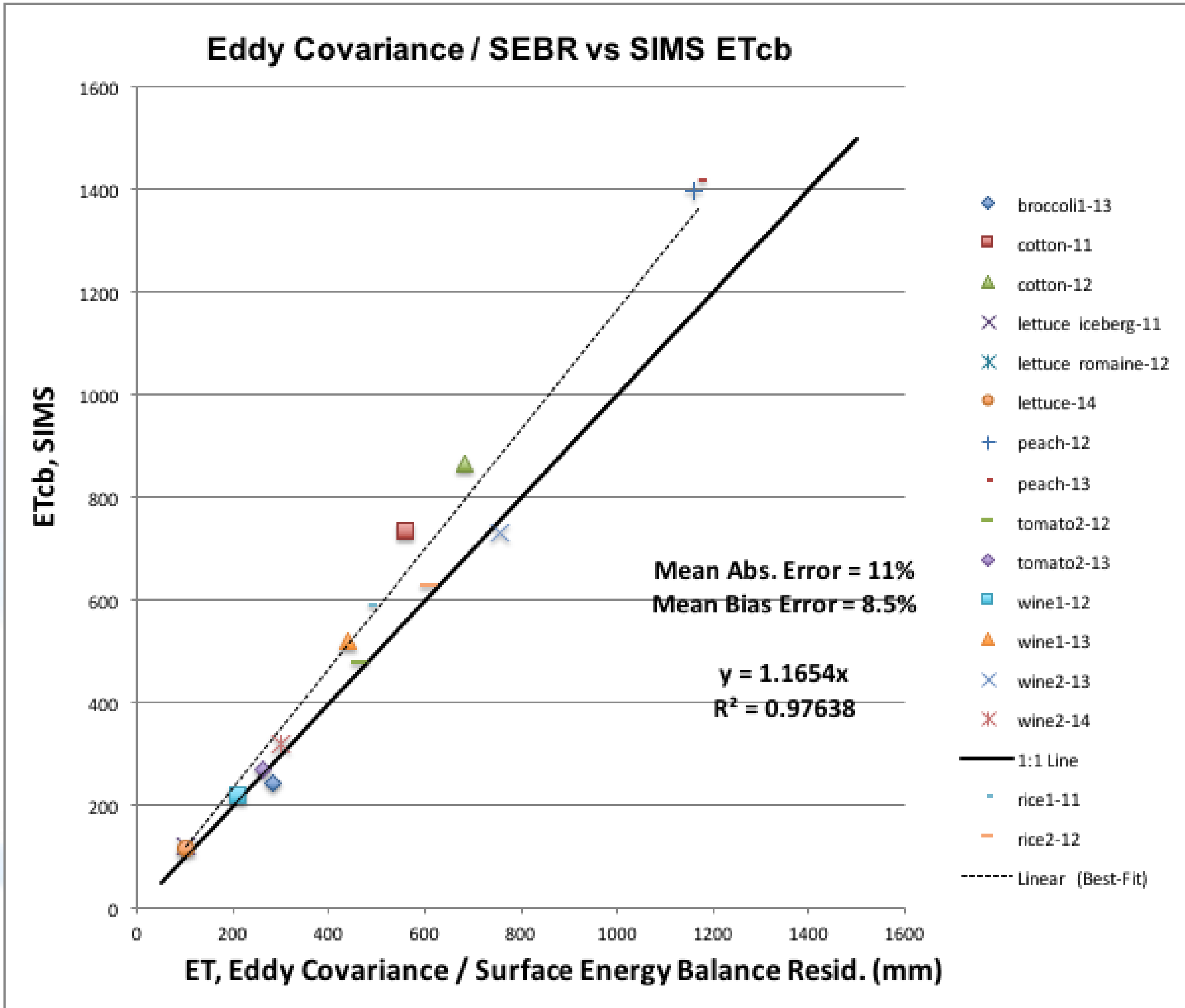
A Few Definitions

- **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-a}):** ET_{cb-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-a})
- **Actual crop evapotranspiration (ET_a):** Total crop evapotranspiration, including soil evaporation and crop stress

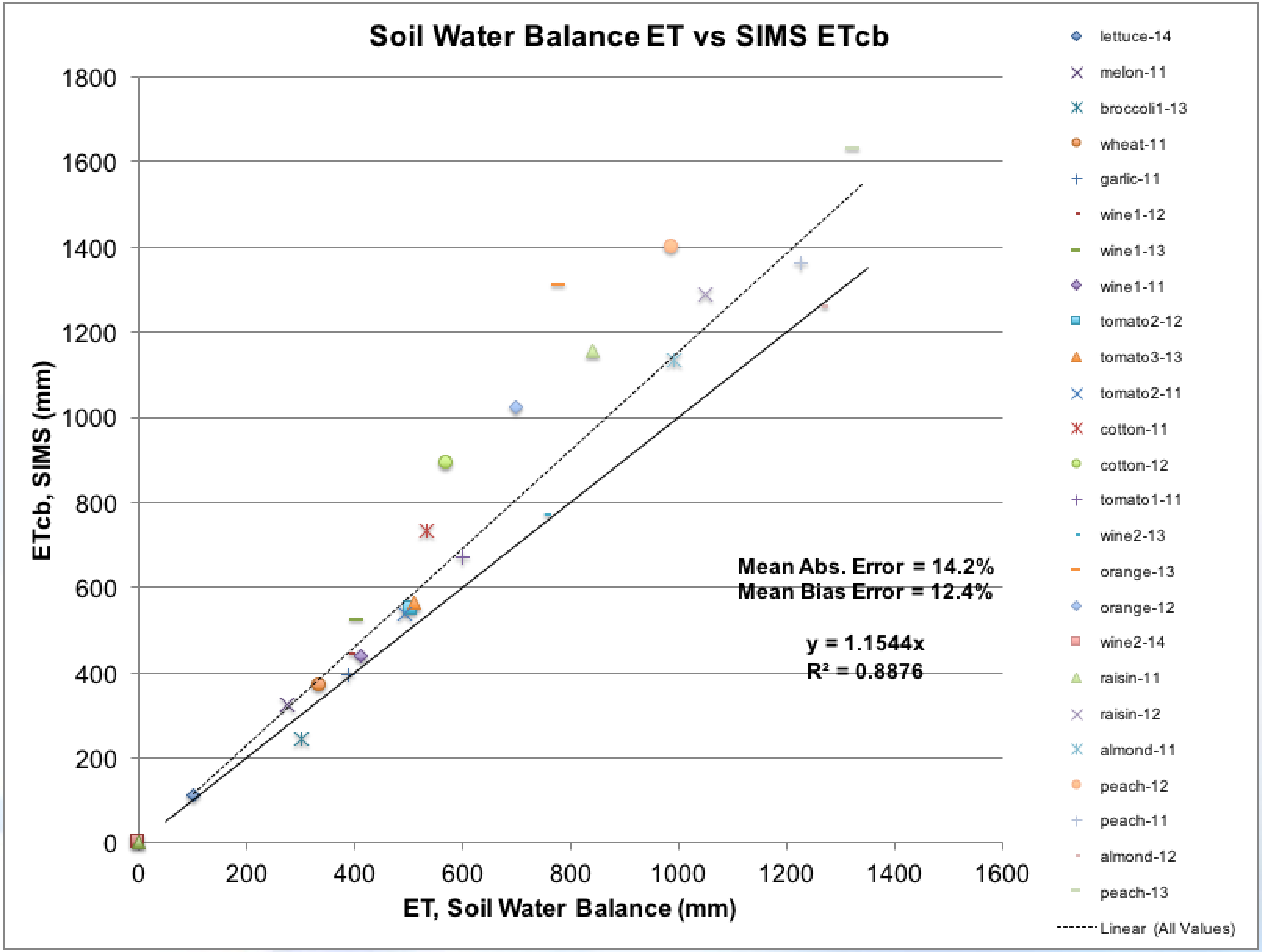
Results: Ground Measurements



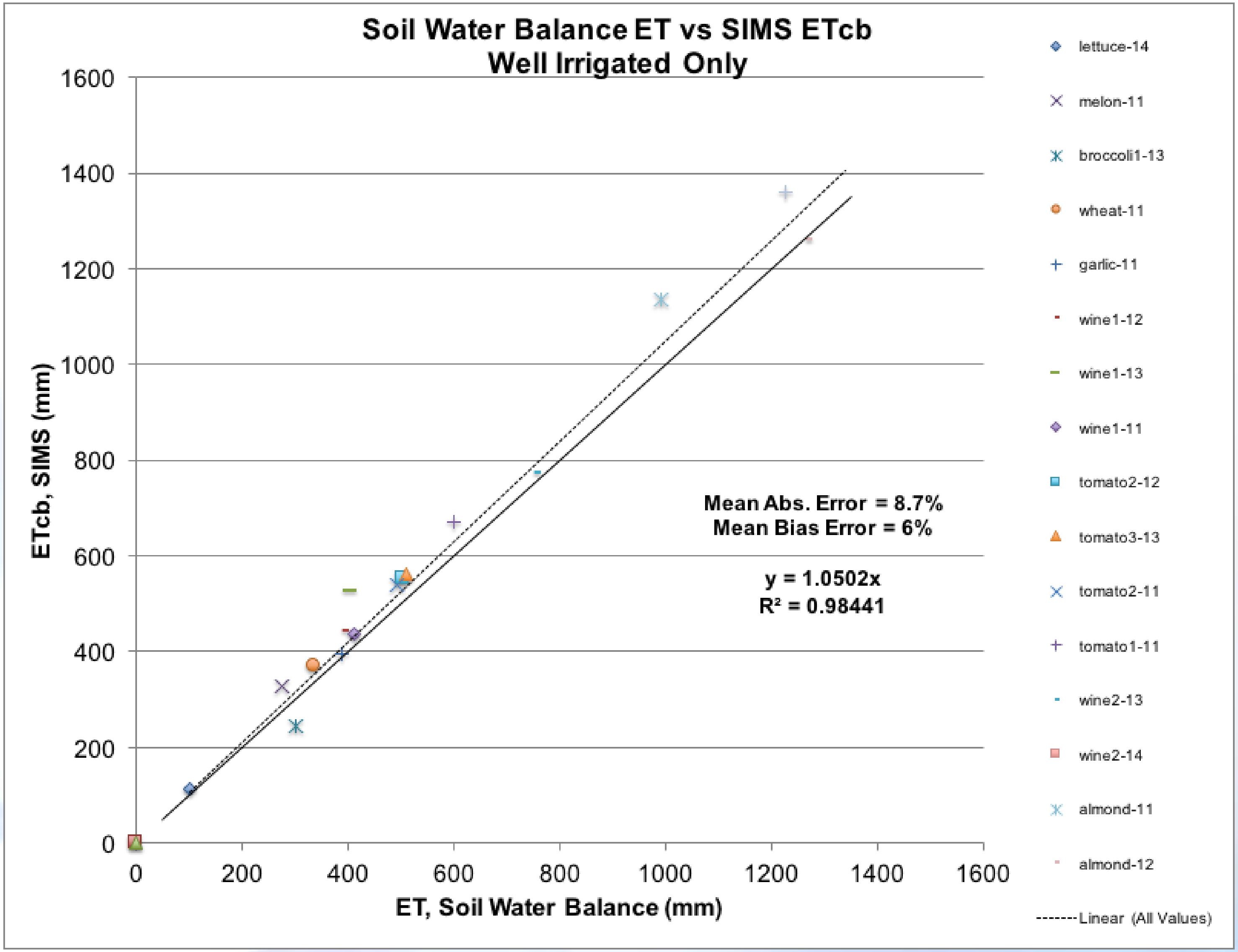
Results: Eddy Covariance vs SIMS ET_{cb}



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

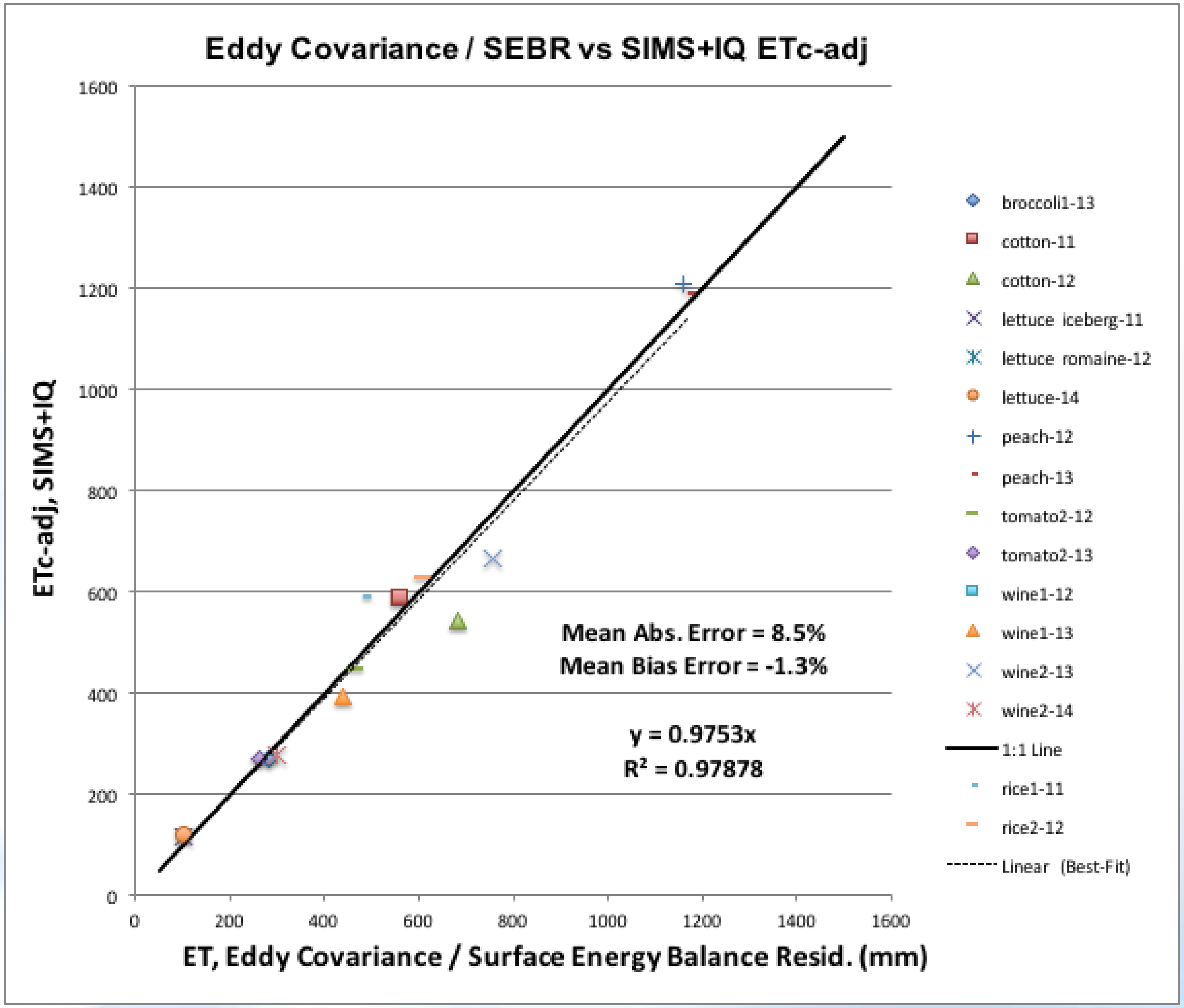


Results: Field Soil Water Balance vs SIMS ET_{cb}



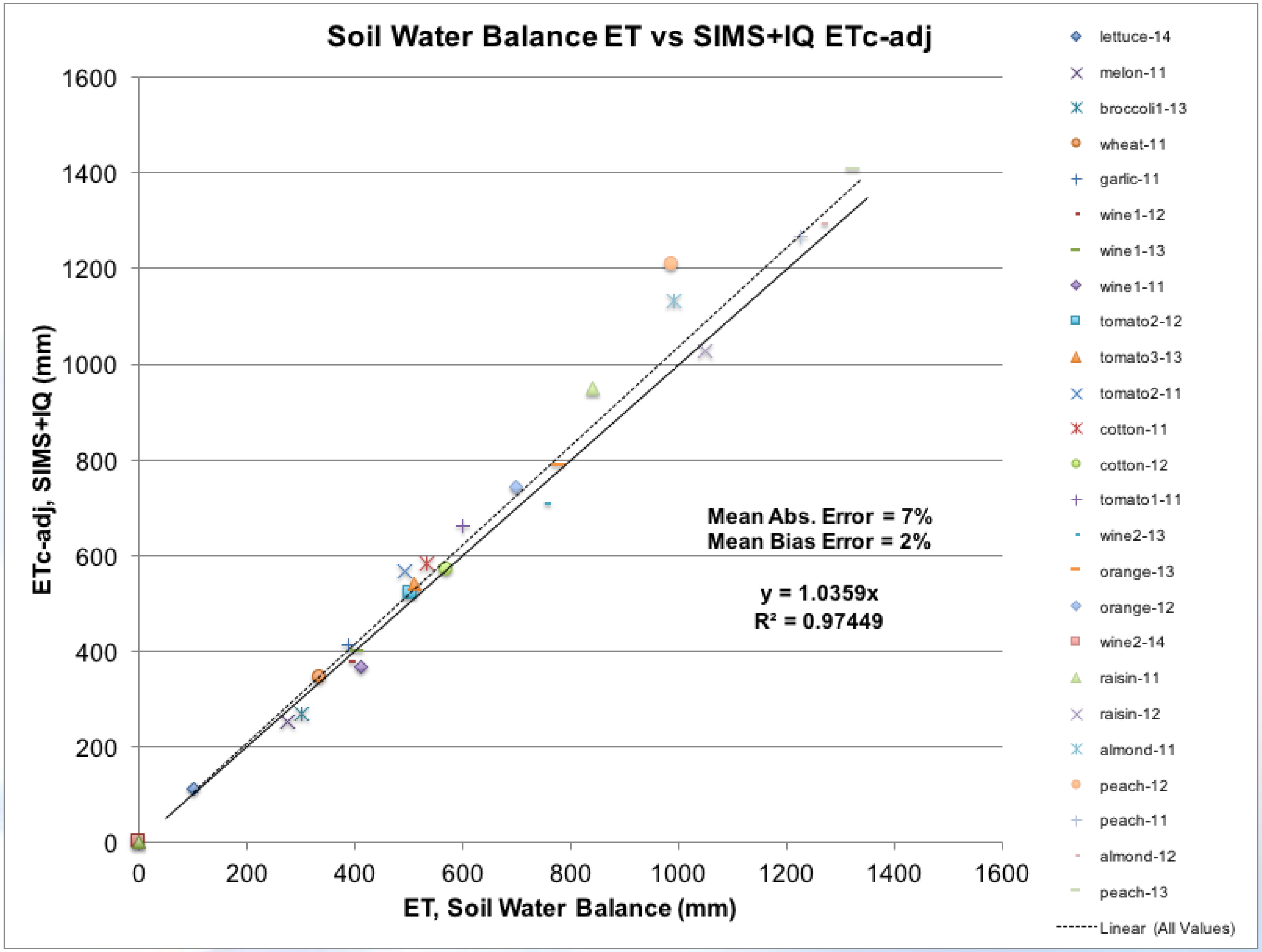
Results: Eddy Covariance vs SIMS $ET_{c\text{-}adj}$

SIMS + IrriQuest



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

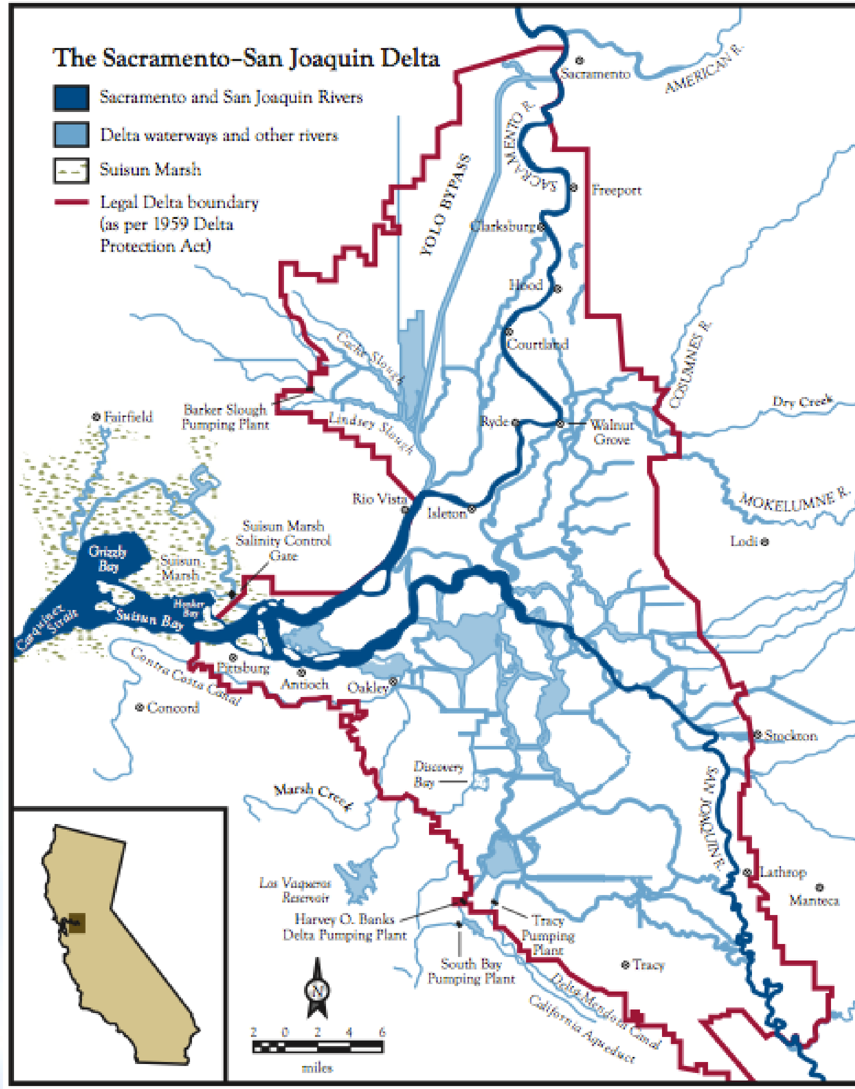
SIMS + IrriQuest



ET Intercomparison Study for the SF Bay Delta

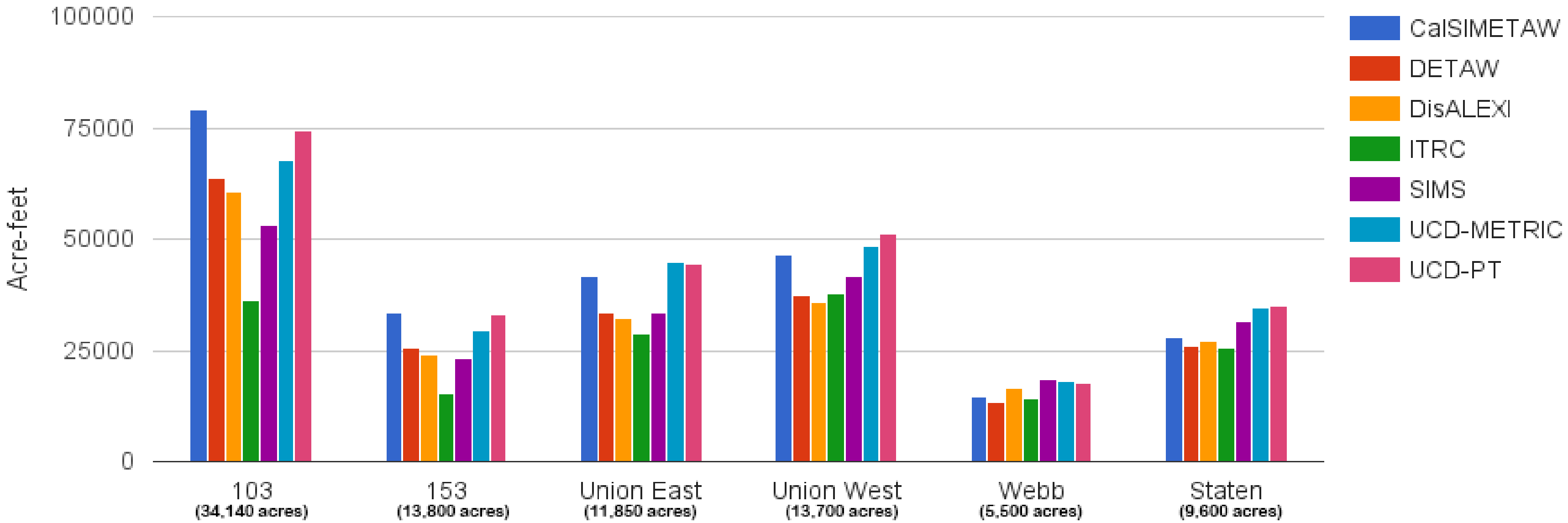
Methods compared:

- 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, Quinn Hart, UC Davis

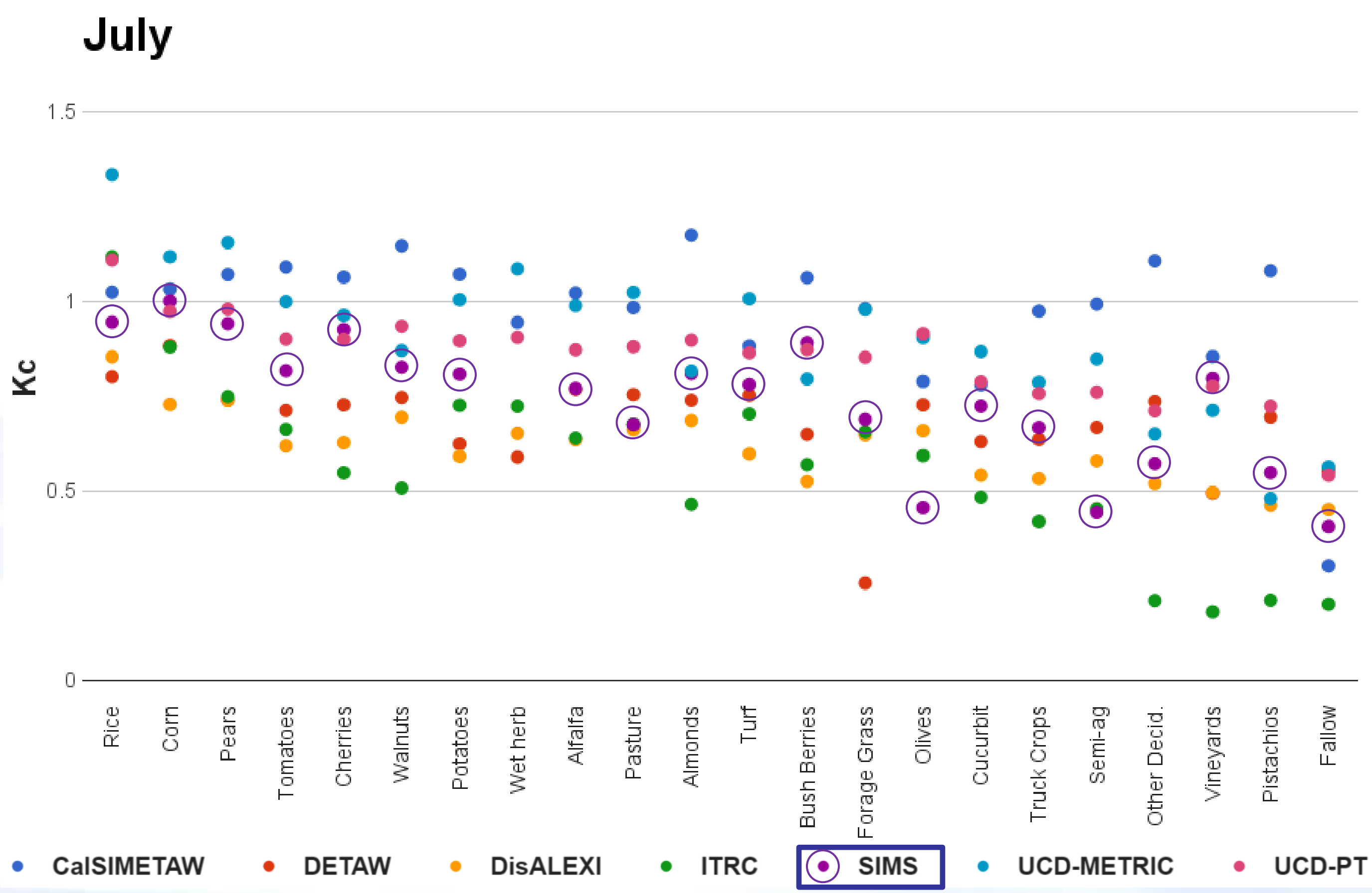
Total Annual ET by CA Delta Subregion



Preliminary results from 1st year of 2-year study

- SIMS (purple) is close to mid-point between two versions of METRIC run by two different expert groups for 5 of the 6 sub-regions: ITRC (green) and UC Davis (aqua blue)

Average Observed ETrf (Kc) by Crop Type for CA Delta

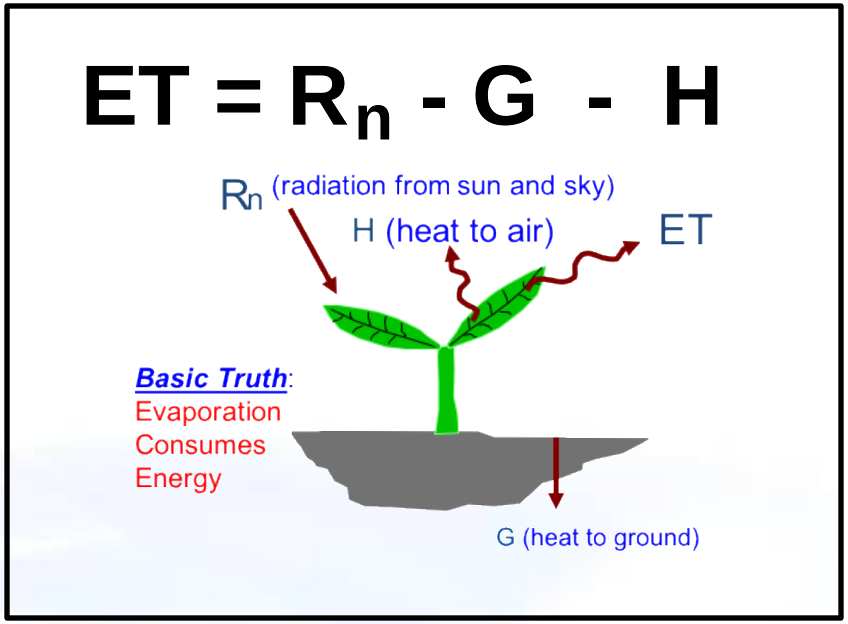


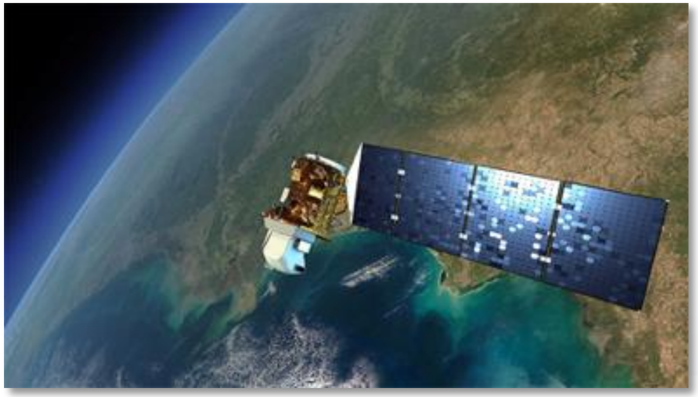
- **SIMS close to median of model ensemble for most crop types**

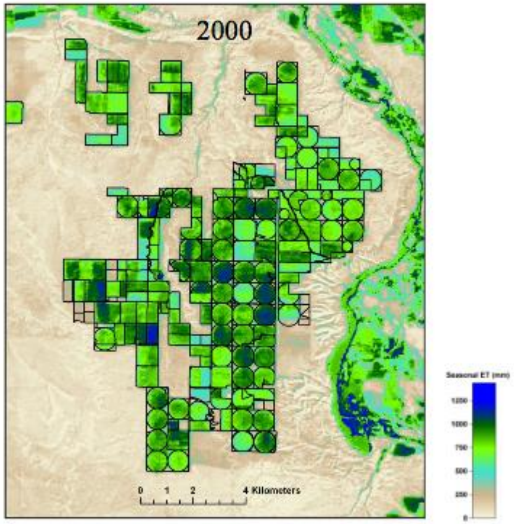
Preliminary results from first year of two-year study

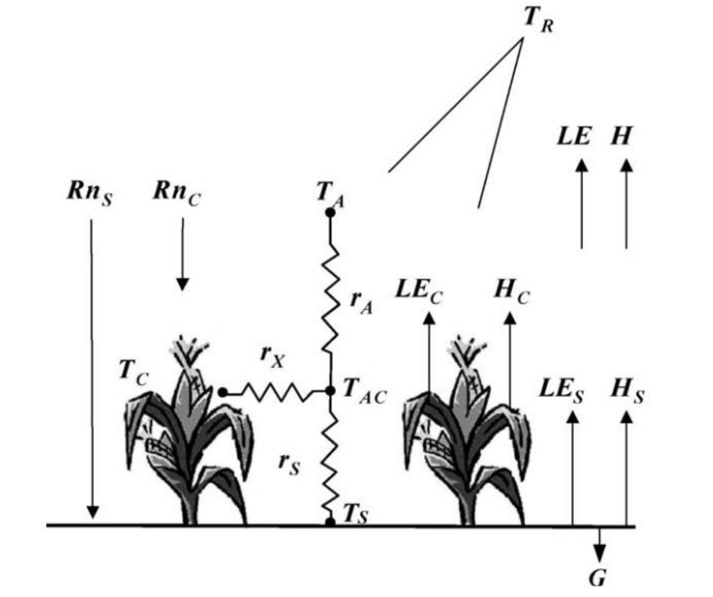
Medillin et al., 2016; https://watershed.ucdavis.edu/project/delta-et

Remote Sensing of Evapotranspiration: Energy Balance Approach







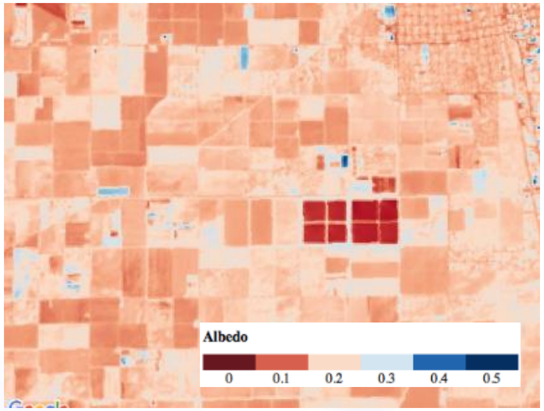


Norman et al., 1995; Bastiaanssen et al., 1998; Allen et al., 2007

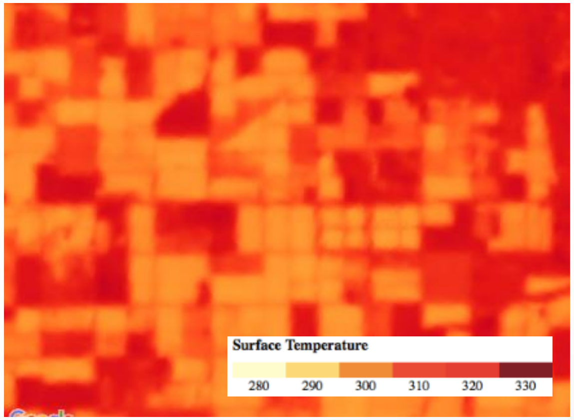
Remote Sensing of Evapotranspiration: Energy Balance Approach

True Color

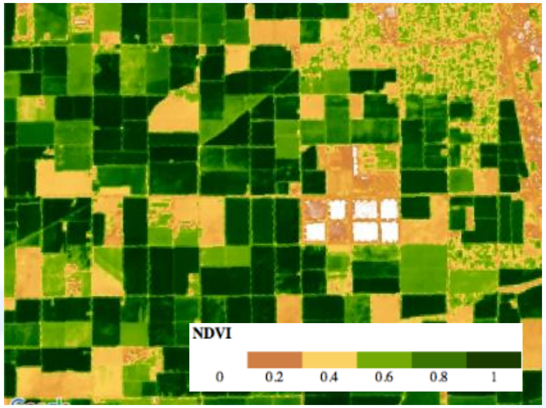
Albedo



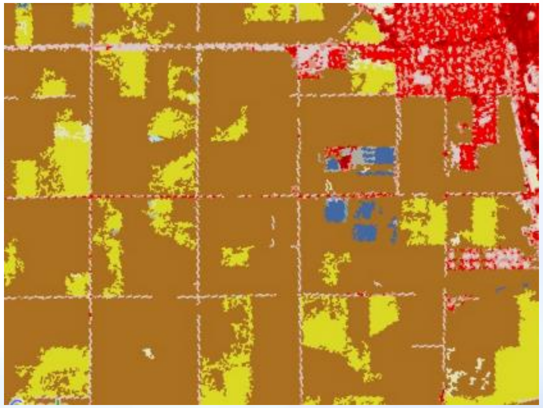
Land Surface Temperature



Vegetation Index (NDVI)



Land Cover



Evapotranspiration