Mitigation of Drought Impacts on Agriculture through Satellite Irrigation Monitoring and Management Support

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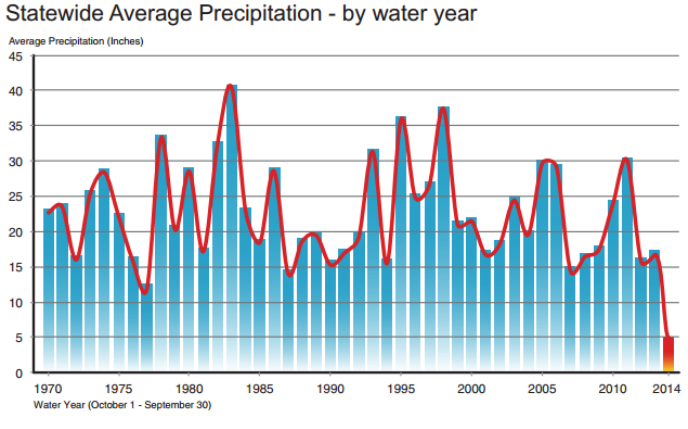
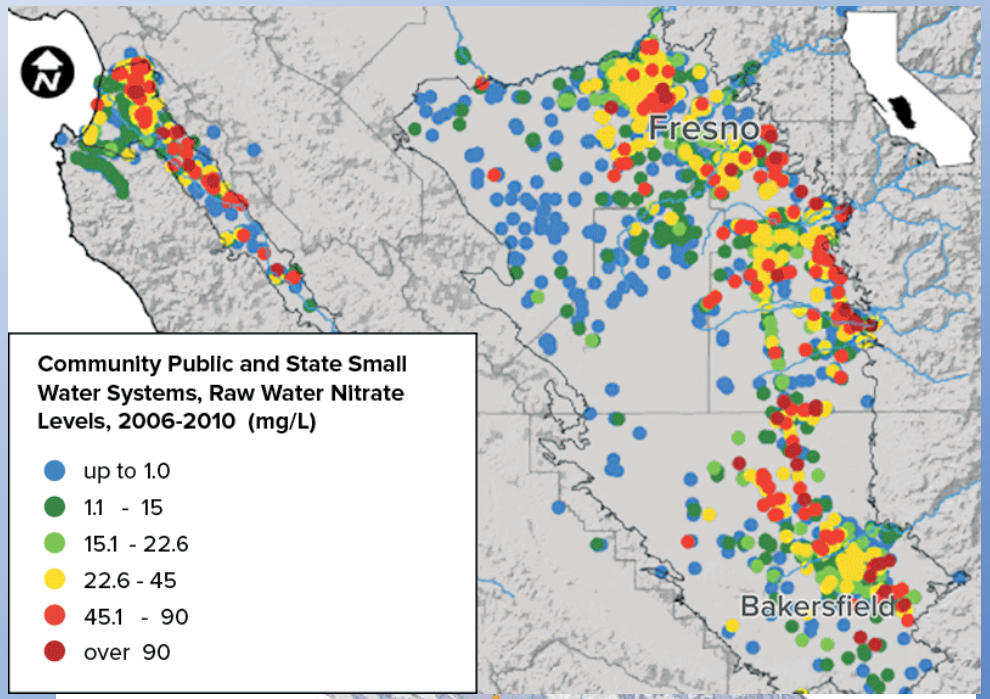
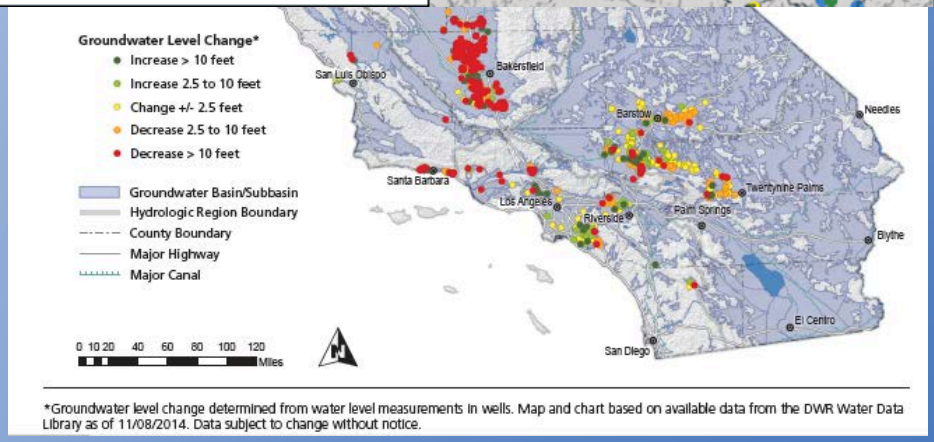
Project support provided by the
NASA Applied Sciences Program, CA Department of Water Resources, and the CSU Agricultural Research Institute

Motivation: Threats to Water Supplies and Water Quality in California







- **2013 driest calendar year on record**
- **2014 warmest year on record**
- **2015 April 1st snowpack 5% of normal**
- **2016 water allocations for growers are 5% south of Bay Delta**
- **Water qual. and groundwater legislation**

Quantifying Benefits of Using ET Information in Irrigation Management

Water, Yield and Total Benefits to Farmers from CIMIS				
Crop	Water $US +	Yield++ $US	Total $US	**Benefit/Hectare $US**
Trees and Vines Sample				
Almonds	246,000	2,426,500	2,672,500	**408**
Apples	900	13,900	14,800	**366**
Avocados	-141,350*	738,000	596,500	**760**
Grapes	100,850	1,336,500	1,437,3500	**730**
Pistachios	370,150	6,755,000	7,125,000	**630**
Plums	556	12,445	13,000	**402**
Vegetable Sample				
Artichoke	2,500	326,200	328,700	**160**
Broccoli	2,750	106,100	108,850	**730**
Cauliflower	5,750	334,100	339,850	**870**
Celery	3,350	345,750	349,100	**1700**
Lettuce	26,000	1,361,000	1,387,000	**920**
Field Crop Sample				
Alfalfa	47,790	325,700	373,500	**100**
Cotton	345,300	810,500	1,155,800	**110**

Source: http://www.cimis.water.ca.gov/cimis/resourceArticleOthersTechRole.jsp

+Money saved due to reduced water bill resulting from using CIMIS.

++Increased income from increased yield resulting from using CIMIS.

*Negative number indicates increased water use with CIMIS.

Average reduction in total applied water: 13%

Average increase in yields: 8%

Parker et al., 1996

Satellite Irrigation Management Support (SIMS): Objectives

1) Develop near real-time estimates of crop water requirements from satellite data to assist growers in optimizing irrigation, and water managers in improving estimates of agricultural water requirements

2) Provide web and mobile data interfaces to increase the ability of the agricultural community to access and use satellite data in irrigation management and crop monitoring

Project Partners and Stakeholders

Water Management
California Department of Water Resources (CDWR)
CA State Water Resources Control Board

Agriculture
Western Growers Association, Booth Ranches, Chiquita, Constellation Brands, Del Monte Produce, Driscoll's, Dole, Inc., E & J. Gallo, Farming D, Fresh Express, Pereira Farms, Ryan Palm Farms, Tanimura & Antle, CDFA, Vineyard Management Group

Research and Extension
Center for Irrigation Technology / CSU Fresno, USDA ARS / NRCS, Univ. of California Cooperative Extension / UC Davis, Desert Research Institute, USGS

Future Project Partners and Stakeholders

Water Management

Nevada State Engineer's Office
Oklahoma Water Resources Board
Central Asia Regional Water Network
USAID

Research and Extension

University of Oklahoma
University of Montana
American University of Central Asia, Kyrgyz Republic
University of Tunis El Manar, Tunisia

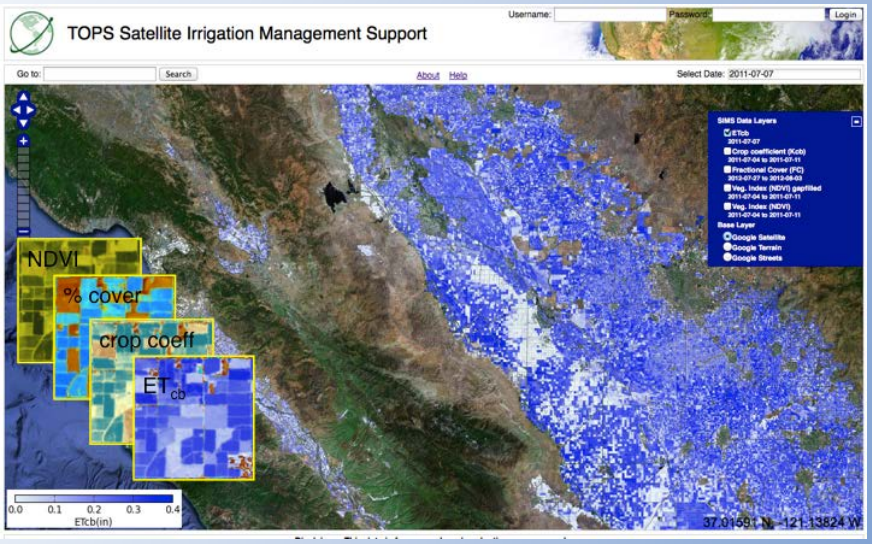
Requirements for Operational ET Mapping

- Field scale
- Cost effective
- 10+ year baseline (30-year preferred)
- Known accuracy
- Timely (latency of <1 month)
- Open data
- Data continuity is critical

Approach to Operational ET Mapping

Combine strength of different methods to ensure data continuity while also providing best available data

Satellite Irrigation Management System (SIMS)
reflectance-based approach



Automated METRIC energy balance approach developed with Python and GDAL

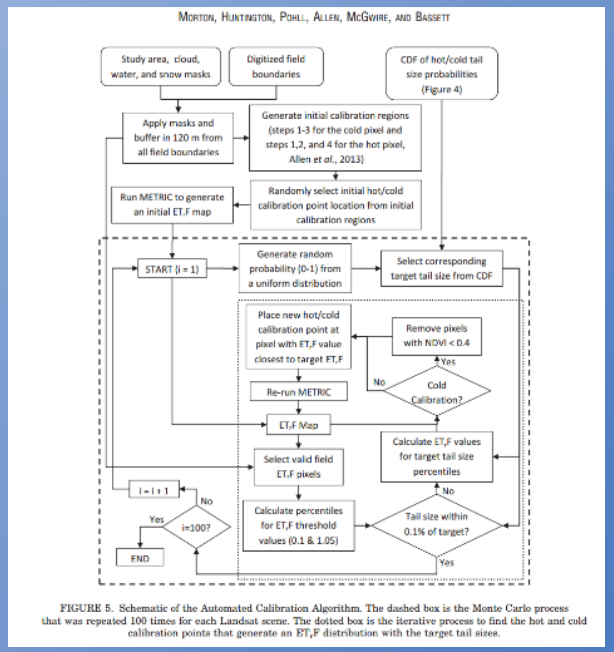


FIGURE 5. Schematic of the Automated Calibration Algorithm. The dashed box is the Monte Carlo process that was repeated 100 times for each Landsat scene. The dotted box is the iterative process to find the hot and cold calibration points that generate an ET_rF distribution with the target tail sizes.

Approach: 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)

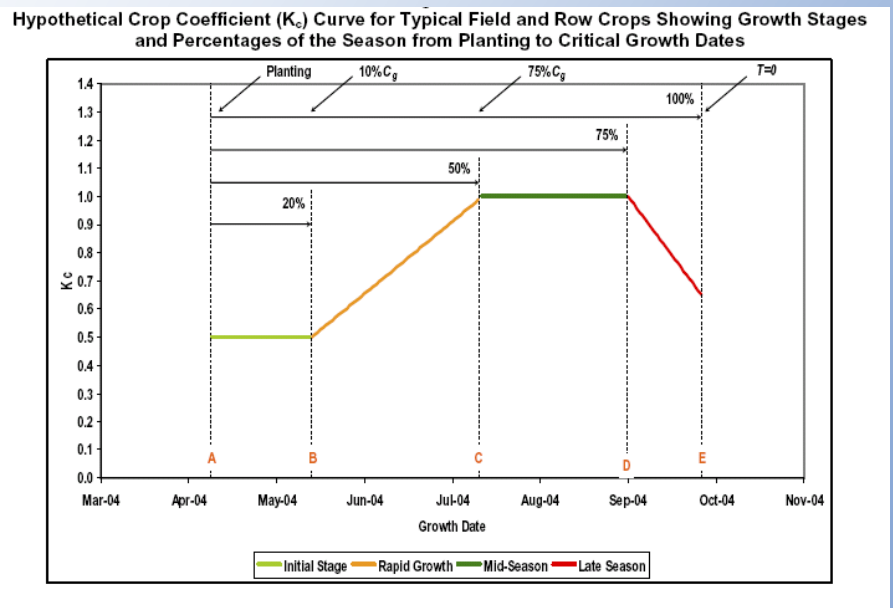
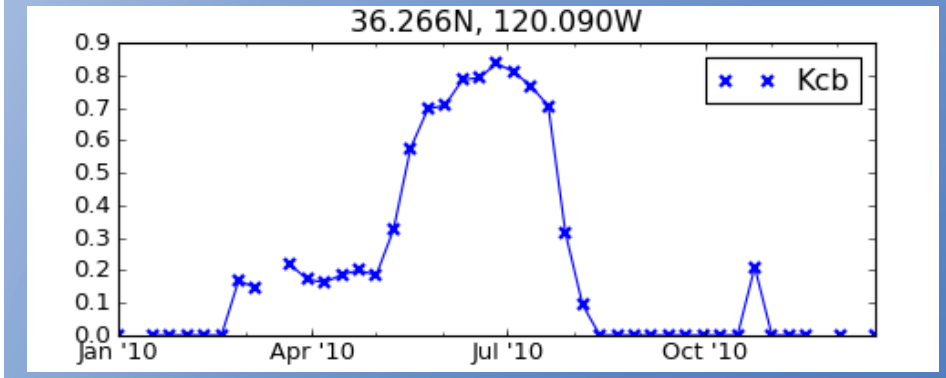


Figure credit: 2005 California Water Plan Update

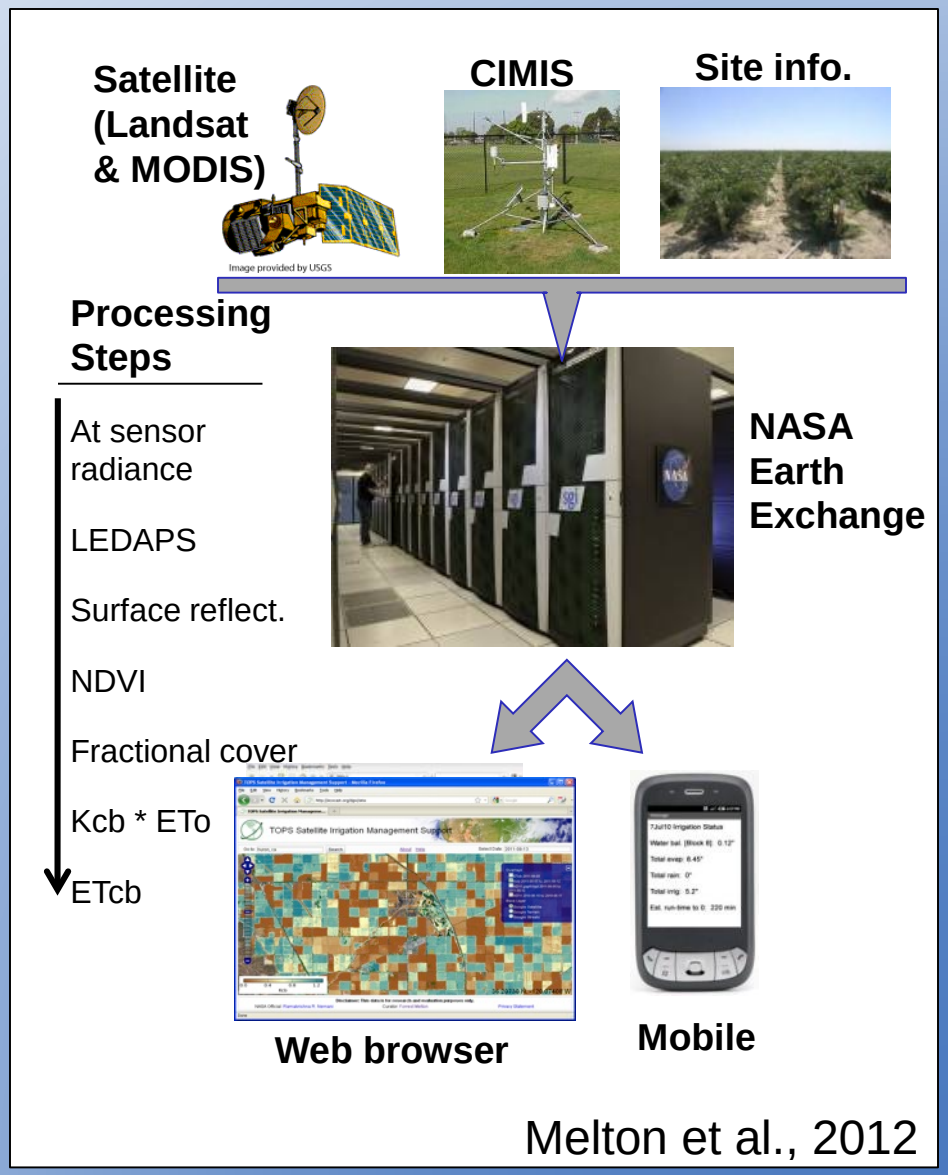
TOPS-SIMS K_{cb} Profile (Automated, Satellite-derived)



Kc profiles via: 1) reflectance based algorithms(NASA Ames); and 2) METRIC surface energy balance (DRI, J. Huntington)

Approach:
Satellite Irrigation Management Support (SIMS) Framework

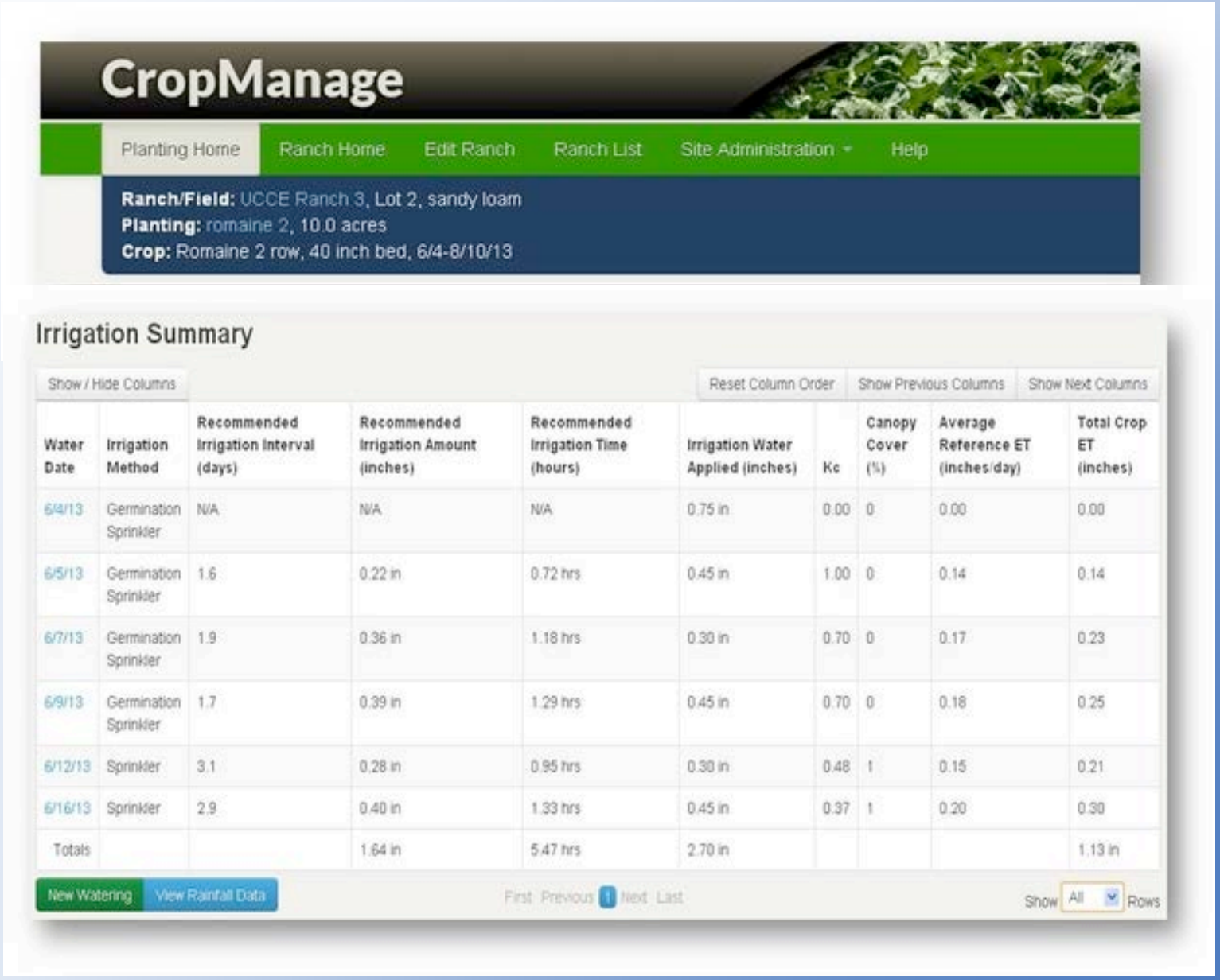
1. Integration of satellite and surface measurements
2. Prototyping accelerated by NASA high end computing resources
3. Integration with irrigation management tools (CropManage)
4. Freely available data
5. Outreach and education through partnerships with Western Growers and ag extension services



Melton et al., 2012

California State University MONTEREY BAY
Extraordinary Opportunity

API for Integration with Other Web-based Tools



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

Automated METRIC

- **Automated METRIC approach developed with Python and GDAL**
- **Approach outlined in Allen et al. (2013) and Morton et al. (2013)**
- **Originally developed in Idaho and Nevada, and applied in Nevada for 2 path rows**
  - irrigated alfalfa and pasture grass as a test case

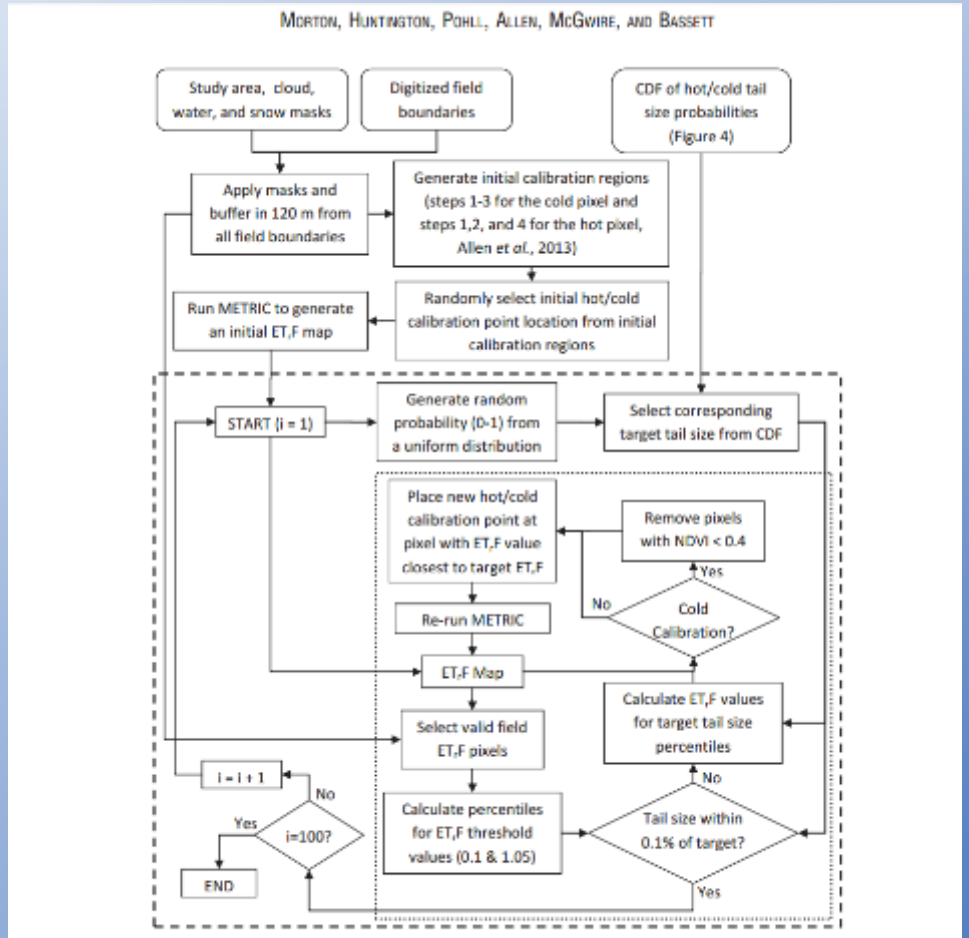


FIGURE 5. Schematic of the Automated Calibration Algorithm. The dashed box is the Monte Carlo process that was repeated 100 times for each Landsat scene. The dotted box is the iterative process to find the hot and cold calibration points that generate an ET,F distribution with the target tail sizes.

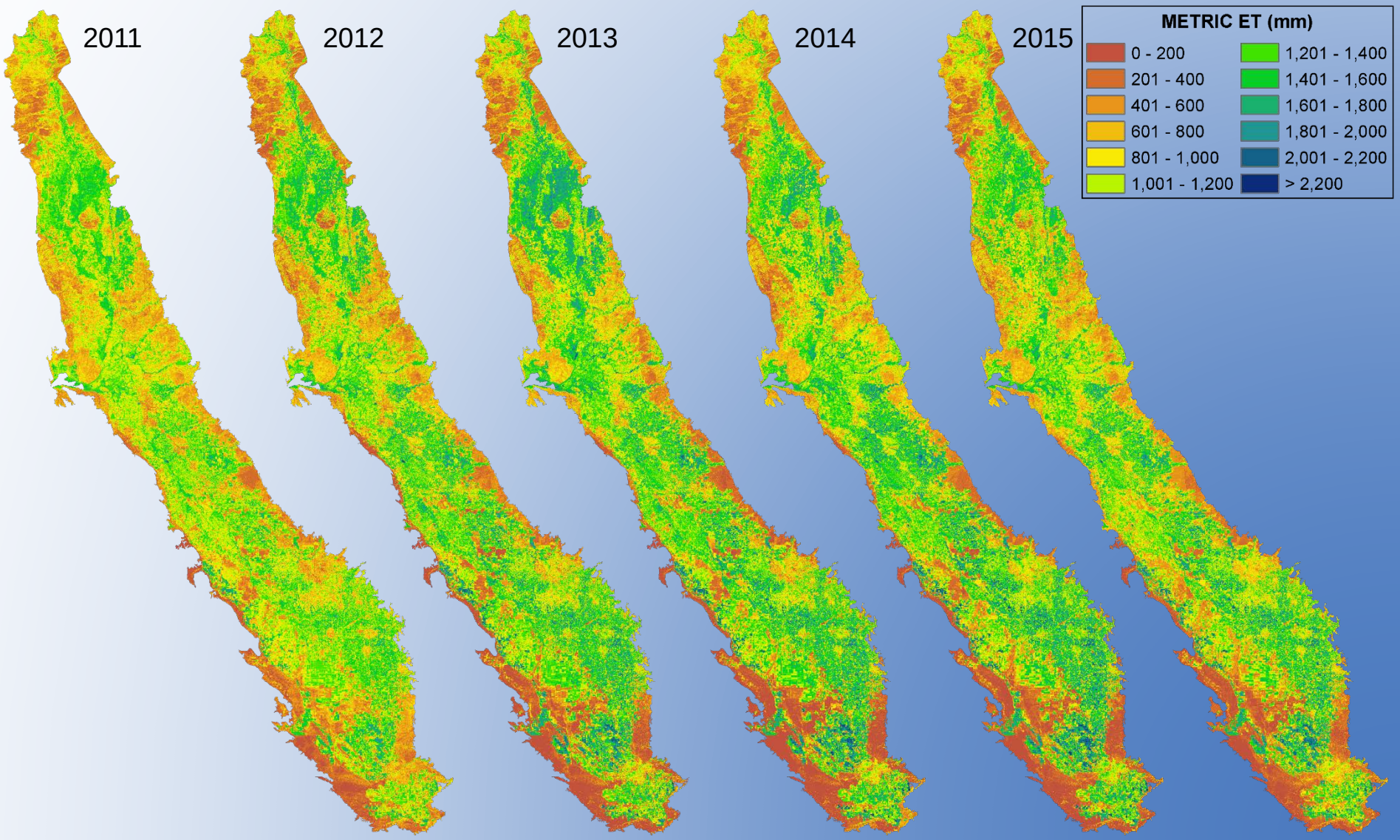
Allen, R.G., et al. (2013). Automated Calibration of the METRIC-Landsat Evapotranspiration Process. Journal of the American Water Resources Association (JAWRA) 49(3): 563-576. DOI: 10.1111/jawr.12056

Morton, C.G., et al. (2013). Assessing Calibration Uncertainty and Automation for Estimating Evapotranspiration from Agricultural Areas Using METRIC. Journal of the American Water Resources Association (JAWRA) 49(3): 549-562.DOI: 10.1111/jawr.12054

Initial Results – ET for the last 5 years

Lower ET during drought in water limited areas

Higher ET during drought in well-watered areas



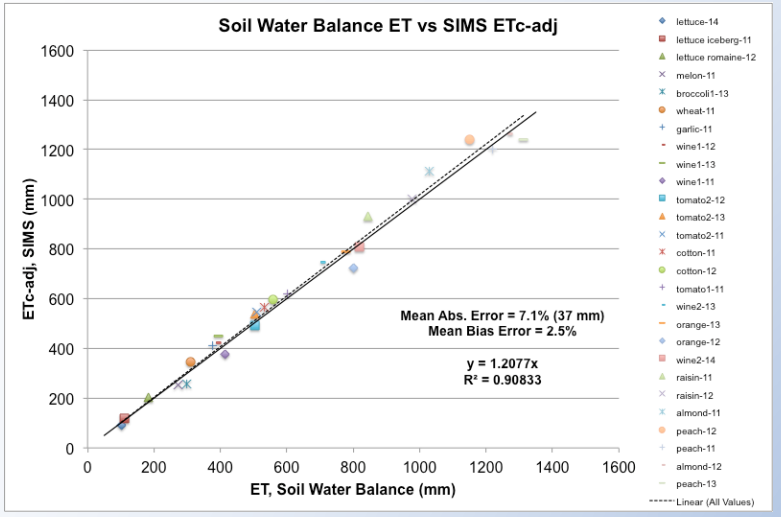
Project Highlights

- Prototype system completed; on-line web and mobile interfaces released to project partners and currently publicly accessible.
- System currently being tested by multiple growers
- Integration with UCCE CropManage framework ongoing
- Prototype calculator for on-farm WUE metrics completed
- Initial METRIC ET estimates for 2011-2015 completed for the Central Valley
- Initiated study with UC Berkeley and CDWR to quantify economic benefits

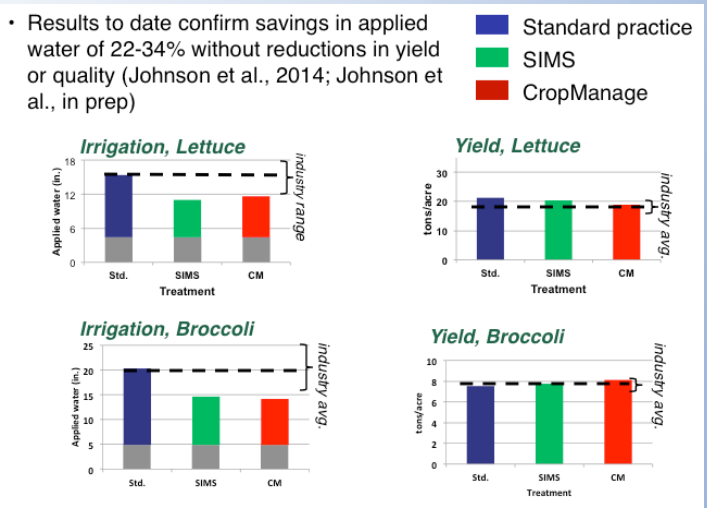
SIMS Web Interface showing example of daily ETcb for San Joaquin Valley

Outreach: >15 presentations given in 2015 at agricultural workshops, conferences, and trainings to growers, water managers, and ag extension specialists.

Highlights: Field Validation



Seasonal ETcb from SIMS + FAO-56 SWB vs field measurements of ET.



Results from yield trials completed in 2012 and 2013 for lettuce and broccoli.

Field Validation

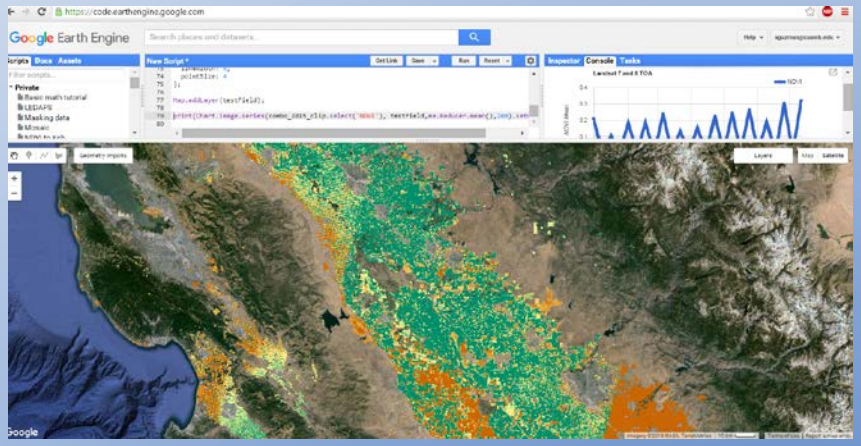
- Field validation campaign completed in partnership with partner growers, CA DWR, CSU Fresno, and USDA ARS.
- Data collected for more than 14 crops at 30 sites.
- Results highly encouraging for seasonal and daily comparisons.

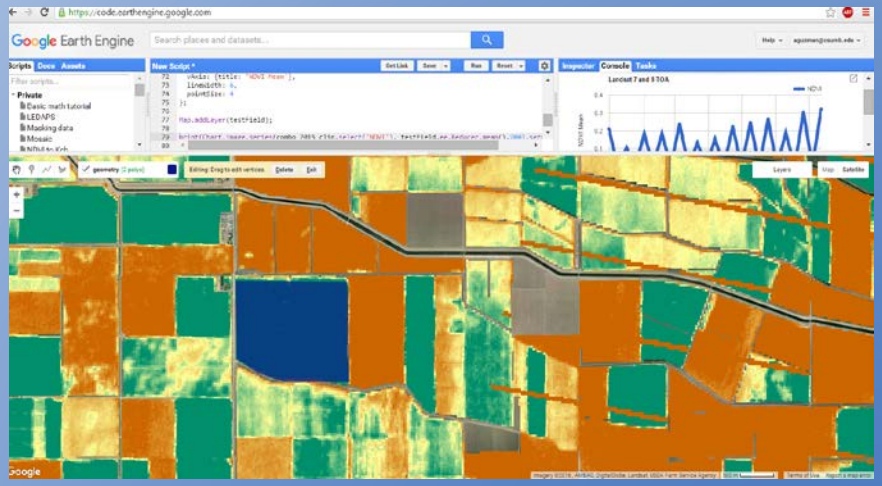
Yield Trials and Demonstration Projects

- Field irrigation trials completed in partnership with USDA ARS and UCCE.
- Results from 3 year study demonstrated 20-40% reduction in applied irrigation with equivalent or improved yields for lettuce and broccoli crops (Johnson et al. 2016).
- CDFA supporting additional trials in 2015-2016.

Transition Strategy

- Report evaluating transition strategy options prepared for CDWR
- Option 1: Algorithms / processing workflows to be transferred to CDWR IT Infrastructure
- Option 2: Algorithms / processing workflows transferred to Amazon EC2 / ESRI ArcGIS Online or Google Earth Engine
- Prototypes implemented on both Earth Engine and Amazon EC2
- CDWR forming working group to evaluate and advise on final transition
- Transition strategy linked to transition strategy for Fallowed Area Mapping project





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) Tradeoffs between complexity and reliability → need for fallback algorithms

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

6) Changes in California water policy creating new opportunities for applications of satellite data for ET mapping

Publications

Johnson, L., M. Cahn, F. Martin, F. Melton, S. Benzen, B. Farrara, and K. Post, 2016. Evapotranspiration-based irrigation scheduling of lettuce and broccoli. *HortScience* (*in press*).

Johnson, L., M. Cahn, F. Martin, F. Melton, C. Lund, B. Farrara, and S. Benzen, 2014. Results from 2012-2013 Salinas irrigation trials – further development of decision support tools for cool season vegetable production. *Proceedings, US Committee on Irrigation & Drainage, Water Management Conference*, 4-7 March, Sacramento.

Melton, F., Johnson, L., Lund, C., Pierce, L., Michaelis, A, Guzman, A., Trout, T., Temesgen, B., Frame, K., Sheffner, E., and Nemani, R. 2012. Satellite Mapping of Crop Condition and Evapotranspiration for Irrigation Management Support with the Terrestrial Observation and Prediction Systems. IEEE J-STARS, special issue on Interoperability Architectures and Arrangements for Multi-Disciplinary Earth Observation Systems. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol.5, no.6, pp.1709-1721, Dec. 2012, doi: 10.1109/JSTARS.2012.2214474.

AghaKouchak, A., Farahmand, A., Teixeira, J., Wardlow, B.D., Melton, F.S., Anderson, M.C., and C.R. Hain, 2015. Remote Sensing of Drought: Progress, Challenges, and Opportunities. *Reviews of Geophysics, 53(2), 452-480.*

Questions?

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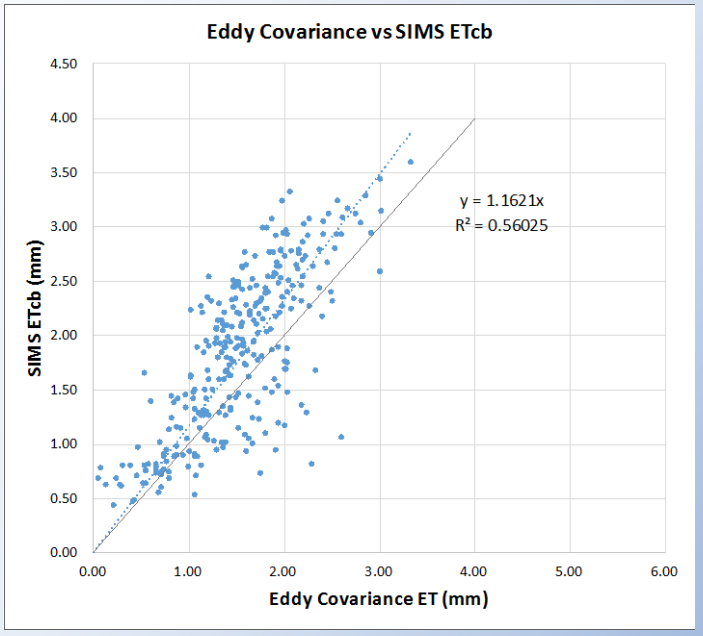
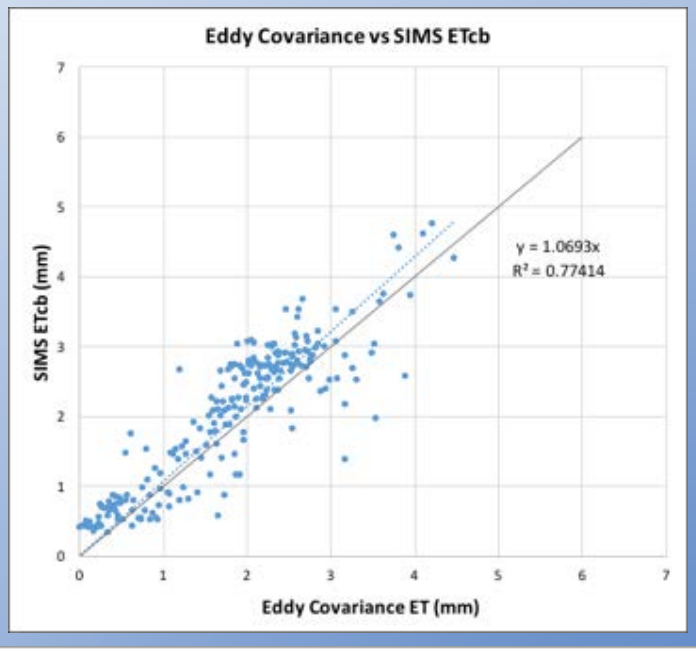
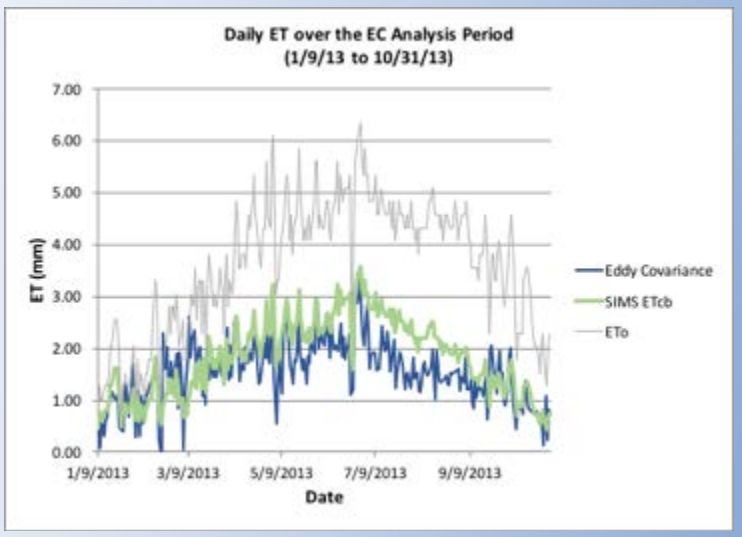
Accuracy Assessment: Pinot Noir, Soledad, CA

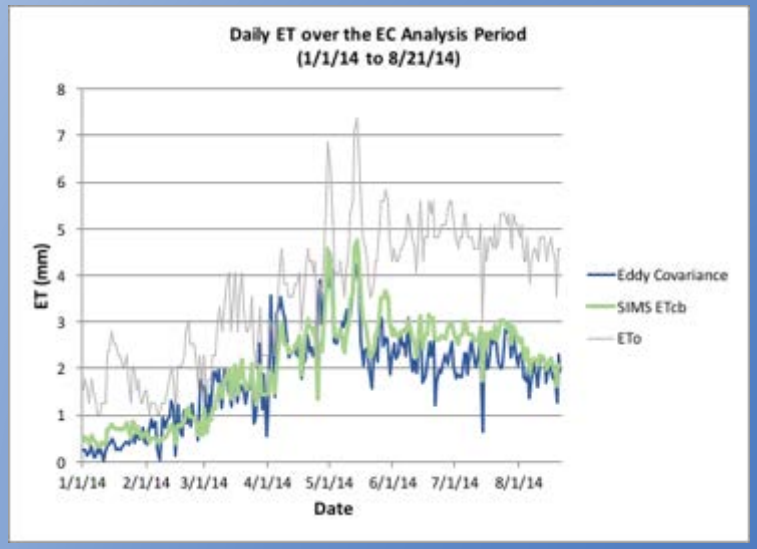
2013



2014



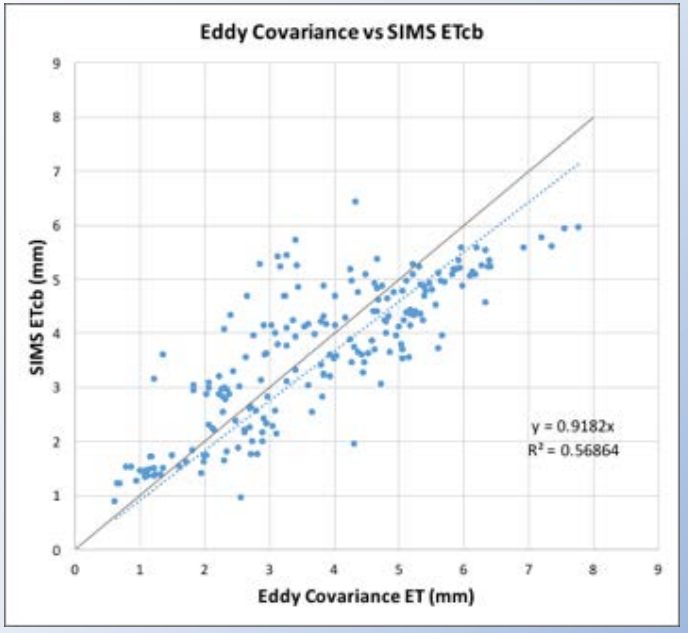




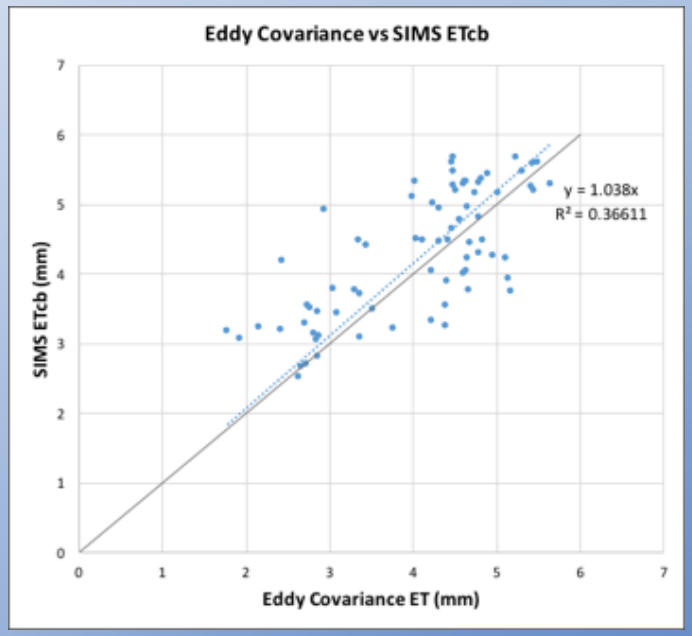
Paper in prep -- please do not distribute.

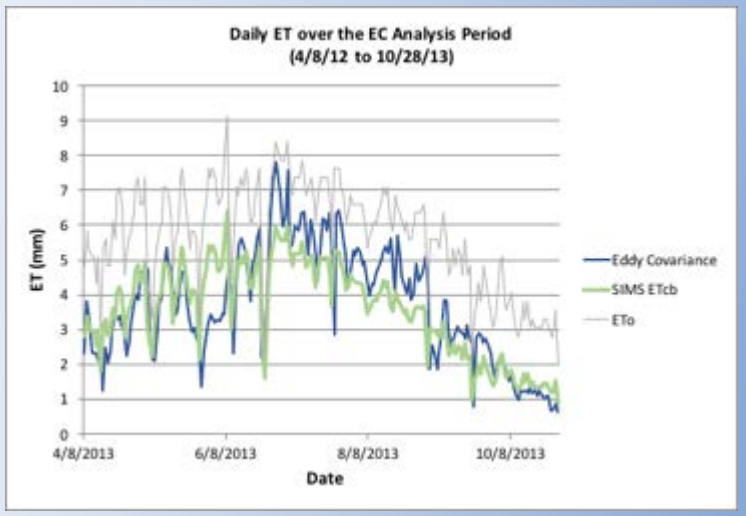
Accuracy Assessment: Pinot Noir, Galt, CA

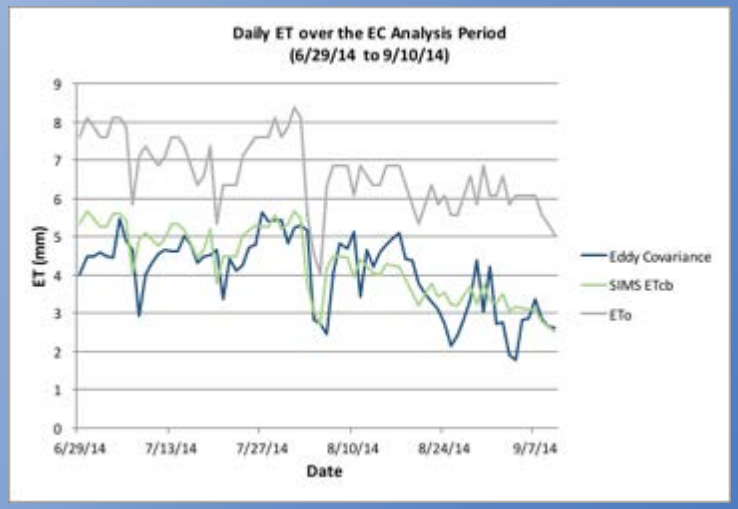
2013



2014







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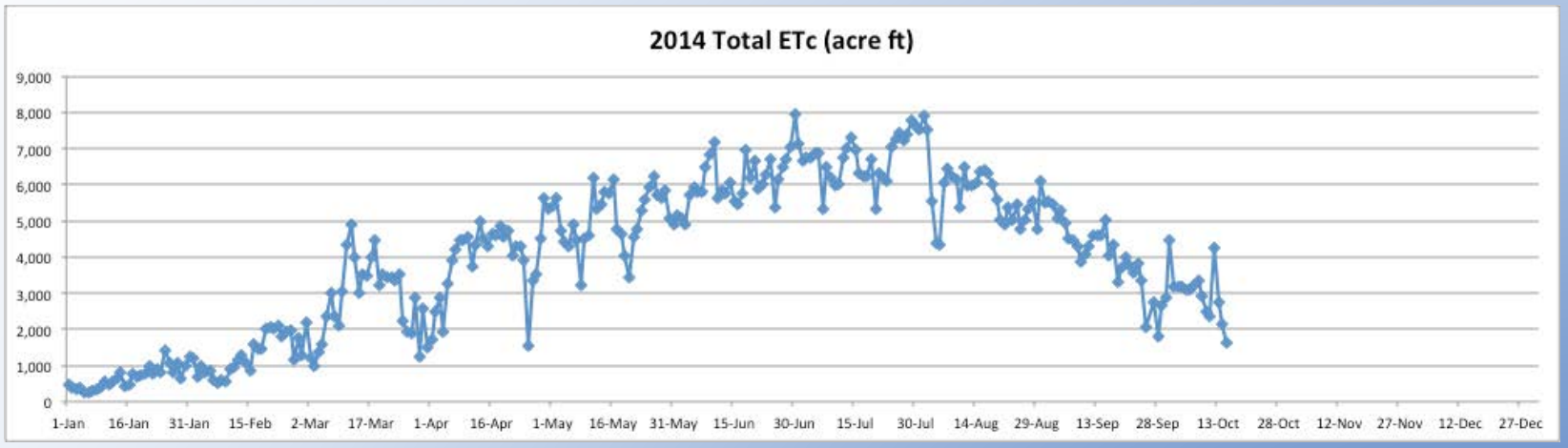
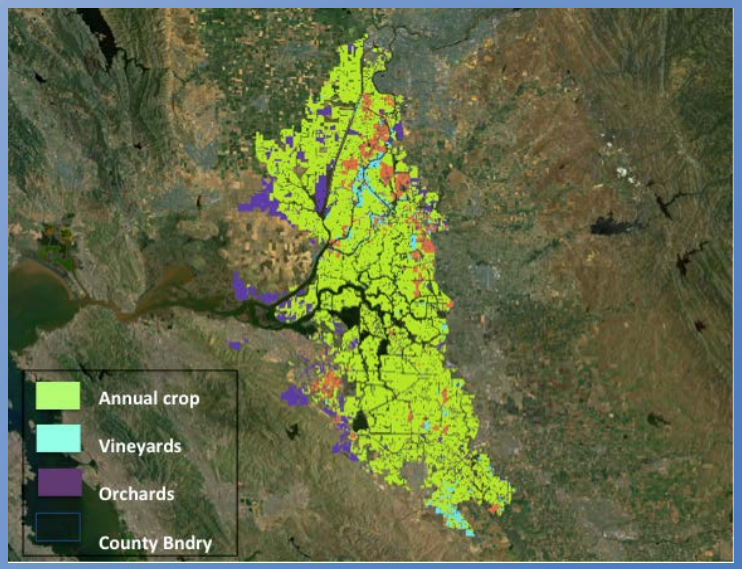
Highlights: Mapping ET in the CA Delta



SIMS daily total ETcb for SF Bay Delta for 2014.

- Fully automated mapping of crop water use in California Delta
- Seasonal results within ~5% of CDWR CalSIMETAW and SEBAL → real-time mapping for Delta water management
- Results presented to CA DWR and Delta Watermaster
- Preparing plan with UC Davis for inter-comparison study + full trial → model for CA statewide mapping?



Map of SF Bay Delta showing major crop categories.