OpenET Satellite-based ET Intercomparisons with Ground-based Measurements: Phase II Results

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November 26, 2022

Abstract

OpenET is a software system that makes satellite-based multi-model estimates of evapotranspiration (ET) accessible at multiple spatial and temporal scales over the U.S. Large-scale ET estimates fill a critical data-gap for irrigation management, water resources management, and hydrological modeling and research. We present the methods and results of the second phase of an intercomparison and accuracy assessment between OpenET satellite-based models (ALEXI/DisALEXI, eeMETRIC, PT-JPL, geeSEBAL, SIMS and SSEBop) and a benchmark ground-based ET dataset with data from nearly 200 eddy covariance towers across the contiguous U.S. Processing steps for the benchmark dataset included gap-filling, energy balance closure correction, calculation of closed and unclosed daily ET, and multiple levels of data QA/QC. The dataset was split into three groups, phase I and II of the intercomparison and a reserve dataset for future studies. To sample satellite-based ET pixels, static flux footprints were generated at each station based on dominant wind speed and direction. Where data allowed, two dimensional flux footprints that are weighted by hourly ETo were developed and used for ET pixel sampling. A wide range of visual and statistical comparisons between satellite and ground-based ET were conducted at each station and against stations grouped by land cover type. Based on key performance metrics including bias, coefficient of determination, and root mean square error, model results show promising agreement at many flux sites considering the inherent uncertainty in station data. Remote sensing models show the highest agreement with closed station ET in irrigated annual cropland settings whereas locations of native vegetation with high aridity and some forested stations show relatively less agreement. The benchmark ET dataset was used to explore different approaches to computing a single ensemble estimate from the six model ensemble, with the goal of reducing the influence of model outliers and selection of weighting and data sampling schemes to reduce the influence of flux stations with sparse or extensive data records. We present the results from the model intercomparison and accuracy assessment and discuss model performance relative to accuracy requirements from the OpenET user community.

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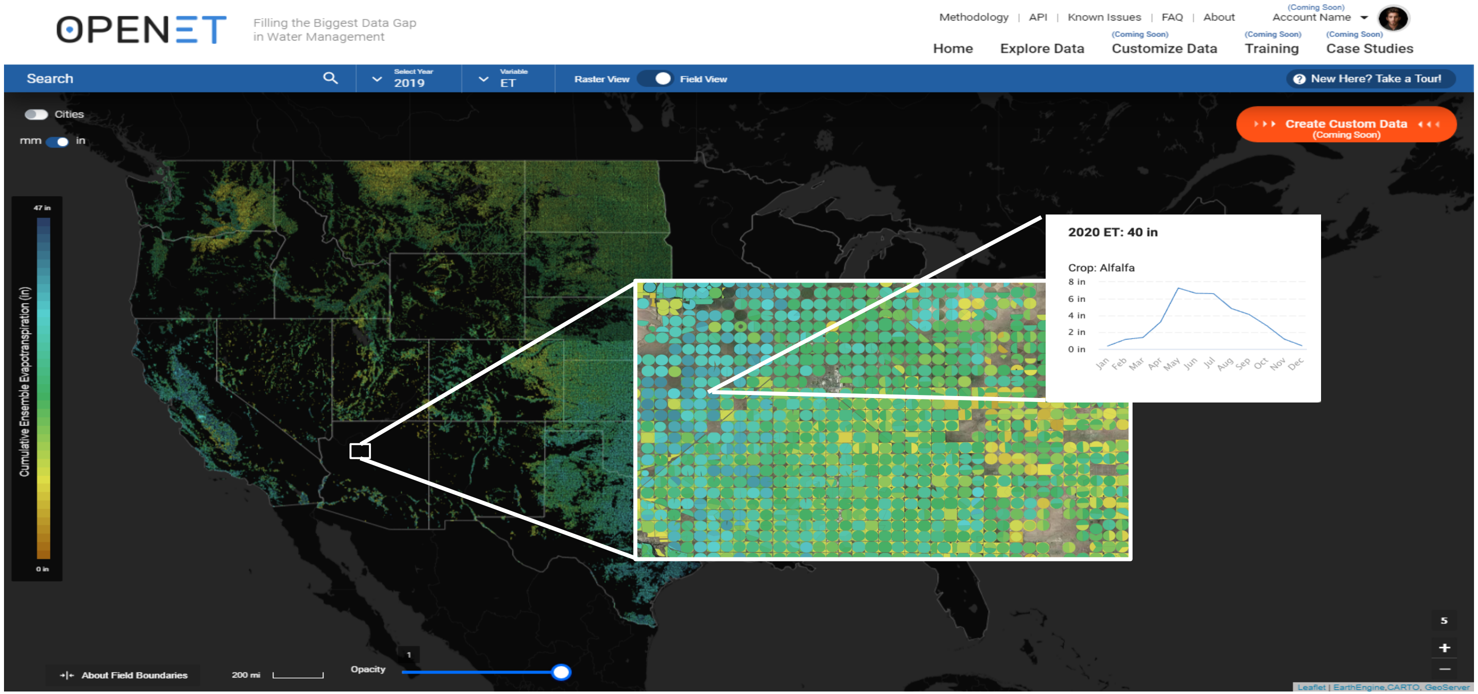
Satellite-based ET Intercomparisons with Ground-based Measurements: Phase II Results



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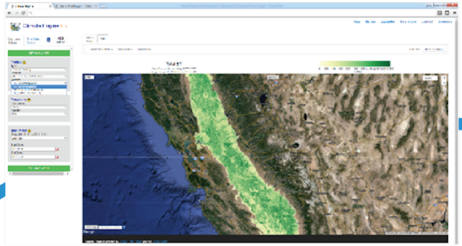
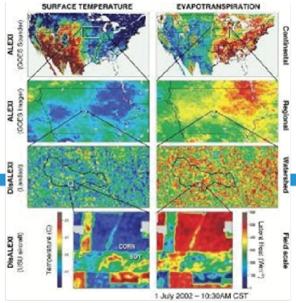
Universidade Federal do Rio Grande do Sul (SEBAL) Anderson Ruhoff

Google Earth Engine Tyler Erickson

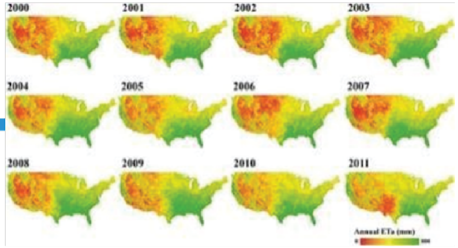
OpenET Uses Well-Established Methods



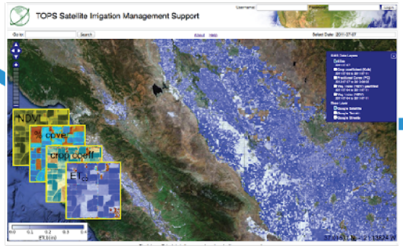
EE METRIC
University of Nebraska,
University of Idaho



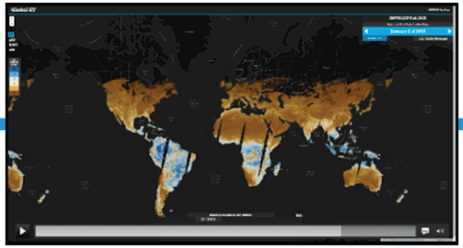
ALEXI/DisALEXI
USDA, NASA, University of Maryland,
University of Wisconsin



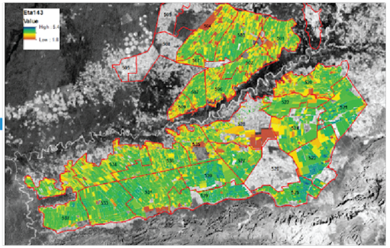
SSEBop
USGS



SIMS
NASA, CSUMB, Stanford University

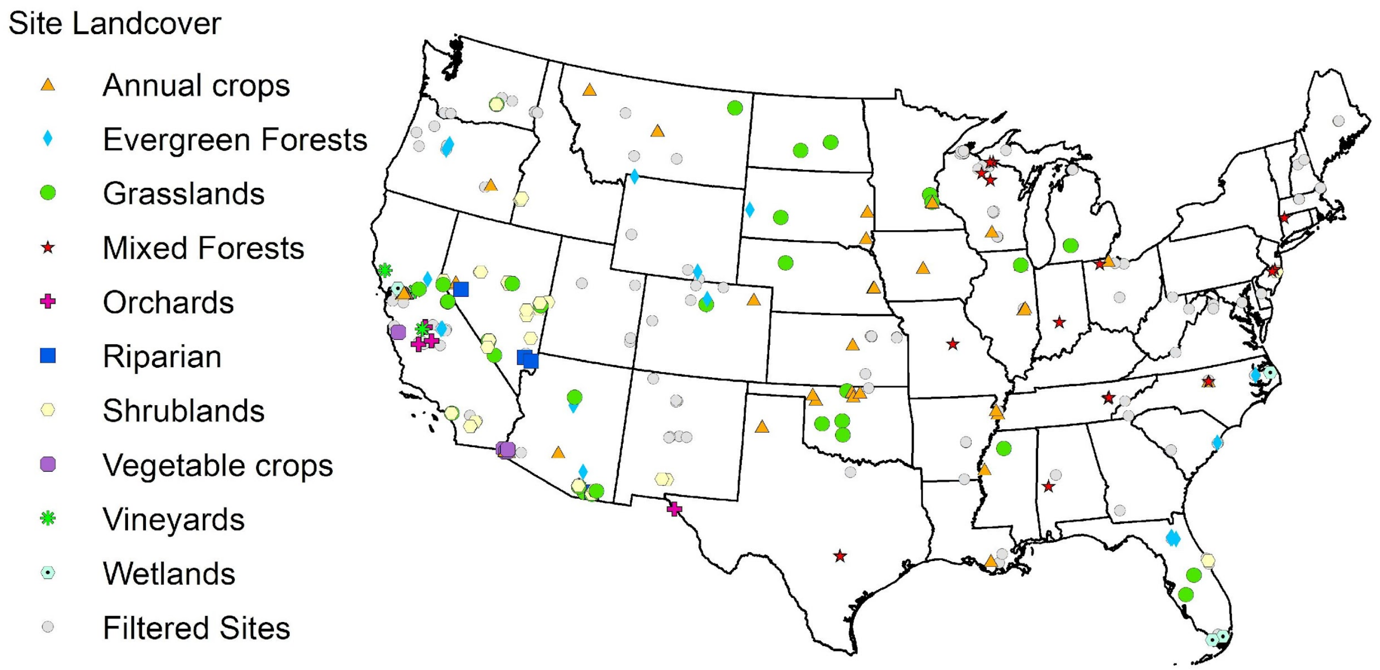


PT-JPL
NASA



SEBAL

Developing a Benchmark ET Dataset From Eddy Flux Towers



Phase I comparison 70 flux tower sites; 24 ag. sites
Phase II comparison for 142 flux tower sites; 70 ag.
33 sites held out for blind model evaluation

Flux Data Processing and Energy Balance Correction

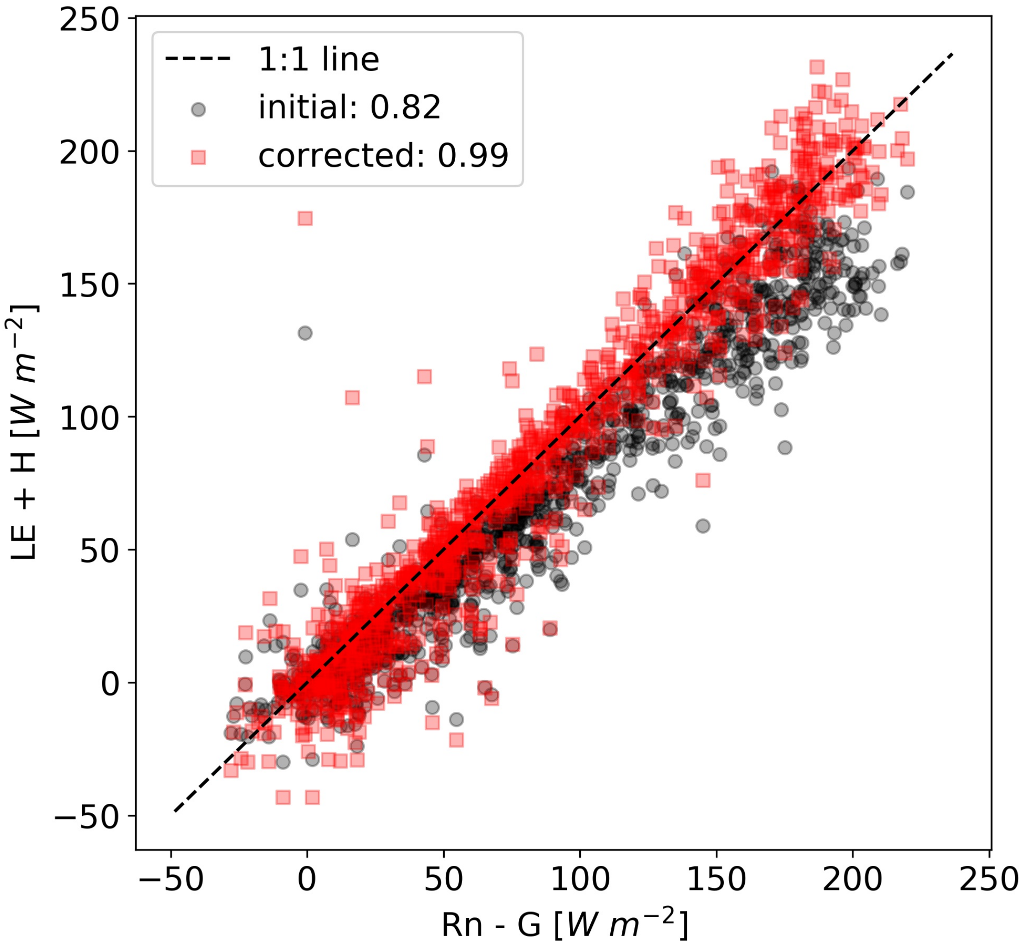
Gap-filling half-hourly energy balance components LE, H, Rn, and G, filling up to 2 hours during the daytime and 4 at night, then take daily average.

Energy balance closure correction that uses the median of daily energy balance ratios (Rn-G)/(LE+H) over sliding windows to correct daily LE using the inverse of the ratio. Based from the FLUXNET2015 method (Pasterello et al., 2020).

Daily gap-filling ET with interpolated EToF x gridMET ETo (Abatzoglou, 2013)

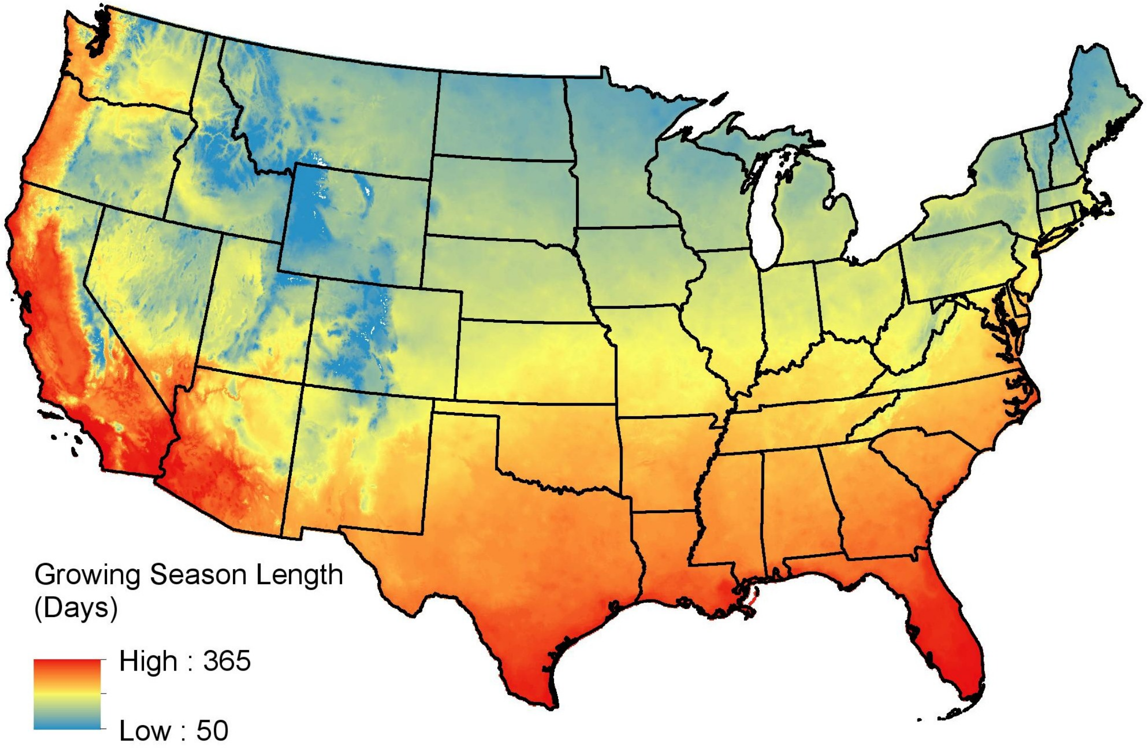
Reproducible methods using the “flux-data-qaqc” Python package (Volk et al., 2021)

Visual QA/QC and data filtering

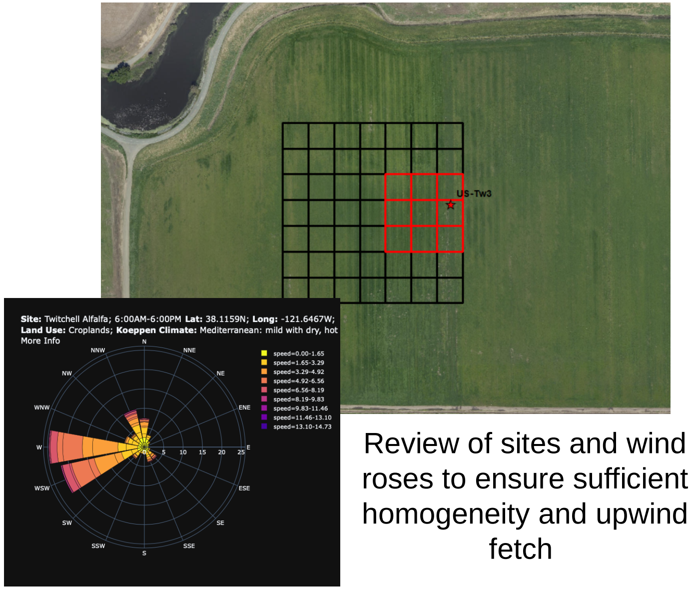


Benchmark ET Dataset Screening Criteria

- 300 deg. C cumulative growing degree day, -2 C killing frost temperatures using ~40 years of data to define growing seasons
- Growing season closure > 75%
- Cold season closure > 60%
- No gap filled daily ET or monthly ET with > 5 gap-filled days

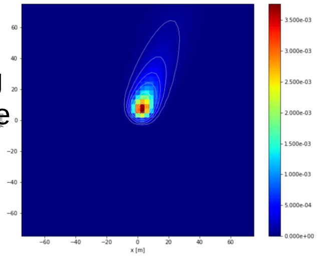


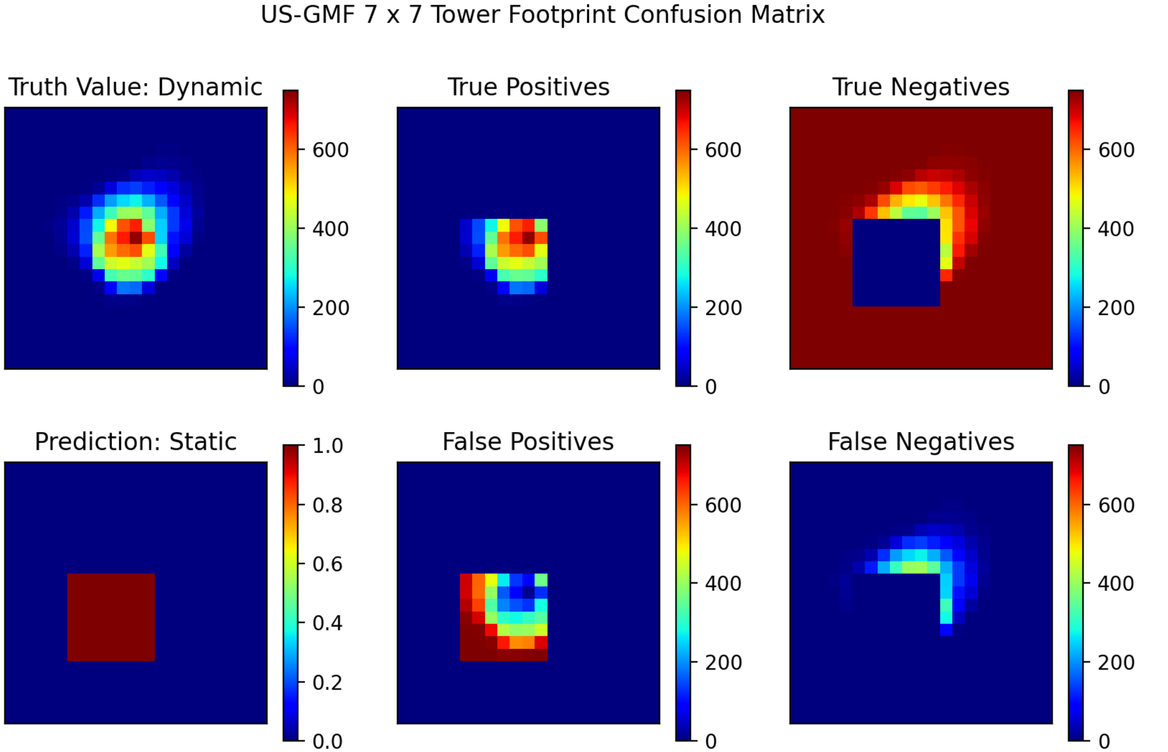
Flux Footprint Generation for Sampling of RSET Pixels



Review of sites and wind roses to ensure sufficient homogeneity and upwind fetch

Dynamic half-hourly footprint analysis following Kljun et al. (2015); example for celery field in Soledad, CA





Statistical Methods For Comparing Models to Ground Data

Grouped weighted mean statistics

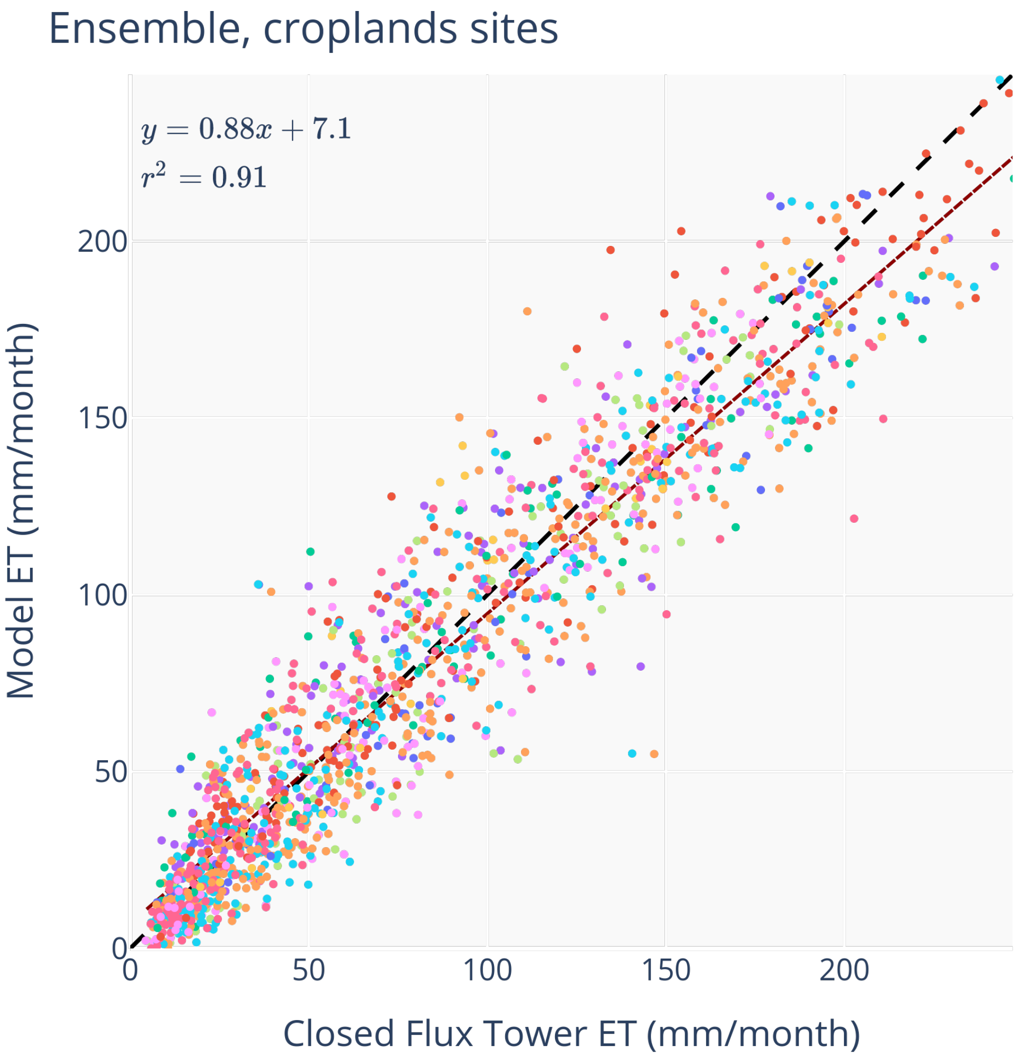
$$STAT_{land} = \frac{\sum \sqrt{n_i} \cdot X_i}{\sum \sqrt{n_i}}$$

Where X_i is the statistic and n_i is the number of paired ET values for the i^{th} site.

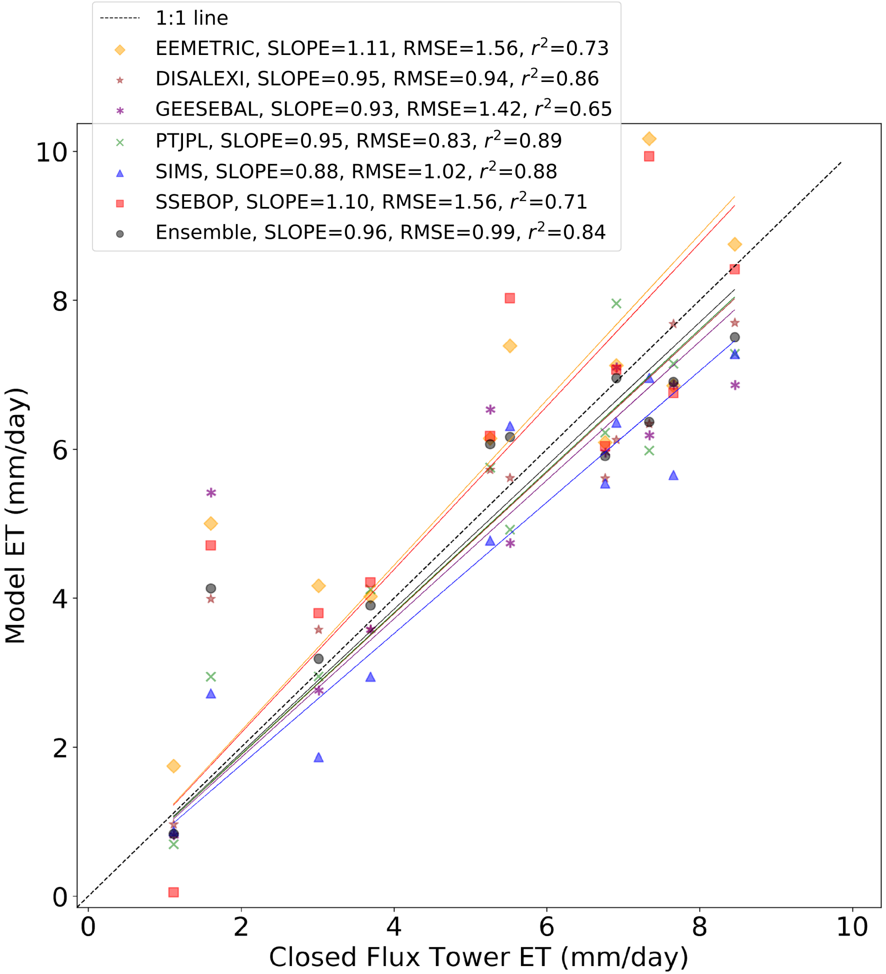
<u>Key summary statistics</u>

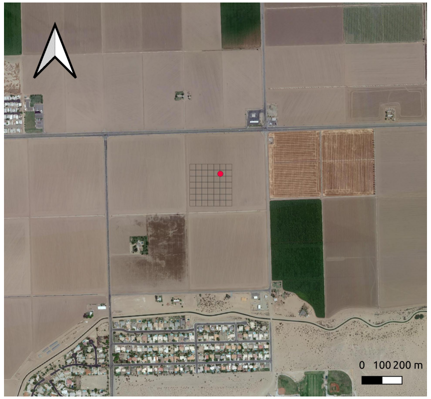
Slope: of linear regression through origin
MBE: mean bias error
MAE: mean absolute error
RMSE: root mean square error
r^2: coefficient of determination (not weighted)

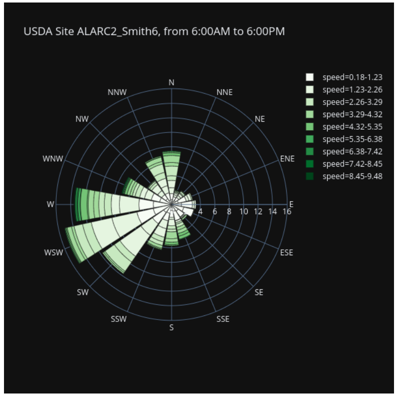
Minimum of 6 days and 3 months of paired data per site for grouped statistics.

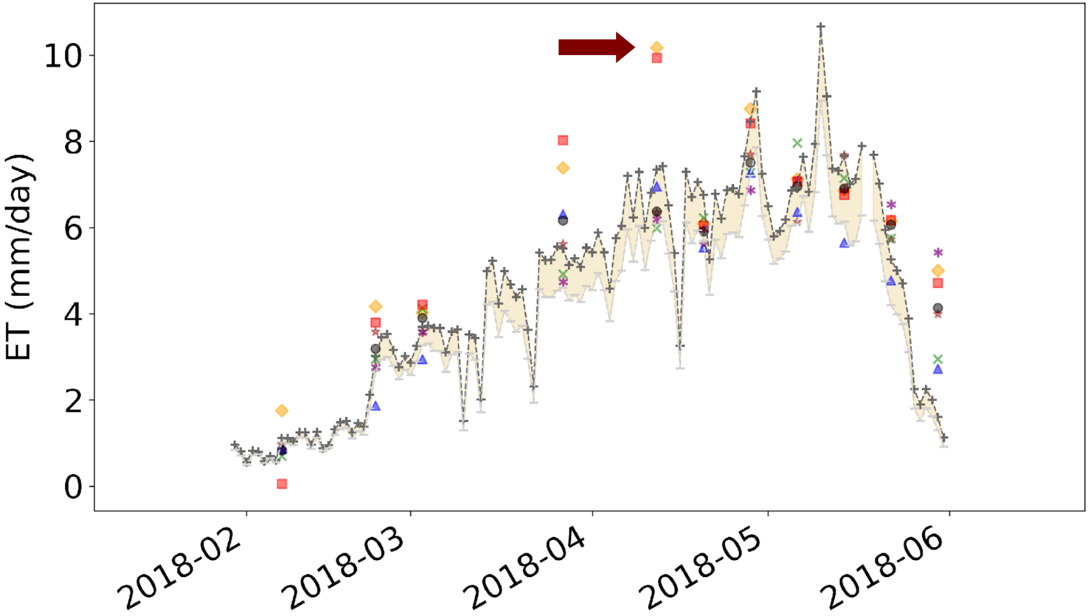


Example Comparison: Arizona Wheat









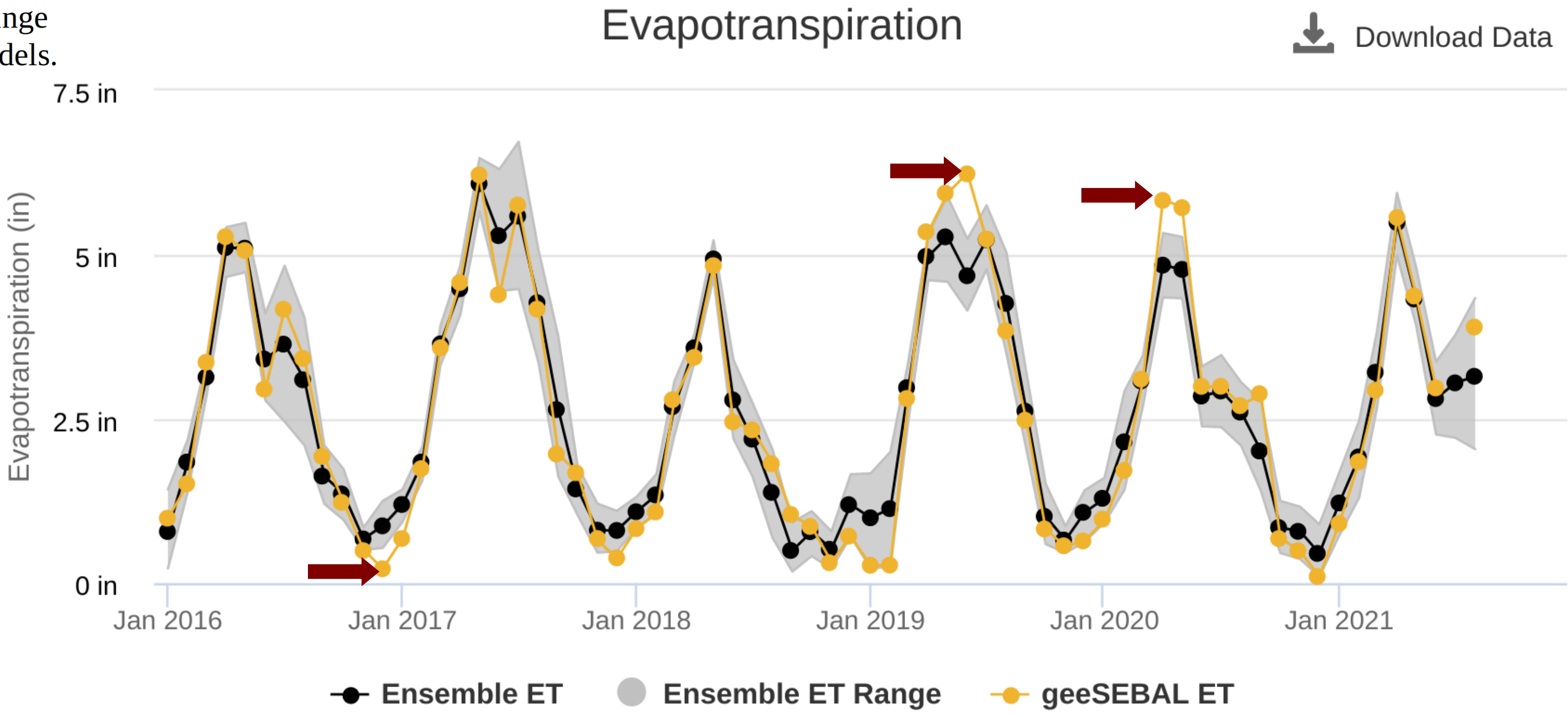
Model Ensemble: Median Absolute Deviation (MAD) Outlier Detection

$$\text{MAD} = 2 \cdot median(|X_i - median(X)|)e$$

Ensemble ET range:

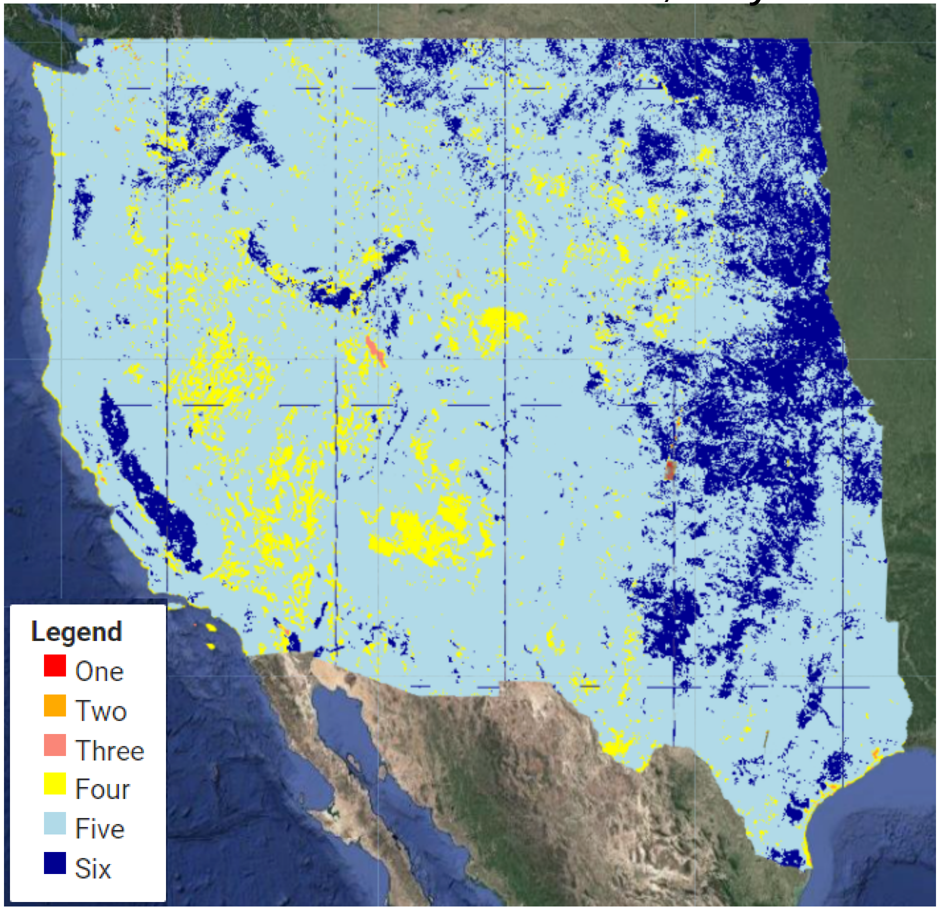
$$median(X) + MAD > ET > median(X) - MAD$$

Average ET within range keeping at least 4 models.

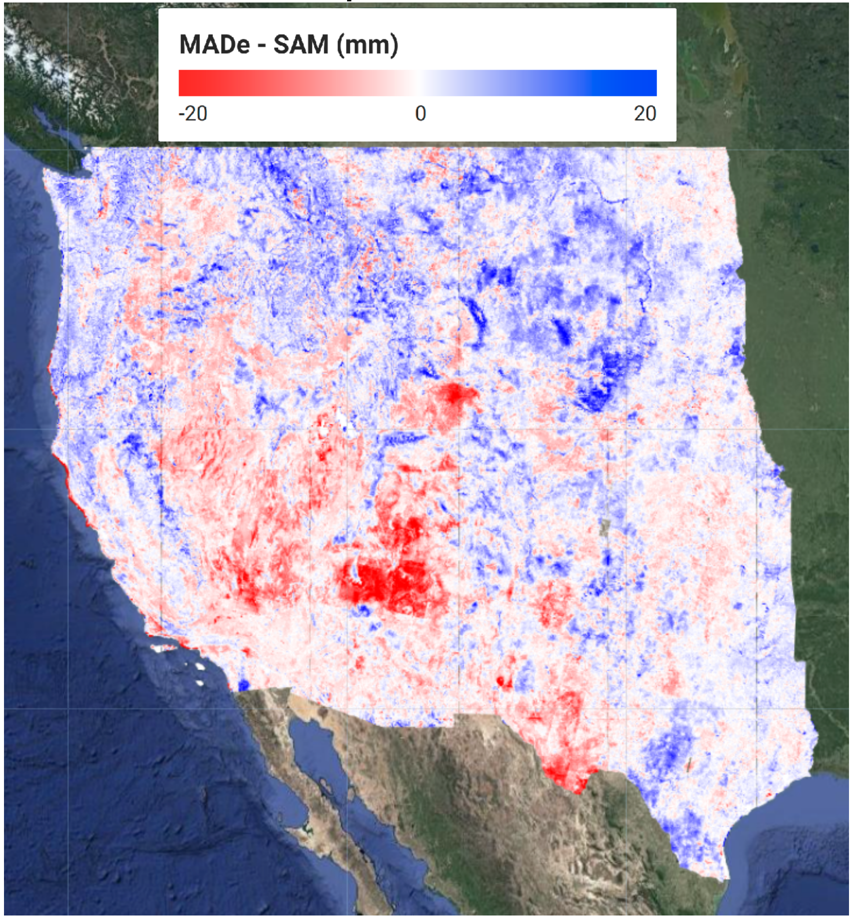


Mapping Ensemble Outliers and Deviation from Simple Mean

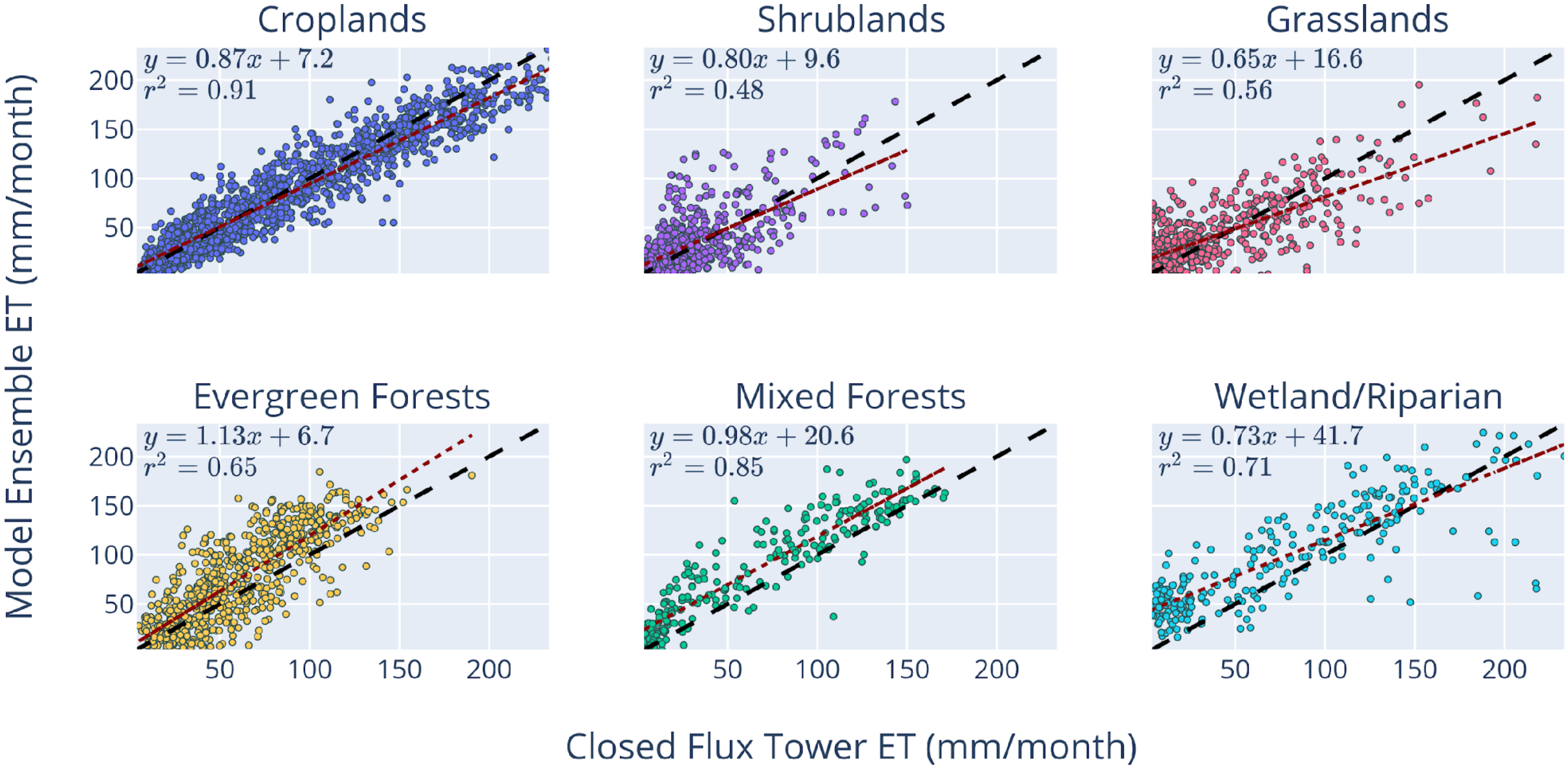
Model count in MAD ensemble, July 2020



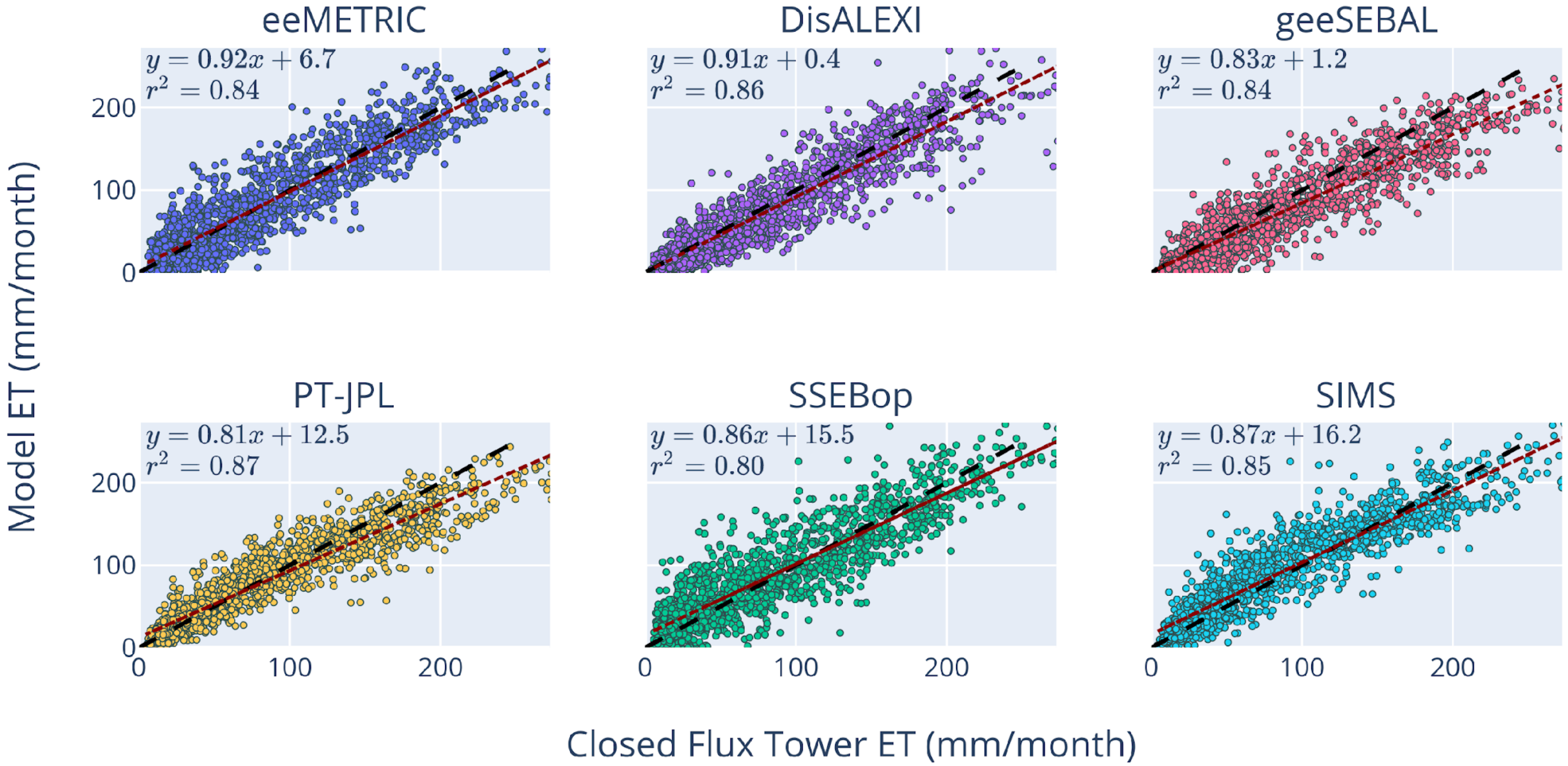
MAD minus simple mean ensemble



Ensemble ET based on Site Land Cover, Monthly ET



Model Comparison Across Cropland Sites, Monthly ET



Accuracy Results and Goals from the User Community

Croplands summary statistics for the phase II intercomparison.

Goals for error relative to closed flux ET, RMSE and MAE: 15-25% (daily); 15-20% (monthly); 10-15% (growing season)

Monthly	**Statistic**	**Ensemble**	**Model Range**
45 sites N = 1682 months Mean closed ET is 93.68 (mm)	**Slope**	0.95	0.86—1.04
	MBE (mm)	-3.64 (3.9%)	-13.77—5.16 (-14.7—5.5%)
	MAE (mm)	15.55 (16.6%)	17.96—22.92 (19.2—24.5%)
	RMSE (mm)	19.97 (21.3%)	23.43—28.72 (25.0—30.7%)
	r^2	0.91	0.8—0.87

Daily	**Statistic**	**Ensemble**	**Model Range**
49 sites N = 4913 days Mean closed ET is 3.64 (mm)	**Slope**	0.88	0.81—0.94
	MBE (mm)	-0.27 (7.4%)	-0.61—0.04 (-16.8—1.1%)
	MAE (mm)	0.83 (22.8%)	0.91—1.14 (25.0—31.3%)
	RMSE (mm)	1.08 (29.7%)	1.21—1.46 (33.2—40.1%)
	r^2	0.81	0.68—0.77

Growing Season	**Statistic**	**Ensemble**	**Model Range**
38 sites N = 151 seasons Mean closed ET is 609 (mm)	**Slope**	1	0.88—1.13
	MBE (mm)	-10.1 (1.7%)	-78.61—47.37 (-12.9—7.8%)
	MAE (mm)	80.25 (13.2%)	91.18—111.8 (15.0—18.4%)
	RMSE (mm)	92.72 (15.2%)	108.7—134.31 (17.8—22.1%)
	r^2	0.88	0.77—0.86

Conclusions

- Comparisons were made between ET estimates from about ~142 eddy covariance flux towers and OpenET remote sensing models

- Flux tower ET underwent thorough and reproducible QA/QC and energy balance closure corrections

- Grouped statistics show good model performance in agricultural settings from all models but there is room for improvement; the intercomparison has already led to model improvements

- Model agreement with ground measurements was poorest in arid regions of native shrublands and grasslands

- Future model evaluations will aim to increase ground-based data coverage

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