Comparing Methods to Estimate Consumptive Use in the Sacramento-San Joaquin Delta: Preliminary Finding

Josué Medellín-Azuara, **Yufang Jin**, Kyaw Tha Paw U, Quinn Hart, Eric Kent, Jenae' Clay, Andy Wong, Andrew Bell, Michelle M. Leinfelder-Miles, Jay R. Lund

University of California, Davis

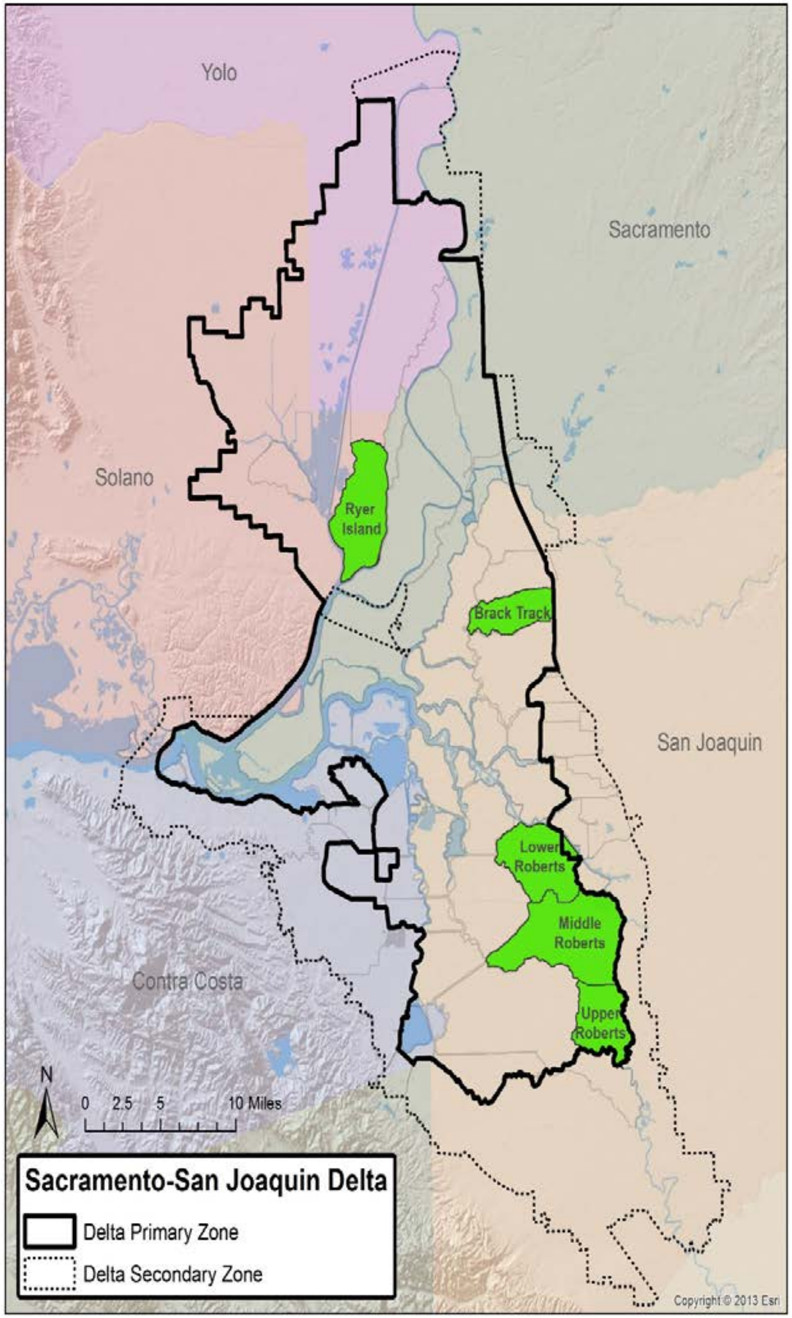
In collaboration with:
Tariq Kadir, Morteza Orang, Bekele Temesgen, Kent Frame (DWR), Forrest Melton (NASA-Ames), Dan Howes (ITRC), and Martha Anderson (USDA)

With Financial and Research Support from:

State Water Resources Control Board, California Department of Water Resources, Delta Protection Commission, Delta Stewardship Council, North Delta Water Agency, Central Delta Water Agency, and South Delta Water Agency

Motivations

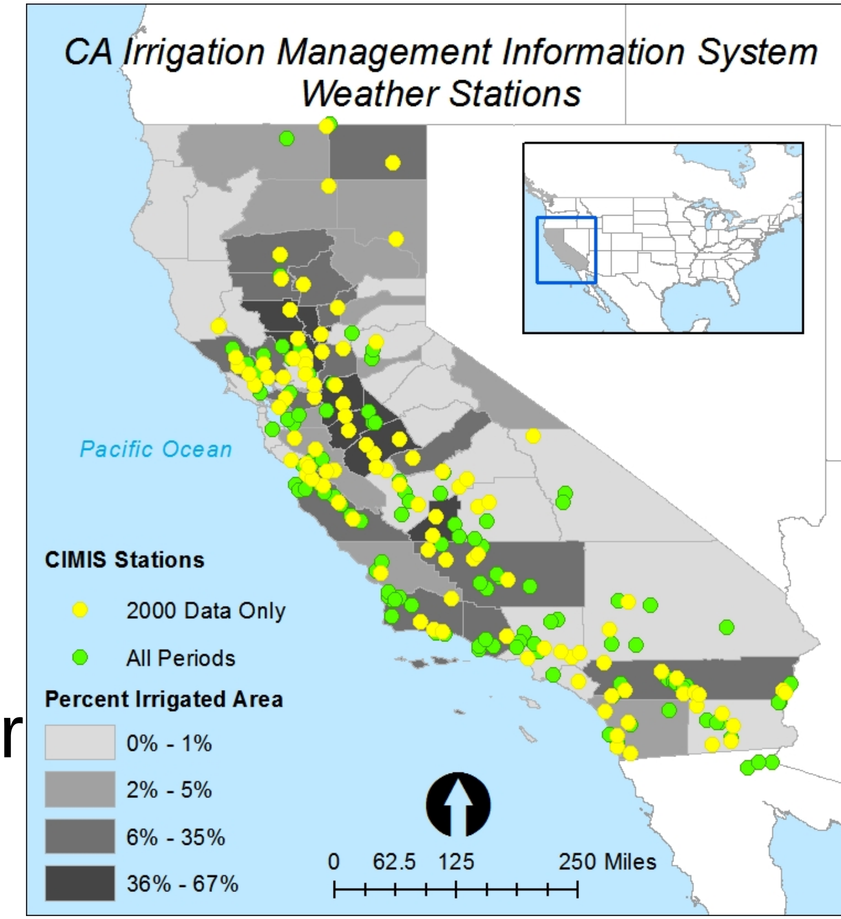
- Area of critical importance
- Water rights administration, management and operations, agricultural water management, and environmental and water quality protection
- Timely, consistent, cost-effective, spatial ET estimate with known uncertainties

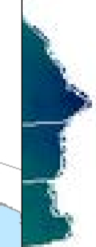


Objectives

- Evaluate approaches to estimate evapotranspiration (ET) in the Delta
- Quantify uncertainties in ET mapping
- Calibration of models to improve consumptive use information
- Improve transparency and accessibility

CIMIS for reference ET





Daily 2km ET_0 on 10/20/2015

- Currently manages over 145 active weather stations throughout the state
- Spatial CIMIS at 2km

Crop Coefficient Based Approach

- $ET = ET_0 * K_c$
  - Reference ET_0 (well-watered alfafa / grass)
  - Adjusted by specific crop coefficient (K_c)
- Crop coefficient (K_c) varies with crop structure and environmental conditions (relative humidity and wind)
- Challenges: spatial and temporal dynamics of Kc

Crop coefficients

- Land cover type based crop coefficient (Kc)

  - California Simulation of Evapotranspiration of Applied Water (**CalSIMETAW**): Published Kc values for each crop type but adjusted for local conditions (DWR)

  - Delta Evapotranspiration of Applied Water (**DETAW**): Kc calibrated with SEBAL (remote sensing based results from 2007 and 2009) (DWR)

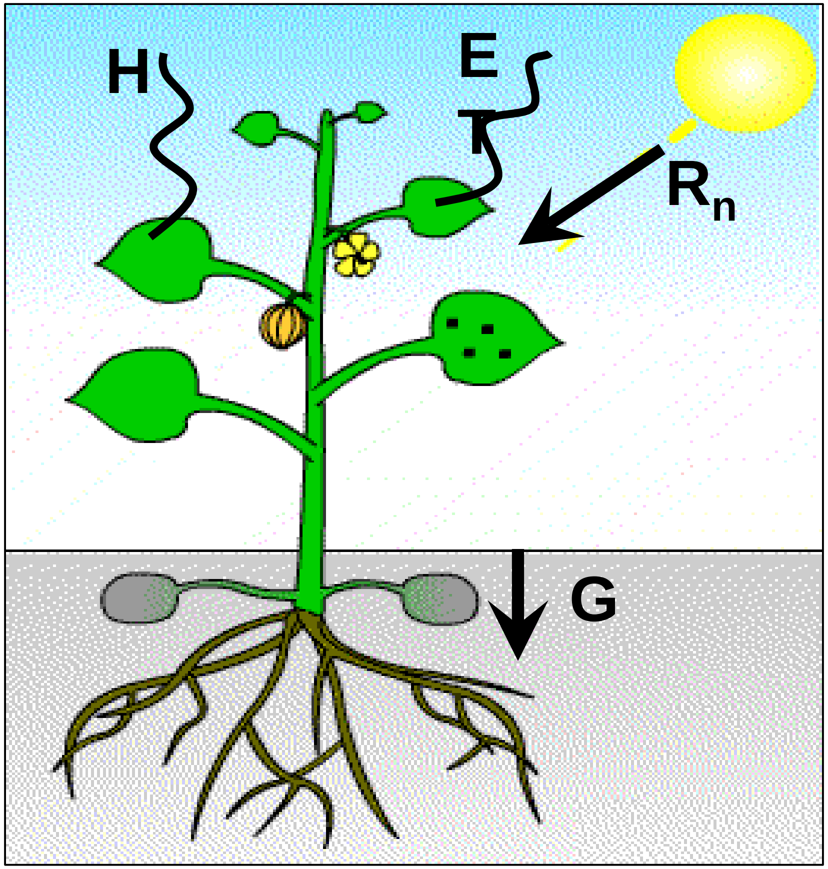
- Remote sensing (RS) based Kc estimates

  - Relationship between K_c and RS measures

  - Calibrated with ground measurements across crop types and environmental conditions

  - Satellite Irrigation Management Support System (**SIMS**): Normalized Difference Vegetation Index (NDVI) based Kc curve (NASA-Ames)

Energy Balance Based Methods



$$ET = R_n - G - H$$

R_n: net radiation

G: ground heat flux

H: sensible heat

Energy Balance approaches

- Mapping EvapoTranspiration at high Resolution with Internalized Calbiration (**METRIC**, Dr. Rick Allan, Univ. of Idaho)

  - Energy balance approach with internal calibration for H

  - **Cal-Poly ITRC-METRIC** (Dr. Dan Howes)

- Disaggregate Atmosphere-Land Exchange Inverse (**DisALEXI**, Dr. Martha Anderson, USDA-ARS)

  - Two source energy balance model

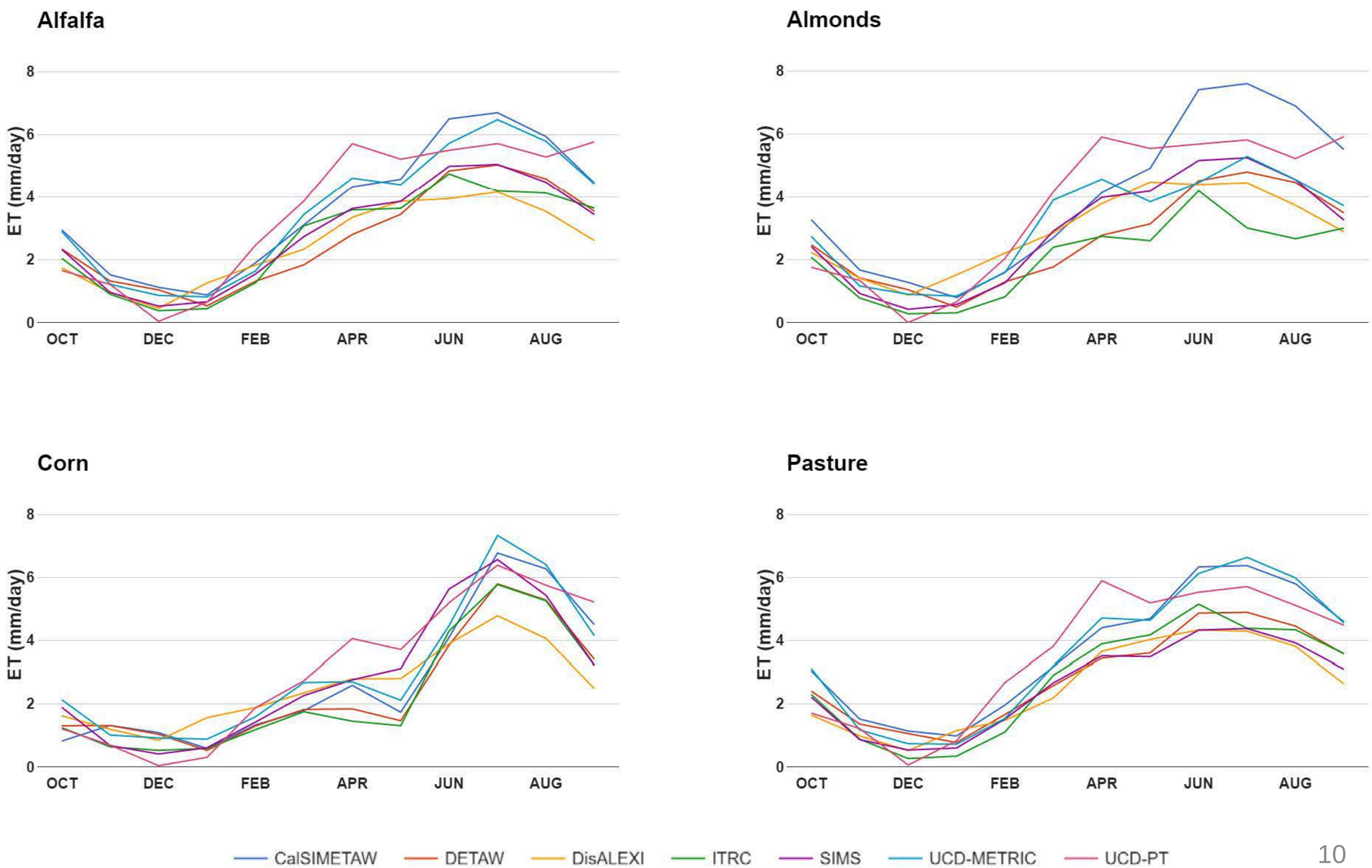
- Semi-empirical Priestley Taylor (**PT**, Dr. Yufang Jin, UCDavis)

  - Partitioning available energy to latent heat by parameterized PTcoefficient

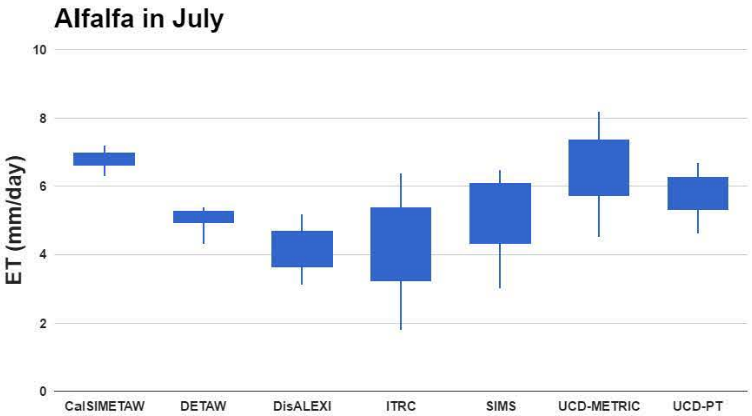
Comparison Methods

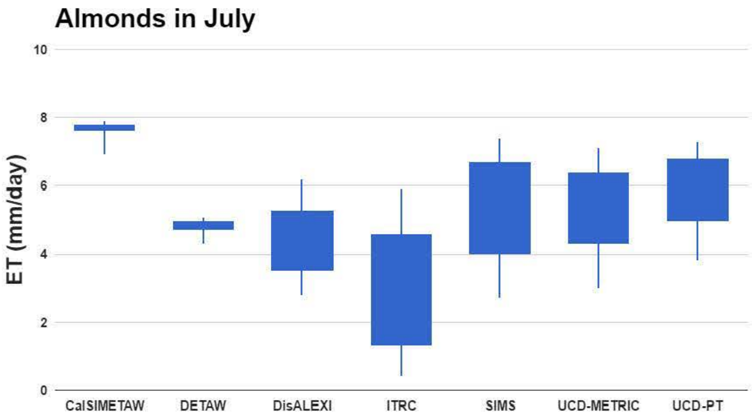
- 2014-2015 water year ET estimate
- Key input data
  - Land use survey (LandIQ)
  - CIMIS reference ET
  - Landsat satellite data (30m, every 16 day)
- Comparison among algorithms
  - By crop type, month, and regions
- Comparison with field measurements
  - Fallowed lands (2015)
  - 3 crop types (corn, pasture, alfafa)

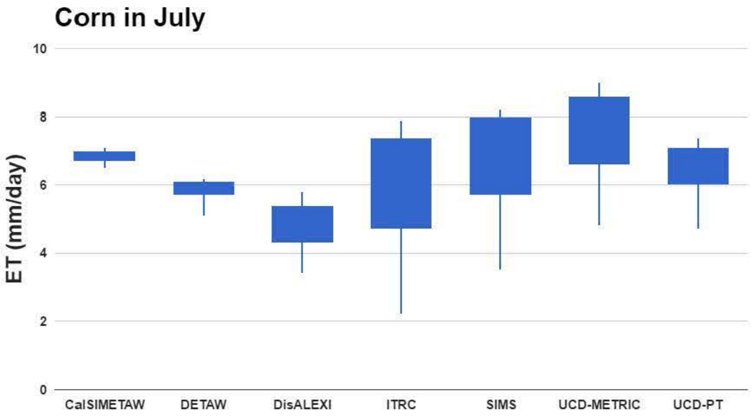
Monthly Average Crop ET

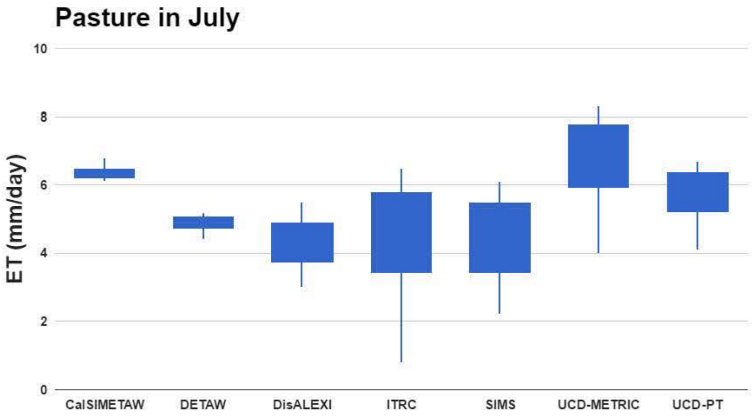


Average Crop ET in July

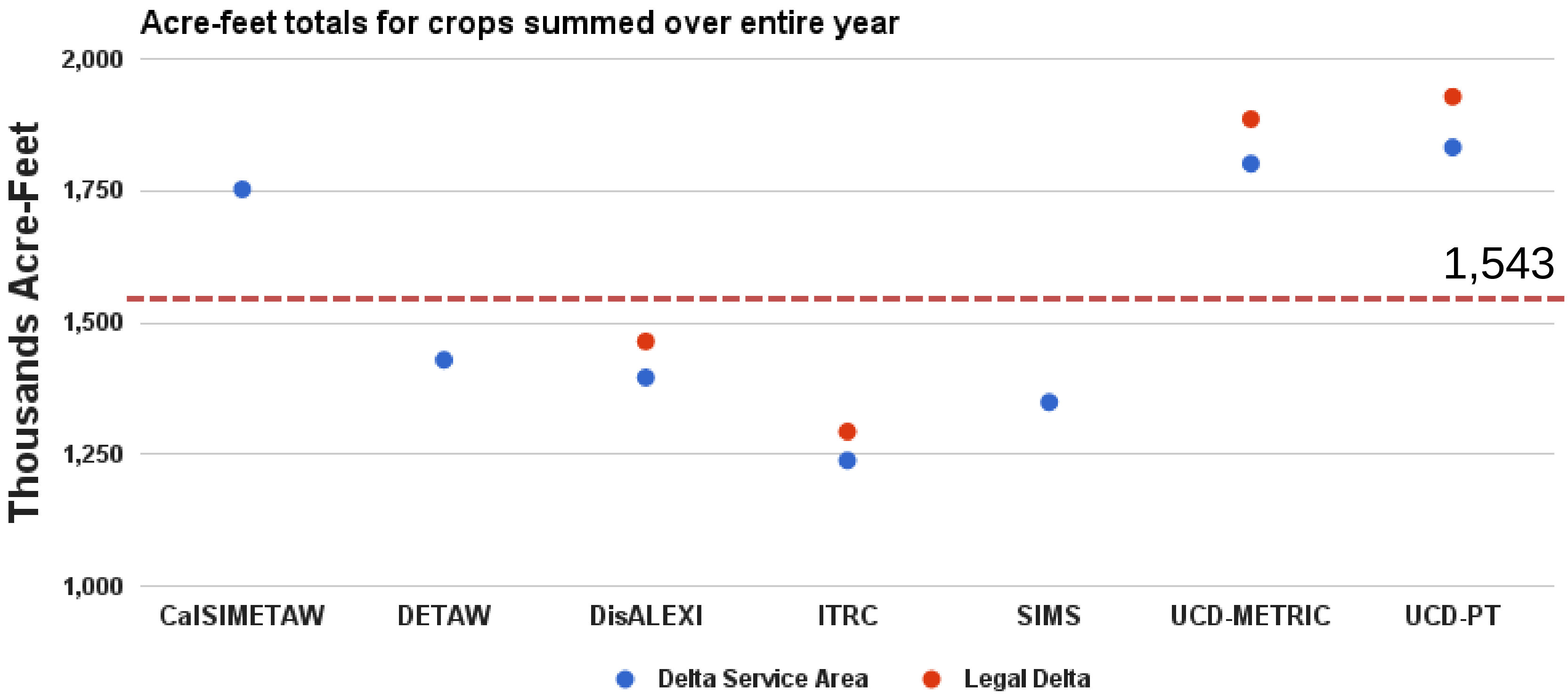






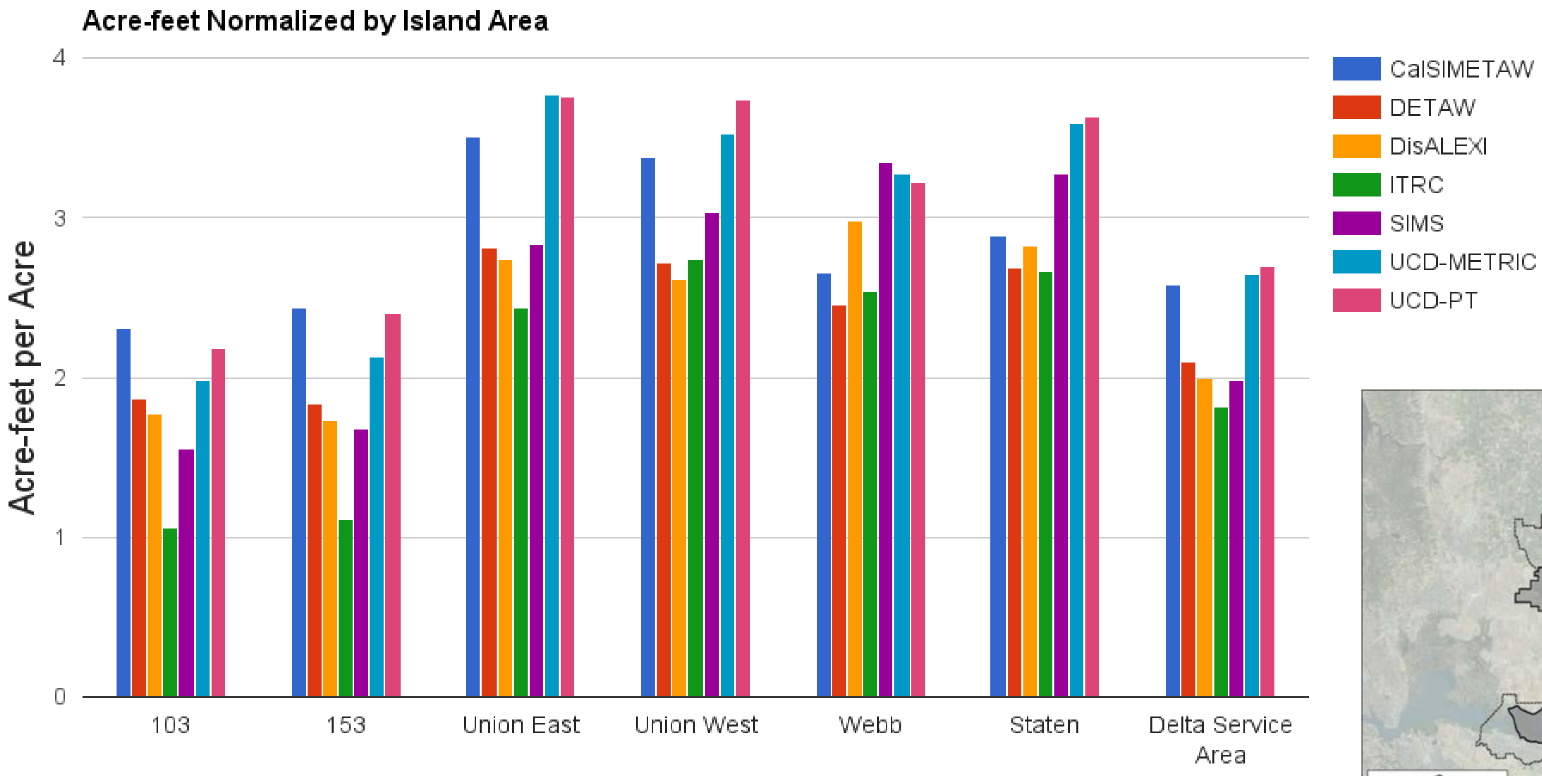


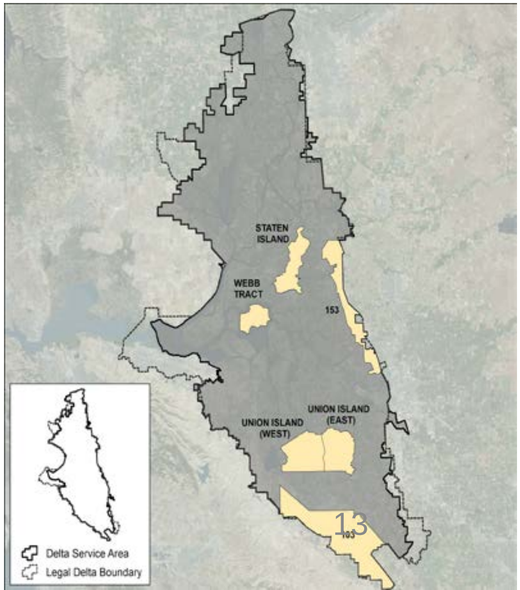
Delta Total Crop ET



Mean: 1,543 Thousand Acre-Feet in Crops for the Delta Service Area

Crop Evapotranspiration by DETAW Region



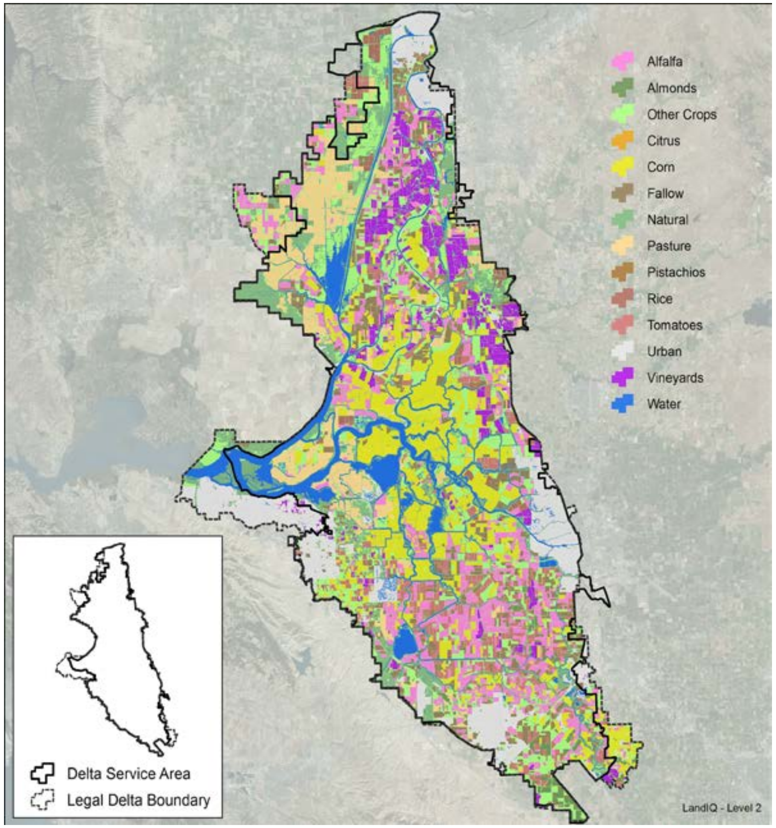


Model Dispersion

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Alfalfa	0.55	0.51	2.08	1.24	0.73	0.66	0.80	0.46	0.51	0.50	0.52	0.87	0.41
Almonds	0.62	0.66	1.47	1.84	0.88	0.84	0.79	0.70	0.71	0.88	0.93	0.87	0.66
Corn	1.01	0.67	1.25	2.15	0.49	0.43	0.97	1.14	0.42	0.40	0.43	0.80	0.30
Pasture	0.64	0.56	2.02	1.05	1.02	0.56	0.63	0.41	0.39	0.48	0.49	0.55	0.38
Potatoes	0.96	0.80	1.33	2.40	0.69	0.67	1.04	0.85	0.70	0.59	0.53	1.83	0.44
Rice	1.19	0.72	1.48	2.48	1.03	0.67	0.56	1.07	0.34	0.52	0.54	0.75	0.52
Tomatoes	0.65	1.09	1.35	2.24	0.72	0.64	0.81	0.78	0.87	0.58	0.64	1.94	0.48
Vineyards	0.56	0.68	1.25	1.94	1.18	0.87	1.32	1.19	0.91	0.94	0.90	1.36	0.82

Lessons of this Preliminary Blind Comparison

- Setting up the infrastructure
- Consolidation of datasets
- Various stages of development in models
- Land use information
- Delta particular conditions



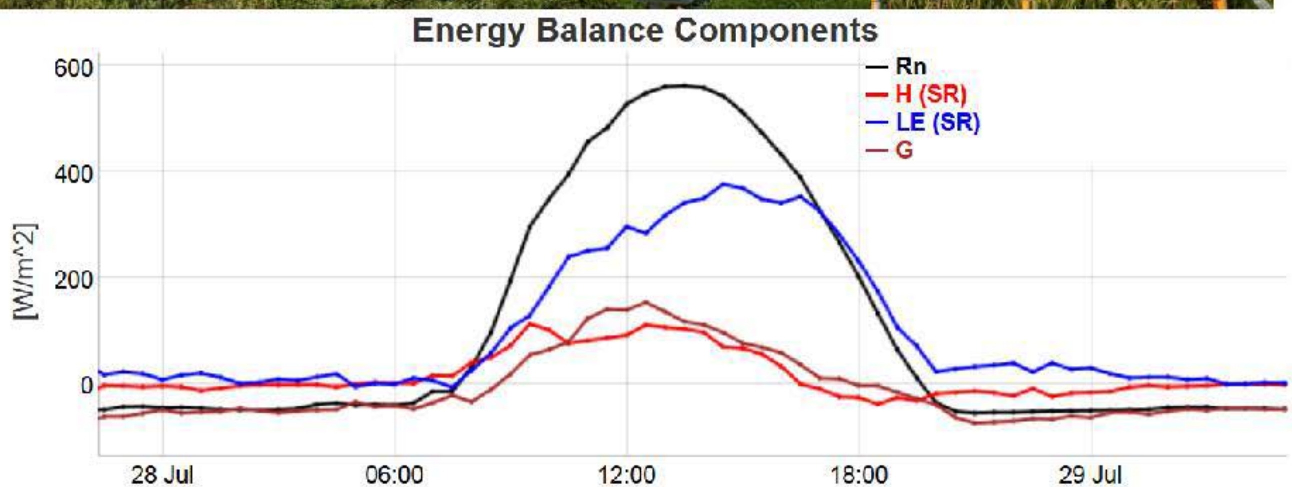
  - Meteorological conditions: wind, fog, cloud, waterways
  - Limited clear-sky imageries in winter and spring
  - Limited CIMIS network stations

Preliminary Conclusions

- The median estimates of Delta crop ET from the dry-run ensemble is broadly consistent with 2013 California Water Plan, ~ 1.5 MAF
- The greatest difference across methods occurs in December and January of the water year. Vineyards, potatoes and tomatoes have higher discrepancies.
- First round provides an initial reference for future comparisons, quantifying variation, and identifying conditions with higher discrepancies
- Improving quantitative understanding of CU in the Delta has the potential of increasing transparency and accuracy of models and reducing costs of water accounting statewide.

https://watershed.ucdavis.edu/project/delta-et


2016: Maize
2016: Pasture
2015: Bare Soil
2016: Alfalfa


Energy Balance Components
Rn
H (SR)
LE (SR)
G
[W/m^2]
600
400
200
0
28 Jul
06:00
12:00
18:00
29 Jul

Next steps

- Standardize common input datasets and refine comparison protocols
- Evaluation against field measured ET
- Sources of differences among various ET estimate approaches
- Calibration of ET approaches
- Final report: spring 2017

Acknowledgments

State Water Resources Control Board, California Department of Water Resources, Delta Protection Commission, Delta Stewardship Council, North Delta Water Agency, Central Delta Water Agency, and South Delta Water Agency

Field Campaign: *Rudi Mussi, David Forkel (Delta Wetland Properties), Juan Mercado (DWR), Dawit Zeleke, Morgan (The Nature Conservancy, Bob Ferguson, James, John (DWR)*

Research support: *Nadya Alexander, J. Andrés Morandé, Barbara Bellieu, and Cathryn Lawrenc*

UC DAVIS CENTER FOR WATERSHED SCIENCES

AMES RESEARCH CENTER

NASA

University of California Division of Agriculture and Natural Resources

Department of LAND, AIR AND WATER RESOURCES University of California, Davis
Climate Change • Sustainable Agriculture
Environmental Quality • Landscape Processes

ITRC moving water in new directions

Delta Protection Commission

DELTA STEWARDSHIP COUNCIL

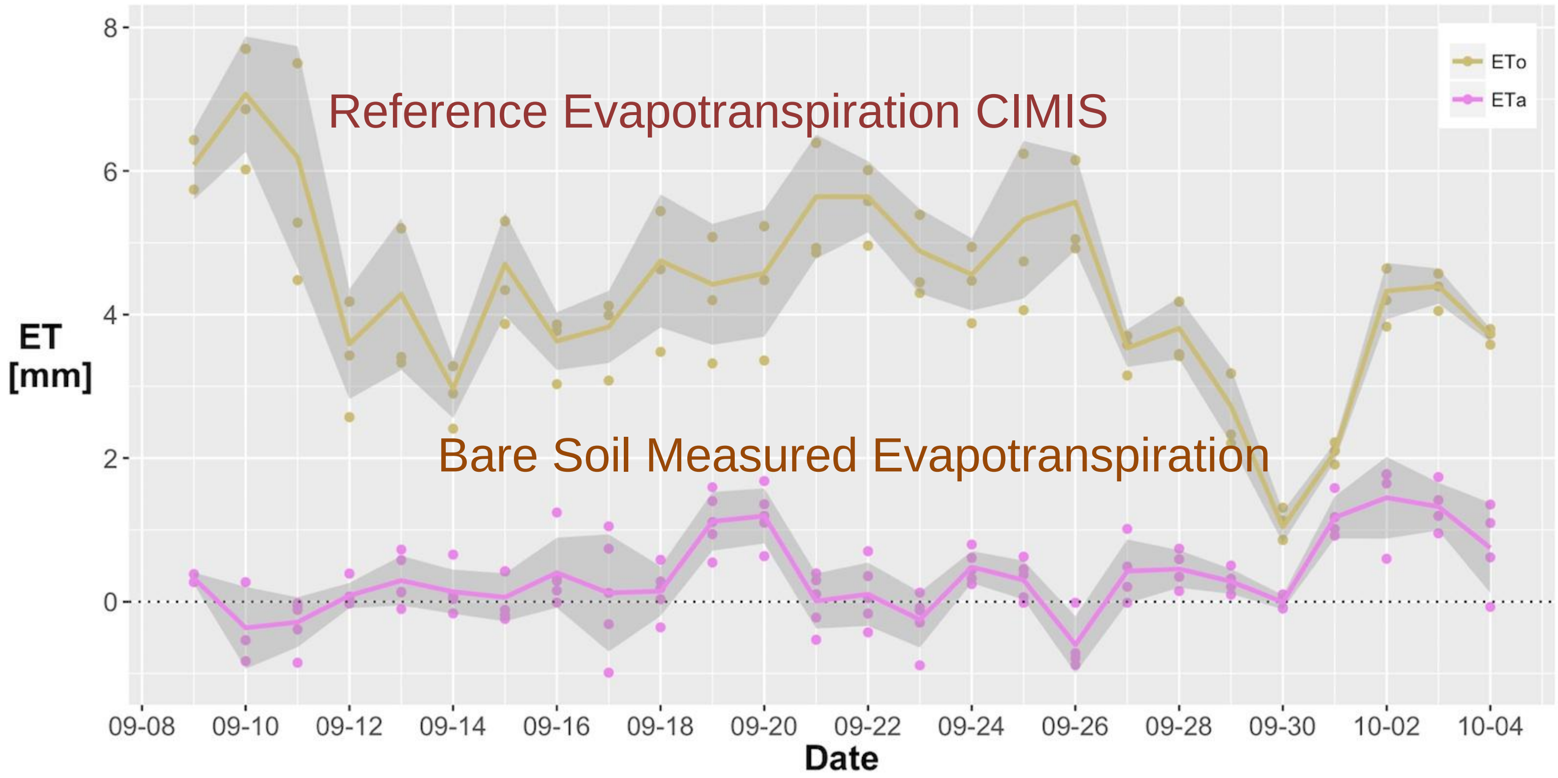
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
STATE WATER RESOURCES CONTROL BOARD

Extra slides

Interim Report Overview

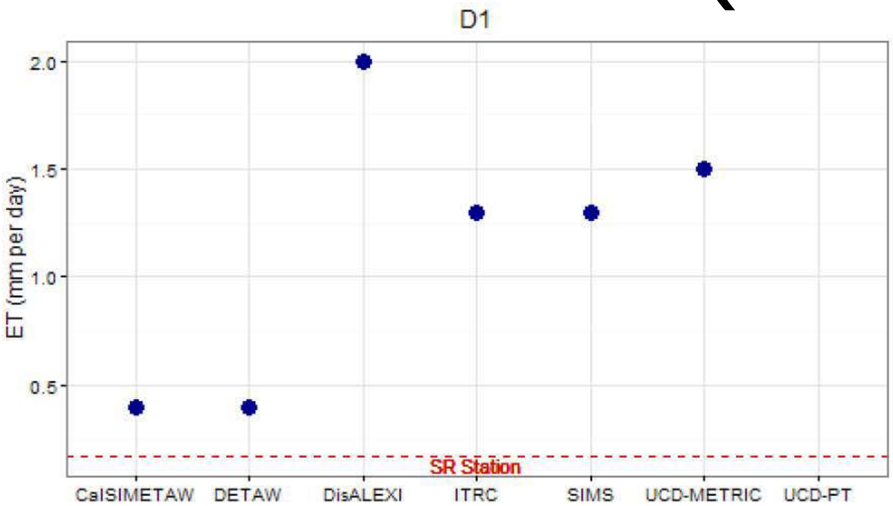
- Dry run of 7 ET estimation models
  - CalSIMETAW, DETAW, DisALEXI, ITRC-METRIC, SIMS, UCD-METRIC, UCD-PT
- Protocols and common datasets
- GitHub Repositories
  - https://github.com/ssj-delta-cu/ssj-overview
- Google Earth Engine platform
- Feedback and iteration, first draft 8/10
- Outcomes
  - Interim main meport
  - 9 supplemental appendices
    - Field campaign, methods, and full set of charts
  - https://watershed.ucdavis.edu/project/delta-et

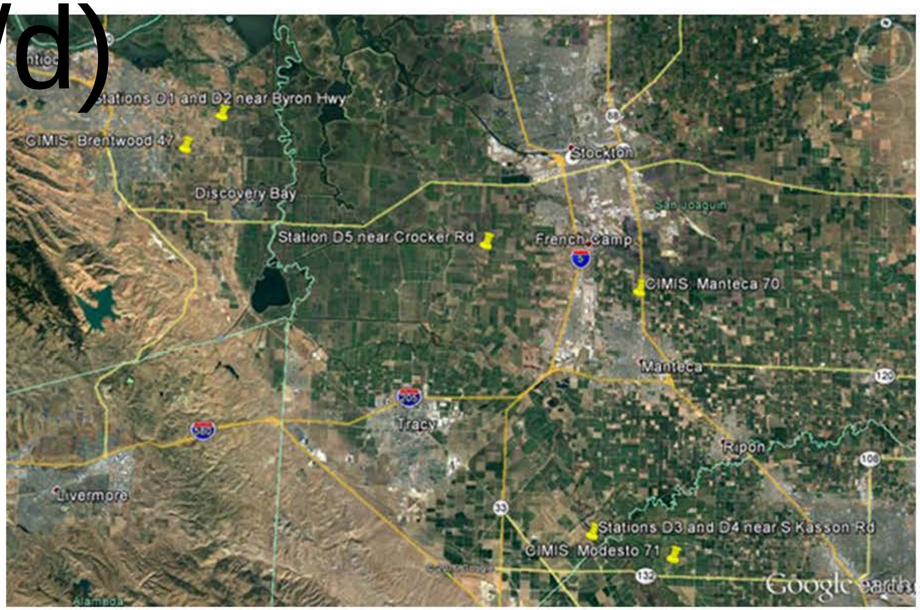
Bare Soil Evapotranspiration

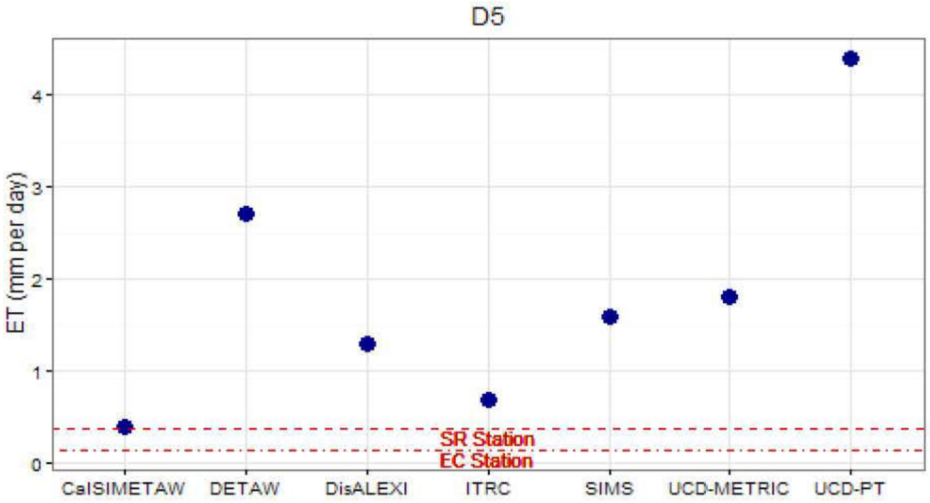


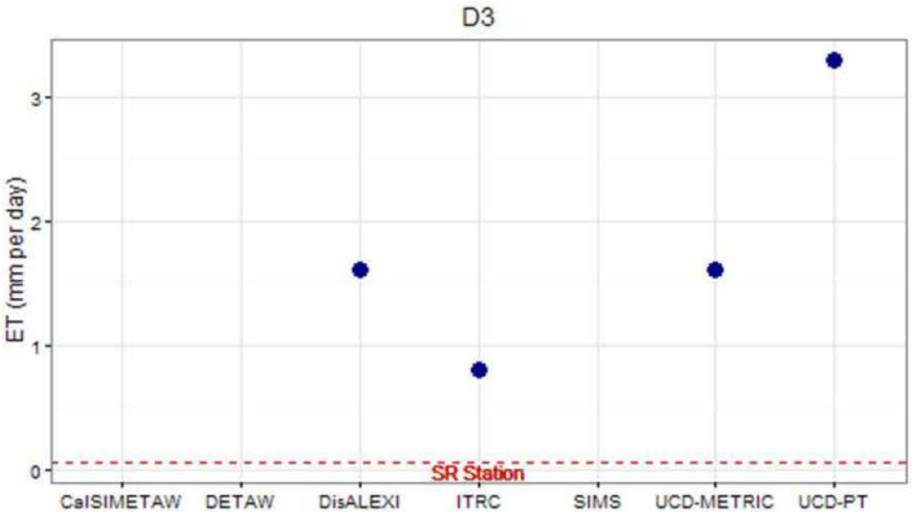
Daily actual ET (ETa) measured from bare soil stations (surface renewal and eddy covariance) along with daily reference ET (ETo) from the nearby CIMIS stations. Lines are mean values across stations and gray shading represents one standard deviation from the mean.

Bare Soil ET (mm/d)









ET from bare soil, Surface Renewal or ET stations versus methods in September

CalSIMETAW

Daily soil water balance approach

ETc = Kc*ETo

- Daily ETo from SpatialCIMIS or further back to 1922 from Hargreaves-Samani Eq. (4x4 km grid => Mean for DAU)
- Published crop coefficients (Kc) but adjusted for local conditions
- Soils information and root zone depth for available water
- Precipitation is included
- User modified management allowable depletion is possible or default.
- Computes potential ETc and ETaw (ET of applied water)

DETAW

Delta Evapotranspiration of Applied Water

Daily soil water balance

ETc = Kc*ETo

- Method tries to partition water supplied from seepage, applied water, precip.
- Originally designed for potential ETc
- Kc was calibrated based on SEBAL (remote sensing of actual ET similar to METRIC) results from 2007 and 2009 to better reflect actual stresses and "actual" ET (ETa)

SIMS

Satellite Irrigation Management Support System

ETc = Kc*ETo

- NDVI Normalized Difference Vegetation Index (NDVI) based Kcb curve (basal crop coefficient)
- NDVI computed from LandSAT 5, 7, 8 Red and Near-Infrared Bands
- ETo using Spatial CIMIS
- Requires land use inputs and is typically considered a potential ET or ET assuming no stress.

DisALEXI

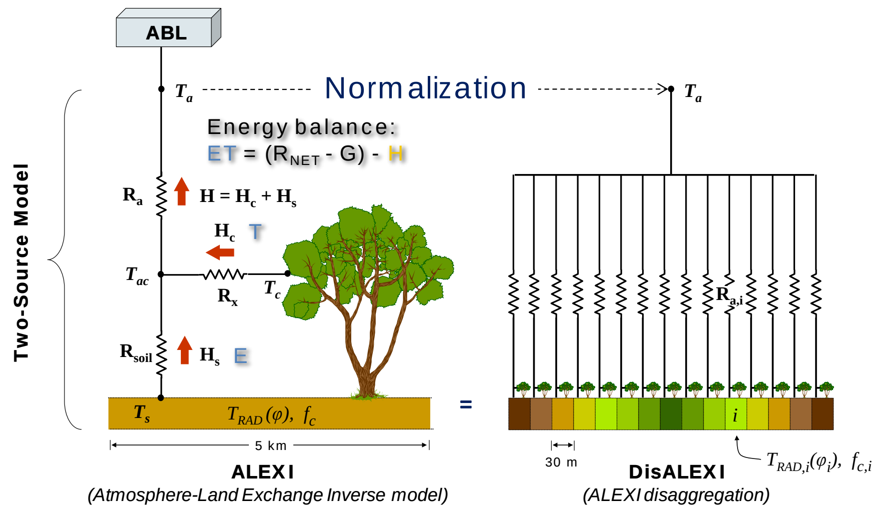
Multiscale flux modeling system

ALEXI – Two-Source Energy Balance (TSEB)

- Regional (5x5 km resolution)
- Daily energy balance
- Daily change/rise in morning temperature (GOES)
- Daily outputs at 8 or 4 km resolution over the US

DisALEXI – Disaggregation Algorithm

- Basically uses the ET results from the first scale (ALEXI) and sharpens it (partitions the ET) to higher resolution
- Partitioning of ET is based on surface temperature, leaf area index, and albedo products
- Final resolution is 30x30 meter



Regional scale

ΔT_{RAD} - Geostationary

T_a - ABL model

Landscape scale

T_{RAD} - Landsat, MODIS

T_a - ALEXI

- H is sensible heat
- T is temperature
- Ra is aerodynamic resistance
- Rx is bulk leaf resistance
- Rs is soil surface resistance
- Ta is temp at blending height

ITRC - METRIC

Surface energy balance with corrections for aerodynamic

- Relies on LandSAT 5, 7, and 8
- Accurate crop type information is not needed
- Requires calibration – ITRC uses a semi-automated calibration procedure
- Computes actual ET for satellite overpass – uses ETo to compute that days actual Kc
- Cubic spline interpolation of Kc actual between image dates
- ITRC uses a corrected Spatial ETo
- Computes actual Kc and ETa (actual ET) accounting for stress

UCD METRIC

Surface energy balance with corrections for aerodynamic

- Relies on LandSAT 5, 7, and 8
- UCD uses manual calibration
- Utilizes alfalfa reference evapotranspiration (ETr)
  - 2015 used single CIMIS station (Twitchell Island)
- Linear interpolation of Kcr between image dates
- Computes actual ET (ETa)

Priestley-Taylor UCD

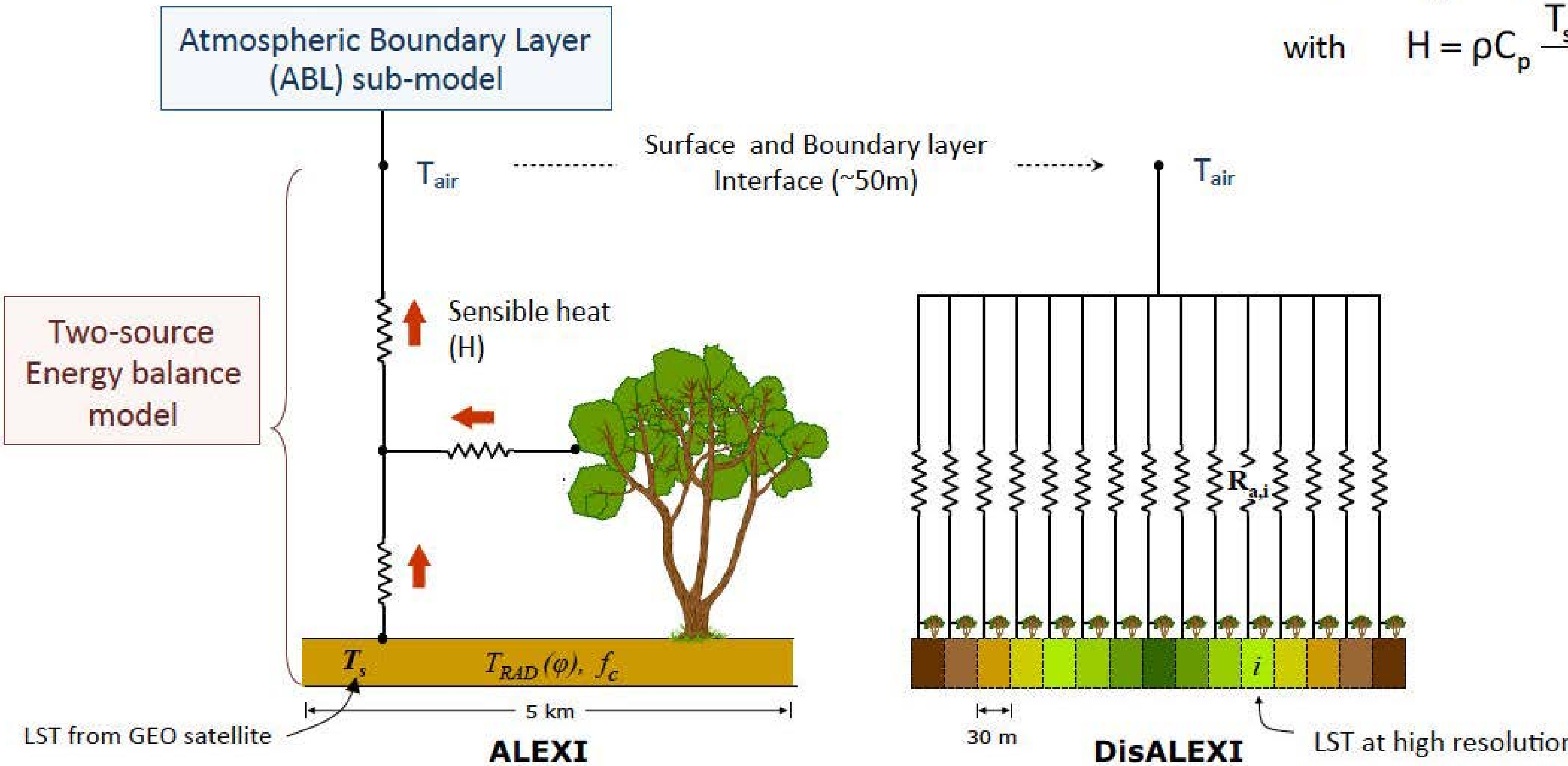
- Utilizes a combination of remotely sensed and ground based measurements.
  - LandSAT, MODIS, and SpatialCIMIS
    - For albedo, LAI, surface temp, air temp, solar radiation
  - PT coefficient computed using empirical function based on:
    - LAI, soil moisture, and temperature (still under development)
  - PT ETc for image date used to compute image date Kc
  - Interpolation between image dates using Spatial CIMIS ETo

ALEXI - The Atmosphere Land-Exchange Inverse model

Co-I: Martha C. Anderson (USDA)

$$ET = R_n - H - G$$

with $H = \rho C_p \frac{T_s - T_{air}}{r_a}$



Step 1: ET at 5km resolution

Coupling surface energy with ABL model to simulate air temperature T_a at 50m

Step 2: ET at high spatial resolution

Downscaling ET at high resolution from step 1 using high resolution LST and VNIR

Idaho Department of Water Resources

Landsat-thermal ET maps are being used for:

- purchase of water rights for endangered species and agreements with native American entities
- water rights management and regulation
- prediction of incidental ground-water recharge from surface irrigation
- quantification of water consumption during water rights litigation
- management of stream diversions for endangered species
- predictions of water consumption changes due to transition of land use from agriculture to city

Allen, et al. 2006