Estimation of Crop Evapotranspiration in the Sacramento San Joaquin Delta: Preliminary Results for the 2014-2015 Water Year

Interim Report

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A report for the Office of the Delta Watermaster

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THIS IS AN INTERIM REPORT ALL RESULTS ARE PRELIMINARY
AND SHOULD NOT BE CITED AS FINAL

Executive Summary

This report provides preliminary estimates of crop evapotranspiration (ET) from the Sacramento San Joaquin Delta (the Delta)[1] for the 2014-2015 water year using seven estimation methods. In addition, direct field measurements of ET from bare soil were taken at several fields using eddy covariance and surface renewal stations. The project also included a land use survey for the 2015 irrigation season to serve as an input for some estimation methods.

The methods applied by the seven independent research teams to estimate crop ET are:

1) California Simulation of Evapotranspiration of Applied Water, "CalSIMETAW" (California Department of Water Resources - DWR),
2) Delta Evapotranspiration of Applied Water, "DETAW" (DWR),
3) Disaggregated Atmosphere-Land Exchange Inverse, "DisALEXI" (United States Department of Agriculture-Agricultural Research Service - ARS),
4) Mapping EvapoTranspiration at high Resolution with Internalized Calibration, "METRIC" (California Polytechnic Institute San Luis Obispo, Irrigation Training and Research Center - ITRC),
5) METRIC (University of California, Davis - UC Davis),
6) Satellite Irrigation Management Support system, "SIMS" (National Aeronautics and Space Administration Ames Research Center- NASA), and
7) Priestley-Taylor, "PT" (UC Davis).

Each method uses meteorological information from existing networks and with or without remotely sensed data from satellites.

The blind comparison undertaken in this phase of the project involved summarizing spatially gridded and tabular information from the various independent research groups. For the most part, data generated was daily evapotranspiration by month and crop for more than 15 land use categories from the concurrently developed 2015 land use survey.

Figure ES-1 shows the estimated ET of selected crops grown in the Delta during the 2014-2015 water year produced by the independent research teams using each of the seven methods in this interim study. Estimates depicted on the graph are derived from monthly average estimates of daily evapotranspiration developed by applying each method to a common set of land use and weather data. The exception was DisALEXI which used its own meteorological data. These interim estimates of ET include selected crop land use classes and exclude native vegetation, open water areas and other land use classes. CalSIMETAW, DETAW and SIMS coverage for this interim report is currently limited to the Delta Service Area; the other five methods developed estimates for both the Legal Delta and the Delta Service Area.

These preliminary results for total crop evapotranspiration from all methods are within the range of estimates from the 2013 California Water Plan Update (DWR 2015 and Snyder et al. 2015), around 1.5 million acre-feet per year, plus or minus 0.25 million acre-feet. The estimates of ET for the 2015 water

[1] According to the Department of Water Resources (DWR) Delta Overview document (http://baydeltaoffice.water.ca.gov/sdb/tbp/deltaoverview/index.cfm), the Legal Delta refers to the official boundary acquired under the passage of the Delta Protection Act of 1959 (Section 12220 of the Water Code). Another delimitation is the Delta Service Area, which refers to the area within the Delta receiving water from its channels. The Legal Delta and the Delta Service Area are largely overlapping, with minor boarder discrepancies along the fringes as depicted in Figure 1 on page 2.

year—a year of extreme drought that induced significant water conservation efforts within the Delta—are roughly in line with the Update's estimate of average year ET. Average evapotranspiration measured in idle fields with bare soil, on the other hand, was small, between 0 to 0.4 mm/day for the fields analyzed during September 2015, well below estimated crop reference ET for this period at all sites.

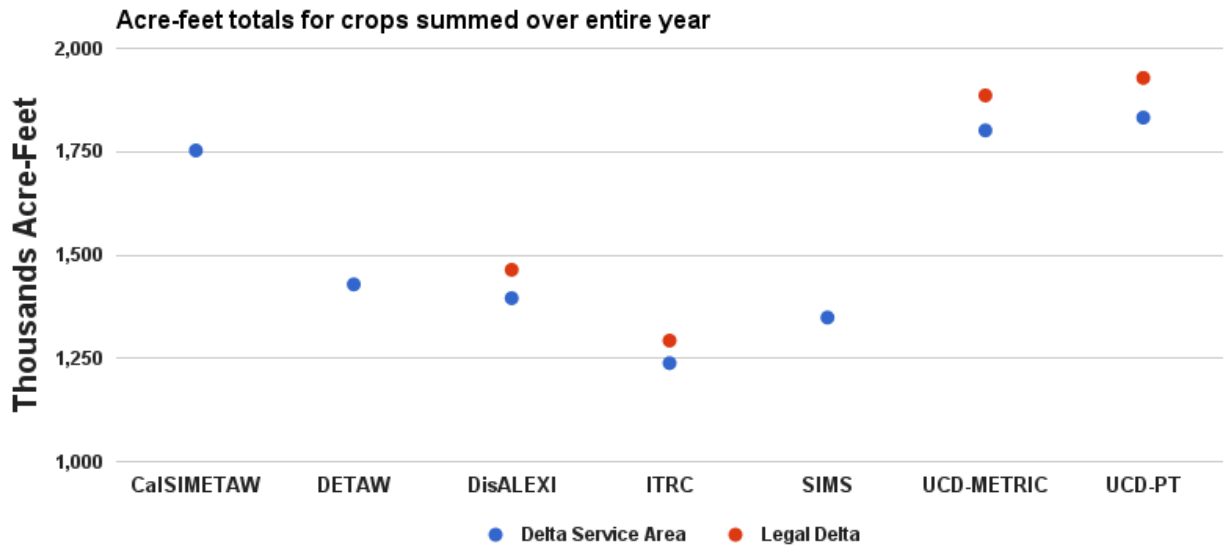

Figure ES-1. Evapotranspiration estimates for crops in the Legal Delta and the Delta Service Area for the 2015 water year (October 2014-September 2015).

Although findings at this interim stage of the Study should be evaluated with caution, the following findings appear to be supported by the 2015 data and experience:

1. Bare soil evapotranspiration measurement for the fields sampled during the late 2015 summer showed very little evapotranspiration relative to the reference evapotranspiration during the same period. Crop coefficient estimates for the idle (bare soil) fields collected during the 2015 drought are well below reference evapotranspiration for the same period from nearby CIMIS stations.
2. Estimates of evapotranspiration from crops in the Delta when averaged among the seven methods under study are broadly consistent with water balance estimates in the California Water Plan and modeling literature. All estimates are within about 20% of the median estimate.
3. The greatest relative differences in crop evapotranspiration estimates across methods are in December and January (of the water year). Crop categories with the highest differences in ET across methods are vineyard, potatoes and tomatoes.
4. Refined estimates produced by all of the methods under study should employ common input datasets and common protocols to enhance the value of inter comparisons conducted in this study. In addition, improved algorithm calibration based on analysis of 2015 data may reduce the range of variation in ET estimates across methods.
5. This first round of ET estimates provides an initial reference for future improvements and comparisons among methods of estimating ET, quantifying the potential variation, and identifying conditions under which higher discrepancies are more likely. Future iterations, improvements, and a more detailed report including comparisons of simultaneous field measurement, and estimation of ET will greatly improve understanding of crop water use in the Delta.

Disclaimer

This is an interim report and estimates of crop evapotranspiration for the 2014-2015 water year are considered preliminary and therefore should not be cited as final. A two-year report covering the period 2014 to 2016 will be completed and published during the 2017 spring.

Suggested Citation

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Introduction

Consumptive use in water systems is defined as the quantity of water use that is not returned to become available for reuse via surface runoff or deep percolation into groundwater. Evapotranspiration (ET), the combination of water evaporated from the soil and transpired from plants, is often the predominant consumptive use from agriculture or natural vegetation. Understanding consumptive use (CU) in the Sacramento-San Joaquin Delta (the Delta) is critical for water rights administration, management and operations, agricultural water management, and environmental and water quality protection.

This research project was convened by the Center for Watershed Sciences at the University of California - Davis with financial support from the California State Water Resources Control Board and other agencies. The objective is to develop a better understanding of consumptive water use in the Delta by coordinating modeling, measurement and other information from a variety of independent research and estimation efforts. Similar research endeavors have been done in arid places like Turkey and combined remotely sensed data, hydrologic models and field data (Kite and Droogers, 2000). Siegfried et al. (2014) conducted a proof of concept for estimating CU in the Delta on Fabian Tract and Staten Island. Results from this current project are divided into two phases each for the 2014-2015 and 2015-2016 water years[2]. These products are: 1) a preliminary report for the 2014-2015 water year (the present report); 2) a final, peer-reviewed report for two water years (2014-2016) expected during the spring of 2017; and 3) an online repository to disseminate detailed estimates and underlying data and methods assembled for the project.

Participating organizations include The University of California-Davis (UC Davis), UC Cooperative Extension, the California Department of Water Resources (DWR), the California Polytechnic Institute San Luis Obispo Irrigation Training and Research Center (ITRC), NASA Ames Research Center and California State University Monterey Bay, and the United States Department of Agriculture Agricultural Research Service (USDA-ARS). The project consolidates information on methods for measuring and estimating consumptive use within the Delta. Land IQ, and independent consulting firm contracted by DWR, provided a land use survey and map for 2015 which served as the basis for selecting land use classes. A subset of methods also used the Land IQ data in developing their estimates of evapotranspiration. In addition, empirical estimates of bare soil evapotranspiration during 2015 were made using field measurement equipment deployed during the late summer and fall. The analysis includes field measurements using eddy covariance, lite and full evapotranspiration measurement stations, and a selection of seven evapotranspiration calculation methods involving remotely sensed data, satellite imagery and ground level meteorological stations (Appendix A). The methods employed to estimate evapotranspiration for this report are:

1. California Simulation of Evapotranspiration of Applied Water (CalSIMETAW, Appendix E), from DWR.
2. Delta Evapotranspiration of Applied Water (DETAW, Appendix G), also from DWR.
3. Mapping EvapoTranspiration at high Resolution with Internalized Calibration (METRIC) different versions employed by ITRC (Appendix F) and UC Davis (Appendix C).
4. NASA Satellite Irrigation Management Support (SIMS) system, from NASA Ames Research Center (ARC) and California State University Monterey Bay (CSUMB, Appendix H)
5. Optimized Priestley-Taylor approach, developed by UC Davis (Appendix B).
6. Disaggregate Atmosphere-Land Exchange Inverse (DisALEXI), from USDA-ARS.

[2] Each water year begins on October 1 and runs through the following September 30.

This report provides preliminary insights from comparing independently developed evapotranspiration estimates for the Delta in 2015 from both bare-soil evapotranspiration measurement, and modeling efforts. This preliminary report also provides a discussion of challenges, limitations and work ahead to improve such estimates over the course of this two-year study effort.

Study Area and Measurements

The Legal Delta area (dashed line in Figure 1) extends over 737,625 acres discharging water from the two main River Basins in California's Central Valley, the Sacramento and the San Joaquin Rivers, and their smaller tributaries. The Delta estuarine system provides habitat for native species, water for irrigation and urban areas within, and also serves as the main hub for California's interconnected water supply system. The Delta Service Area on the other hand covers just above 679,525 acres of land (solid line in Figure 1).

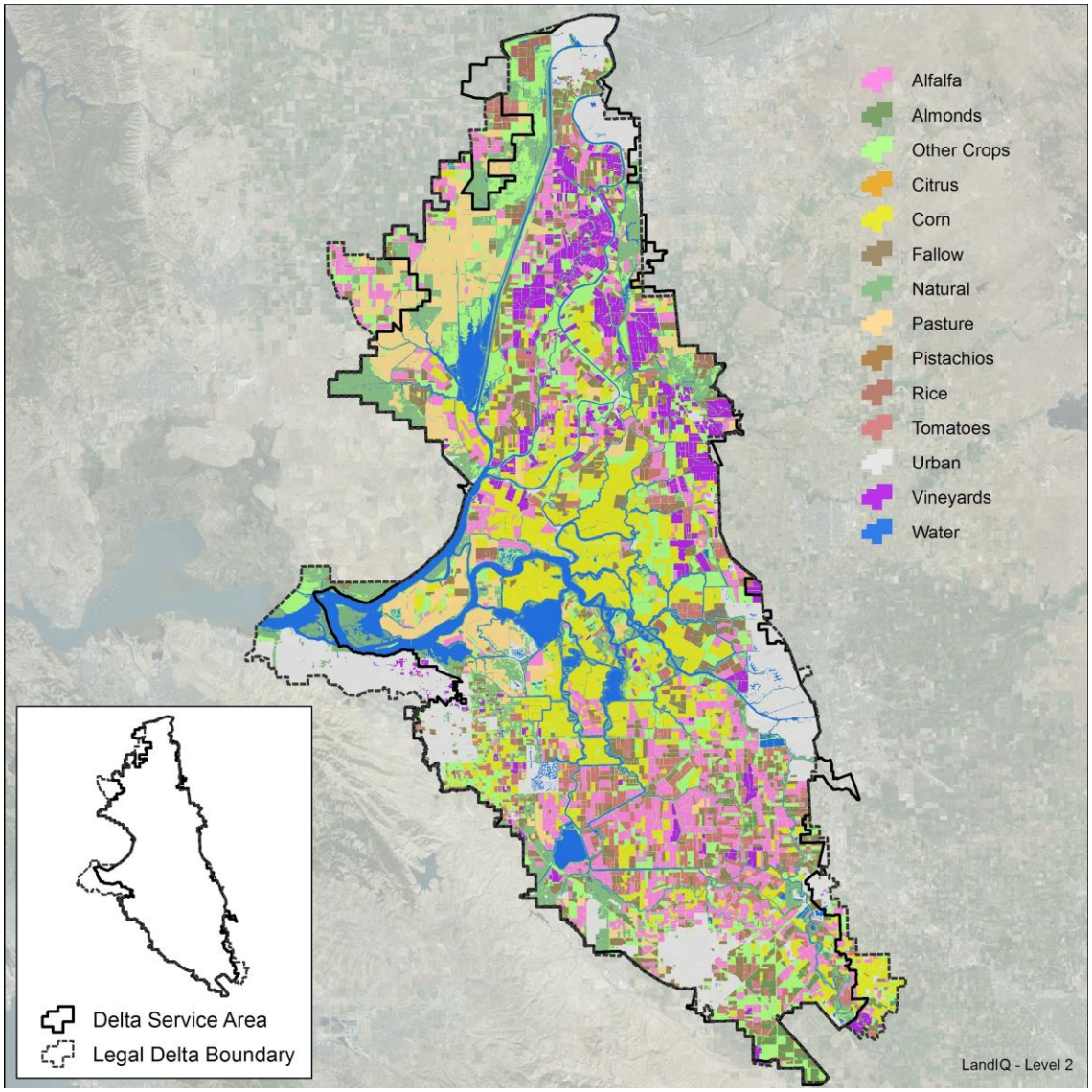


Figure 1. Land use classes in the Delta Service Area (Land IQ 2015)

The Delta's agricultural landscape within the Delta Service Area (Figure 1), consists of about 450,815 acres of agricultural land (Figure 1). Open water, and native plus other land classes occupy 60,197 and 168,716 acres respectively. During 2015, alfalfa, corn and pasture were the dominant crops grown in the Delta (Table 1). Other major crops grown in the Delta are grapes, almonds, rice, tomatoes, field and vegetable crops. Table 1 provides a breakdown of the main land use categories using the information from the 2015 Land IQ dataset.

Table 1. Land use classes in the Delta Service Area (Land IQ 2015). Irrigated crops are marked with asterisks; no asterisk denotes areas which do not receive applied irrigation.

Commodity (* denotes irrigated crop)	Acres	Percent of Selected Delta Land Use
Alfalfa*	80,201	11.80%
Almonds*	5,210	0.77%
Bush Berries*	1,186	0.17%
Cherries*	2,069	0.30%
Citrus*	8	0.00%
Corn*	91,833	13.51%
Cucurbit*	3,923	0.58%
Fallow	51,955	7.64%
Floating Vegetation	3,559	0.52%
Forage Grass	4,507	0.66%
Olives*	1,451	0.21%
Other Deciduous*	7,713	1.13%
Pasture*	48,062	7.07%
Pears*	5,947	0.87%
Pistachios*	148	0.02%
Potatoes*	4,144	0.61%
Rice*	7,637	1.12%
Riparian Native Vegetation	21,585	3.18%
Semi-agricultural/Row Crops*	48,523	7.14%
Tomatoes*	36,290	5.34%
Truck Crops*	9,547	1.40%
Turf*	2,175	0.32%
Upland Herbaceous*	54,344	7.99%
Urban	62,147	9.14%
Vineyards*	36,930	5.43%
Walnuts*	3,474	0.51%
Open Water	60,197	8.86%
Wet herbaceous/sub irrigated pasture	24,960	3.67%
SUM	**679,725**	**100.00%**

This preliminary report for the 2015 season provides ET estimates from each of the seven estimation methods for the irrigated crops listed above. In the case of bare soil (idle or fallow land), measurements in the field were taken late in the 2015 growing season at several locations, in addition to model estimates for the time period in which bare soil measurement and estimates overlap. The following section shows seasonal average and monthly average evapotranspiration by method, region and crop category.

Field Measurements of ET from Fallow Land for the 2015 Season

Evaporation from bare soil has been a source of uncertainty in water balance studies for the Delta. Estimates of evaporation from bare soil in the Delta must account for a variety of unique conditions such as wind, levee infrastructure and seepage from the channels surrounding Delta islands. To measure soil evaporation under these conditions, the research group of UC Davis Professor Paw U deployed equipment in four fallow fields in three locations from September 7, 2015 to October 5, 2015, yielding reliable measurements from September 9, 2015 through October 4, 2015. Stations were located in the vicinity of Byron Highway (two stations), Kasson Road (two stations) and Crocker Road (one station). An energy balance residual approach was employed in conjunction with eddy covariance and surface renewal measurements. A full description of the methods and equipment employed appears in Appendix A of this report.

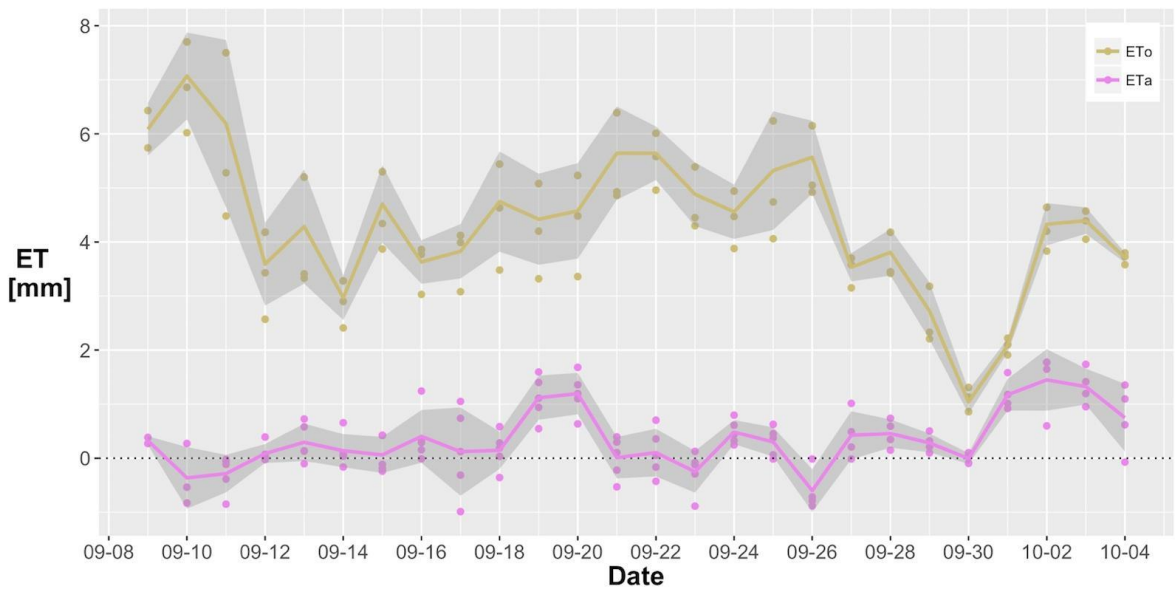


Figure 2. Daily actual ET (ETa)[3] measured from bare soil stations (surface renewal and eddy covariance) along with daily reference ET (ETo) from the nearby CIMIS stations. Lines are mean values across stations and gray shading represents one standard deviation from the mean.

The evapotranspiration measurements from these fallow fields were significantly lower than the reference evapotranspiration from the nearby CIMIS stations (Figure 2), with the exception of some rainy days at the end of the time period. Five stations showed an average of 0.22 millimeters per day (mm/d) of evapotranspiration, with values ranging from 0.05 mm/d to 0.39 mm/d, for this limited period of time (month of September) and for stations of this elevation (between 1.5 m and 17 m above sea level). The higher values were for a field with some weeds, and the other two were in a field with a low elevation (1.5 meters above sea level) that raised the possibility that tidal variations of the water levels surrounding the island could enhance the near surface soil moisture available for evaporation. The crop coefficients

[3] For a description of the variations on evapotranspiration (ET), see the box on page 7.

(Kc, quotient of the ETa over ETo) were low and close to zero, whereas after a rain event on October 1st, Kc ranged between 0.4 and 0.75. Fallowed fields below sea level were not available for study in this initial field campaign.

Measurements for the 2016 season are currently being taken for 14 fields containing corn, irrigated pasture, and alfalfa, across the Delta. This should help improve understanding of both idle land and crop evapotranspiration in the Delta as the season progresses from early in the growing season to harvest.

Evapotranspiration Estimation Methods and Comparison Protocol

A summary of the methods with peer reviewed references is provided in Table 2. The independent groups developing model estimates provided monthly estimates of evapotranspiration in millimeters per day (mm/d) averaged over the corresponding month to the 1/10th of a millimeter precision level in a raster format (METRIC, DisALEXI, SIMS, UCD-PT), at a 30-meter resolution or in tabular form (CalSIMETAW and DETAW). Monthly results were aggregated for the water year (October 2014-September 2015) to obtain water year evapotranspiration. Summary statistics including mean, median, minimum, maximum, first and third quartiles were calculated for the Legal Delta and/or for the Delta Service Area.

Table 2. Method description and published references.

Method	Description	Attributes (relative)
CalSIMETAW (Orang et al. 2013 also described in Appendix E)	Estimates daily soil water balance to determine ETc[4] and ETaw for use in California Water Plan Update. The model uses daily weather data, derived from monthly PRISM climate data and daily US National Climate Data Center climate station data to cover California with 4 km grid spacing. Reference evapotranspiration (ETo) is estimated using the Hargreaves-Samani equation calibrated to provide regional Penman-Monteith ETo to account for spatial climate differences. Cal-SIMETAW can use near-real-time data from Spatial CIMIS, combines weather station data and remote sensing to provide a statewide grid of ETo. The model uses SSURGO (Soil Survey Geographic Database) soil characteristic data and crop information with precipitation and ETc data to generate hypothetical water balance irrigation schedules to determine ETaw, an estimate of the seasonal irrigation requirement assuming minimal water stress and 100% application efficiency.	Implementation Cost Initial: Low Annual: Low Expertise: Low Intrusiveness: Low Spatial Resolution: DAU-CO
DETAW (Snyder et al. 2006, Kadir 2006, also described in Appendix G)	Computerized ground surface water balance model for 168 subareas within the California Delta. Utilizes ETo computed using Hargreaves-Samani equation with historical weather data. ETo is adjusted based on calibration factors over the Delta. DETAW estimates depth and volumetric daily ETc, and actual ET of applied water for 11 crop categories, native vegetation, riparian vegetation, urban, and open water areas, for the period WY 1922-present.	Implementation Cost Initial: Low Annual: Low Expertise: Medium Intrusiveness: Low Spatial Resolution: 168 areas
DisALEXI (Anderson et al. 2011)	A multi-scale energy balance approach which uses land-surface temperature retrieved from thermal infrared satellite sensors, or by aircraft or Unmanned Aerial	Implementation Cost Initial: Medium

[4] See box in page 7 for definitions of evapotranspiration.

	Vehicles (UAVs). The land-surface representation in DisALEXI partitions surface temperature and fluxes between soil and canopy sub-pixel elements, providing an estimate of total ET as well as soil evaporation and transpiration components. Daily ET maps retrieved from Landsat and MODerate-resolution Imaging Spectroradiometer (MODIS) are fused to generate ET daily data cubes at 30 meter resolution.	Annual: Medium Expertise: High Intrusiveness: Low Spatial Resolution: 30-meter pixel
ITRC-METRIC (Howes et al. 2012, also described in Appendix F)	A modified Mapping of EvapoTranspiration with Internal Calibration (METRIC) procedure to compute actual evapotranspiration using Landsat Thematic Mapper (Landsat) data. ITRC has made modifications to the original METRIC procedures including using a grass reference instead of alfalfa, a semi-automated calibration procedure, spatially interpolated ETo, modifications to the aerodynamic resistance and albedo computations for specific crops, etc.	Implementation Cost Initial: Medium Annual: Medium Expertise: Medium Intrusiveness: Low Spatial Resolution: 30-meter pixel
SIMS (Melton et al. 2012 also Appendix H)	Uses measurements in the red and near-infrared wavelengths from multiple satellites to track crop canopy development and estimate crop fractional cover and basal crop coefficients in near real-time. Originally developed to support irrigation management and optimization, SIMS integrates the satellite derived crop coefficients with ETo data from CIMIS to estimate basal crop evapotranspiration (ETcb), which is the crop evapotranspiration under well-watered conditions and irrigated so that the exposed soil surface (not beneath the crop canopy) is maintained in a dry condition. Comparisons with field measurements for a range of crops in California has shown that SIMS ETcb estimates are within 10% mean absolute difference of the measured seasonal ET for well-watered crops, which are much of the Delta's agricultural acreage.	Implementation Cost Initial: Low Annual: Low Expertise: Low Intrusiveness: Low Spatial Resolution: 30-meter pixel
UCD-PT (Priestley-Taylor) (Jin et al. 2011, also Described in Appendix B)	The semi-empirical Priestley-Taylor (PT) equation is used to estimate actual ET (ETa). The UCD-PT approach was originally developed by integrating MODIS satellite data and AmeriFlux tower ET measurements to estimate monthly ET at a 1 kilometer resolution. The eco-physical constraint on ET is optimized as a function of vegetation characteristics for each plant functional type and soil moisture using AmeriFlux ground measurements. UCD-PT is adapted here for the first time to use Landsat satellite data to improve the spatial resolution of ET estimates. UCD-PT is not yet calibrated for crops and soil moisture constraint is not yet implemented in this preliminary report.	Implementation Cost Initial: Low Annual: Low Expertise: Low Intrusiveness: Low Spatial Resolution: 30-meter pixel
UCD-METRIC (Allen et al. 2007a and 2007b, also described in Appendix C)	Application of the original Mapping EvapoTranspiration at a high Resolution and with Internalized Calibration (METRIC) developed by the University of Idaho Kimberly Research Center. METRIC is an energy balance approach to calculate ET as a residual, which employs both satellite multispectral imagery and ground-based reference evapotranspiration.	Implementation Cost Initial: Medium Annual: Low Expertise: Medium Intrusiveness: Low Spatial Resolution: 30-meter pixel

Among the methods described in Table 2 above, SIMS, CalSIMETAW and DETAW do not estimate evapotranspiration via the energy balance residual approach and instead directly estimate the fraction of reference evapotranspiration (ETo) using crop coefficients. The other methods either estimate or calculate the terms in the energy balance equation (sensible heat flux, ground flux and net radiation) to estimate evapotranspiration as the residual of the surface energy balance.

The methods employed in the study vary in implementation costs (subdivided into upfront costs and maintenance costs), expertise requirements, level of intrusiveness, and resolution. While there are not consistent and perfect metrics for these characteristics, they should be considered on a case-by-case basis in selecting among the methods for a particular purpose. Some of these considerations are outlined below and will be expanded in the final report covering the 2015 and 2016 seasons.

Implementation Costs

Up front infrastructure needs include computer processing capacity and software licenses. Advances in computer technology and cloud storage and processing, and the proliferation of open source software should continue to decrease these costs in the years to come. Nevertheless, the highest level of investment is for expert human capital to establish and calibrate the estimation frameworks. Annual costs, once the system is in place and calibrated, may be much lower for most methods. Some of these costs involve maintaining software licenses, data backup and storage, and personnel required to run, maintain, inspect results, and periodically upgrade the system. Although the satellite datasets used in this analysis are freely available from USGS and NASA, methods that rely on computer analysis of remote sensing data often use proprietary software that can be costly for some applications. Also, for some methods, their complex and constantly evolving algorithms merit a high degree of expert involvement and/or entry cost. For fully automated methods that rely on cloud-computing resources, the implementation costs can be substantially reduced.

Expertise

Most methods and applications require a combination of agronomic, GIS, and computer science expertise. Some routine tasks demand less training in some of these areas; however, general knowledge of the ranges of crop ET under various conditions is needed to conduct quality assurance and quality control of model inputs and outputs. This implies significant expertise devoted to the project. As with other costs, the demand for such expertise should recede as more of the complexity is embedded in self-correcting algorithms.

Resolution

Remote sensing based methods like DisALEXI, SIMS, METRIC and PT by construction will have a 30 meter by 30-meter resolution based on the current satellite resolution. CalSIMETAW and DETAW work with tabulated data over larger areas, respectively DAU-County and DETAW 168 areas.

Relative Accuracy

Accuracy ranges have been published in the peer reviewed literature for some methods yet it remains to be assessed for report. Previous studies using METRIC have reported accuracies for seasonal ET of ±10% relative to measured ET across a range of crops and vegetation types, as does the SIMS model though for well-watered crops only. An accuracy range of about 20% would be inclusive of all methods. Again, because these estimation techniques are being constantly improved through experience and

because greater spatial and temporal resolution is becoming available on a cost-effective basis, it is likely that overall accuracy in ET estimates will increase with time.

A Primer on Evapotranspiration and Consumptive Use

Consumptive water use is water that is lost from a watershed via evapotranspiration over time and is not available for other uses. Evapotranspiration is the sum of evaporation from soil and transpiration from plants measured in linear units over time. Consumptive use and evapotranspiration are often used indistinctively.

Several methods exist for estimating evapotranspiration. Abetew and Melese (2012) provide a description of ways of measuring and calculating evapotranspiration in crops and other natural and manmade systems in a watershed.

Direct measurement methods include: pan evapotranspiration, lysimeter, eddy covariance, Lidar, and surface renewal. Estimation methods involve measured inputs and empirical approximations. Some of these are pan method with coefficients, temperature based methods such as Blaney-Criddle, and Hargreaves-Samani; and radiation based methods such as Abetw, Priestley-Taylor, Turc, Solar Radiation Maximum Temperature, Mass Transfer. Another category is conformed by complex methods such as the Penman, and Penman-Monteith which are closer to a physical model. Lastly, remote sensing methods including SEBAL, SEBS, METRIC, and others use satellite images.

Some simple models work for applications in which meteorological and other data are limited. More data and time availability may facilitate adoption of more complex and accurate methods.

Some definitions common in evapotranspiration literature are:

ET_o: Reference evapotranspiration, evaporation of a well-watered reference crop. Depending on the method, it can be grass or alfalfa (Allen et al. 2005). Pan evaporation can also be used as a reference ET.

ET_p: Potential evapotranspiration, maximum evapotranspiration that could occur under the prevailing meteorological conditions (Abtew and Melese, 2012).

ET_a: Actual crop evapotranspiration, is the actual amount of water evaporated from the crop soil and transpired from the plant.

ET_{aw}: Evapotranspiration of applied water, the fraction of applied water in irrigation that is lost to the atmosphere through evapotranspiration.

K_c: Crop coefficient is the ratio of the estimated crop ET versus a reference ET_o

Estimates of 2015 Evapotranspiration

All independent research teams participating in the Study estimated ET using their existing methods and input datasets, and submitted daily-average ET calculated for each month in the analysis period (October, 2014-September, 2015) to compartmentalized repositories in GitHub for a blind comparison. A more extensive description of the project and the research protocols appears in https://github.com/ssj-delta-

cu/ssj-overview. Some public access information is available at this address. For this preliminary report, we only provide evapotranspiration values for agricultural land use classes.

For this preliminary study of the 2015 season, the methods employ different assumptions on the available land use classes and spatial extent. This will be reconciled for the final report upcoming in spring of 2017. Teams used maps with some spatial coverage differences. Therefore, it is not possible in all cases to make direct comparisons over various extents within the Delta. Figure 3 shows an example of ET raster estimations for each method (for July 2015). The upper left panel shows that the rasters delivered by most comparison methods completely cover the Delta Service Area (green) but do not cover the Legal Delta boundary (red). However, some areas in the Delta Service Area are not covered by the Legal Delta.

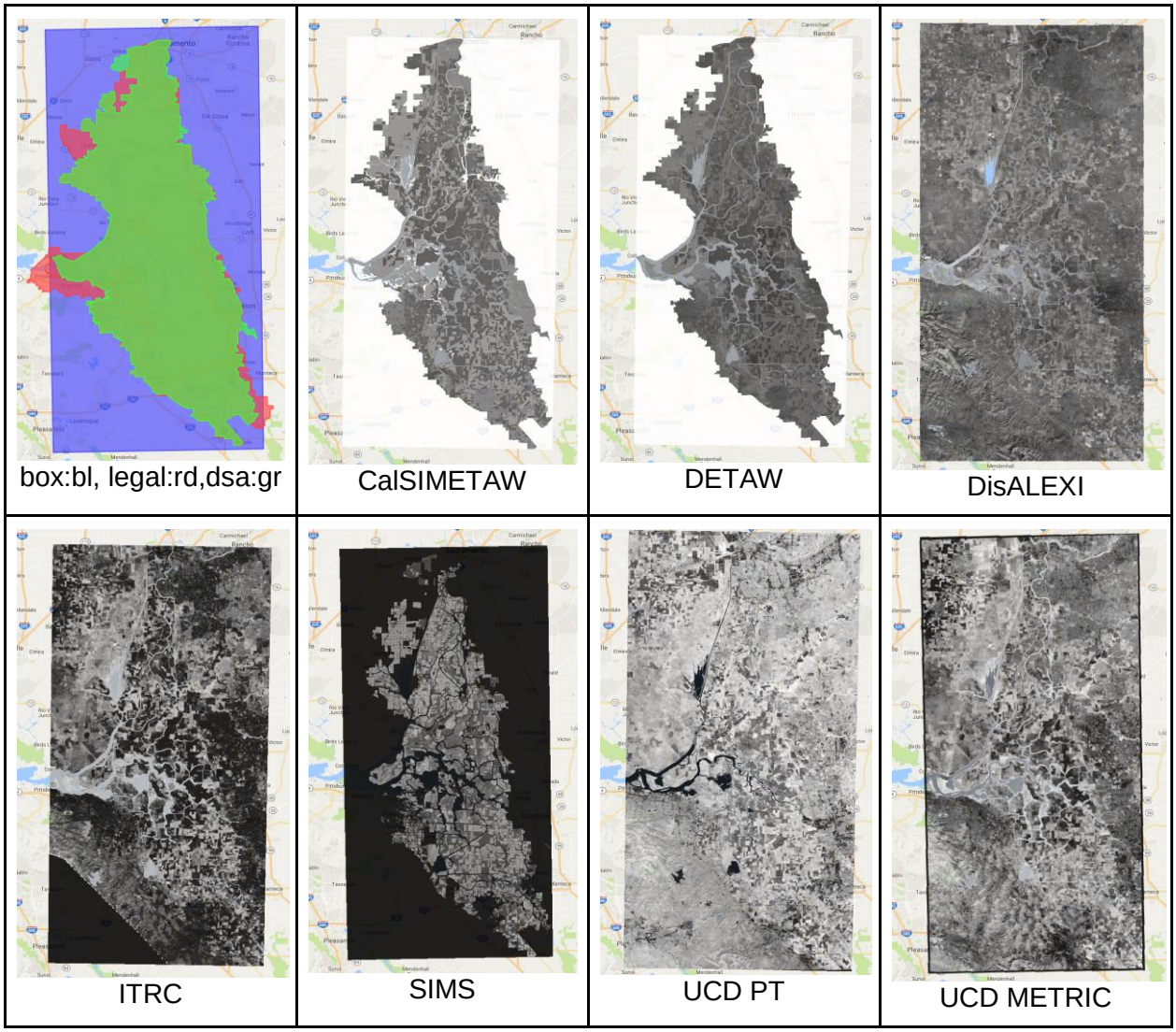


Figure 3. Illustration of study area and evapotranspiration maps in July 2015 from all seven methods showing coverage and estimated ET values using their own monochromatic scale.

For comparison, the Land IQ map (Figure 1) covers the Legal Delta. Both CalSIMETAW and DETAW and SIMS currently provide data for subareas within Delta Service Area, and were not extrapolated outside of that region's boundary for this report. Areas outside of the domain of estimates of CalSIMETAW and DETAW are shown in white. SIMS shows areas and land classes excluded for the

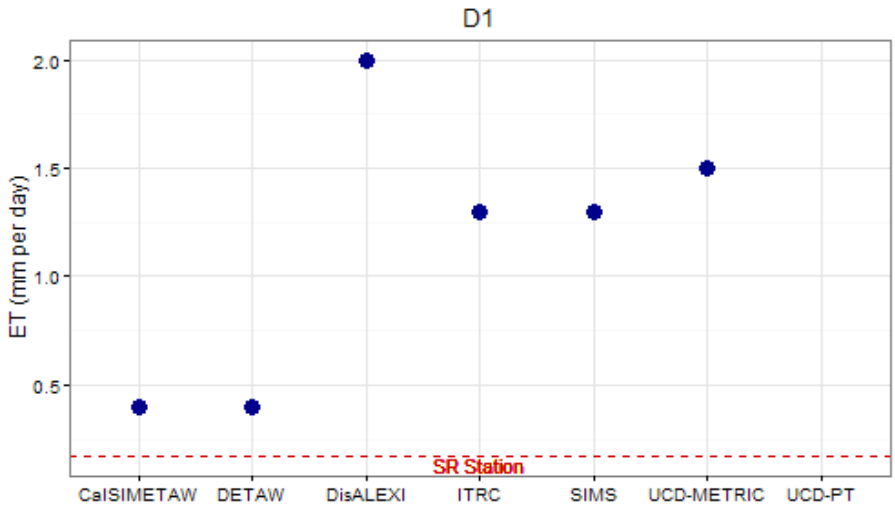
current analysis in dark black (Figure 3). Other considerations: SIMS currently makes estimates only for agricultural land cover, while UCD-PT does not include estimates for evaporation from open water. All estimates can be directly compared for all Land IQ agricultural sites over any region in the Delta service area. The DisALEXI, ITRC, SIMS, UCD-PT, and UCD-METRIC datasets cover greater areas outside of the Delta Service Area (Figure 3).

Evapotranspiration for Fallow Land

Estimates of evapotranspiration from bare soil from each of the seven methods under study are compared to field measurements at four fallowed fields during the September 7 through October 5, 2016 period. This is done by overlapping the geolocation of the measurement station with the corresponding pixel in the rasters of evapotranspiration (Panel in Figure 3 above) for each method during September. A location map for all the measurement stations appears in Appendix A. All four stations are above sea level. Stations D1 and D2 are located near Byron Highway (Central Delta), Station D3 is by Kasson Road (South Delta) and Station D5 is near Crocker Road (Central Delta).

Figure 4 below shows the results of the comparison, with a horizontal red line showing measured daily ET from the stations. Overall, CalSIMETAW and DETAW tend to report values of evapotranspiration in bare soil closer to zero. The range of evapotranspiration estimates among methods for bare soil goes from fractions of a millimeter per day to above 4 mm/d for the UCD-PT method at station D5. The average of daily bare soil ET estimates by all seven methods is about 1 mm/d for stations D1 and D2, 1.8 mm/d for station D3, and 1.8 mm/d for station D5. Relevant reference ET estimates for the sites are provided in Appendix A with interquartile ranges between 4 and 6 mm/d across sites.

Zero value pixels are excluded from the charts. Stations located outside of the Delta Service Area will not have ET estimate report values from the CalSIMETAW or DETAW, for example. In other cases, such as for the UCD-PT method, the estimate was based on clear sky condition only and water limitation control was not implemented yet in this interim report; thus, the currently constrained UCD-PT method probably overestimates evapotranspiration in bare soil. This bare soil evapotranspiration comparison will serve as a reference to refine estimation methods over the course of the full two-year Study. As a result, the researchers expect discrepancy across methods will be reduced as calibration is refined.



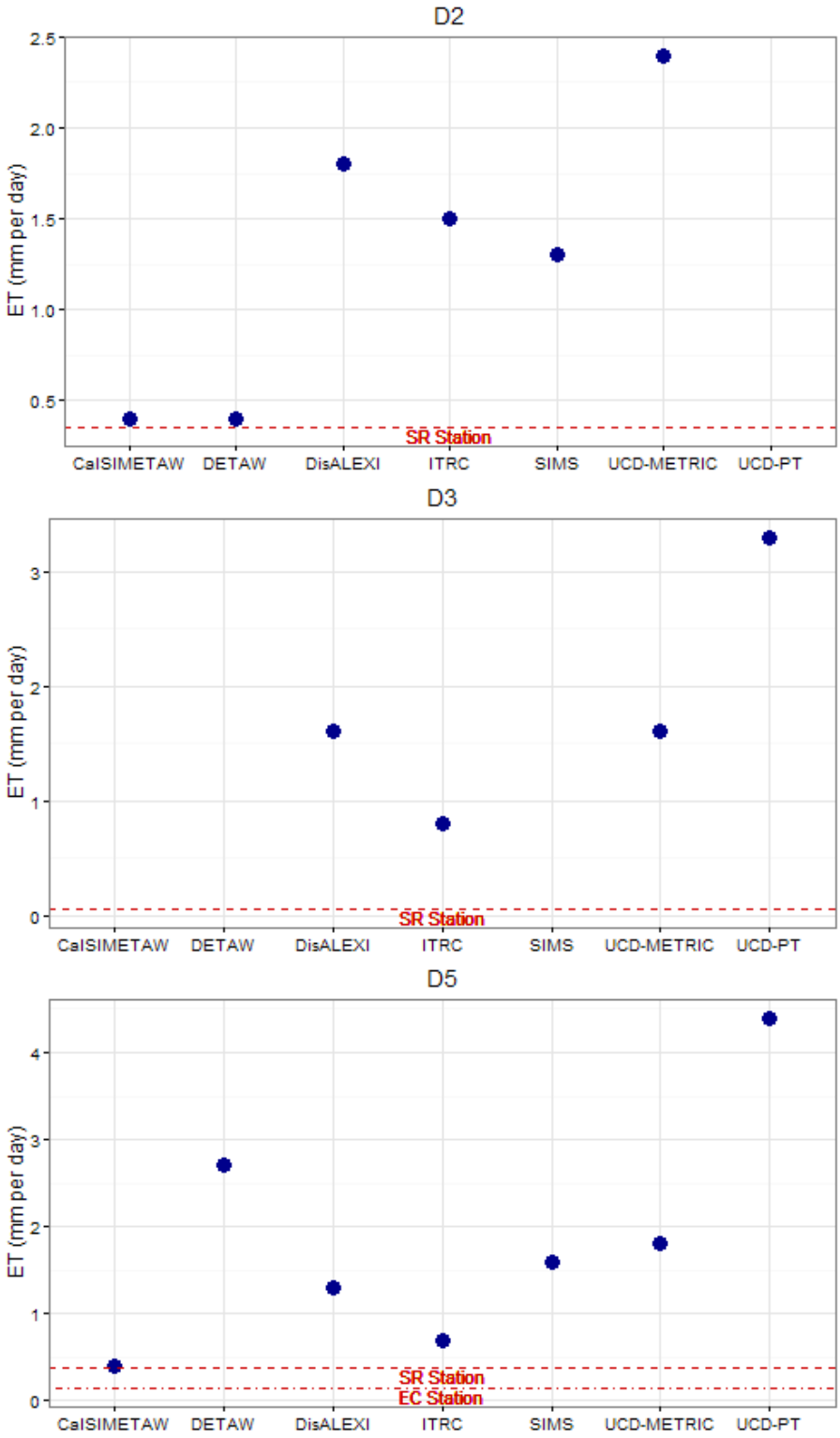


Figure 4. Bare soil evapotranspiration estimates at four monitoring sites (D1, D2, D3, and D5) in the Delta. Data shown is the monthly average daily ET by method at the corresponding station for September 2015. The red horizontal line is the average daily ET measured at the site between using the surface renewal station between September 9 and 30, 2015. The dash-dot line in site D5 shows measured ET using a full ET station.

Evapotranspiration from Crops in the Delta

Table 3 compares the overall estimates of evapotranspiration from crops for selected agricultural land use classes over both the Delta Service Area (column 2) and the Legal Delta (column 3), a delimitation inherent in the CalSIMETAW and DETAW models. Crop evapotranspiration estimates over the 450,815 acres in crops within the Delta Service Area average 1,543 thousand acre-feet (TAF) across all methods. If the coverage considered is the Legal Delta, average evapotranspiration for the 2014-2015 water year was estimated at 1,643 TAF across methods. ITRC-METRIC and DisALEXI produced the lowest estimates; whereas UCD-METRIC, UCD-PT, and CalSIMETAW fall at the higher end (Figure 5). DETAW and SIMS were in between, but generally closer to the estimates from ITRC and DisALEXI. Land use classes excluded in the aforementioned estimates are crops with minor acreages such as citrus, safflower, sunflowers, and upland herbaceous plants as well as other land use classes like floating and riparian vegetation, fallow, urban and open water areas. Together, evapotranspiration of the excluded land use classes in the Delta Service Area average 583 TAF across methods for the 2014-2015 water year.

Among the methods compared, the spread in the preliminary METRIC estimates by ITRC and UCD seems more than expected. Sources of discrepancy between these applications of METRIC in this blind comparison are being investigated explain and improve in the final report on this two-year study, due in the spring of 2017. The sources of possible discrepancy already identified include: dates of the satellite images employed, calibration of the hot (bare soil) and cold (alfalfa for UC Davis and pasture for ITRC) pixels, thermal sharpening, cloud masking, temporal interpolation due to missing clear sky satellite data, and the raster layers for ground level meteorological information. The researchers expect that these differences will decrease to some extent as input data protocols are implemented, some of the METRIC processing steps are closer, and some intermediate processes are refined. The final report, which will include data and experience developed during both the 2015 and 2016 seasons, will discuss remaining discrepancies among all methods.

Table 3. Tabulated evapotranspiration estimates in thousands of acre-feet for crops in the Legal Delta and the Delta Service Area (October 2014-September 2015). Estimates are derived from monthly average estimates of daily evapotranspiration for each method. CalSIMETAW and DETAW coverage is limited to the Delta Service Area.

Method	Delta Service Area (1000 acre-feet)	Legal Delta (1000 acre-feet)
CalSIMETAW	1,753	-
DETAW	1,429	-
DisALEXI	1,396	1,464
ITRC-METRIC	1,238	1,293
SIMS	1,349	
UCD-METRIC	1,801	1,886
UCD-PT	1,832	1,928
Average	**1,543**	**1,643**
Median	**1,429**	**1,675**

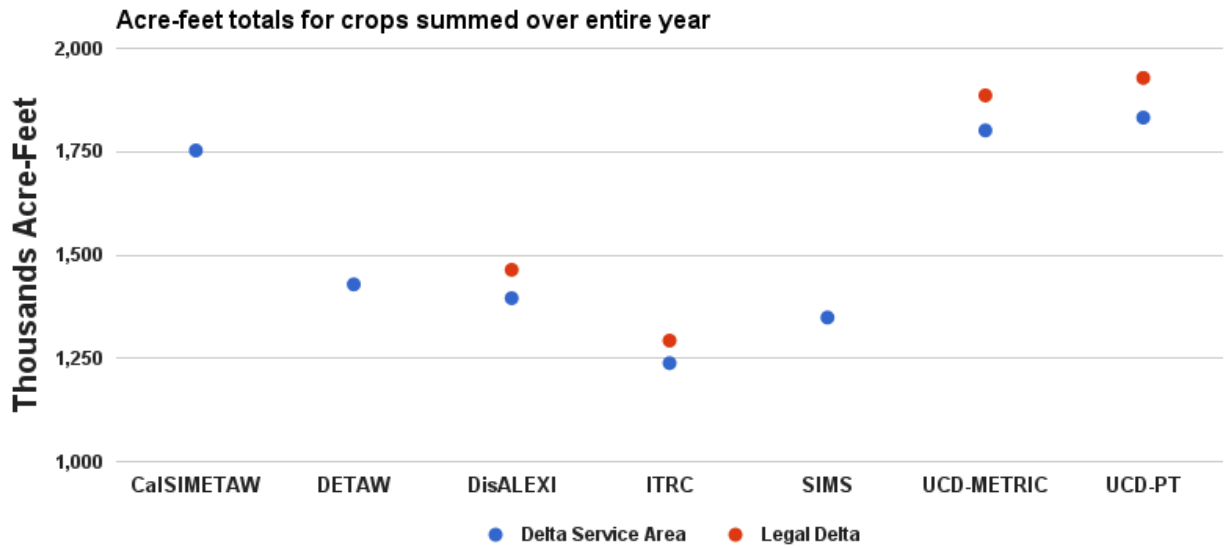


Figure 5. Total evapotranspiration estimates for selected crops in the Legal Delta and the Delta Service Area (October 2014-September 2015). Estimates are derived from monthly average estimates of daily evapotranspiration for each method. CalSIMETAW and DETAW coverage is limited to the Delta Service Area.

Monthly evapotranspiration estimates, by method, for a selection of crops over the course of the water year are shown in the panels of Figure 6 below. The horizontal axis shows months over the water year starting in October, 2014 and ending in September, 2015. The vertical axis scale shows average daily evapotranspiration by month in millimeters per day, averaged over all pixels in the crop category within each method's covered area. CalSIMETAW and DETAW data are for the Delta Service Area; other methods cover the entire Delta (the maximum area in both the Legal Delta and the Delta Service Area).

Overall, ITRC-METRIC SIMS, DETAW and DisALEXI models tend to produce the lower estimates for most crops over the course of the year. CalSIMETAW, UCD-METRIC and the UCD-PT tend to produce higher estimates of evapotranspiration for most crop classes. CalSIMETAW is expected to show higher ET, because it calculates *potential* evapotranspiration (assuming 100% application efficiency) DisALEXI, METRIC, and PT, on the other hand, report estimates of *actual* ET. The DETAW crop coefficients have been calibrated through a past comparative study using a 2007 application for the Delta of the Surface Energy Balance Algorithm for Land (SEBAL) model[5], so reported evapotranspiration is closer to *actual*.

Dispersion among estimates from the various methods as a percent of the median is higher during the winter months of December and January. However, both irrigation and evapotranspiration are usually lower in these months. Likewise, the end of the 2015 growing season, when irrigation tapered off and harvest reduced the amount of crop growth (September), shows a broader range of discrepancies among ET estimates.

[5] SEBAL stands for Surface Energy Balance Algorithm for Land (Bastiaanssen et al. 2005). SEBAL is a remote sensing approach to calculate evapotranspiration using the energy balance approach. SEBAL quantifies the energy balance using satellite data as an input along with meteorological data, such as wind speed, humidity, solar radiation and air temperature. SEBAL extrapolates the 'instantaneous' energy balance computed to calculate daily evapotranspiration. A sequence of satellite and meteorological data can be used to calculate weekly, monthly, and yearly evapotranspiration.

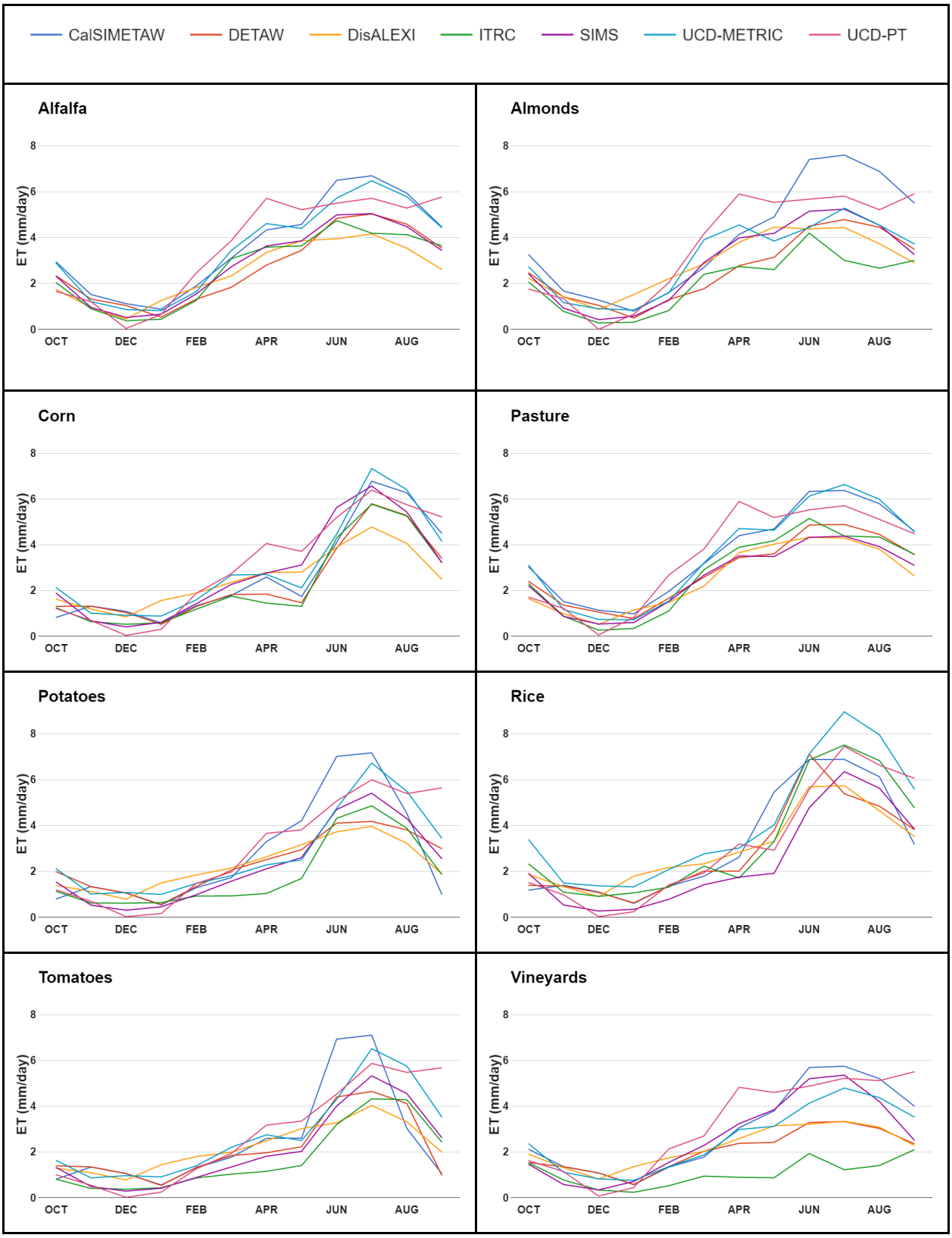
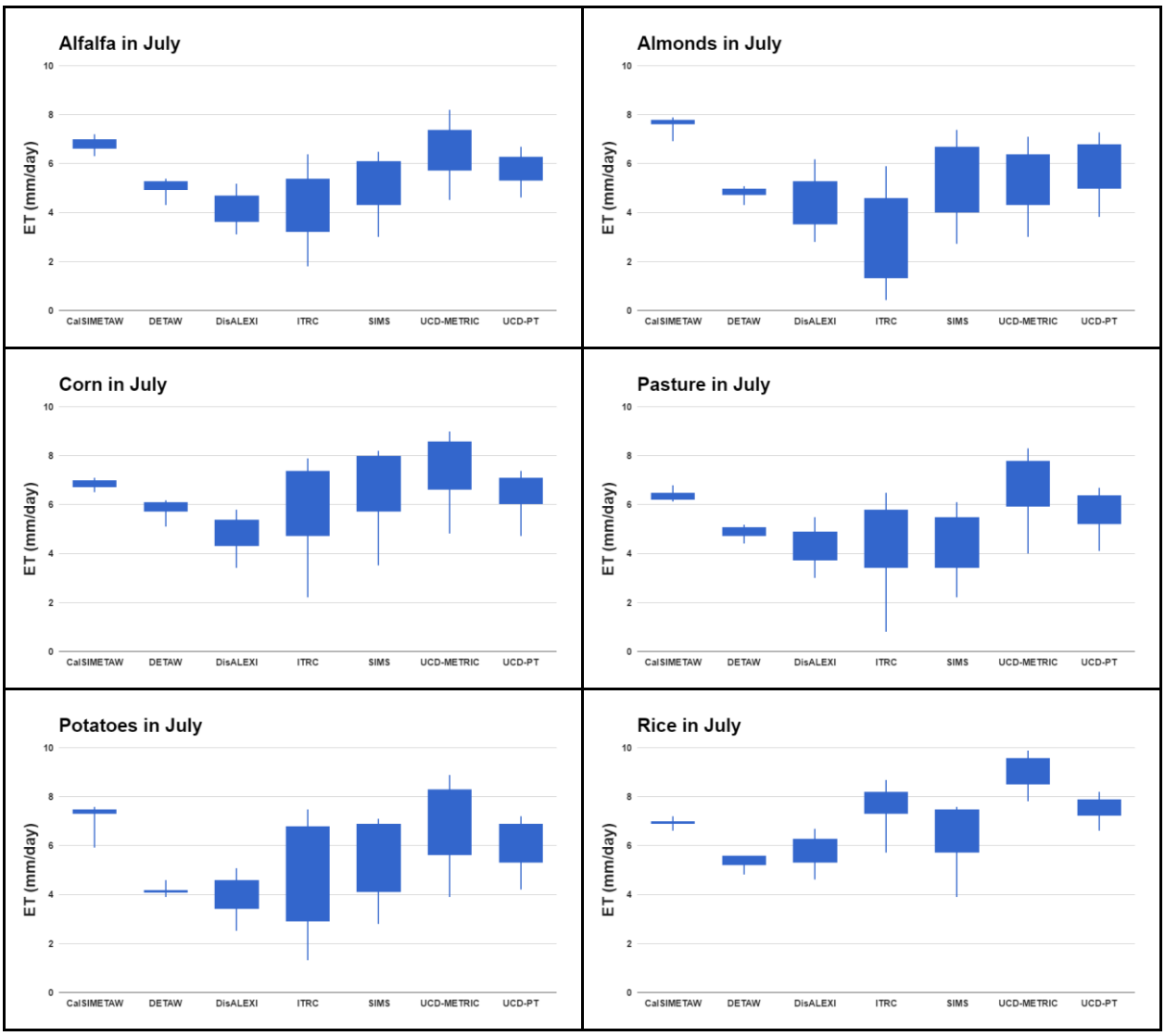


Figure 6. Monthly estimates of average evapotranspiration, by method, for selected crops.

From the selection of crops evaluated, vineyards and almonds have the highest range across estimates, particularly in summer. Some causes of these discrepancies could be the way the irrigation schedule is characterized in models, the various stages of stress among orchards, the way ages in trees are modeled, and how the temporal interpolation is implemented.

A more detailed comparison for the same selection of crops is shown in Figure 7 for July, 2015, with the 9th percentile, 91st percentile as well as first and third quartiles of pixels presented in whisker plots. Once again DisALEXI and ITRC-METRIC are often at the lower range whereas CalSIMETAW and UCD-METRIC tend to produce estimates at the higher end, followed by UCD-PT. DETAW and SIMS produce estimates that fall in the middle of the range. Estimates for alfalfa show more agreement in the month of July across methods, while vineyards tend to have more disparities. Among the selection of crops, potatoes tend to show the largest variation across fields consistently for all remote sensing based approaches. The ITRC-METRIC model shows low estimates for vineyard compared to other methods.



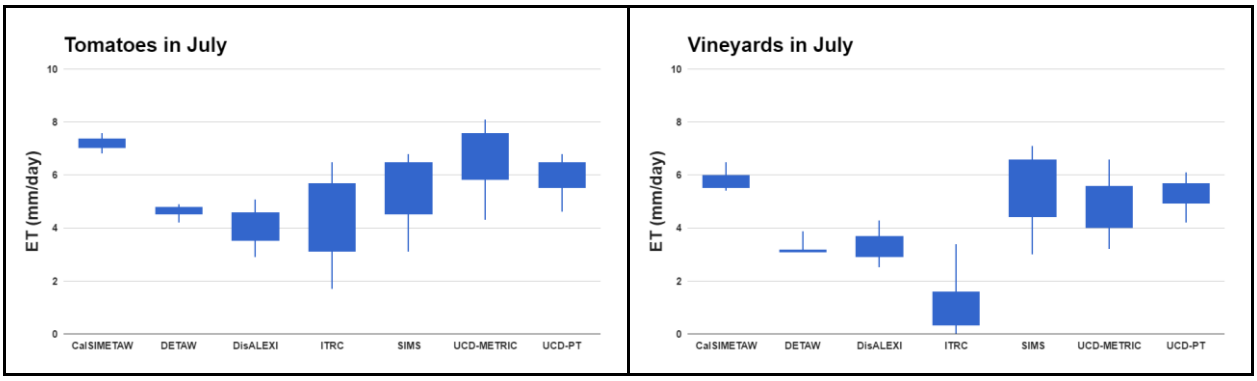


Figure 7. Comparison of daily average evapotranspiration for selected crops in July 2015 among seven methods. Boxes represent the first and third quartiles; the 9th and 91st percentiles are represented by the vertical line.

Figures 8 A through G show, for the same selection of crops, monthly whisker bar charts representing maximum, minimum, first and third quartiles for each method. CalSIMETAW and DETAW have a narrow range between the quartiles because they use a single crop coefficient for each crop type within the Delta. CalSIMETAW provides estimates by Detailed Area Unit-County (DAU-CO, six in the Delta) while DETAW makes finer distinctions among 168 areas in the Delta. Estimates from all other methods use 30-meter pixel resolution, so their range of variation is much wider, reflecting actual more localized variation in conditions within the Delta. With the exception of vineyards, ITRC-METRIC captures the widest interquartile range for most crops, followed by the SIMS model.

Generally, variation in ET estimates across fields within each method is larger in spring and summer. Some apparent model anomalies for tomatoes in CalSIMETAW for August, 2015 are being investigated. Likewise, anomalies for DETAW and tomatoes in September, 2015 are also being examined more closely. The implicit crop coefficients are calibrated to a crop calendar ending by August when most Delta tomatoes have been harvested. SIMS and DisALEXI show consistent interquartile ranges for all months and crops. For this preliminary results the UCD-PT methods has not been calibrated for individual crop type yet, e.g., the sensitivity of how much available energy is used for was generalized based on a very limited number of AmeriFlux agriculture sites outside of California. Further investigation of differences identified in this preliminary review will be undertaken to refine calculations for the 2016 irrigation season which will be presented in the Study's final report.

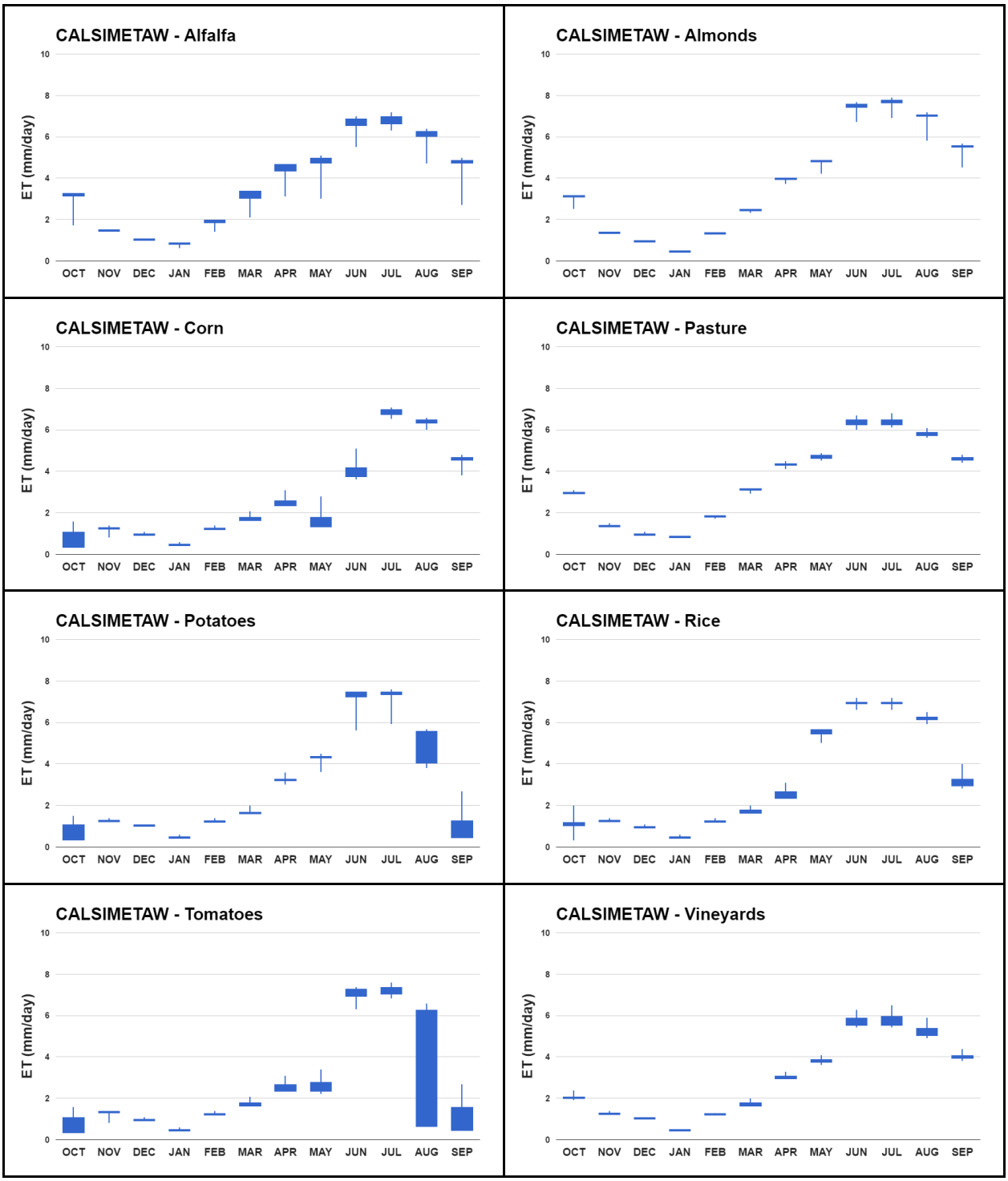


Figure 8A. Daily average ET by month estimated by CalSIMETAW for selected crops. Boxes show the first and third quartiles; the 9th and 91st percentiles are represented by the ends of the vertical lines.

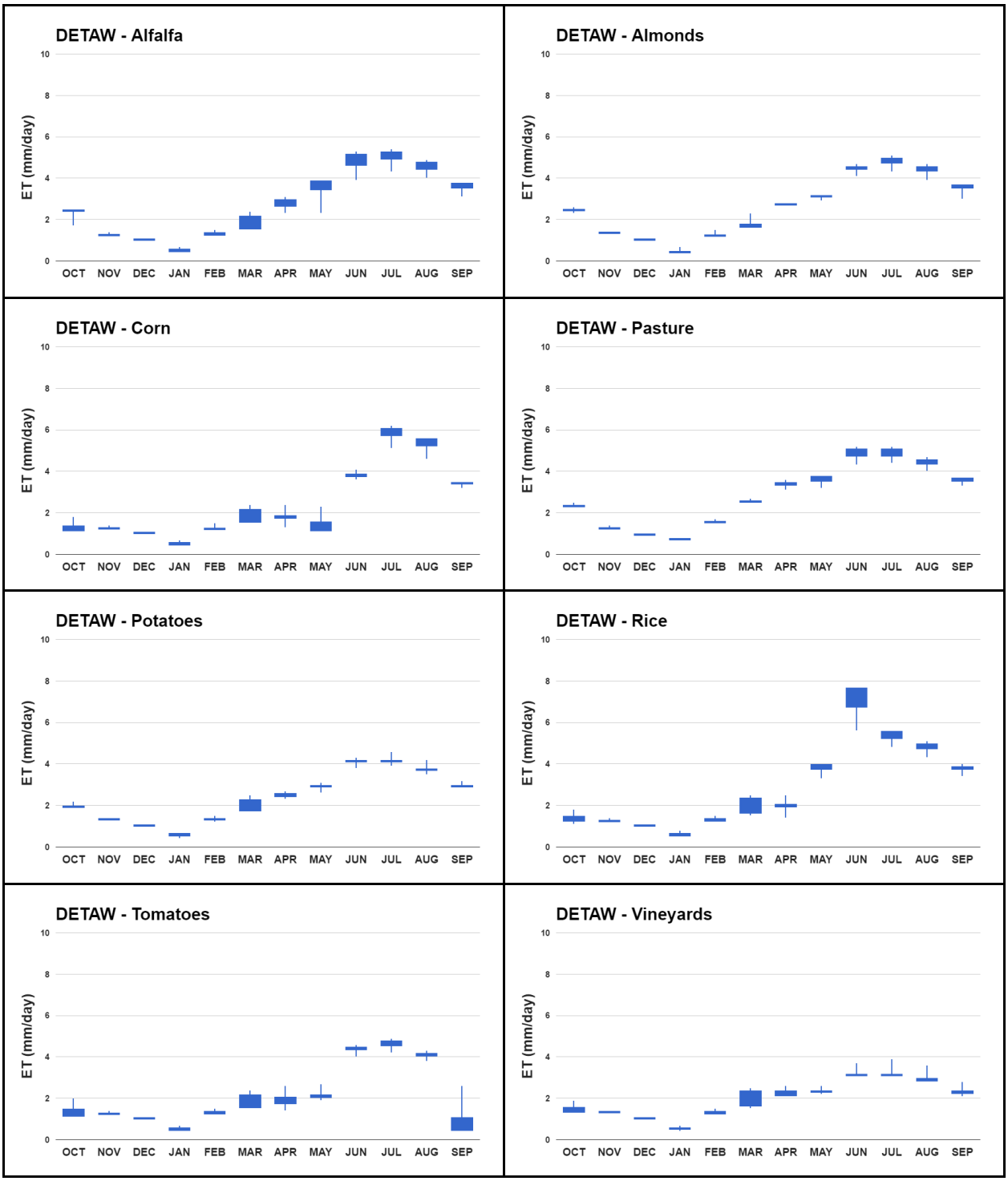


Figure 8B. Daily average ET by month estimated by DETAW for selected crops. Boxes show the first and third quartiles; the 9th and 91st percentiles are represented by the ends of the vertical lines.

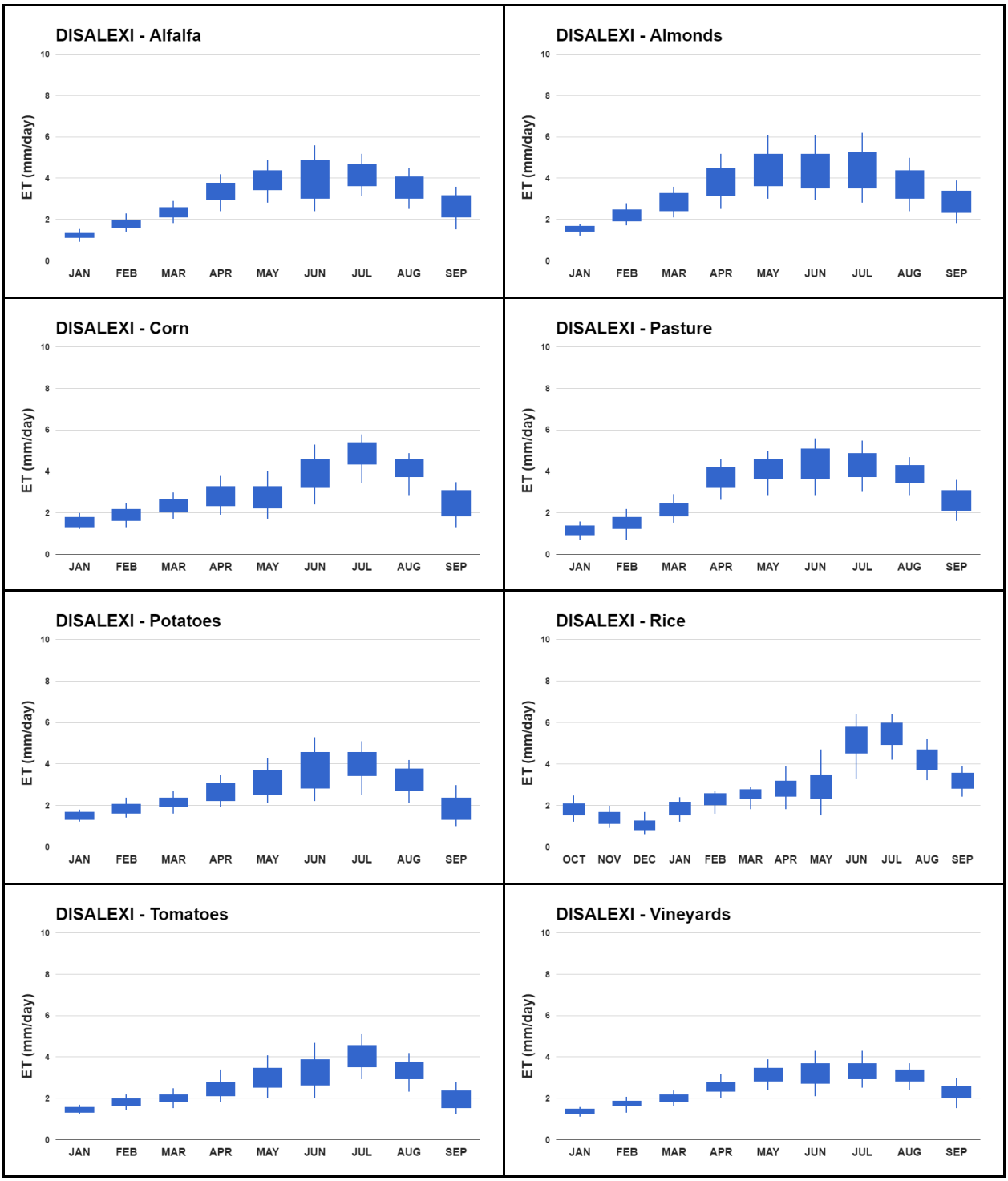


Figure 8C. Daily average ET by month estimated by DisALEXI for selected crops. Boxes show the first and third quartiles; the 9th and 91st percentiles are represented by the ends of the vertical lines.

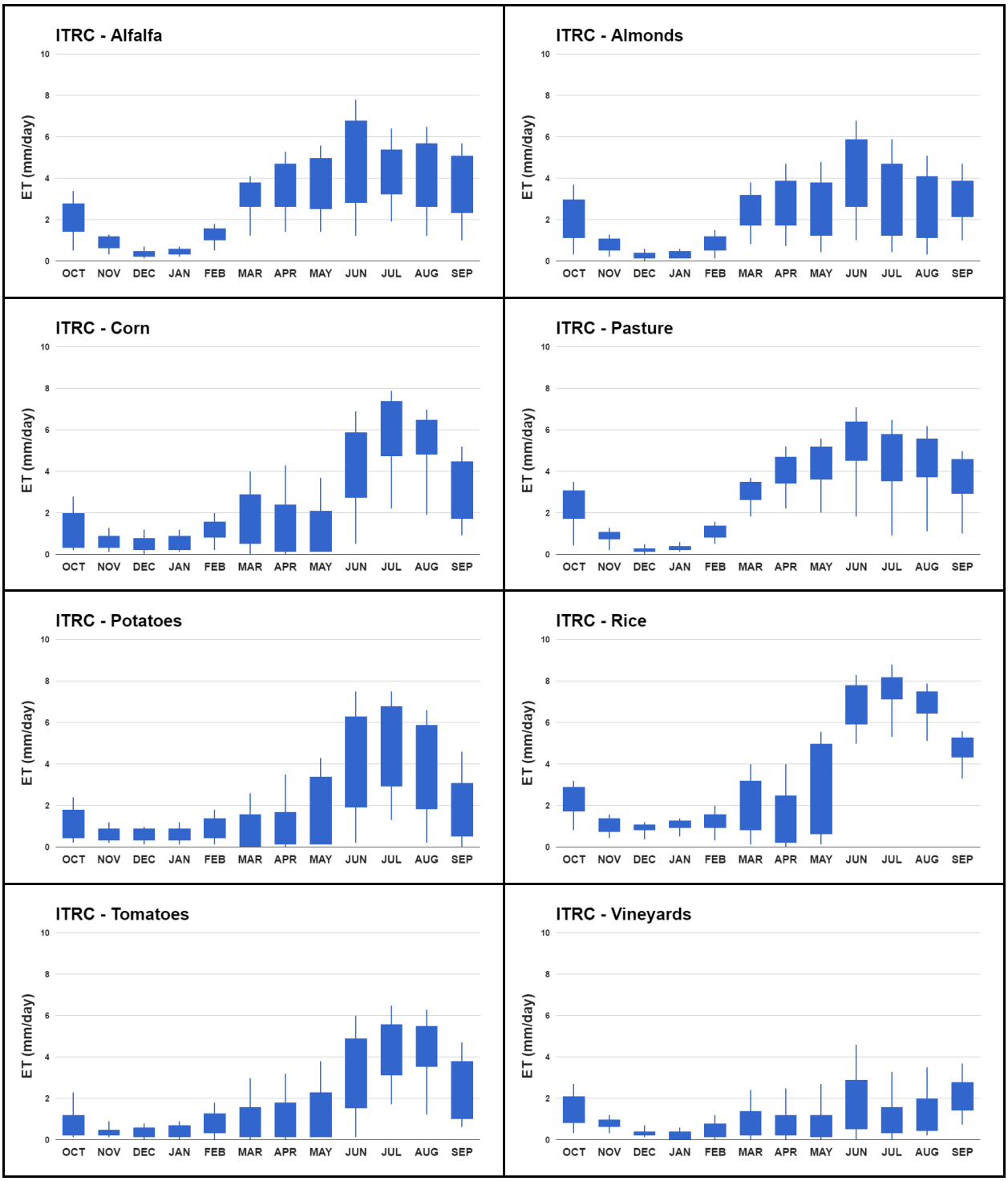


Figure 8D. Daily average ET by month estimated by ITRC for selected crops. Boxes show the first and third quartiles; the 9th and 91st percentiles are represented by the ends of the vertical lines.

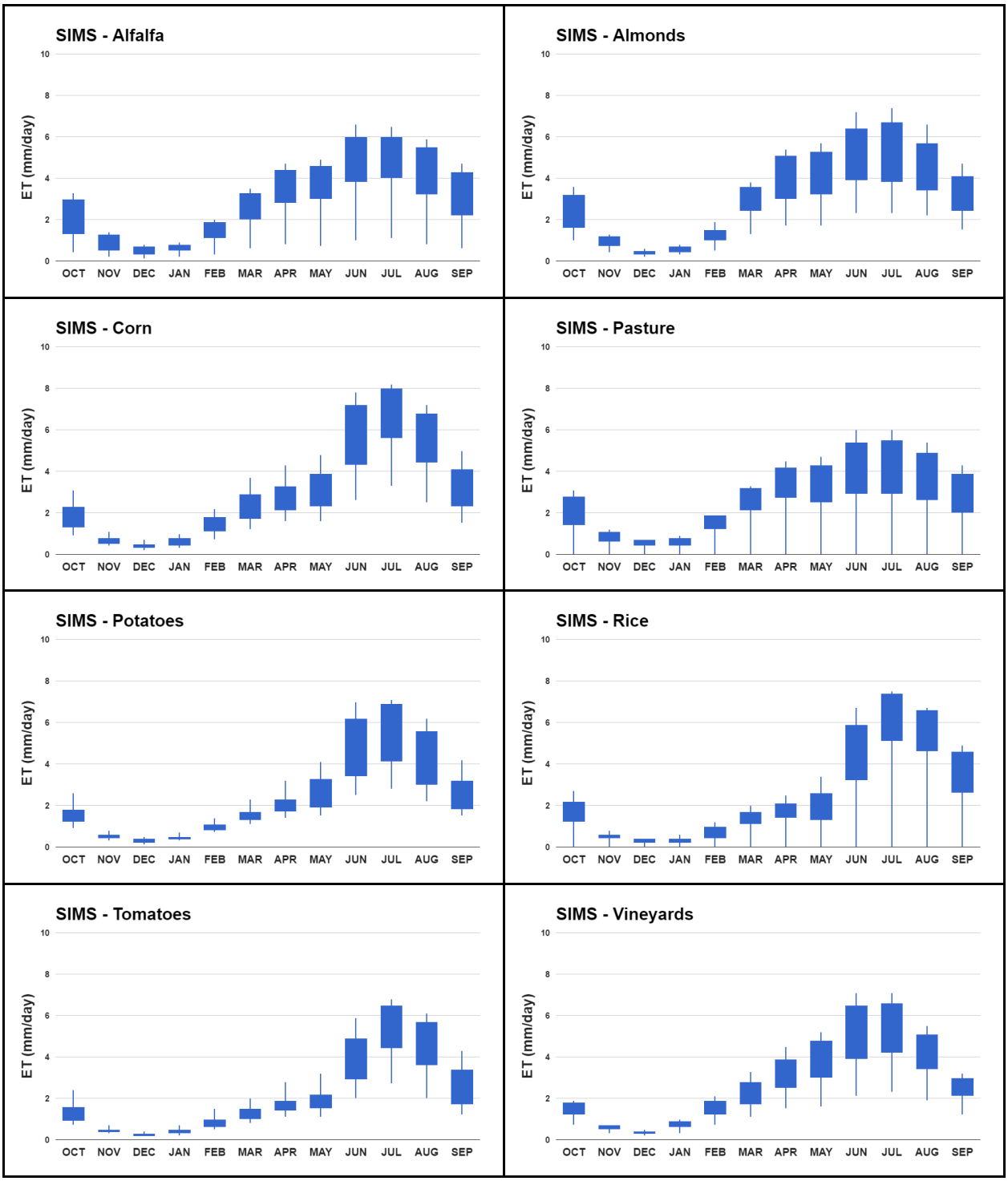


Figure 8E. Daily average ET by month estimated by SIMS for selected crops. Boxes show the first and third quartiles; the 9th and 91st percentiles are represented by the ends of the vertical lines.

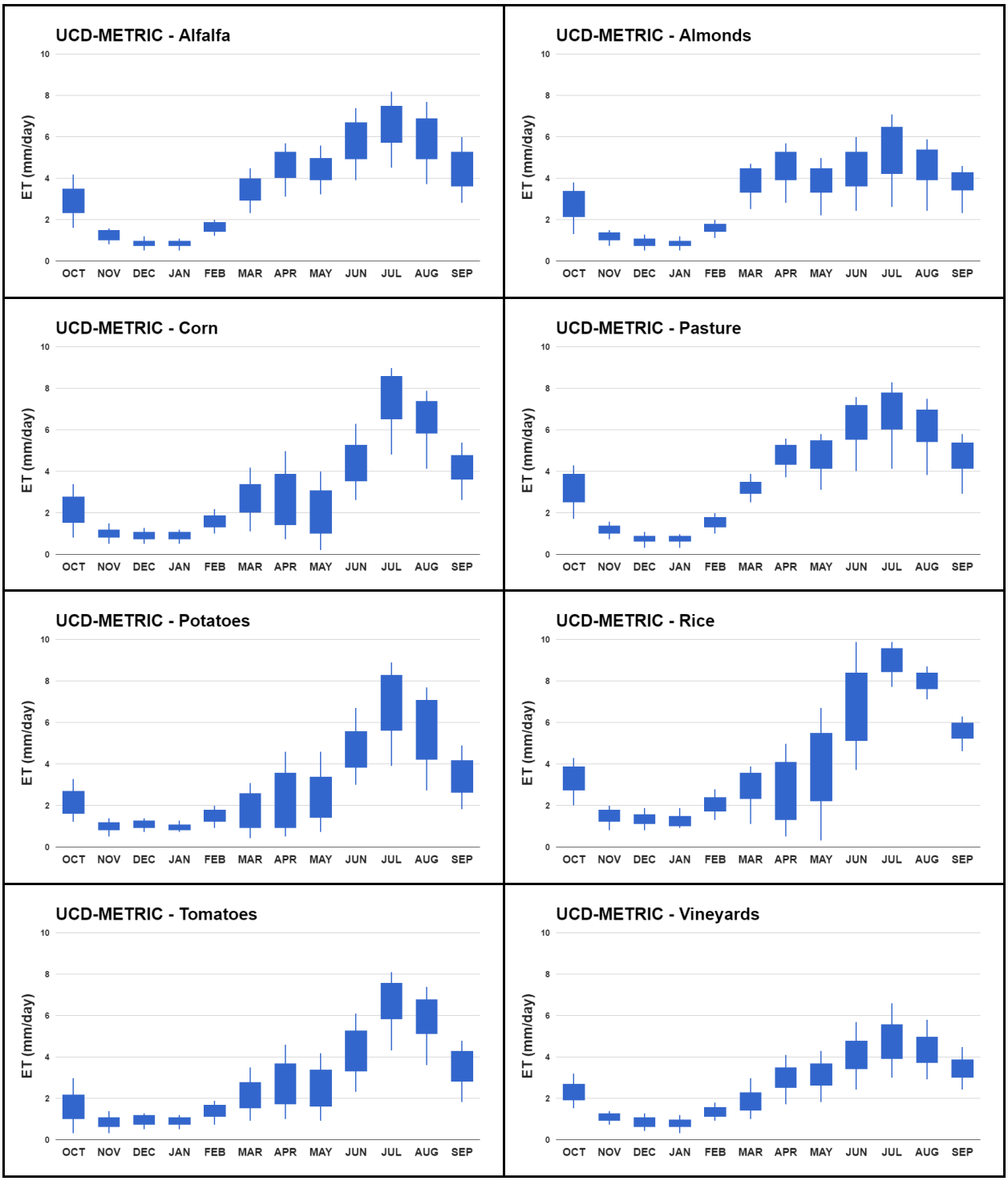


Figure 8F. Daily average ET by month estimated by UCD-METRIC for selected crops. Boxes show the first and third quartiles; the 9th and 91st percentiles are represented by the ends of the vertical lines.

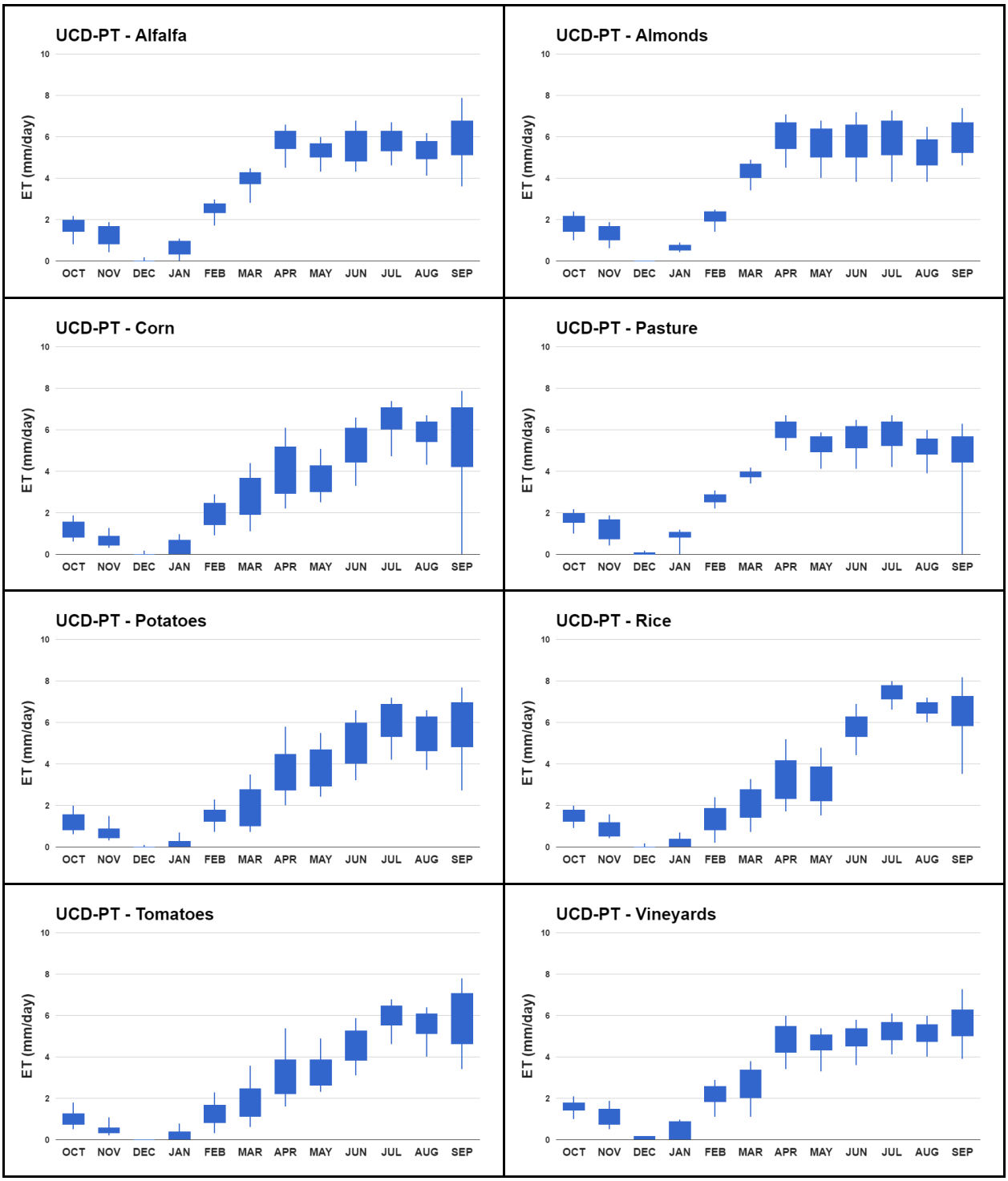


Figure 8G. Daily average ET by month estimated by UCD-PT for selected crops. Boxes show the first and third quartiles; the 9th and 91st percentiles are represented by the ends of the vertical lines.

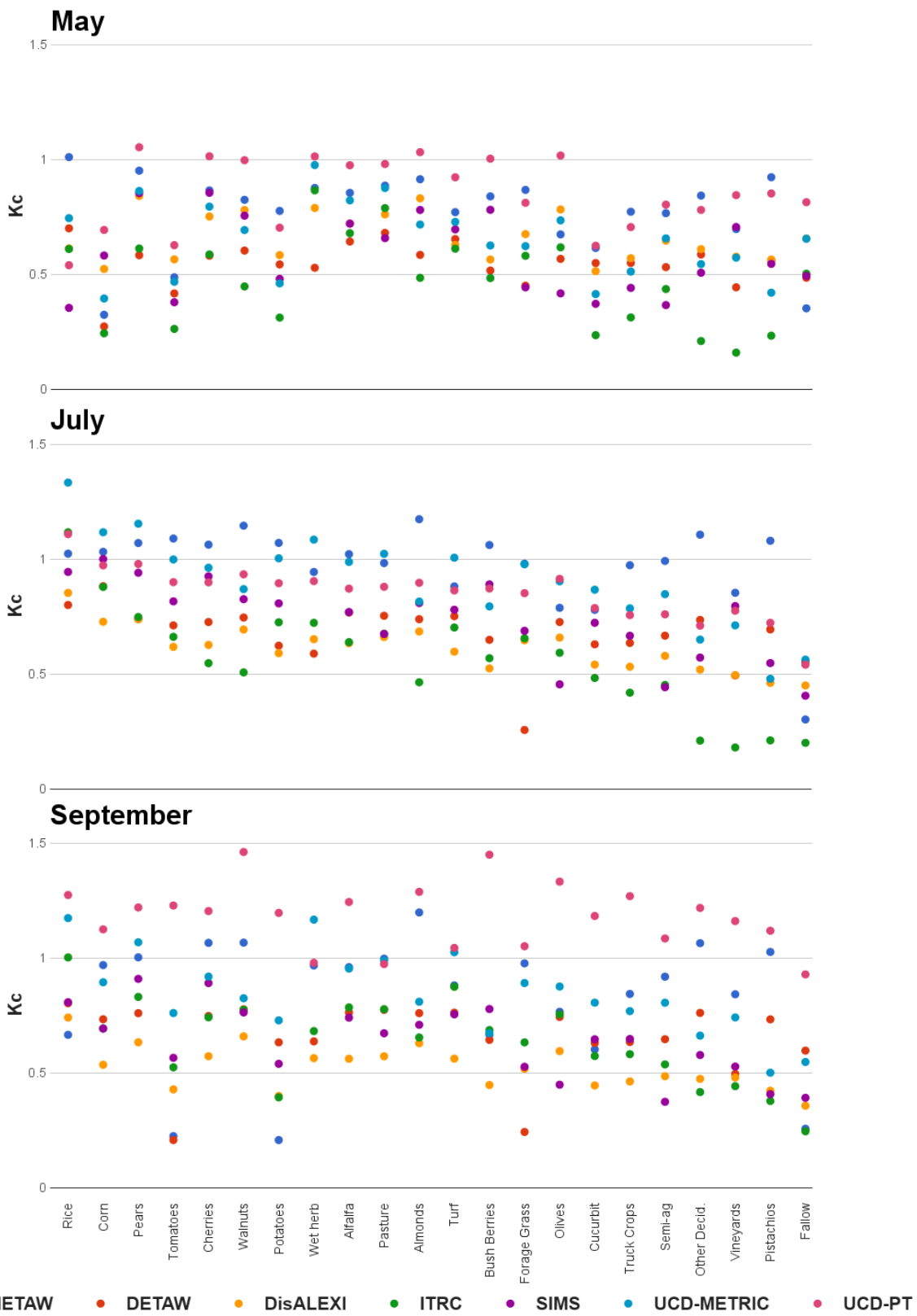


Figure 9. Crop coefficient (Kc) by method for May, July, and September, 2015. Note that SIMS did not estimate certain land use types (i.e., open water, riparian, etc.). Crop coefficients are sorted by land use category using the average Kc for all seven methods in descending order.

Crop Coefficients by Method

Another preliminary comparison can be made of crop coefficients by method for the selected crops. Figure 9 above shows the crop coefficients for each method for May, July and September of 2015 based on the estimated daily average ET for the month. Crop coefficients (Kc) are derived by dividing the estimated daily average evapotranspiration by their corresponding reference evapotranspiration using Spatial CIMIS. This shows variations in how the different methods represent the different crops.

CalSIMETAW and UCD-METRIC have the highest Kc in July for almost all land uses. Among the methods, Kc values derived from DisALEXI are intermediate in May but at the lower end in July and September. Higher Kc values from UCD-PT estimates are likely caused by the fact that only clear sky conditions are considered and by the lack of water stress controls during the 2015 analysis period. These limitations are expected to be reduced prior to estimations for the 2016 water year and the final report.

Evapotranspiration for Selected Crops by Delta Sub-regions

An additional comparison is across the estimates of full evapotranspiration from crops for the season in a selection of sub-regions in the Delta as defined by DETAW. Selected sub-regions are shown in Figure 10 and include: Staten Island, Webb Tract, Area 153, Union Island (West), Union Island (East) and Area 103. The main reason for selecting these areas was to have a balanced cross section including the East, Central and South Delta.

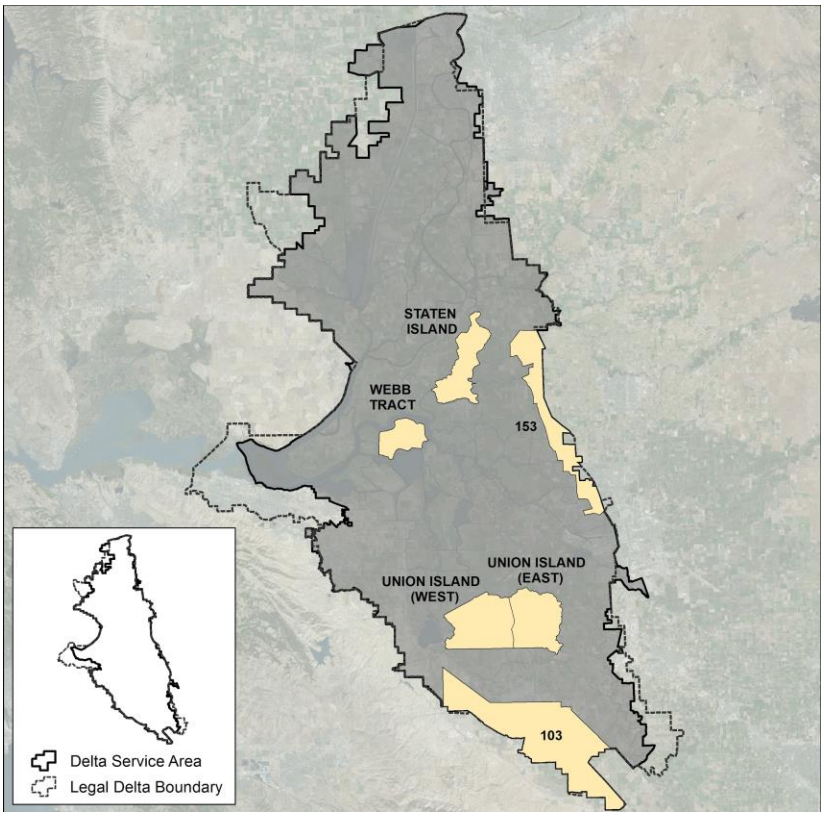


Figure 10. Map of selected Delta sub-regions.

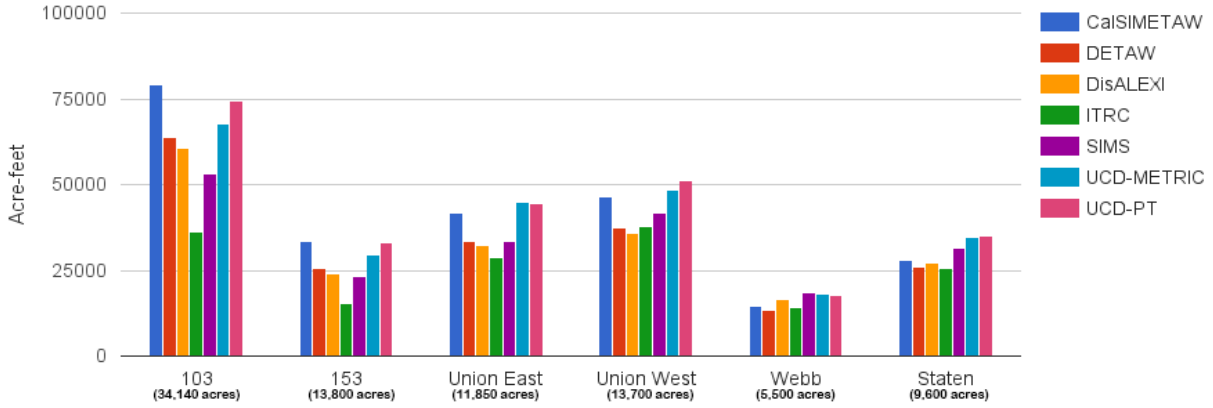


Figure 11. Annual estimates of total evapotranspiration from selected crops for the 2015 water year, by method, for six Delta sub-regions as shown in Figure 10.

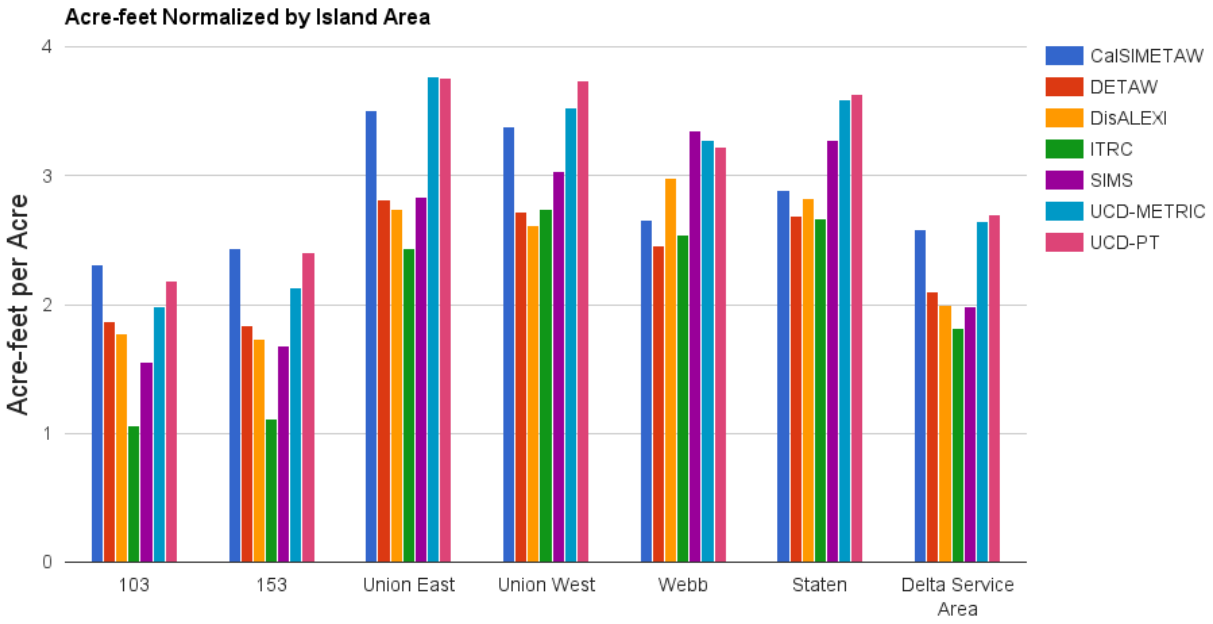


Figure 12. Yearly total evapotranspiration from selected crops for the 2015 water year, by method, for six Delta sub-regions and the Delta Service Area normalized by acreage.

Estimates of ET for the year, by method, are compared in Figures 11 and 12. In general, trends in the estimates by method are preserved among the areas analyzed with the exception of Webb Tract and Staten Island, where estimates appear more even. ET estimates converted to a per acre basis for the same areas and the full Delta Service Area (Figure 12) confirm a similar pattern shown in Figure 10 totals. For the most part, the two UCD methods claim the high end along with the potential evapotranspiration from CalSIMETAW. DETAW, ITRC-METRIC and SIMS vary more across the analyzed sub-regions. Siegfried et al. (2012) found for Staten Island net channel depletion of about 2 acre-feet per acre, yet this includes all land use classes in the island.

Lastly, Figure 13 below shows the ratio of the range to the mean across methods by crop and month for of the selected crops. This measure allows visualizing months and crop groups for

which the methods show the greatest relative differences. Higher ranges of variation of ET estimate were found in December and January (warmer colors). The summer shows moderate levels of agreement (cooler colors) with the exception of vineyards. Tomatoes, vineyards and potatoes have the highest degree of variation in monthly ET estimates. On an annual basis, almonds, vineyards and rice had the highest variation among ET estimates. In December, UCD-PT estimates of ET were remarkably low compared to other methods and CalSIMETAW is at the high end. In January there is not a clear trend, but average overall crop ET estimates appear high for DisALEXI and low for UCD-PT. Lastly, the differences in estimates of ET at the end of the irrigation season in September are attributable to differences between UCD-PT and DisALEXI, and to some anomalies for potatoes and tomatoes by CalSIMETAW (likely related to embedded harvest calendars). These differences provide information that will likely lead to improved calibration and reduced anomalies in algorithms for the final report of this two-year study.

	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

Less Dispersion **More Dispersion**

Figure 13. Ratio of range to the median of monthly and annual ET estimates among all methods by month for selected crops.

Technical Comparative Discussion

This preliminary report summarizes ET estimates from multiple established methods and models for a range of crops grown in the Delta. It is intended to illustrate the range of methods and their current implementation stages for estimating crop ET in the Delta and to inform technical discussions and improvements in ET estimation for this complex region. The final report for the project, expected in Spring of 2017, will summarize findings from the exploration of the data presented in this initial report, further improvements, and findings from the 2016 growing season including additional field estimates of crop ET.

Because the 2015 field campaign was quite limited (roughly a month near the end of the prime growing season, and only for bare soils) and because five additional CIMIS stations have been deployed within the Delta, 2016 data are expected to be more robust. Thus, preliminary data for 2015 presented here should be cautiously interpreted. The researchers anticipate that the real value of this preliminary report of 2015

findings will be in identifying (1) consumptive use variation between drought and more normal years and (2) the systematic variation among estimation methods (which may be resolved or narrowed based on improvements for 2016 results).

Having identified these potential bases for discrepancies among methods through analysis of the 2015 data and compilation of this preliminary report, the researchers expect to improve the explanation of difference and, perhaps, resolve some of them in the remainder of the study.

Measured Evapotranspiration in Bare Soil

Bare soil evapotranspiration measurement for the fields sampled shows little evapotranspiration relative to the reference evapotranspiration during the late 2015 summer. Crop coefficient estimates for the idle (bare soil) fields from the data collected to date are well below reference evapotranspiration from nearby CIMIS stations. The average measurements of ETa for bare soil for late summer were low; mean ET was 0.22 mm/day, and ranged from 0.05 mm/day to 0.39 mm/day, for the dry month of September, and at these fields that ranged in elevation from 1.5 m to 17 m above sea level. The ETa values are slightly higher using the assumption of zero ground heat flux averaged over a day; than when using measured and estimated ground heat flux. All ETa measurements were substantially less than the reference ETo from the CIMIS stations, when averaged over the dry period of measurements. When the daily ETa values were examined day-by-day, all stations registered the rain on October 1, 2015 at the end of the measurement period. On September 19 and 20, the average ETa of all stations was between 0.5 mm/day and 2 mm/day; on a few other days, the averages were low (below ~0.5 mm). These few days corresponded to high nighttime humidities of around 100%, and there were indications of regional advective conditions (horizontal flow from wind) that would decrease the accuracy and validity of all energy budget residual methods used, both field experimental and remotely-sensed based. Horizontal advective flow is the process during low turbulence conditions when much of the moisture flux from the ground mix into the lowest layer of the atmosphere and then flows horizontally, parallel to the ground as the wind blows above the ground, with much smaller vertical turbulent fluxes. Hence apparent vertical moisture fluxes for these days could actually not be coming from the bare soil, but instead originate from horizontal moisture flow converging (pushing against the air ahead of it), resulting in a vertical moisture flux from this convergence, and not from the ground surface. Another possibility is that high tides in the Bay area could have induced higher water table levels in the soil, increasing fallow field evapotranspiration, which would then imply the measurements were real and not an artifact of horizontal convergence. The daily crop coefficients reflect the same results, that most days showing a crop coefficient near zero, but have an increase on September 19th and 20th, 2015. Details are in Appendix A.

Estimated Evapotranspiration from Crops

Average estimates of consumptive use from crops across methods shown in Table 2 lie within the range reported on water budgets for the Delta in the California Water Plan Update and other documents. Further error discovery and analysis within the various methods will be part of the full report. Native vegetation, fallow land, minor crops and open water areas will add to the estimated totals in Table 3. Methods not involving remote sensing such as DETAW and CalSIMETAW do not necessarily agree in their respective ET estimates. Overall, DETAW offers lower ET estimates than CalSIMETAW, which falls at the high end of the range of models included in this analysis, with some exceptions. Among the methods involving remote sensing information, ITRC-METRIC and DisALEXI generally provided lower ET estimates for most crops and months. METRIC implemented by UCD, and Priestley-Taylor (which were not yet calibrated for individual crops types and did not include moisture constraints in this interim report), were often in the high range, along with the potential ET estimates from CalSIMETAW.

The SIMS approach is in the middle of the ensemble range for some of the regions and crop categories analyzed in more detail in this preliminary report.

Some factors contributing to the ET differences include use of different thermal layers, variation in methods of processing satellite imagery, different temporal interpolations for cloudy days or days without satellite overpass, use of different meteorological information from CIMIS or other reference evapotranspiration stations, in addition to the algorithm differences.

Some of the 2014-2015 UCD-METRIC preliminary crop coefficients (Kc) are of the range of what is expected under plant physiology. In most cases, Kc values skew high, but there are cases in which these seem too low. Crop coefficients from METRIC are back calculated by dividing the UCD-METRIC actual crop ET by a reference ET, which in this case was Spatial CIMIS. Sources of bias include selection of hot and cold pixels, lack of cloud masking, and use of some processes such as thermal sharpening and calculation of reference evapotranspiration from Spatial CIMIS which are still under development. These issues will be addressed with caution as estimates for the 2016 season unfold.

As a first cut to estimate crop ET for a complete water year over the entire Delta, many factors contributed to the differences and spread of ET estimates among methods, in addition to algorithm differences. The primary input data for the five remote sensing based methods are images from Landsat 8 satellite with a 16-day revisit time, but DisALEXI also fused the daily MODIS satellite images at a coarser resolution to increase the temporal frequency. Variation in methods of processing satellite imagery, i.e., sharpening of Landsat thermal data to 30 m resolution, potentially led to discrepancies in some key input data to the ET algorithms, and thus ET differences. Moreover, different temporal interpolation techniques were used to estimate ET for days without Landsat satellite overpass or cloudy days (especially in winter), further contributing to the differences in monthly ET estimate across the models. Use of different meteorological or reference evapotranspiration information from CIMIS (e.g., stations vs. Spatial CIMIS) also introduced an additional source of discrepancies in ET estimates.

These sources of differences among the models are expected to be reduced for estimates during the 2016 season as the independent research groups improve coordination and discussion of common input data and protocols, and as some estimation algorithms are calibrated with improved field measurements.

Conclusions and 2016 Work

This preliminary report presents a preliminary presentation and comparison of efforts by various independent research groups specializing in estimating evapotranspiration, with an emphasis on agricultural lands. The Delta has challenges for estimating crop evapotranspiration given its unique and widely variable conditions of soils, wind, crops, and infrastructure. A limited field campaign for measuring ET in bare soil during 2015, and initial comparisons of seven estimation methods (CalSIMETAW, DETAW, DisALEXI, ITRC- METRIC, UCD-METRIC SIMS and PT) for evapotranspiration provide only the starting point to examine consumptive use in the Delta.

Micrometeorological measurements of ETa were made over four fallow fields with five stations in the Delta, representing a range of Delta microclimates. However, all of the fallowed fields were in the southern part of the Delta at elevations above sea level. During the dry month of September, average ETa values measured at these stations were low (0.22 mm/day average) compared to the reference evapotranspiration. After a period of rain near the end of the measurement campaign, substantial ETa was measured.

The preliminary analysis at this interim stage of the Study should be evaluated cautiously, more as a guide to necessary refinements based on 2016 data than an authoritative analysis of crop ET in 2015. Nonetheless, the following findings appear to be supported by the 2015 data and experience:

1. Bare soil evapotranspiration measurement for the fields sampled during the late 2015 summer showed very little evapotranspiration relative to the reference evapotranspiration during the same period. Crop coefficient estimates for the idle (bare soil) fields collected during the 2015 drought are well below reference evapotranspiration for the same period from nearby CIMIS stations.
2. Estimates of evapotranspiration from crops in the Delta when averaged among the seven methods under study are broadly consistent with water balance estimates in the California Water Plan and modeling literature. All estimates are within about 20% of the median estimate.
3. The greatest relative differences in crop evapotranspiration estimates across methods are in December and January (of the water year). Crop categories with the highest differences in ET across methods are vineyard, potatoes and tomatoes.
4. Refined estimates produced by all of the methods under study should employ common input datasets and common protocols to enhance the value of inter comparisons conducted in this study. In addition, improved algorithm calibration based on analysis of 2015 data may reduce the range of variation in ET estimates across methods.
5. This first round of ET estimates provides an initial reference for future improvements and comparisons among methods of estimating ET, quantifying the potential variation, and identifying conditions under which higher discrepancies are more likely. Future iterations, improvements, and a more detailed report including comparisons of simultaneous field measurement, and estimation of ET will greatly improve understanding of crop water use in the Delta.

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Table of Acronyms

CalSIMETAW	California Simulation of Evapotranspiration of Applied Water
CIMIS	California Irrigation Management Information System
Spatial-CIMIS	Web Application Programming Interface (API) for CIMIS
CSUMB	California State University Monterey Bay
CU	Consumptive use
DAU	Detailed Analysis Unit
DAU-CO	Detailed Analysis Unit area within a county
DETAW	Delta Evapotranspiration of Applied Water
DisALEXI	Disaggregated Atmosphere-Land Exchange Inverse
DWR	California Department of Water Resources
ET	Evapotranspiration [see explanation box]
ITRC	California Polytechnic Institute San Luis Obispo. Irrigation Training and Research Center
Kc	Crop Coefficient, the ratio of crop ET over Reference ET [see explanation box]
METRIC	Mapping EvapoTranspiration at high Resolution with Internalized Calibration
MODIS	MODerate-resolution Imaging Spectroradiometer
SIMS	NASA Satellite Irrigation Management Support system
NASA-ARC	National Aeronautics and Space Administration Ames Research Center
PT	Priestley-Taylor approach
SEBAL	Surface Energy Balance Algorithm for Land
SSURGO	Soil Survey Geographic Database
TAF	Thousand Acre-Foot
UAV	Unmanned Aerial Vehicles
UCD	University of California, Davis
USDA-ARS	United States Department of Agriculture-Agricultural Research Service

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