Remote Sensing of California Agriculture for Drought Impact Assessment and Mitigation

Forrest Melton, NASA ARC-CREST
forrest.s.melton@nasa.gov

Forrest Melton, Lee Johnson, Kirk Post, NASA ARC-CREST / CSU Monterey Bay
James Verdin (Project PI), Prasad Thenkabail, John Dwyer, Cynthia Wallace, USGS
Rick Mueller and Audra Zakzeski, USDA NASS
Rama Nemani, NASA Ames Research Center
Kent Frame, Bekele Temesgen, Jeanine Jones, California Department of Water Resources

Support from NASA Applied Sciences Program and NIDIS

Drought Impacts on Land Fallowing

- **Background:** Mapping of fallowed areas during drought identified as a research priority for NIDIS by CA Department of Water Resources (CDWR)

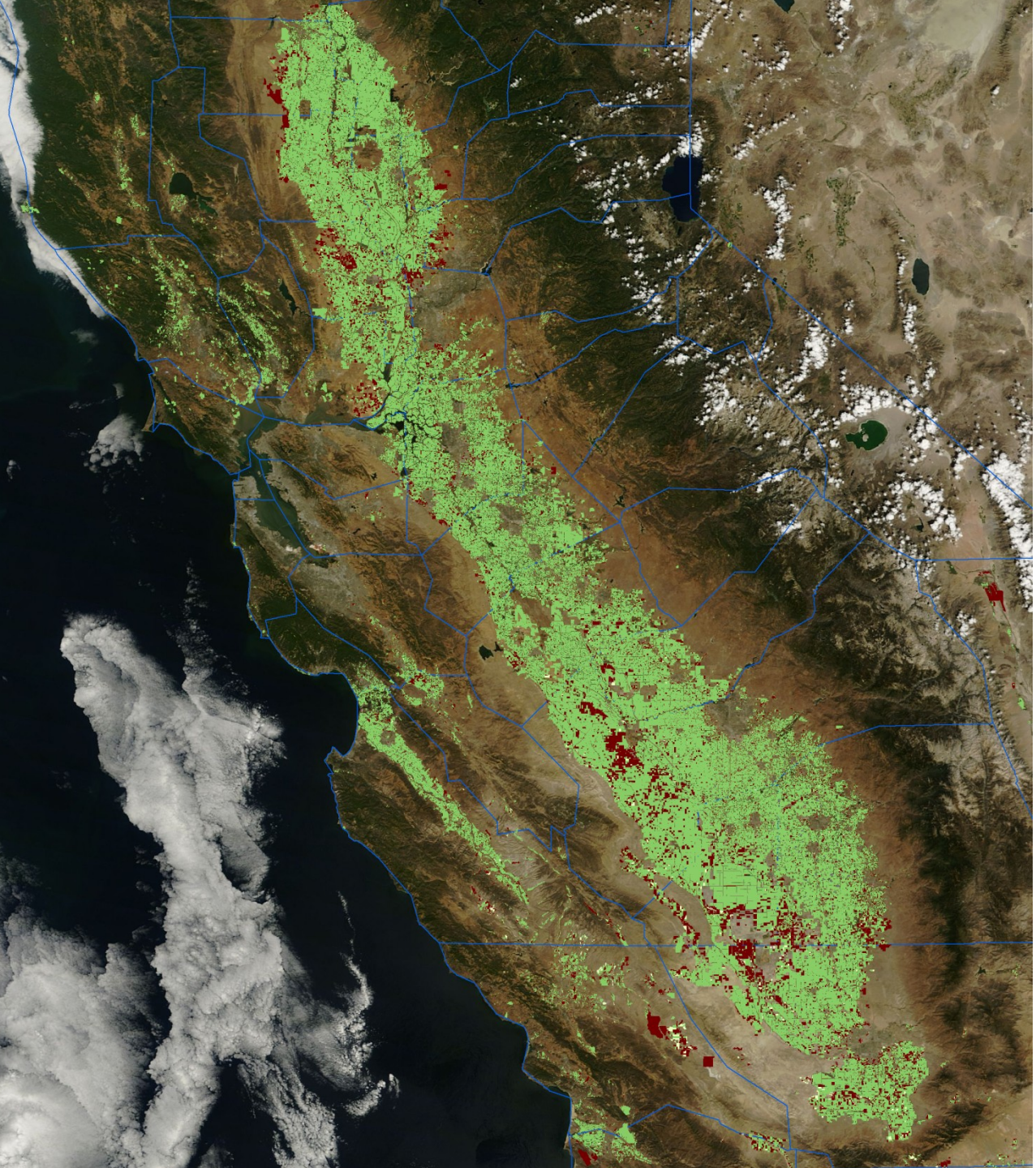
- **Information needed:** Product similar to ‘idle lands’ class in NASS crop data layer for California, but on a monthly basis during growing season(s)

- **Project objective:** Apply satellite data to provide information that will allow CDWR and other stakeholders to identify extent of, or change from historical conditions in, fallowed acreage due to water shortage

Drought Impacts on Land Fallowing

- **Decisions supported**:
  - State proclamations of emergency pursuant to the California Emergency Services Act and allocation of drought relief funding
  - State priorities for providing assistance with and processing of local water transfer requests
  - State concurrence in county-level requests for USDA drought disaster designations

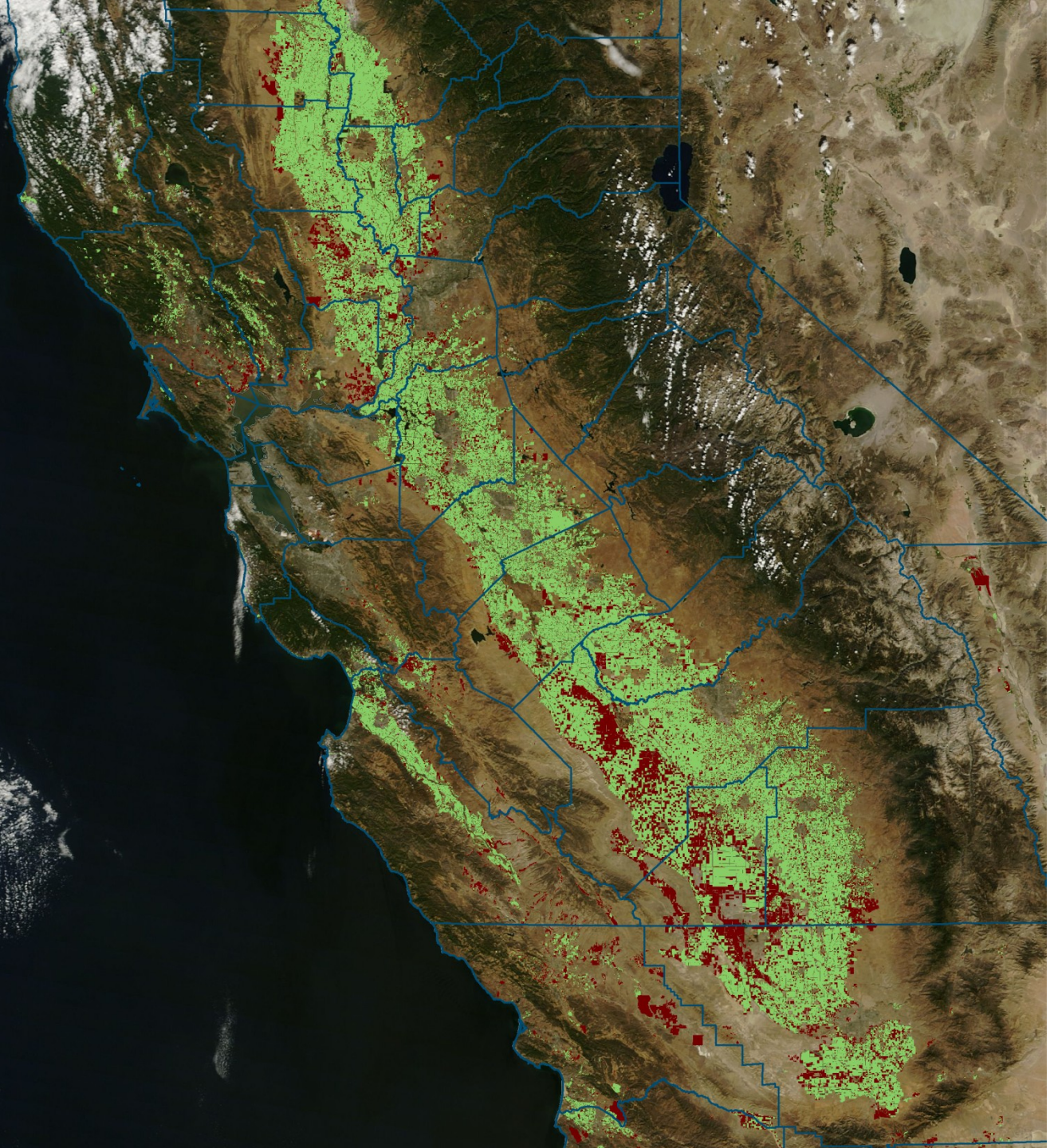
- **Limitations of previously available information:**
  - USDA NASS Cropland data layer (CDL) considered confidential and market sensitive during the growing season
  - Fallowed acreage reports from other sources do not follow standard definitions or data collection methods → often generate conflicting estimates



Sept 22, 2011
Central Valley
Summer Conditions
(June 1 – Sept 22)

- **Summer Idle**
- **Cultivated**
- **Emergent**
- **County Bndry**

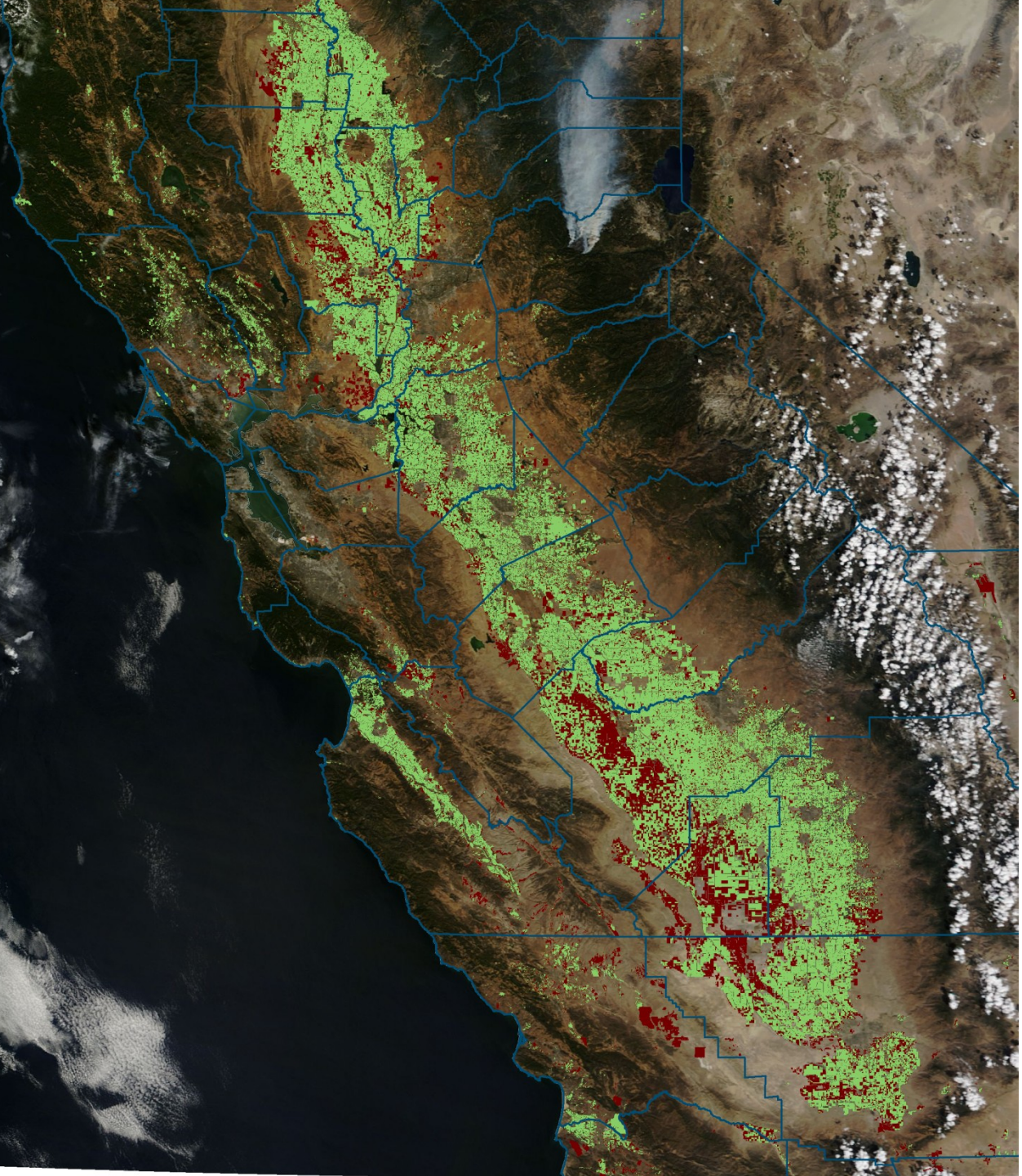
Data source: NASA / CSU Monterey Bay. Map derived from data from Landsat 7, Landsat 8, Terra and Aqua satellites. Satellite observations for ~200,000 fields obtained every 8 days.



Sept 22, 2013
Central Valley
Summer Conditions
(June 1 – Sept 22)

- **Summer Idle**
- **Cultivated**
- **Emergent**
- **County Bndry**

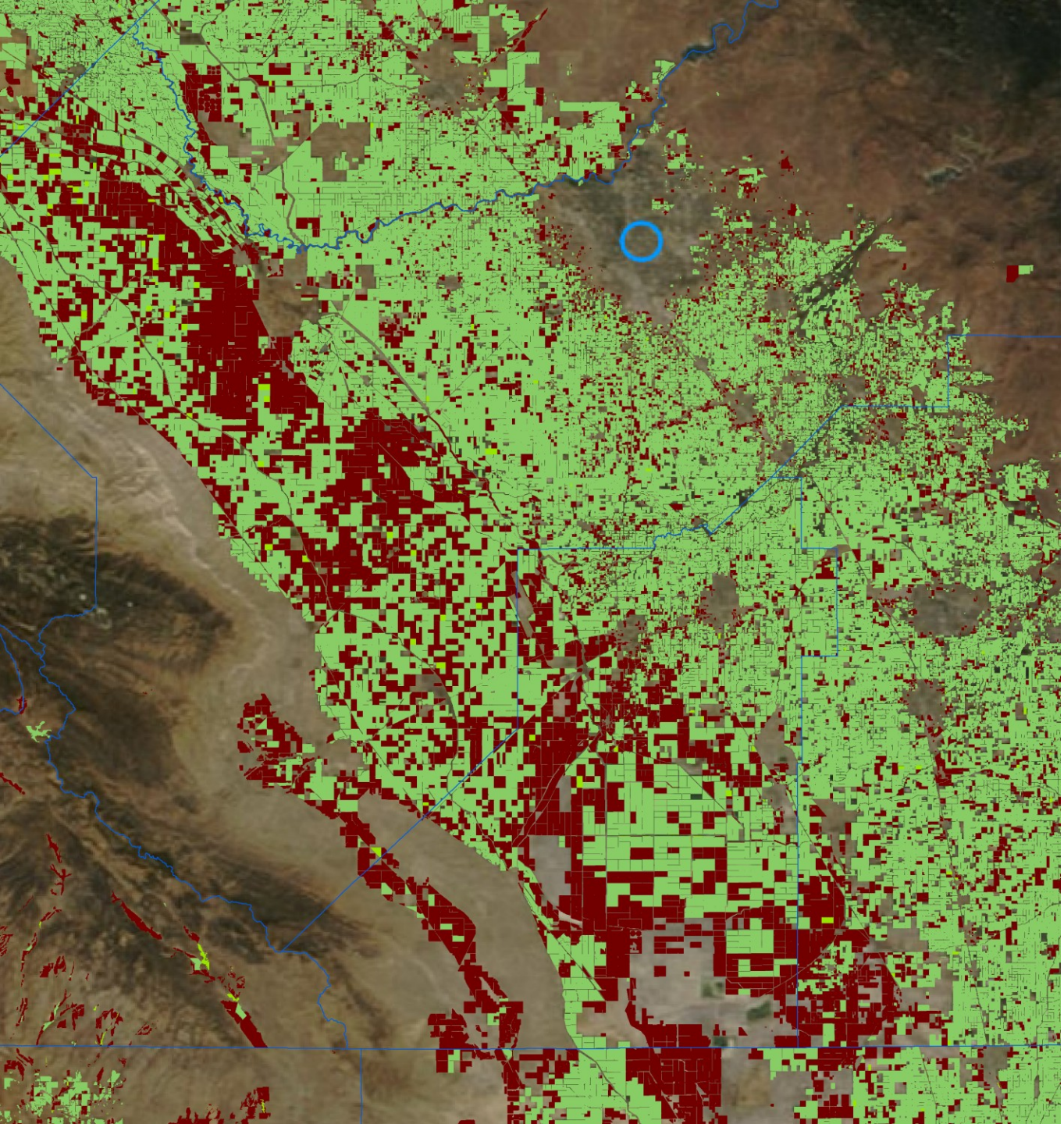
Data source: NASA / CSU Monterey Bay. Map derived from data from Landsat 7, Landsat 8, Terra and Aqua satellites. Satellite observations for ~200,000 fields obtained every 8 days.



Sept 22, 2014
Central Valley
Summer Conditions
(June 1 – Sept 22)

- **Summer Idle**
- **Cultivated**
- **Emergent**
- **County Bndry**

Data source: NASA / CSU Monterey Bay. Map derived from data from Landsat 7, Landsat 8, Terra and Aqua satellites. Satellite observations for ~200,000 fields obtained every 8 days.



Sept 22, 2014
San Joaquin Valley
Summer Conditions
(June 1 – Sept 22)

- **Summer Idle**
- **Cultivated**
- **Emergent**
- **County Bndry**

Data source: NASA / CSU Monterey Bay. Map derived from data from Landsat 7, Landsat 8, Terra and Aqua satellites. Satellite observations for ~200,000 fields obtained every 8 days.

Idle Acreage Summary

Central Valley, Total Idle Acreage (through September 22)		
Year	**Summer Idle (idle Jun 1 – Sept 30)**	**Annual Idle (idle since Jan 1)**
2014	1,552,508	1,030,755
2013	1,502,190	745,569
2011	1,146,647	185,735
2014 – 2011 (change)	**405,861**	**845,020**

Notes:

- Data source: NASA Ames Research Center / CSU Monterey Bay
- Accuracy for the estimates from NASA is +/- 16%, based on comparisons with monthly field observations collected across the Central Valley from April-Sept, 2014.
- Data provided for current year (2014), previous year (2013), and most recent year with average or above average precip during winter (2011)

Central Valley Summer Acreage Summary (2014 vs 2011)

	2014 Summer to Date (June 10 - Sept 22)					2011 Summer to Date (June 10 - Sept 22)			
COUNTY	Cropped	Idle	Total			Cropped	Idle	Total	
ALAMEDA	3,444	4,138	7,582			4,429	3,153	7,582	
AMADOR	4,486	827	5,313			5,227	86	5,313	
BUTTE	221,355	12,259	233,614			227,538	6,076	233,614	
CALAVERAS	1,855	1,189	3,044			1,712	1,332	3,044	
COLUSA	261,889	45,097	306,986			281,065	25,921	306,986	
CONTRA COST	32,663	2,239	34,902			32,196	2,706	34,902	
EL DORADO	322		322			322		322	
FRESNO	817,036	370,990	1,188,026			950,585	237,441	1,188,026	
GLENN	221,095	44,700	265,795			233,656	32,139	265,795	
KERN	682,038	298,584	980,622			727,949	252,673	980,622	
KINGS	319,707	230,975	550,682			397,761	152,921	550,682	
MADERA	297,356	47,041	344,397			305,111	39,286	344,397	
MARIPOSA	184	365	548			194	354	548	
MERCED	382,249	80,084	462,333			415,783	46,550	462,333	
PLACER	20,636	16,257	36,893			22,320	14,573	36,893	
SACRAMENTO	122,558	26,302	148,860			124,810	24,050	148,860	
SAN JOAQUIN	422,400	54,613	477,013			432,992	44,020	477,013	
SOLANO	123,823	34,891	158,714			123,075	35,639	158,714	
STANISLAUS	290,492	26,928	317,420			301,882	15,538	317,420	
SUTTER	230,990	28,234	259,223			244,038	15,186	259,223	
TEHAMA*	6,369	963	7,332			6,059	1,273	7,332	
TULARE	551,875	123,159	675,034			553,318	121,716	675,034	
YOLO	245,322	91,677	336,999			272,643	64,355	336,999	
YUBA	83,784	10,997	94,781			85,122	9,659	94,781	
Total Acres	**5,343,927**	**1,552,508**	**6,896,435**			**5,749,788**	**1,146,647**	**6,896,435**	

* Data only available for southern Tehama County at this time. Estimate for Tehama County will be revised.

Central Valley Summer Idle Acreage by Crop Type (June 1 - July 27)

	2014				
Commmodity	**Cropped**	**Emergent**	**Idle**	**Total Acres**	**2014 - 2011 Idle**
Total, All Crops	4,970,545	32,058	1,706,038	6,708,641	**692,805**
MISC CROP, UNCULT. IN 2013	164,827	7,070	468,225	640,122	**169,836**
COTTON	267,434	4,089	144,858	416,381	**108,079**
ALFALFA	528,320	1,432	116,588	646,340	**79,885**
RICE	519,029	2,134	70,378	591,541	**56,589**
TOMATO PROCESS	122,886	2,541	57,106	182,532	**47,799**
WHEAT	174,556	287	276,919	451,763	**30,378**
BARLEY	32,588	229	56,469	89,287	**24,024**
CORN/WHEAT/OAT FOR FODDER	258,404	1,501	86,829	346,734	**35,049**
OTHER HAY/NON ALFALFA	38,800	840	26,553	66,193	**14,018**
SAFFLOWER	27,202	1,033	18,583	46,818	**12,400**
OATS	25,126	412	32,203	57,741	**11,163**
GRAPE, WINE	153,055	504	15,422	168,981	**10,724**
GRAPE, RAISIN	106,319	44	12,476	118,839	**10,250**
CARROT	13,371	588	20,798	34,758	**9,156**
CORN	72,121	374	16,968	89,463	**8,678**
DBL CROP WINWHT/CORN	52,632		10,928	63,560	**6,858**
GRAPE WINE	49,071	3	6,178	55,253	**5,382**
GARLIC	7,650	241	7,889	15,780	**5,263**
CANTALOUPE	7,435	241	6,576	14,251	**4,323**
POMEGRANATE	27,110	101	6,406	33,617	**3,930**
…	…	…	…	…	**…**

Idle acreage by crop type for summer 2014, and the difference between 2014 and 2011 summer idle acreage for the top 20 crop types by idle acreage. Data for additional crops available. Crop type for each field is based on 2013 data.

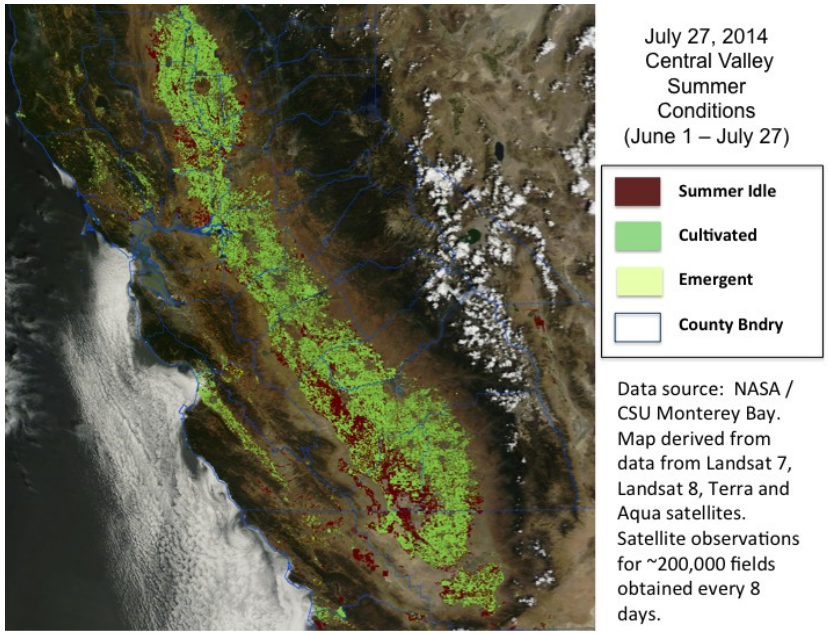
Project Highlights

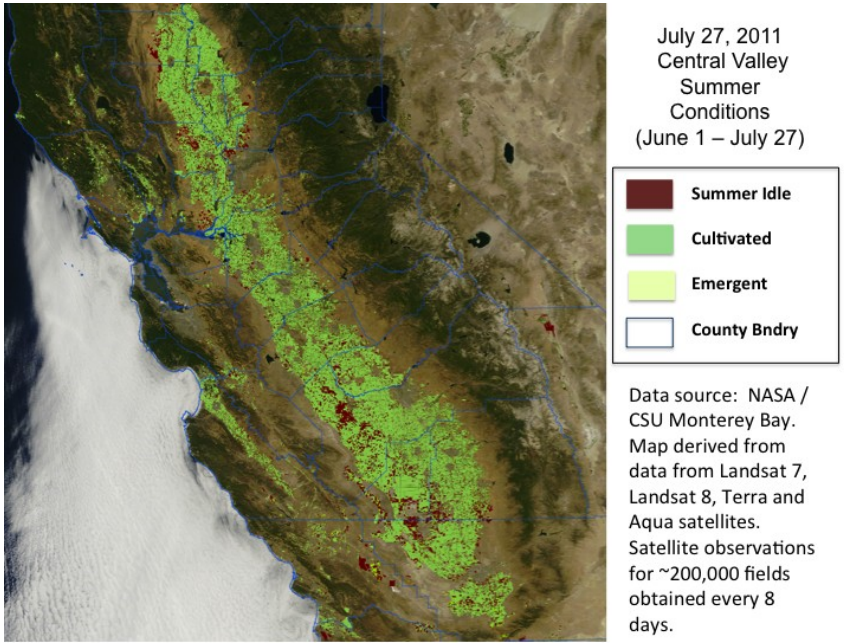
- Collaborative, interagency effort between USGS, NASA, USDA, and CA DWR → responds to request from CA DWR

- Successfully demonstrated capability for within season mapping of idle acreage (advanced delivery of information >10 months).

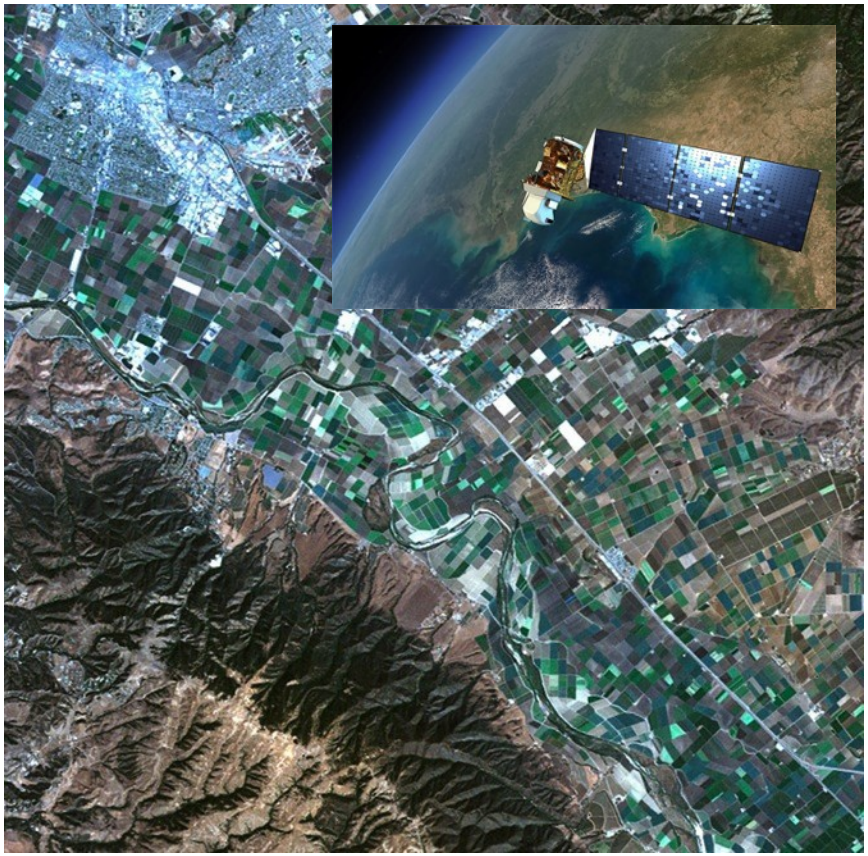
- Monthly estimates generated by the project team for March – July, 2014 and delivered to DWR within two weeks of end of month. Mapping will continue through September.

- Overall accuracy has been approx. +/- 15% or better in all months.





Satellite Data

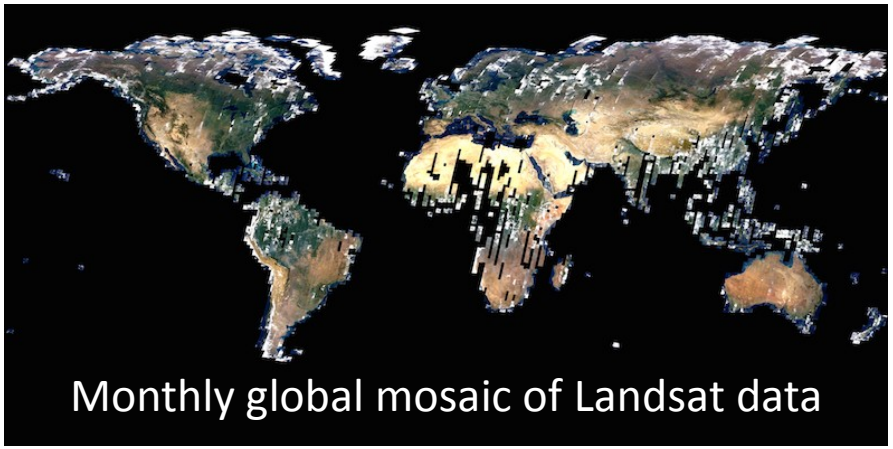


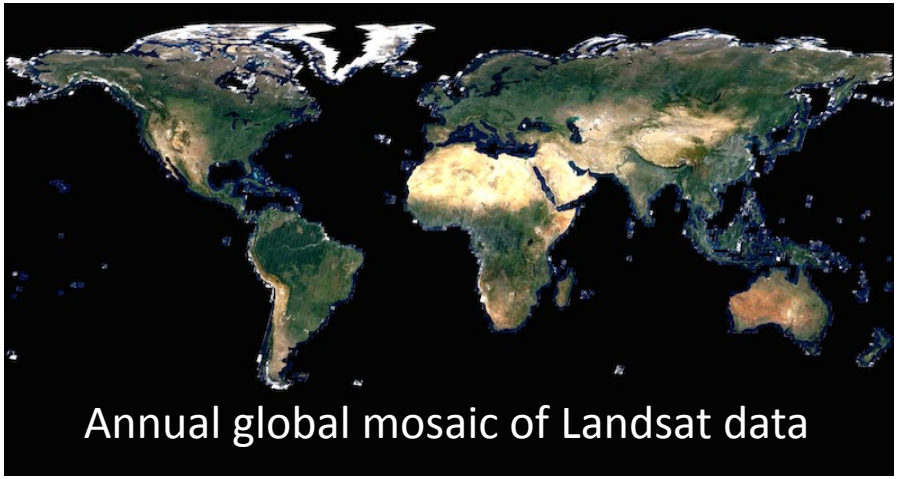
Landsat (TM / ETM+ / OLI)
30m / 0.25 acres
Overpass every 8-16 days

Terra / Aqua (MODIS)
250m / 15.5 acre
Daily overpass

Data Processing on the NASA Earth Exchange (NEX)

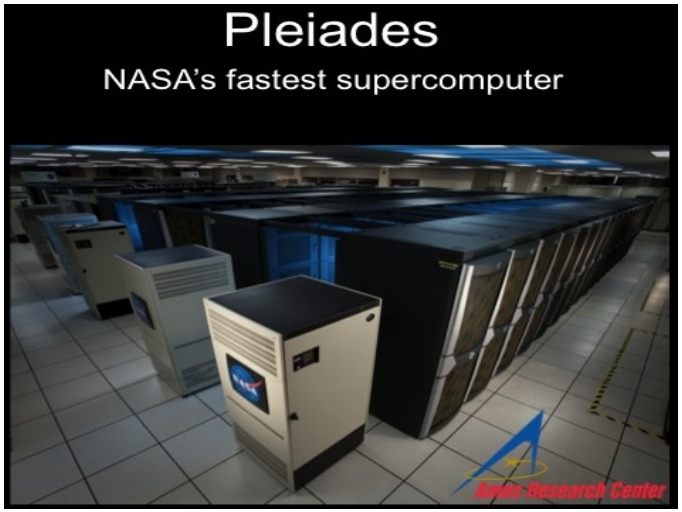
http://nex.nasa.gov





- **Global processing of up to 18,000 scenes in less than 5 hours**
- **Input and output data volumes = 1PB**
- **18 years of global Landsat science products with applications for ag, forestry, water mgmt, disaster mgmt, public health**

COLLABORATION
(over 340 members)



COMPUTING
(9PB, 180,000 cores)

Centralized Data Repository
(over 500 TB of data)

TOPS Satellite Irrigation Management Support

TOPS Satellite Irrigation Manag...

ecocast.org/dgw/sims

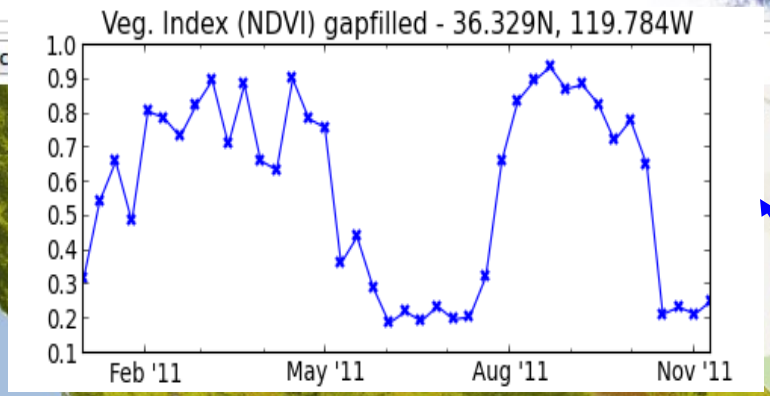
Google

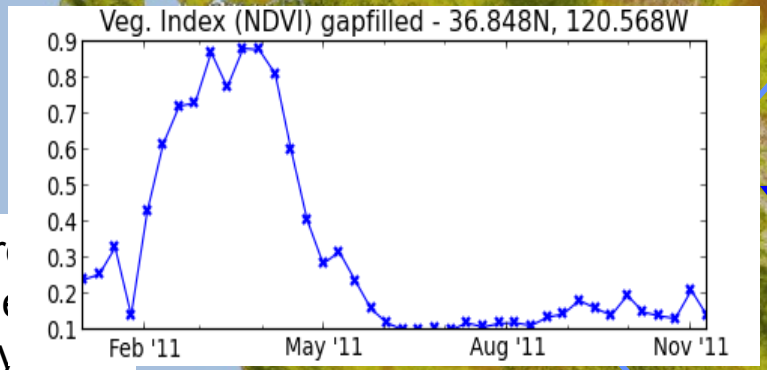
Username: Password: Login

TOPS Satellite Irrigation Management Support

Go to: Searc

Select Date: 2011-07-07





SIMS Data Layers

- ETcb 2011-07-07
- Crop coefficient (Kcb) 2011-07-04 to 2011-07-11
- Veg. Index (NDVI) gapfilled 2011-07-04 to 2011-07-11
- Veg. Index (NDVI) 2011-07-04 to 2011-07-11

Base Layer

Normalized Differ
Vegetation Inde
(NDVI); 8-day
composite from Landsat
and MODIS

0.0 0.2 0.5 0.8 1.0
NDVI

North L
Vegas
Vegas

35.39402 N, -119.85320 W

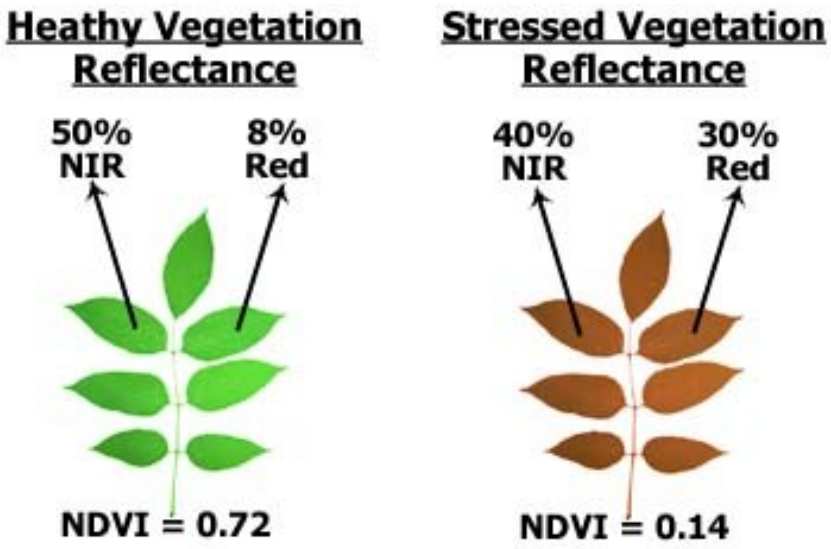
Disclaimer: This data is for research and evaluation purposes only.

NASA Official: Ramakrishna R.Nemani

Curator: Forrest Melton

Privacy Statement

Normalized Difference Vegetation Index

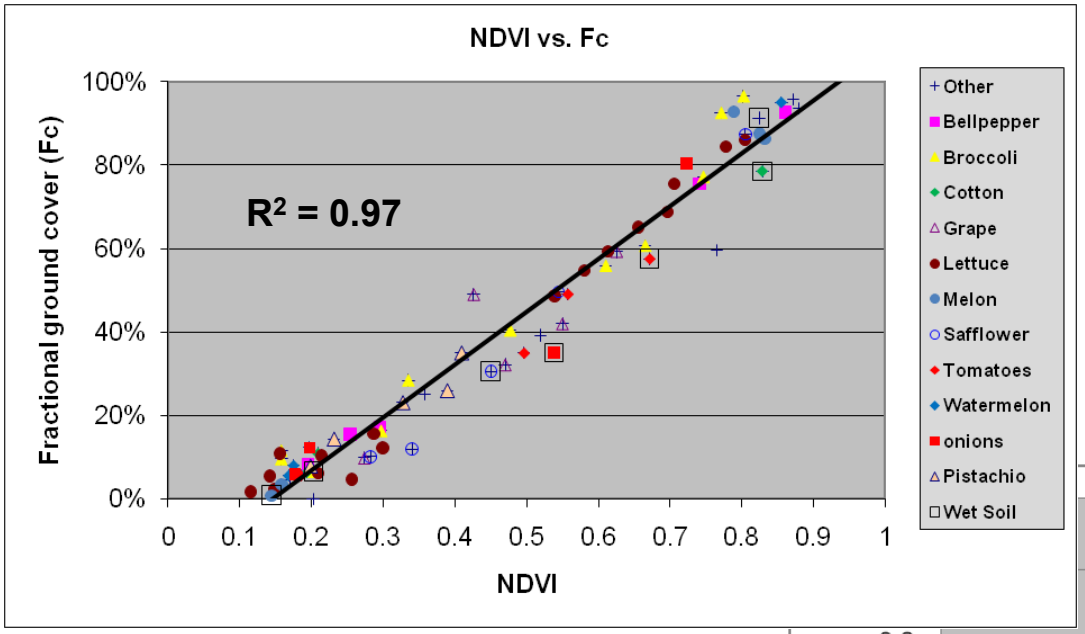


$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Credit: ODIS

Commonly used remote sensing index of vegetation condition

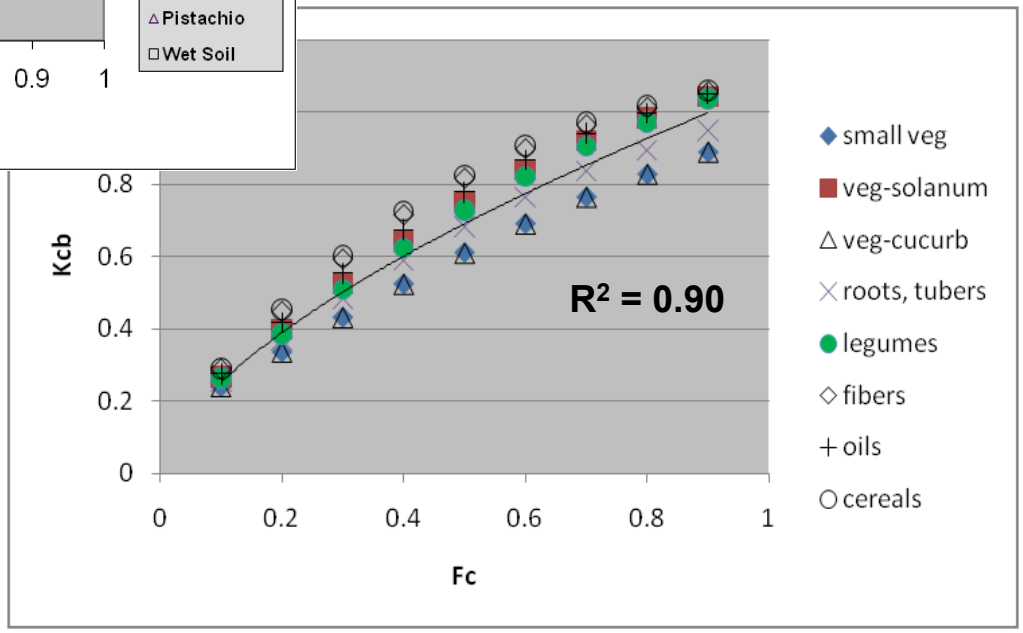
Mapping Crop Coefficients and Indicators of Crop Water Requirements from Satellite Data



Trout et al., 2008; Johnson & Trout, 2011

USDA studies provide basis for linking satellite vegetation indices (NDVI) to fractional cover.

Annuals



Studies by Allen & Pereira (2009) and others provide basis for linking fractional cover to K_{cb} for a range of crops.

Also see Bryla et al., 2010; Grattan et al., 1998; Hanson & May, 2006; Lopez-Urrea et al., 2009

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Combining Surface and Satellite Data: Mapping of Crop Water Requirements at Field Scales

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

CIMIS (AgriMet, AZMET, CoAgMet)

satellite

Standard K_c Profile (manual)

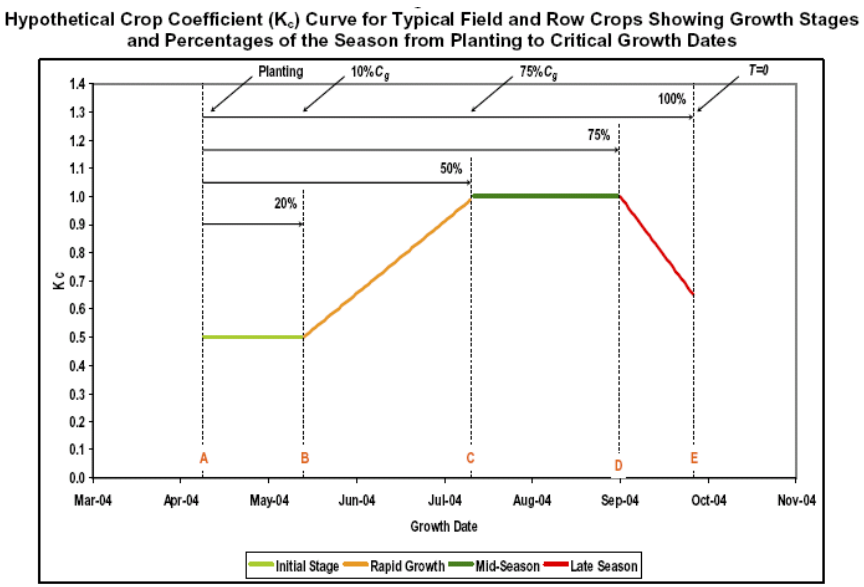
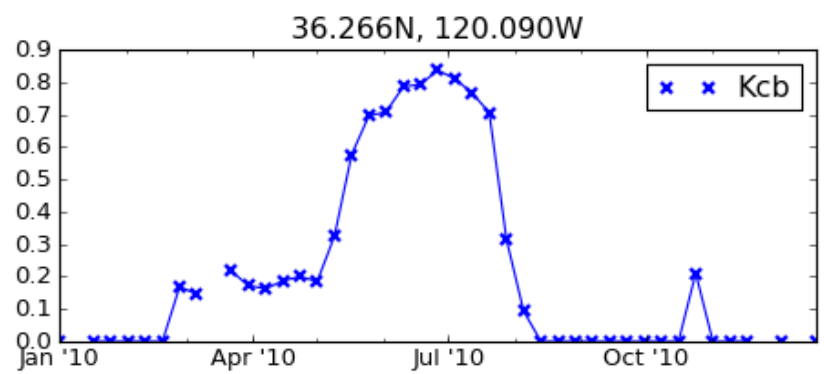


Figure credit: 2005 California Water Plan Update

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



Benefits of Using Ag Weather Information in Irrigation Management

- California Department of Water Resources and UC Berkeley surveyed growers in 1990s
- Growers who utilized CIMIS ET_o data reported an increase in yields of 8% and a decrease in applied irrigation of 13% (DWR, 1997)

Method Used by Farmers to Decide When to Irrigate, USDA Farm & Ranch Irrig. Survey, 2008

	Percent of Farmers	
Method	CA	US
Condition of Crop	66%	78%
Feel of soil	45%	43%
Personal calendar schedule	32%	25%
Soil moisture sensing device	14%	9%
Daily ET reports	**12%**	**9%**
Scheduled by water delivery org.	11%	12%
Commercial or government scheduling service	10%	8%
When neighbors irrigate	6%	7%
Other	6%	9%
Plant moisture sensing device	3%	5%

Growers may report more than one method, so total of all methods may exceed 100%.

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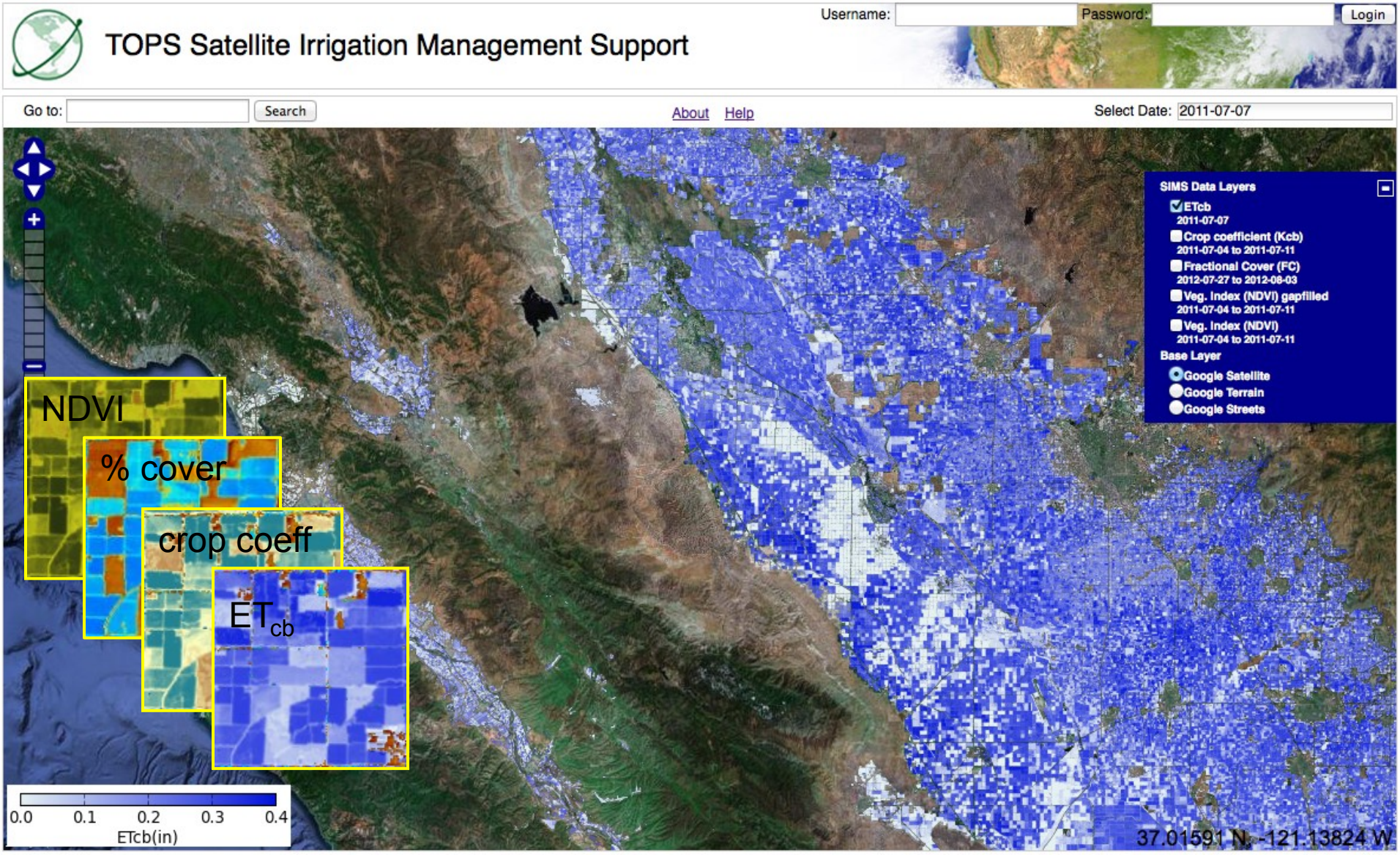
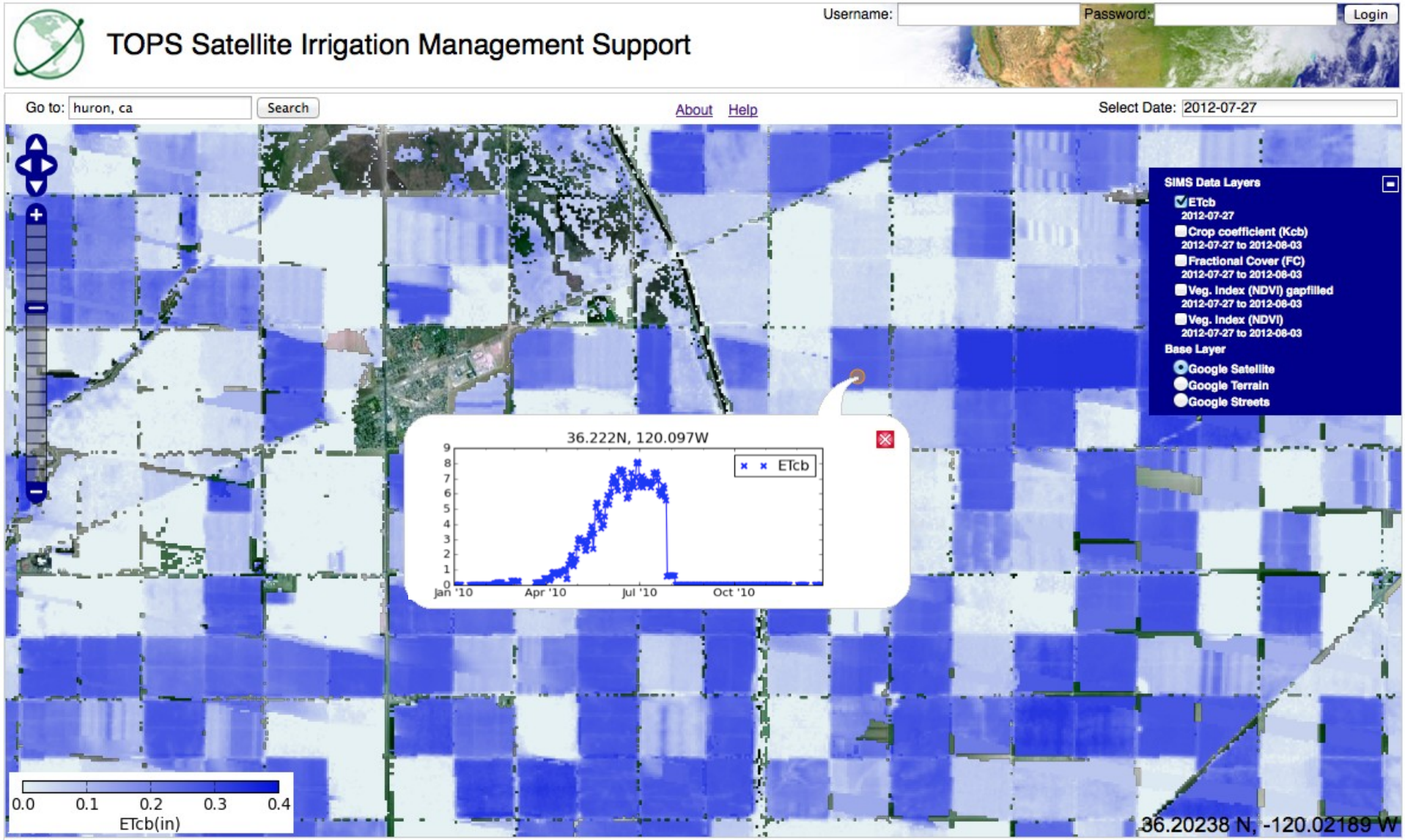
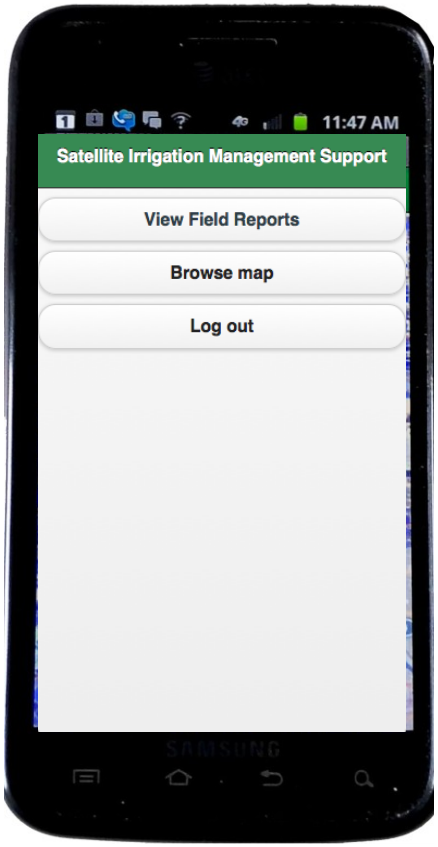
Satellite Irrigation Management Support (SIMS)

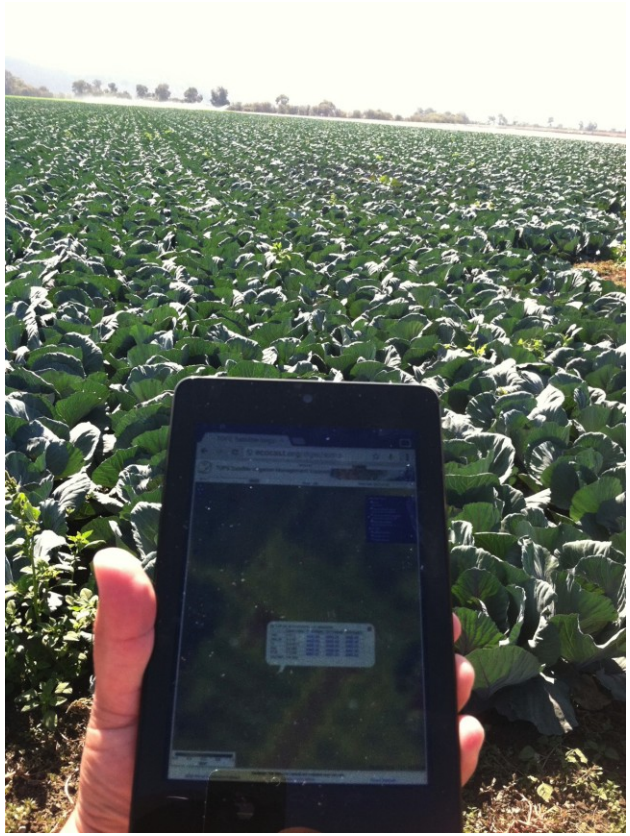


Satellite Irrigation Management Support (SIMS)



Delivering Data to the Field: Mobile Interfaces





Mobile-based interfaces important for enhancing access to data

Verification and Validation: Sensor Networks

Sensor Network Installations

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

***Surface renewal instrumentation.**

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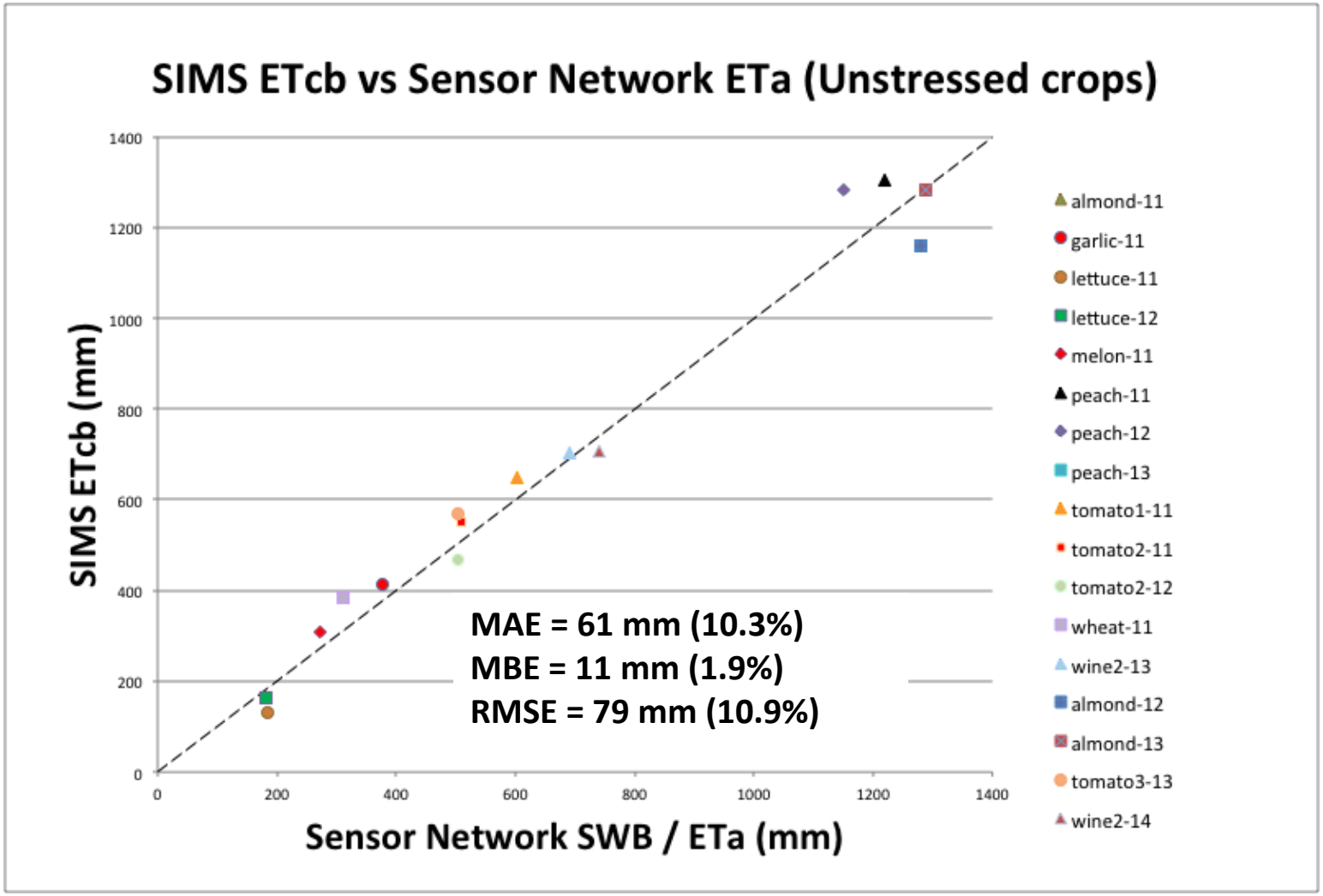
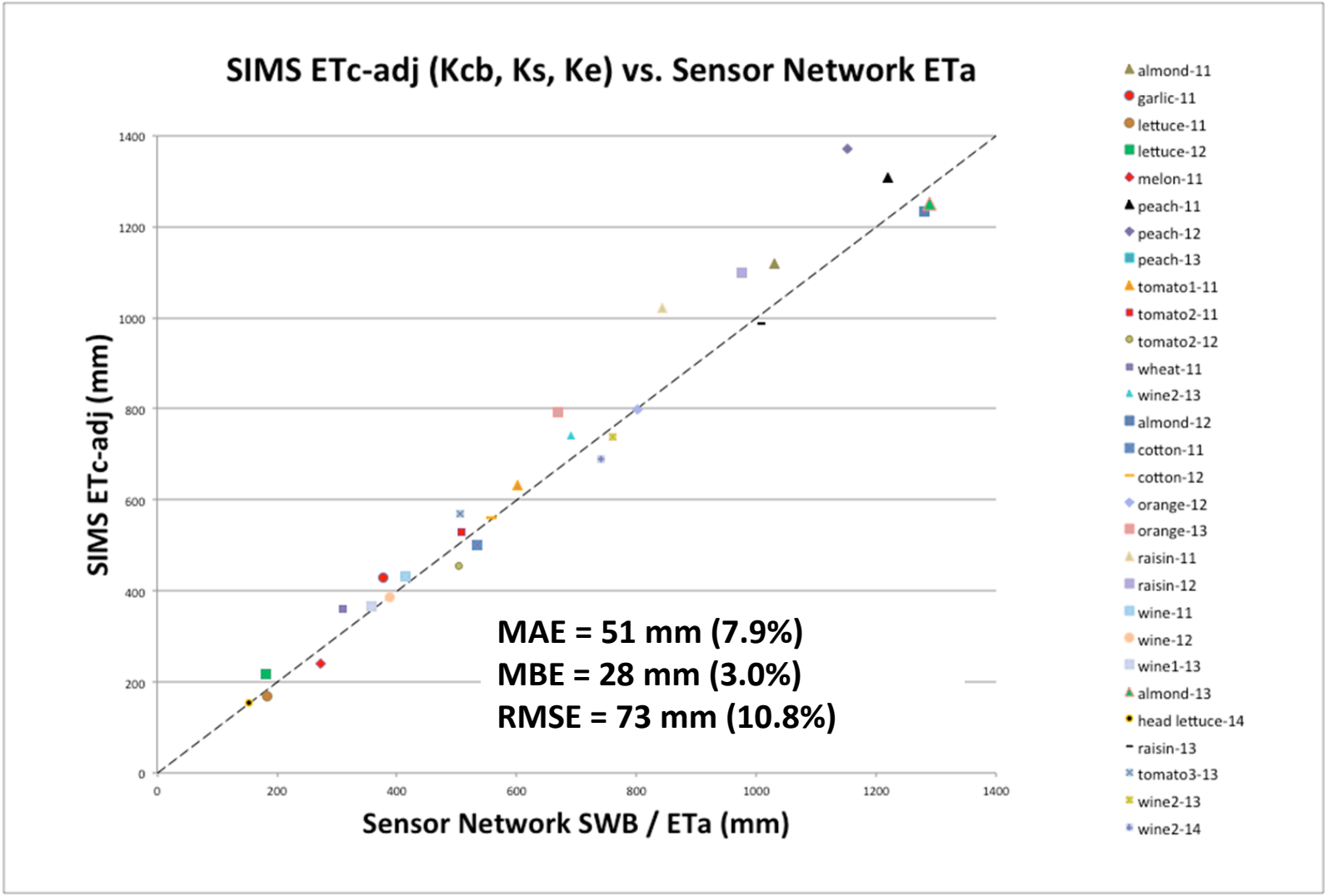
Verification and Validation: Results to Date



Comparison of seasonal ET totals from SIMS and the sensor network for sites instrumented in 2011-2013, excluding intentionally stressed crops (wine grapes, raisins, cotton, oranges).

Verification and Validation: Results to Date

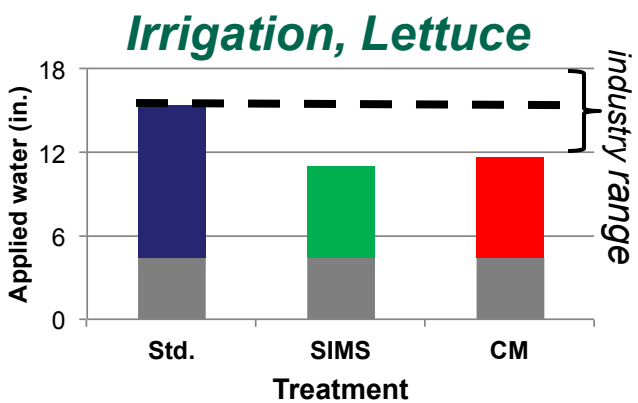


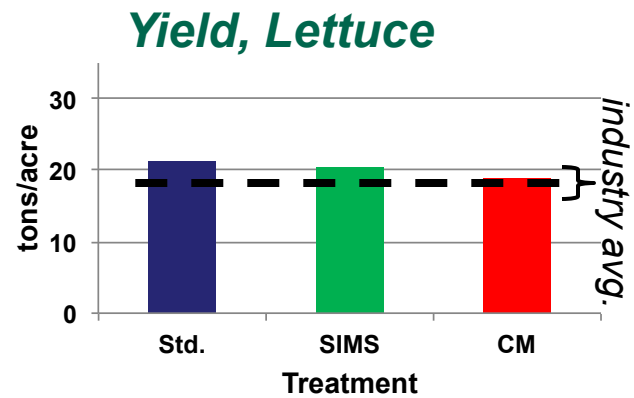
Comparison of seasonal ET totals from SIMS and the sensor network for sites instrumented in 2011-2013. Ke and Ks coefficient via a soil water balance model based on FAO-56 (Allen et al., 1998).

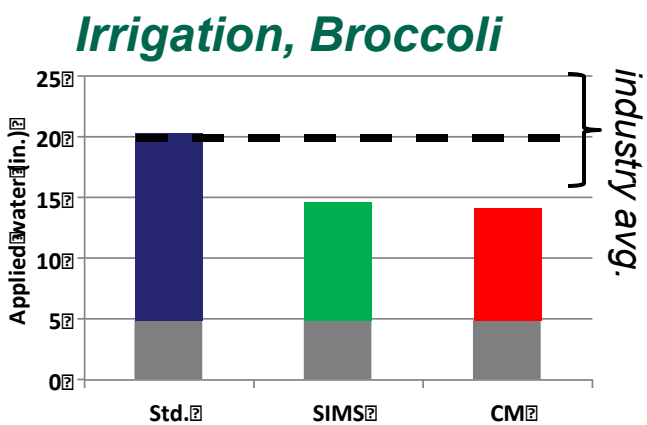
Yield Trials: Results to Date

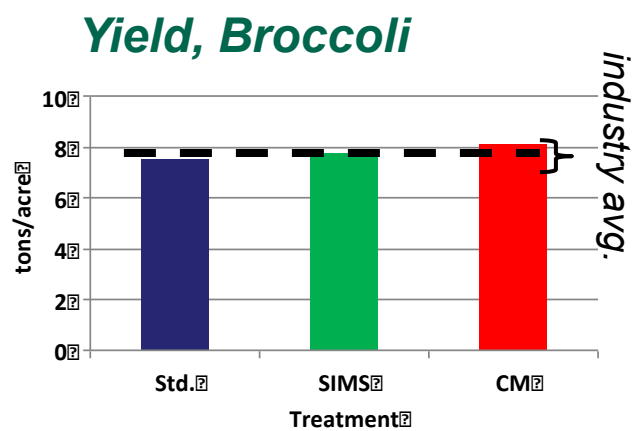
- Results to date confirm savings in applied water of 22-34% without reductions in yield or quality (Johnson et al., 2014; Johnson et al., in prep)

Standard practice
SIMS
CropManage

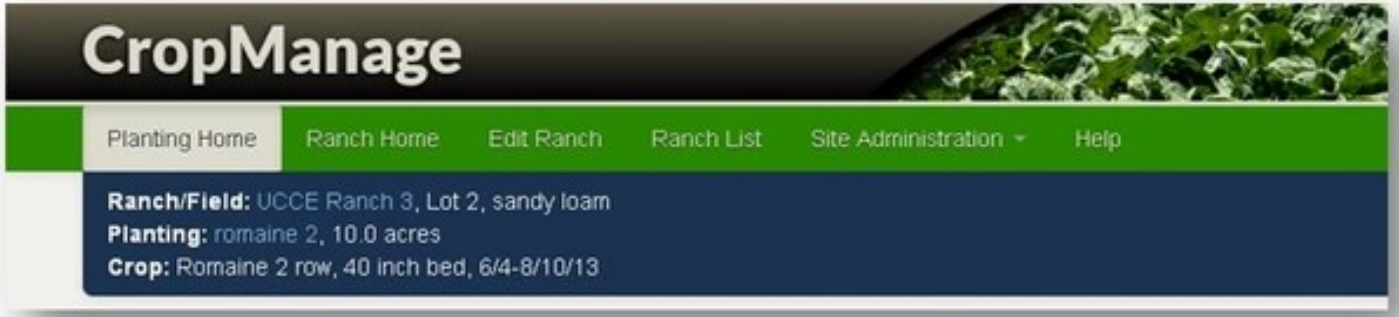








API for Integration with Other Web-based Tools



Irrigation Summary

Show / Hide Columns | Reset Column Order | Show Previous Columns | Show Next Columns

Water Date	Irrigation Method	Recommended Irrigation Interval (days)	Recommended Irrigation Amount (inches)	Recommended Irrigation Time (hours)	Irrigation Water Applied (inches)	Kc	Canopy Cover (%)	Average Reference ET (inches/day)	Total Crop ET (inches)
6/4/13	Germination Sprinkler	N/A	N/A	N/A	0.75 in	0.00	0	0.00	0.00
6/5/13	Germination Sprinkler	1.6	0.22 in	0.72 hrs	0.45 in	1.00	0	0.14	0.14
6/7/13	Germination Sprinkler	1.9	0.36 in	1.18 hrs	0.30 in	0.70	0	0.17	0.23
6/9/13	Germination Sprinkler	1.7	0.39 in	1.29 hrs	0.45 in	0.70	0	0.18	0.25
6/12/13	Sprinkler	3.1	0.28 in	0.95 hrs	0.30 in	0.48	1	0.15	0.21
6/16/13	Sprinkler	2.9	0.40 in	1.33 hrs	0.45 in	0.37	1	0.20	0.30
Totals			1.64 in	5.47 hrs	2.70 in				1.13 in

New Watering | View Rainfall Data

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2009

California Water Conservation Act

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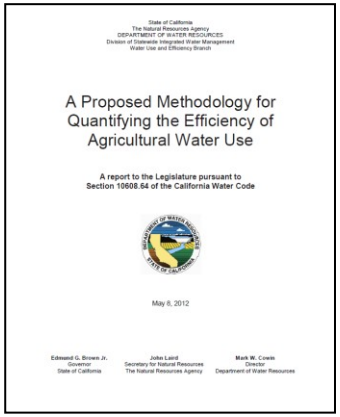
Water Conservation Requirements (SBX7 7)

in Conservation Regulatory Affairs 2009 Legislative Package Implementation

The 2009 legislative package requires a statewide 20% reduction in urban per capita water use by 2020. It requires that urban water retail suppliers determine baseline water use and set reduction targets according to specified requirements, and requires agricultural water suppliers prepare plans and implement efficient water management practices.

The Department of Water Resources (DWR) is required to adopt an alternative method for setting targets through a public process. DWR, in consultation with the California Urban Water Conservation Council (CUWCC), is to develop standardized technical methodologies and criteria for calculating per capita water use, baseline use, population and other analytical metrics. DWR is also directed to convene a representative Commercial, Industrial and Institutional (CII) Task Force to develop standard metrics and best management practices (BMPs) for CII water use.

DWR-recommended Efficiency Metrics


State of California
The Natural Resources Agency
DEPARTMENT OF WATER RESOURCES
Division of Statewide Integrated Water Management
Water Use and Efficiency Branch

A Proposed Methodology for Quantifying the Efficiency of Agricultural Water Use

A report to the Legislature pursuant to Section 10608.64 of the California Water Code

May 8, 2012

Edmund G. Brown Jr. Governor State of California | John Laird Secretary for Natural Resources The Natural Resources Agency | Mark W. Cowin Director Department of Water Resources

Retrospective evaluation of irrigation efficiency → identification of opportunities to enhance efficiency

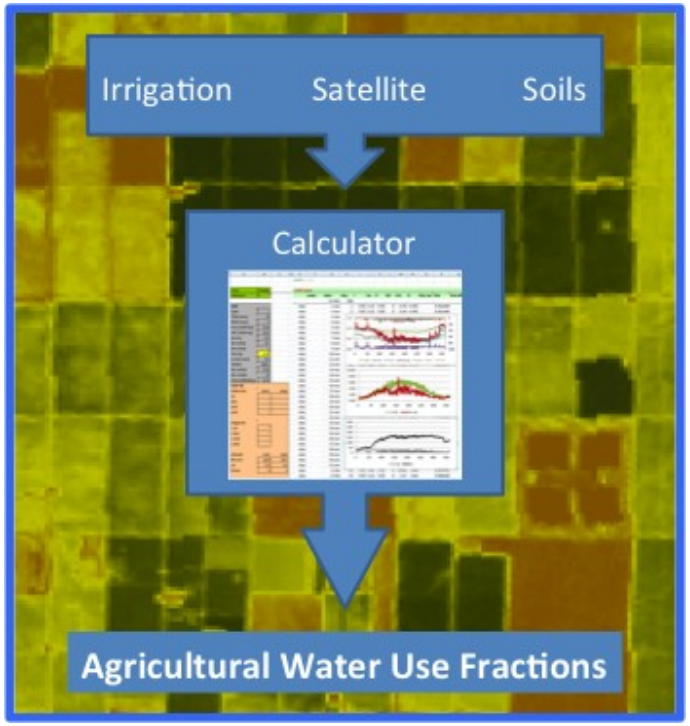
CCUF = ET of applied water / total applied water

AWUF = (ET of applied water + agronomic use) / total applied water

Method for quantifying efficiency of agricultural water use[2]
Crop consumptive use fraction (CCUF) *Method evaluates the relationship between the consumptive use of a crop and the quantity of water applied.* CCUF = ETAW/(AWb)
Agronomic water use fraction (AWUF) *Method evaluates the relationship between the consumptive use plus the agronomic use of a crop and the quantity of water applied.* AWUF = [ETAW+AU]/(AWb)
Total water use fraction (TWUF) *Method expands on the CCUF by including water for crop agronomic use and to meet environmental objectives.* TWUF = (ETAW+AU+EU)/AWb
Water management fraction (WMF) *Method estimates the recoverable water available for reuse at another place or time in the system.* WMF = (ETAW+ RF)/AWb

<u>ET estimation per CDWR:</u>

- Ground instrumentation
  - -Eddy covariance
  - -Surface renewal
  - -Bowen ratio
- Crop coefficients
  - -Prior guidelines
  - -Empirical (eg, ***remote sensing***)



Summary

- Remote sensing provides a low-cost approach for tracking crop development and mapping:
  → drought impacts/fallowing
  → mapping crop water req'ts
  → mapping consumptive use

- Increased access to information on crop evapotranspiration can support California growers in improving on-farm water use efficiency

SIMS Project Team

Forrest Melton, Lee Johnson, Alberto Guzman, Kirk Post, Carolyn Rosevelt, Aimee Teaby, Sean Windell, Andy Michaelis, Chris Lund, A.J. Purdy, Ty Brandt, Rama Nemani
NASA ARC-CREST / CSU Monterey Bay

Kent Frame, Bekele Temesgen, CA Dept. of Water Resources

Partners:
CA Dept. of Water Resources, Western Growers Association, Center for Irrigation Technology / CSU Fresno, USDA ARS / NRCS, Univ. of California Cooperative Extension, USGS, Booth Ranches, Chiquita, Constellation Wines, Del Monte Produce, Dole, E & J. Gallo, Farming D, Fresh Express, Pereira Farms, Ryan Palm Farms, Tanimura & Antle

Interagency and public-private partnerships are critical to addressing major water management challenges in California.

California State University
MONTEREY BAY
Extraordinary Opportunity

Thank you

forrest.s.melton@nasa.gov

Opportunities to Accelerate Adoption of BMPs for Irrigation and Nutrient Management

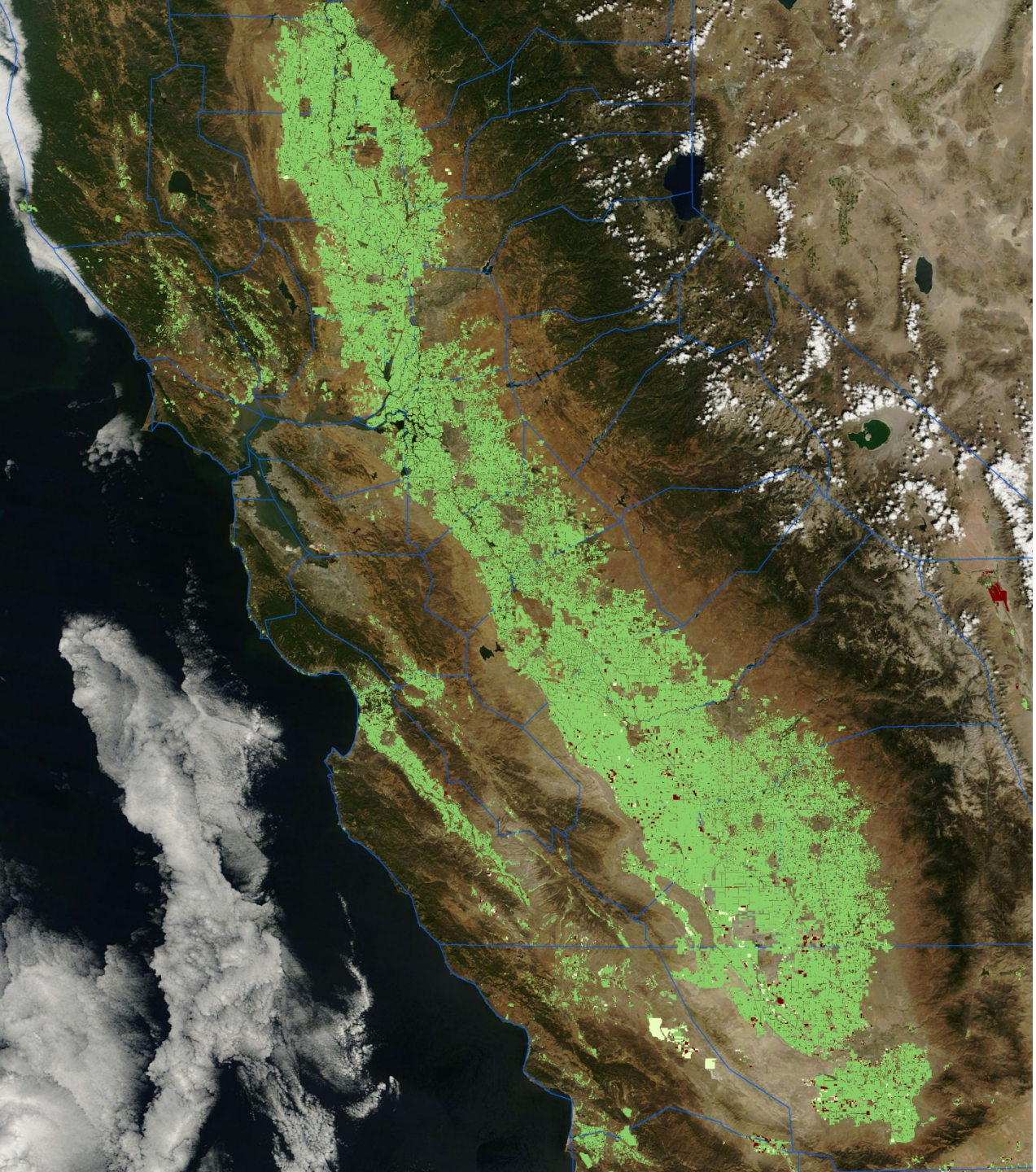
1. **Reduce risk associated with testing new BMPs:** Yield indemnification insurance programs for specialty crop growers for BMP adoption and testing → AgFlex BMP Challenge Pilot

2. **Increase incentives for improving on-farm water use efficiency:** Connect sustainability metrics (SISC, Walmart, Whole Foods, California SBx7-7) with statewide recognition and pricing

3. **Training:** Additional support for training programs in English and Spanish

4. **BMP Development and Testing:** Additional support to accelerate R&D and verification and validation efforts → small grant sizes are a big barrier to interagency teams and incorporation of software engineering efforts to build and support software tools

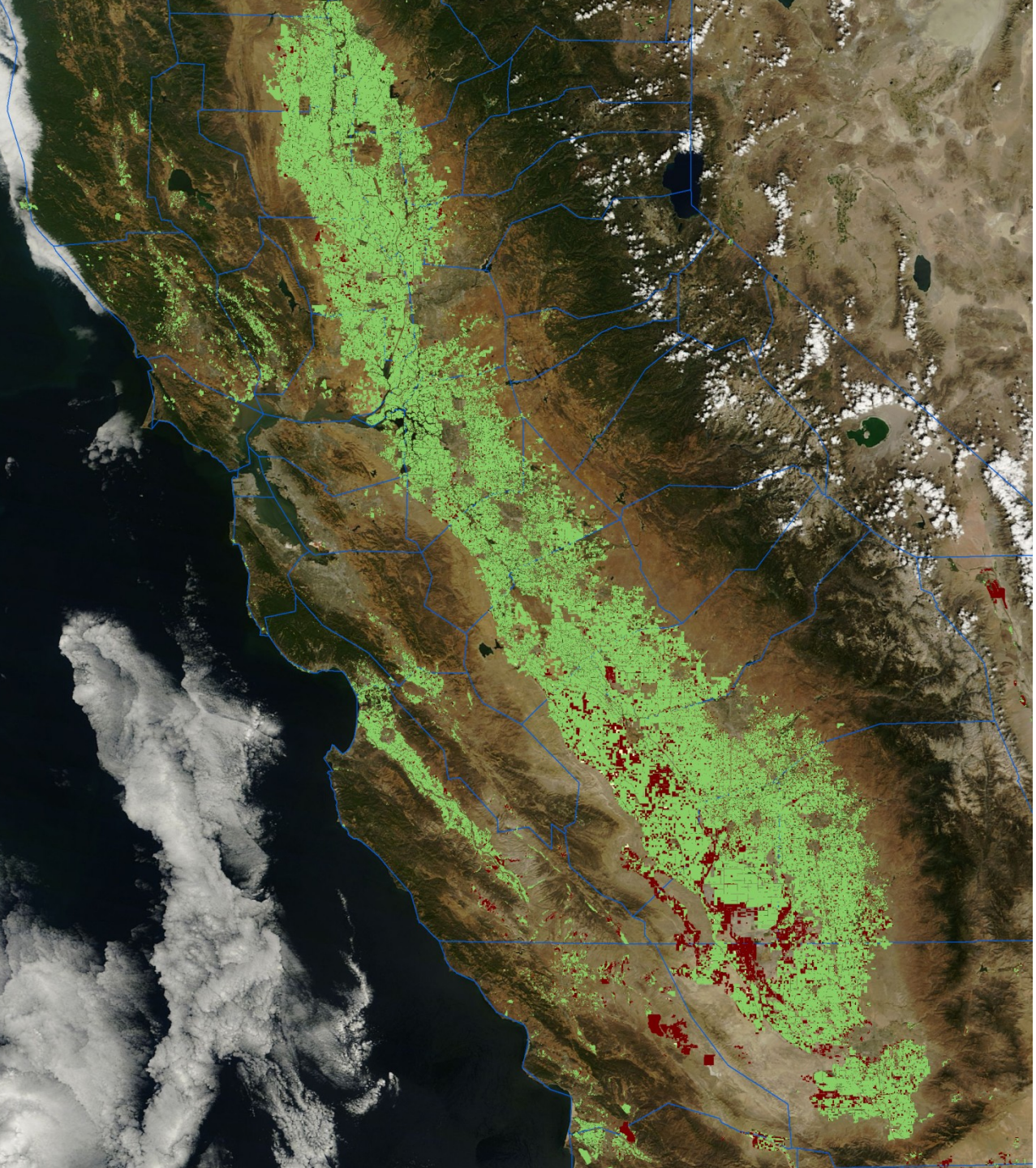
5. **Maintain existing observing networks:** To provide information to growers, must maintain DWR CIMIS and NASA/USGS satellites



August 27, 2011
Year to Date
Conditions
Central Valley

- **Annual Idle**
- **Cultivated**
- **Emergent**
- **County Bndry**

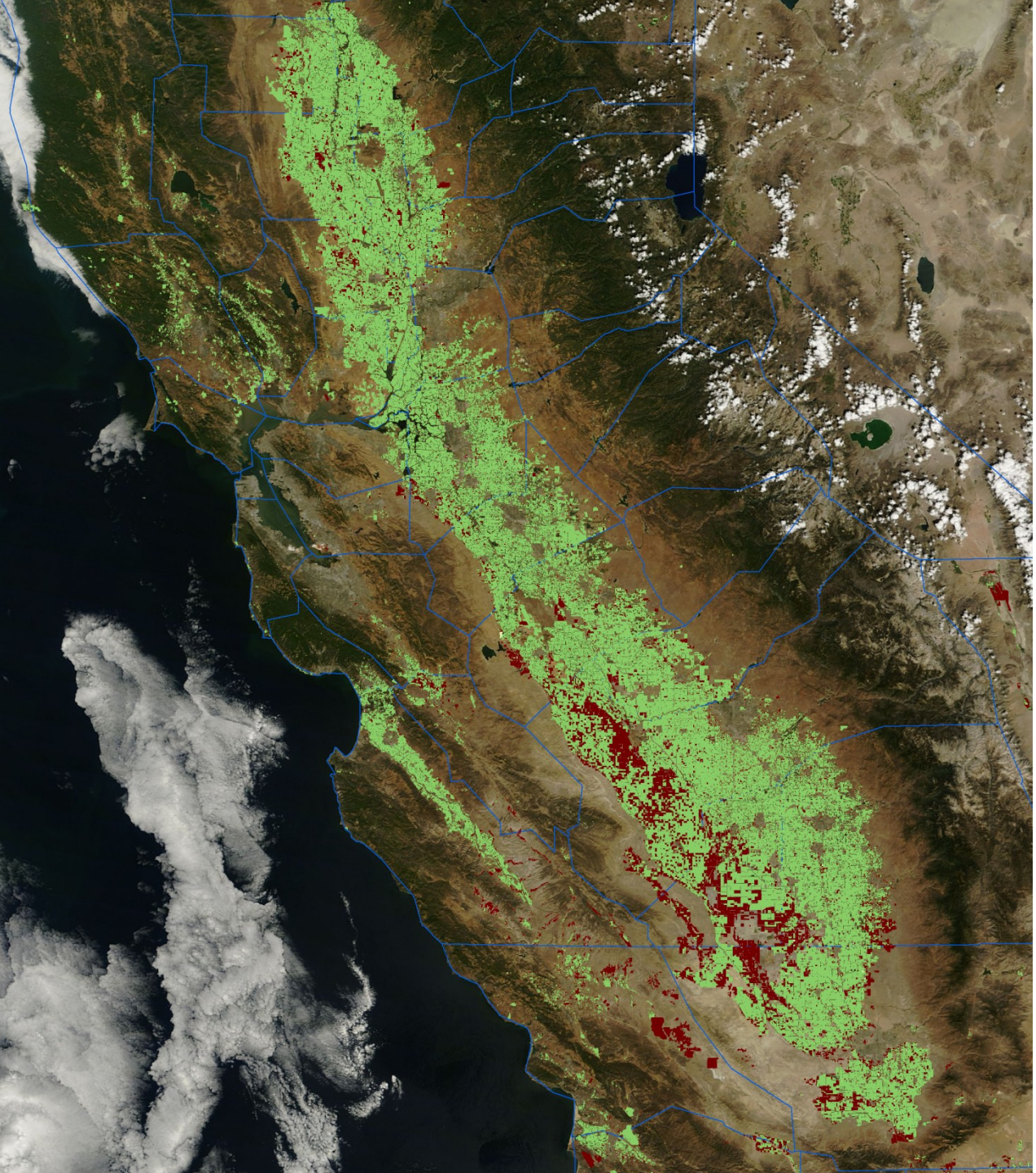
Data source: USDA NASS. Map derived from data from Landsat 7, Landsat 8, and DMC satellites. Pixel-based classification for entire state.



August 27, 2013
Year to Date
Conditions
Central Valley

- **Annual Idle**
- **Cultivated**
- **Emergent**
- **County Bndry**

Data source: NASA / CSU Monterey Bay. Map derived from data from Landsat 7, Landsat 8, Terra and Aqua satellites. Satellite observations for ~200,000 fields obtained every 8 days.



August 27, 2014
Year to Date
Conditions
Central Valley

Annual Idle

Cultivated

Emergent

County Bndry

Data source: NASA / CSU Monterey Bay. Map derived from data from Landsat 7, Landsat 8, Terra and Aqua satellites. Satellite observations for ~200,000 fields obtained every 8 days.

Transition Strategy

- USDA NASS mapping will be supported by NASS as part of the Cropland Data Layer program

- Evaluating options for March – June estimates
  - Option 1: Algorithms / processing workflows to be transferred to CDWR and/or public cloud
  - Option 2: Implemented on EROS Enterprise Science Processing Architecture (ESPA)

- The ESPA Framework has been created to support Terrestrial Monitoring applications at USGS/EROS

- The EROS/Enterprise Science Processing Architecture is designed to enable science users to bring their algorithms to the archive to better and more quickly serve their needs

Field Validation Strategy

Goal: Calculate daily ET for a wide range of crops and growth forms (graminoids, short forbs, tall forbs, vines, and trees) using two cost-effective and independent approaches at each site.

Approach 1) Water Balance: $ET = P + I - D - \Delta S$

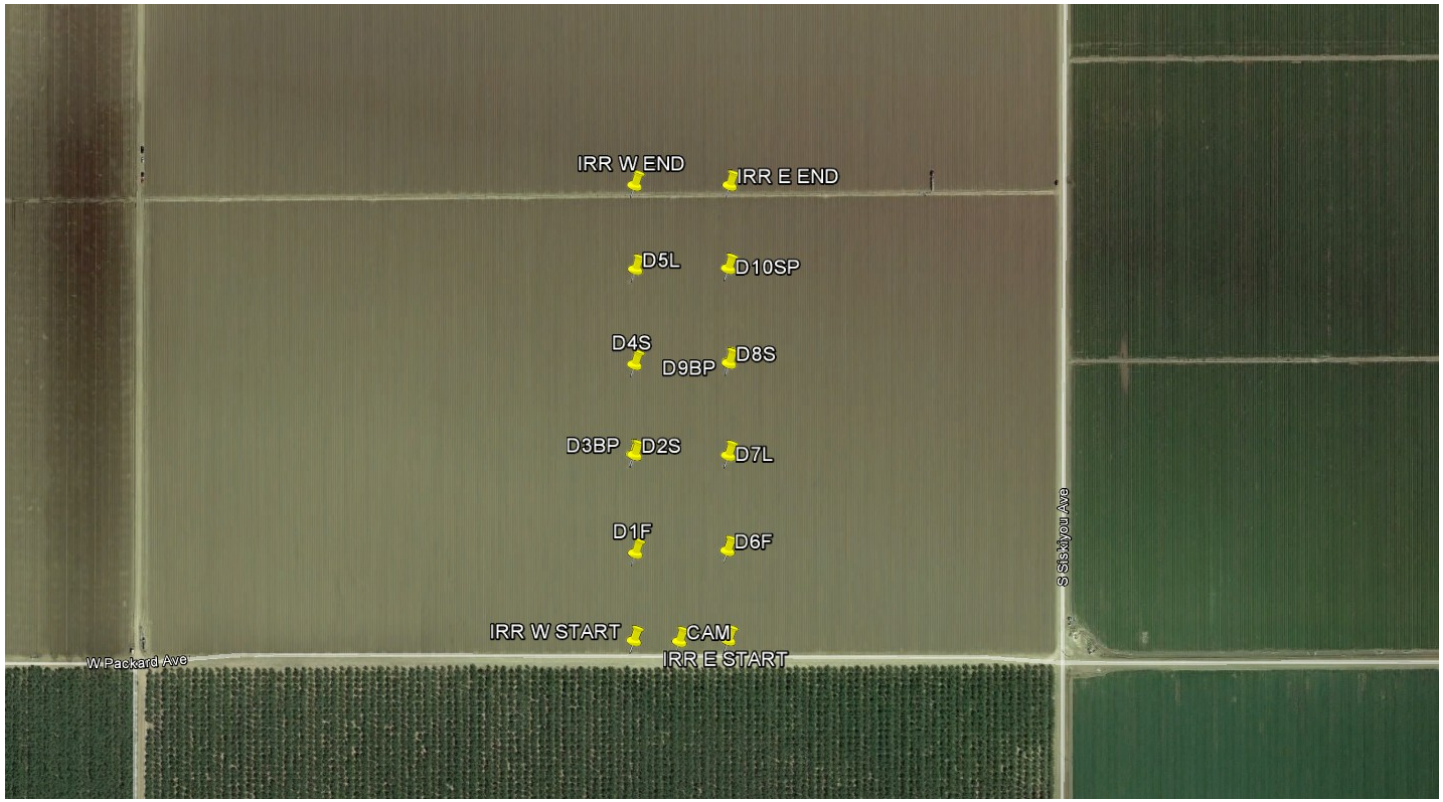
Where ET is evapotranspiration, P is precipitation, I is irrigation, D is drainage below the root zone, and ΔS is change in volumetric water content

Approach 2) Surface Renewal Energy Balance:

$$ET = R_n - H - G$$

Verification and Validation: Sensor Networks

Instrumentation Layout



Point configuration (10):

- P1 10HS 0-4”
- P2 10HS 12-16”
- P3 10HS 24-28”
- P4 MPS-1 14”
- P5 10HS 36-40” / G3 Passive Capillary Lysimeter 44”

Other Instruments:

- SR station
- MET station
- In-line flow meter

Site Info:

- Block #4
- Bed Width: 60”
- Furrow: 20”
- Between plants 20”
- Transplant-Double row
- 12” emitter spacing

Instrumentation Layout

S

N

Point configuration (8)

- P1 10HS 0-4”
- P2 10HS 16-22”
- P3 10HS 32-36”
- P4 MPS-1 18”
- P5 10HS 48-52” / G3 Passive Capillary Lysimeter

Other Instruments:

- USDA Eddy Covariance
- MET station
- In-line flow meter

Site Info:

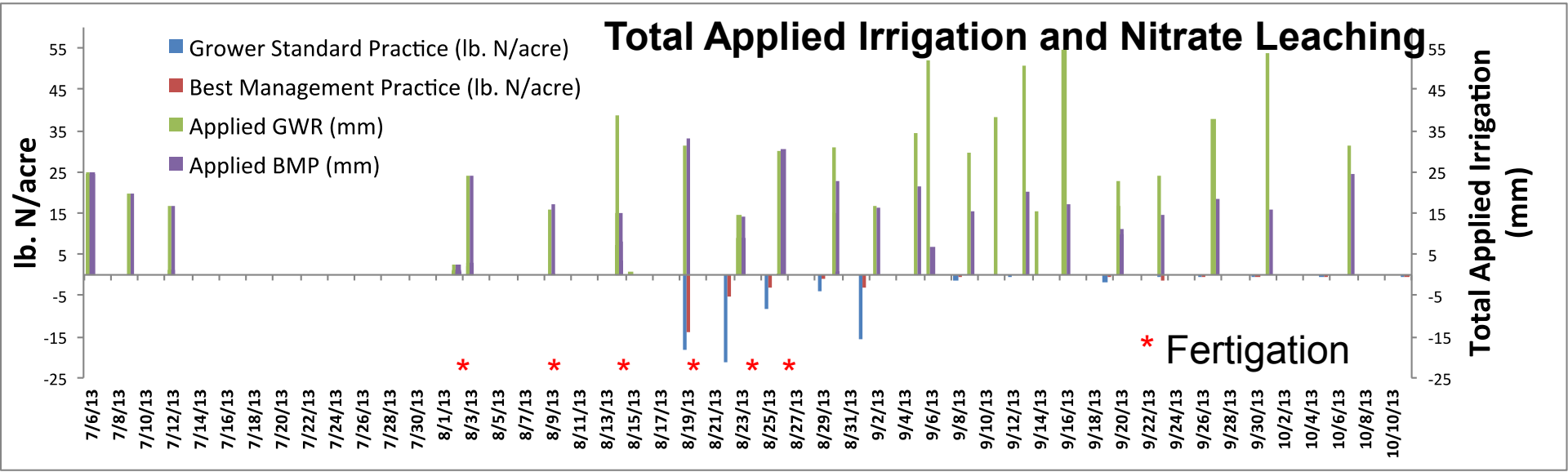
- Row Width: 130”
- Vine spacing: 60”
- Dimensions: Aisle CC12”
- Cover crop: grass

California State University MONTEREY BAY Extraordinary Opportunity

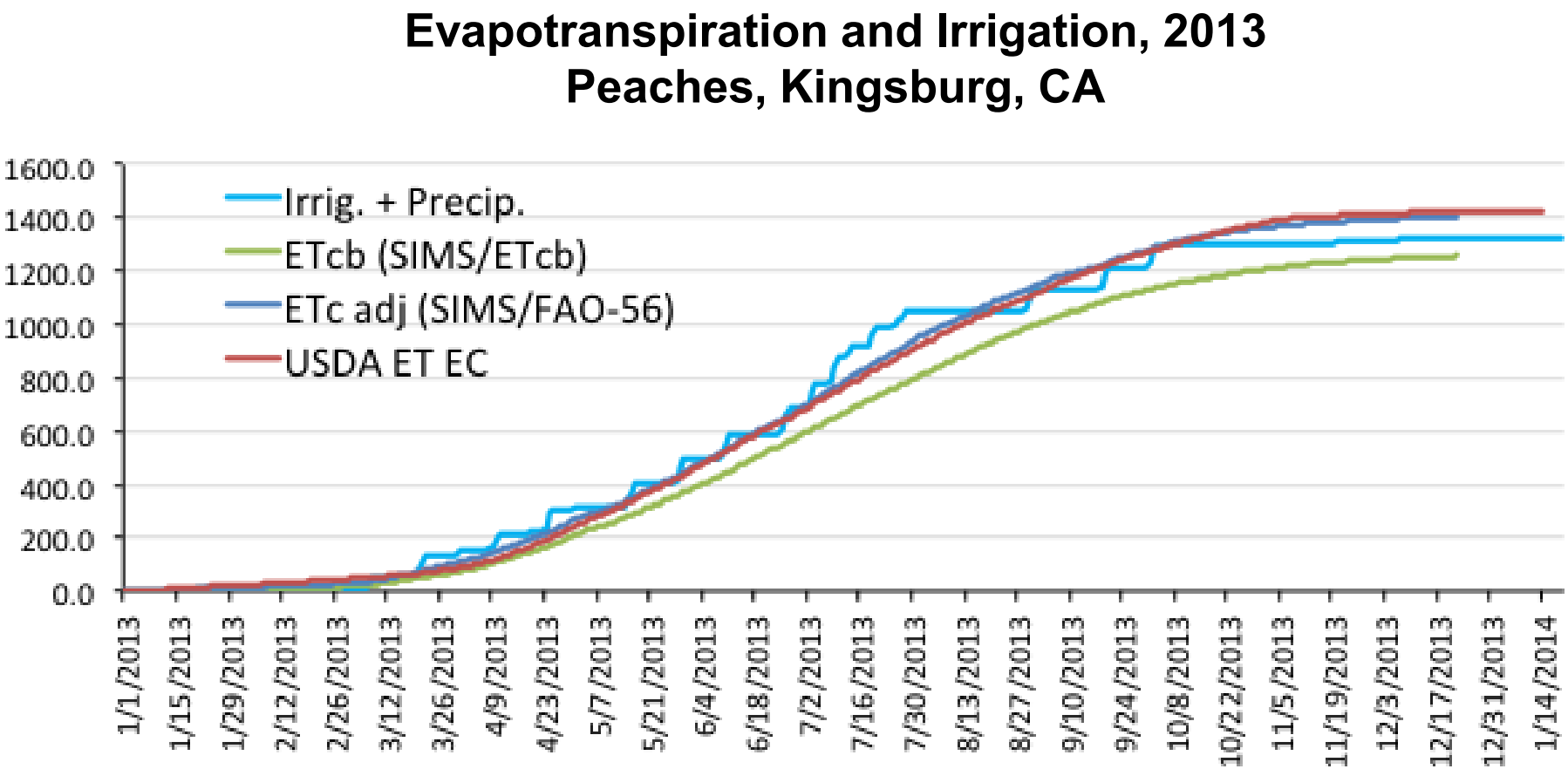
Yield Trials: Results to Date

- Co-benefits for nutrient management and reductions in nitrate leaching

Treatement	Grower Standard Practice	Crop Manage / SIMS BMP	
N as Urea-20 applied	186.7	186.7	lb./N per acre
Leachate	71.89	29.72	lb./N per acre
% loss	38.5	15.9	



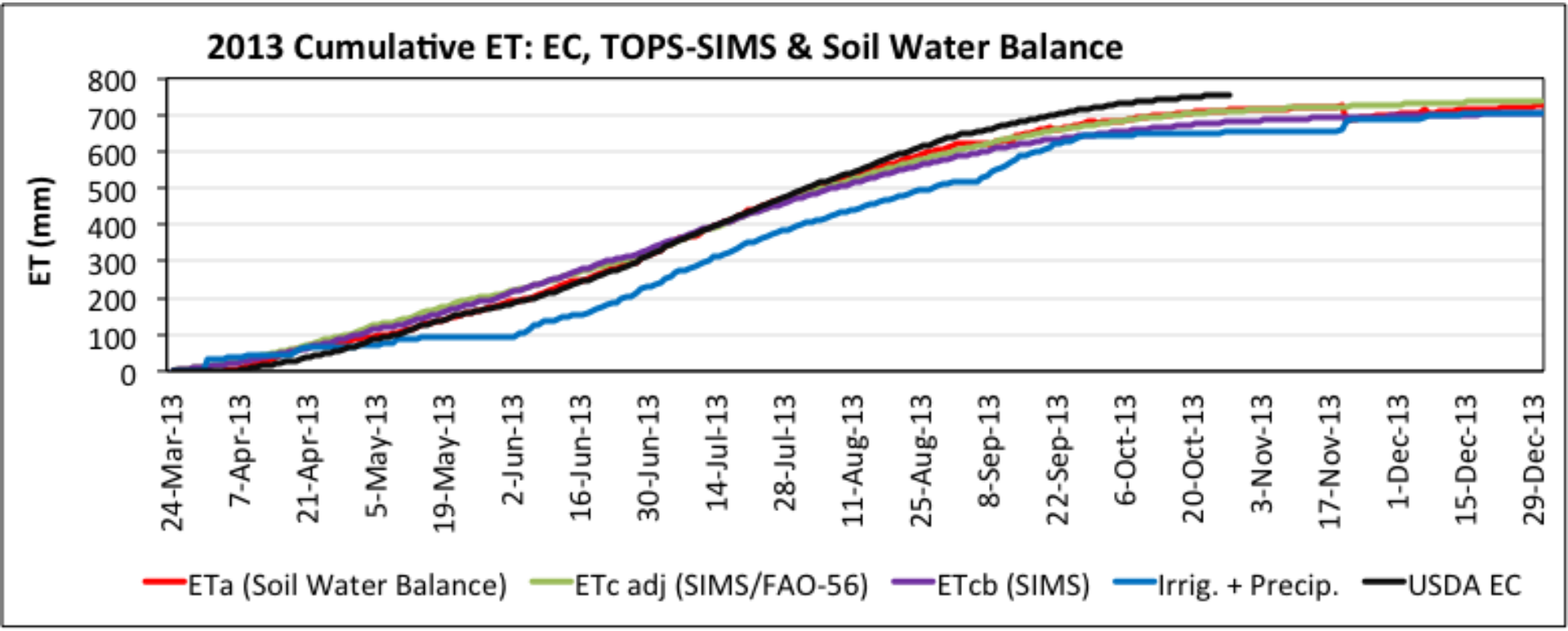
Validation Datasets: Eddy Covariance



Eddy covariance data courtesy R. Anderson, USDA ARS

Validation Datasets: Eddy Covariance

Evapotranspiration and Irrigation, 2013
Pinot Noir, Galt, CA

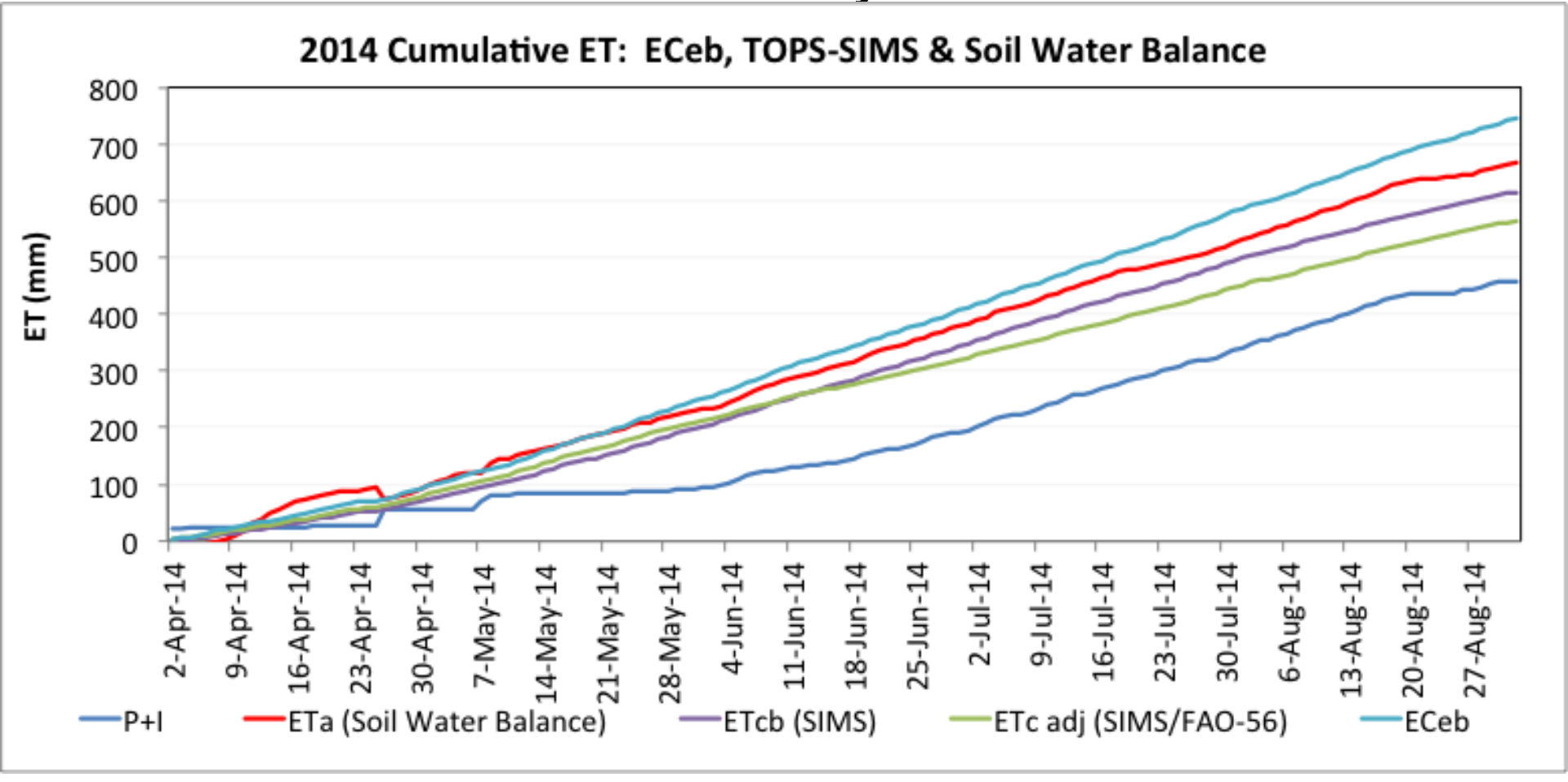


Eddy covariance data courtesy J. Alfieri,

Validation Datasets: Surface Renewal

Evapotranspiration and Irrigation, 2014
Pinot Noir, Galt, CA

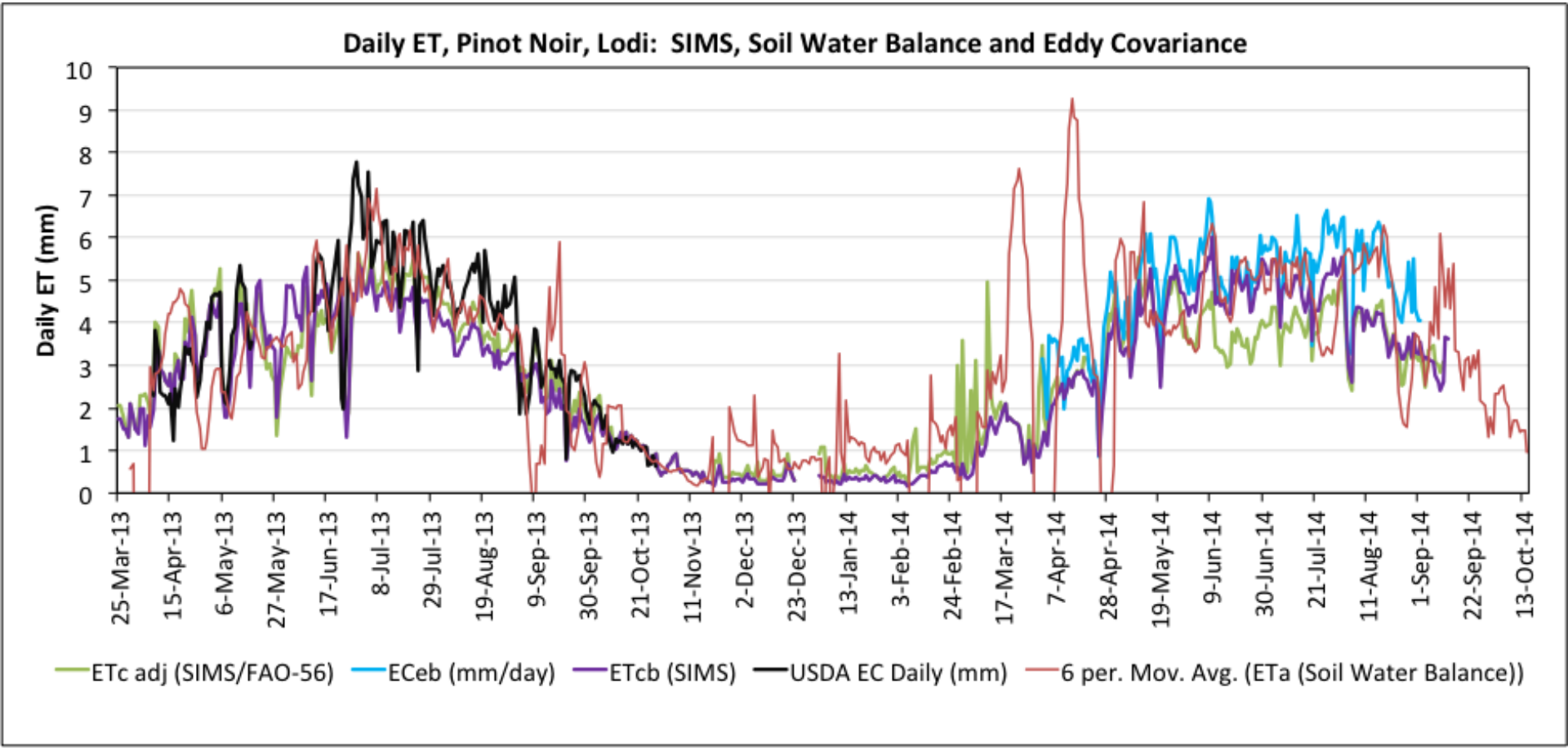
Preliminary data



Validation Datasets: EC / Surface Renewal

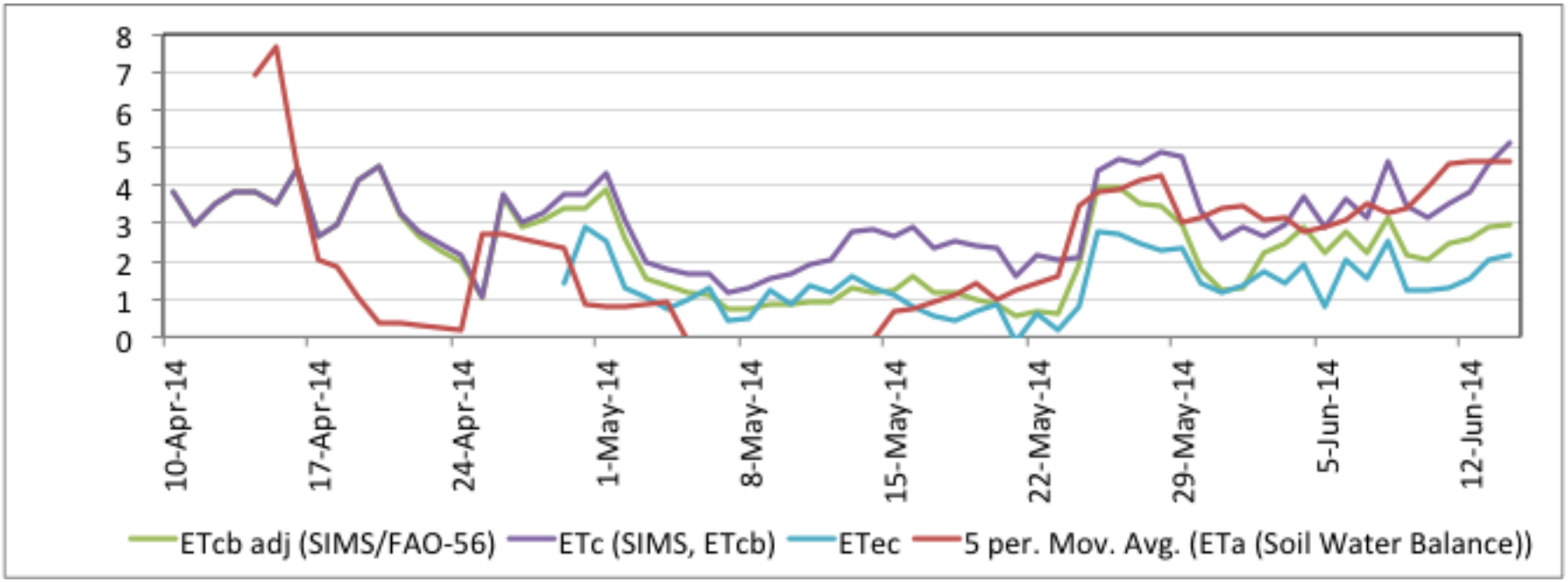
Daily Evapotranspiration and Irrigation, 2013-2014
Pinot Noir, Galt, CA

Preliminary data



Validation Datasets: EC / Surface Renewal

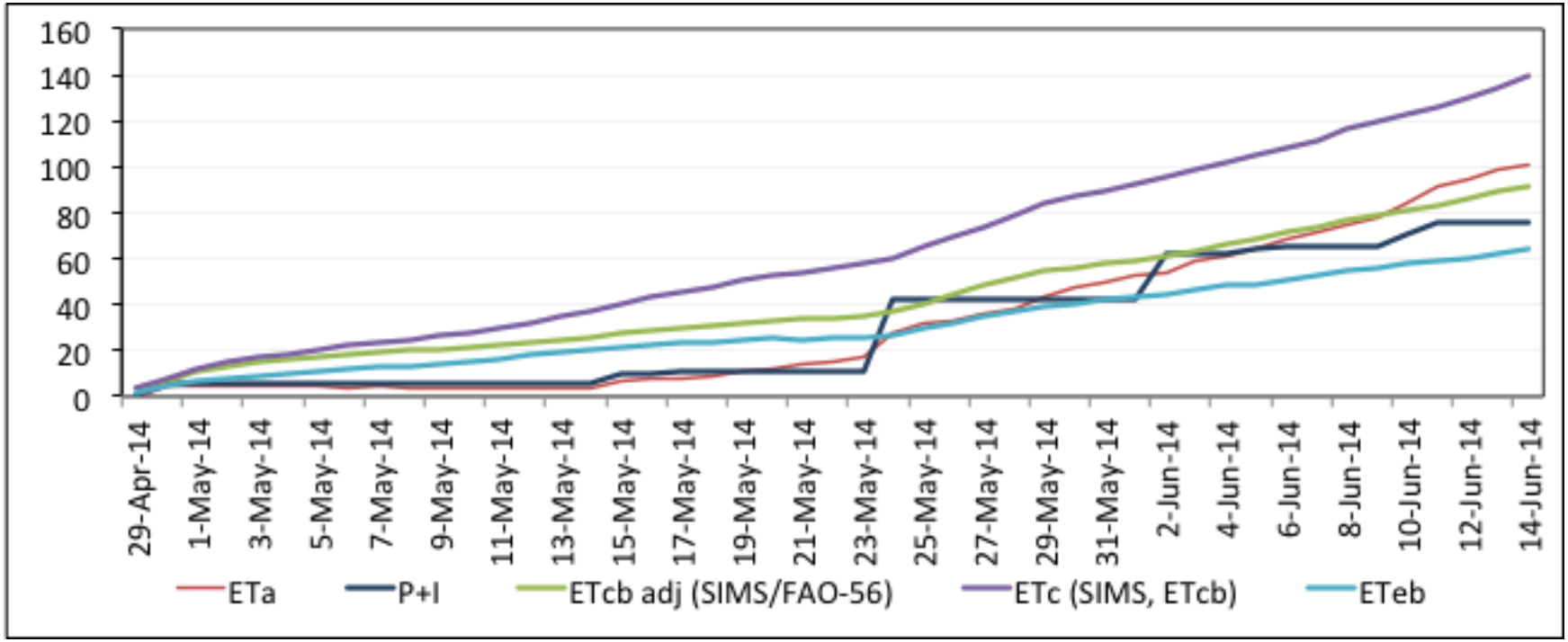
Daily Evapotranspiration 2014
Lettuce, Salinas, CA

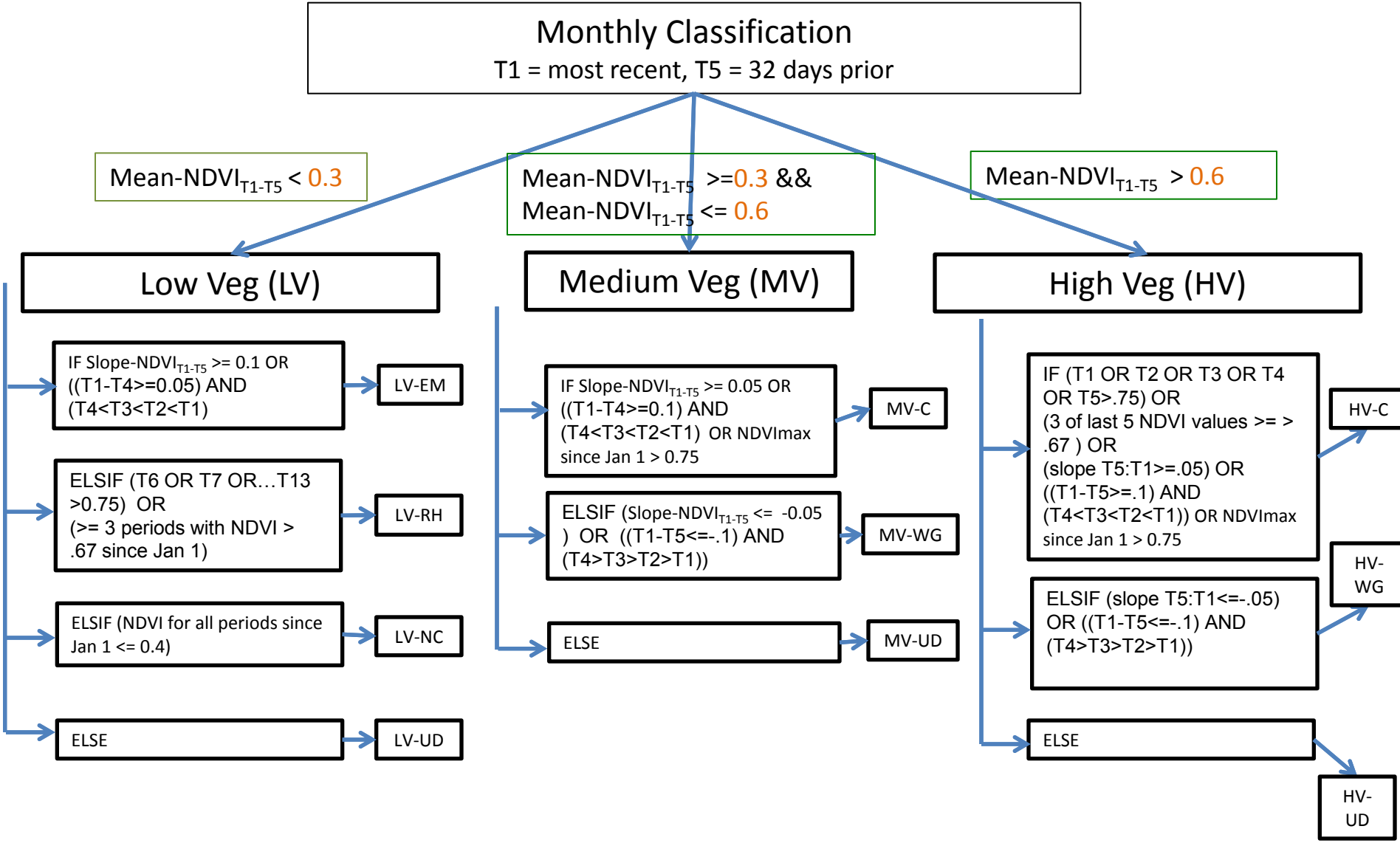


Validation Datasets: EC / Surface Renewal

Cumulative Evapotranspiration 2014
Lettuce, Salinas, CA

Preliminary Data




Monthly Classification
T1 = most recent, T5 = 32 days prior
Mean-NDVI$_{T1-T5}$ < 0.3
Mean-NDVI$_{T1-T5}$ >=0.3 && Mean-NDVI$_{T1-T5}$ <= 0.6
Mean-NDVI$_{T1-T5}$ > 0.6
Low Veg (LV)
Medium Veg (MV)
High Veg (HV)
IF Slope-NDVI$_{T1-T5}$ >= 0.1 OR ((T1-T4>=0.05) AND (T4<T3<T2<T1)
LV-EM
ELSIF (T6 OR T7 OR…T13 >0.75) OR (>= 3 periods with NDVI > .67 since Jan 1)
LV-RH
ELSIF (NDVI for all periods since Jan 1 <= 0.4)
LV-NC
ELSE
LV-UD
IF Slope-NDVI$_{T1-T5}$ >= 0.05 OR ((T1-T4>=0.1) AND (T4<T3<T2<T1) OR NDVImax since Jan 1 > 0.75
MV-C
ELSIF (Slope-NDVI$_{T1-T5}$ <= -0.05) OR ((T1-T5<=-.1) AND (T4>T3>T2>T1))
MV-WG
ELSE
MV-UD
IF (T1 OR T2 OR T3 OR T4 OR T5>.75) OR (3 of last 5 NDVI values >= > .67) OR (slope T5:T1>=.05) OR ((T1-T5>=.1) AND (T4<T3<T2<T1)) OR NDVImax since Jan 1 > 0.75
HV-C
ELSIF (slope T5:T1<=-.05) OR ((T1-T5<=-.1) AND (T4>T3>T2>T1))
HV-WG
ELSE
HV-UD