WaterSciCon24
Catalyzing Collaborations • St. Paul, MN • 24–27 June 2024

Workshop 105 – Ballroom E

June 2024

Retrieval and Application of On Demand Global Field-scale Actual Evapotranspiration Data Since 1982

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Overview of Remote Sensing Evapotranspiration

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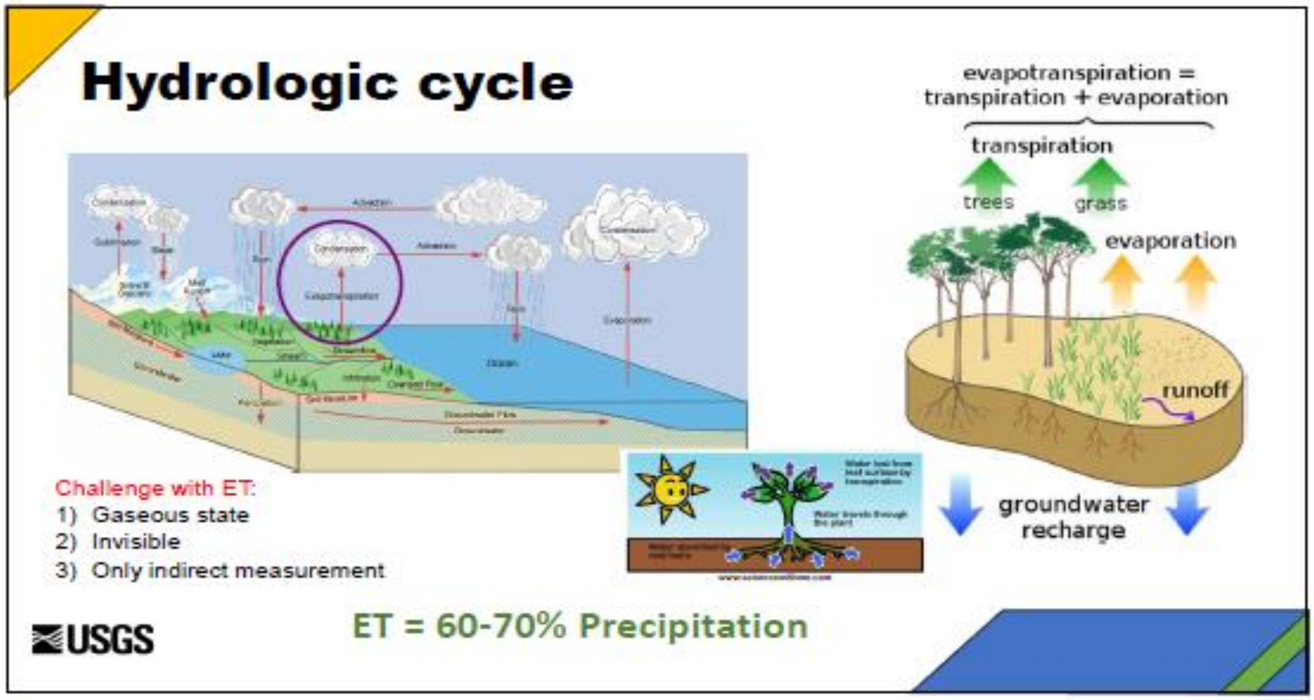
Work performed under USGS Contract 140G0124D0001.

Overview of Remote Sensing Evapotranspiration



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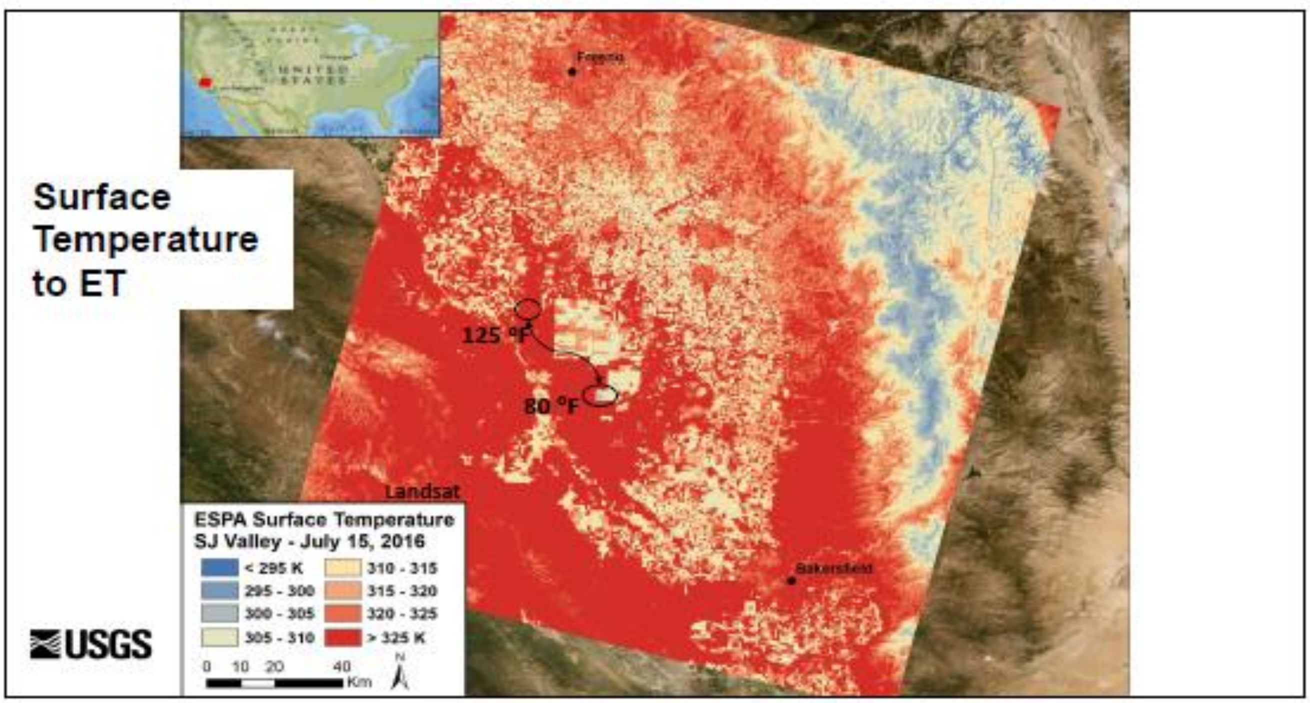

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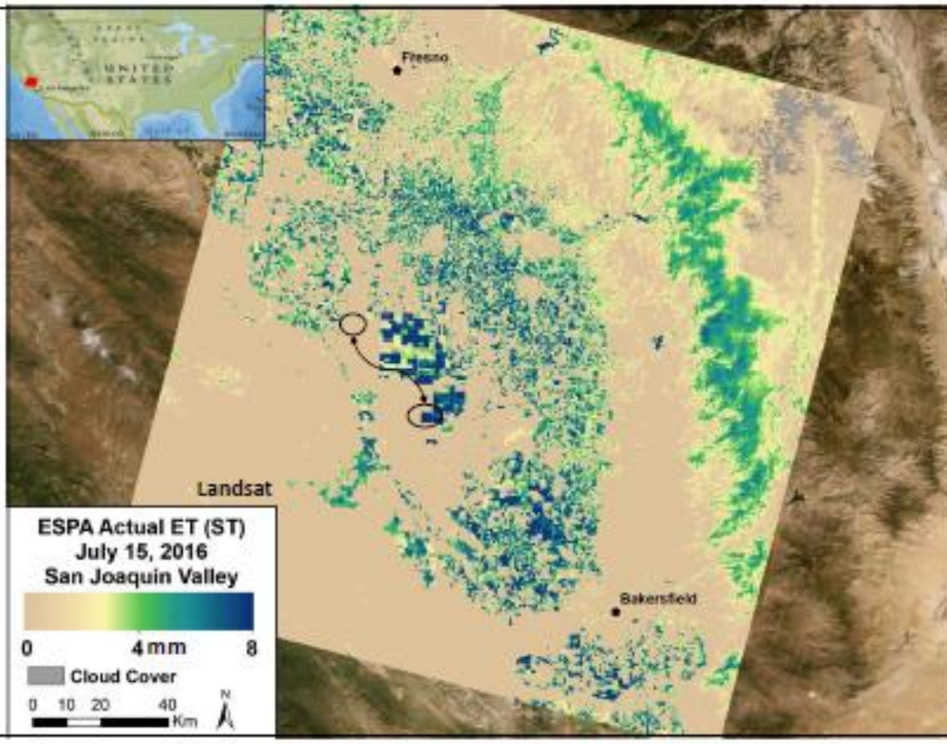

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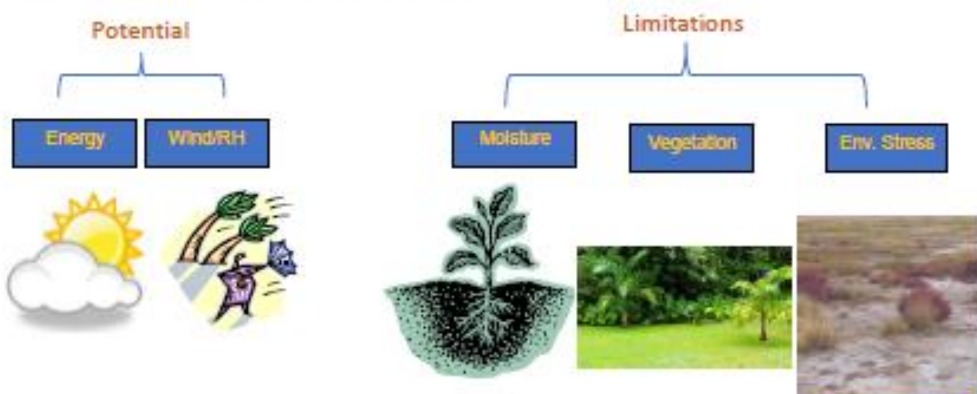
ET Estimation in Agriculture...

- It is a RESPONSE variable as opposed to precipitation (driver)
- It -reflects the integrated effects of energy/aerodynamics, soil moisture, vegetation, and environmental stress



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Challenge: ET under potential vs water limiting conditions

- Landscape is at different levels of stress; thus,
  actual ET is <= potential

- Allen et al. (1998)
  - **ET = Ks * Kc * ETo**
    - Kc = type and stage of crop (~0.15 – 1.2)
    - Ks = soil moisture stress factor (0 to 1.0)

(This requires knowledge of crop types, stage and moisture distribution.)

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More direct estimation of stress using remote sensing approaches…

Land surface temperature (LST) derived from remotely sensed imagery can be used to estimate the combined effects of soil moisture and environmental stress factors on vegetation.

ET = ETf * ETo

Ks * Kc

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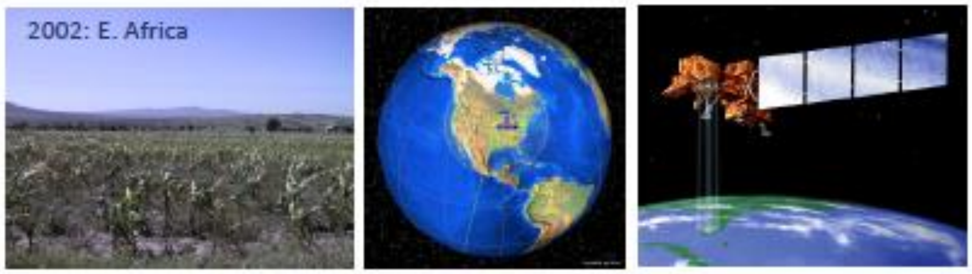
Satellite data: The Great Equalizer!



Global Monitoring using Satellite Data and Evapotranspiration Modeling

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Role of Remote Sensing: Input Data

- Land Surface Temperature (Energy Balance Method)
  - Landsat (~100m)
  - MODIS/VIIRS (1km)
  - AVHRR (1km)
  - GOES (10km)
- Precipitation Estimate (Water Balance Method)
  - NOAA NEXRAD (5km): US
  - METEOSAT RFE/CHIRPS (10km): Global
  - NASA TRMM, IMERG (25km), etc.: Global

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Several Approaches…

- Soil Moisture Modeling
  - Land Surface Models such as Noah, SWAT, VIC…
- Vegetation Index based
  - NDVI/LAI-based: MOD16, P-M, P-T
- Mixed Approach
  - NDVI-LST (Trapezoid, Triangle…)
- Surface Energy Balance
  - SEBAL/METRIC, SEBS, Two-Source, ALEXI, S-SEBI, SSEBop…

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SSEBop Evapotranspiration

Background and Principles: "Satellite Psychrometry"

Psychrometry: the science of measuring the water-vapor content of the air.

Rn = H + ETa + G
ETa = Rn – H – G
ETa = Rn – H; G ~ 0 at daily time step

ETa = ETf * ETo/ETr

$$ETa = ETo - \gamma^{s}(Ts - Tc)ETo$$

Rn = net radiation
H = sensible heat
G = ground heat flux
ETa = actual ET
ETo (ETr) = reference ET (maximum)
ETf = ET Fraction (0-1.0)
Ts = Land Surface Temperature (LST)
Tc = wet reference boundary; f(Ts, γ^s, NDVI)
γ^s = surface psychrometric constant; f(Rn, air density)

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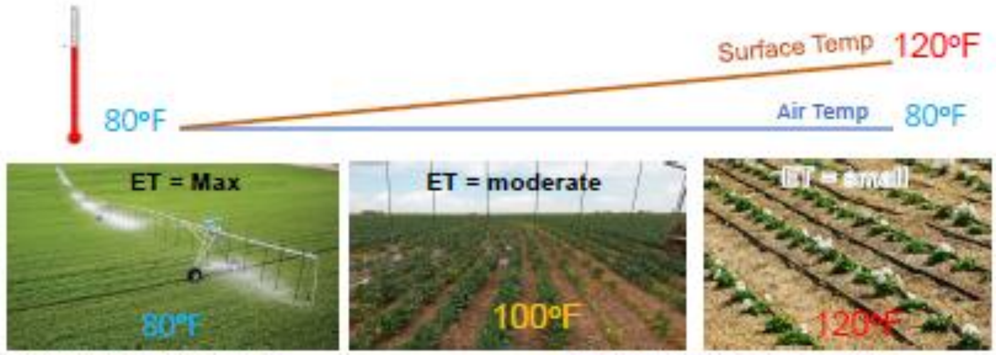
SSEBop: ET Fraction

- Land surface temperature differences are used to measure landscape water use rates through the effect of evaporative cooling



http://www.croplife.com/equipment/ https://www.irrigationaustralia.com.au/

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$$ETf = 1 - \gamma^{s}(Ts - Tc)$$

Air vs. Satellite Psychrometry

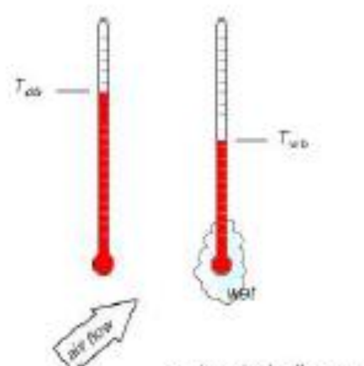
$$ETa = ETo - \gamma^{s}(Ts - Tc)ETo$$

Satellite Psychrometry

$$ea = es - \gamma\ (Td - Tw)$$

$$\gamma = \frac{CpP}{\varepsilon\lambda} = 0.665 * 10^{-3} P$$

Air Psychrometry



engineeringtoolbox.com

ea = actual vapor pressure (kPa)
es = saturated vapor pressure (kPa) at Tw
Td: dry bulb (ambient) air temp, $°C^{-1}$
Tw: wet bulb air temp, $°C^{-1}$
γ = psychrometric constant [kPa $°C^{-1}$]
P = atmospheric pressure [kPa]
λ = latent heat of vaporization, 2.45 [MJ kg^{-1}]
c_p = specific heat of air at constant pressure, 1.013 10^{-3} [MJ kg^{-1} $°C^{-1}$]
ε ratio = molecular weight of water vapor/dry air = 0.622

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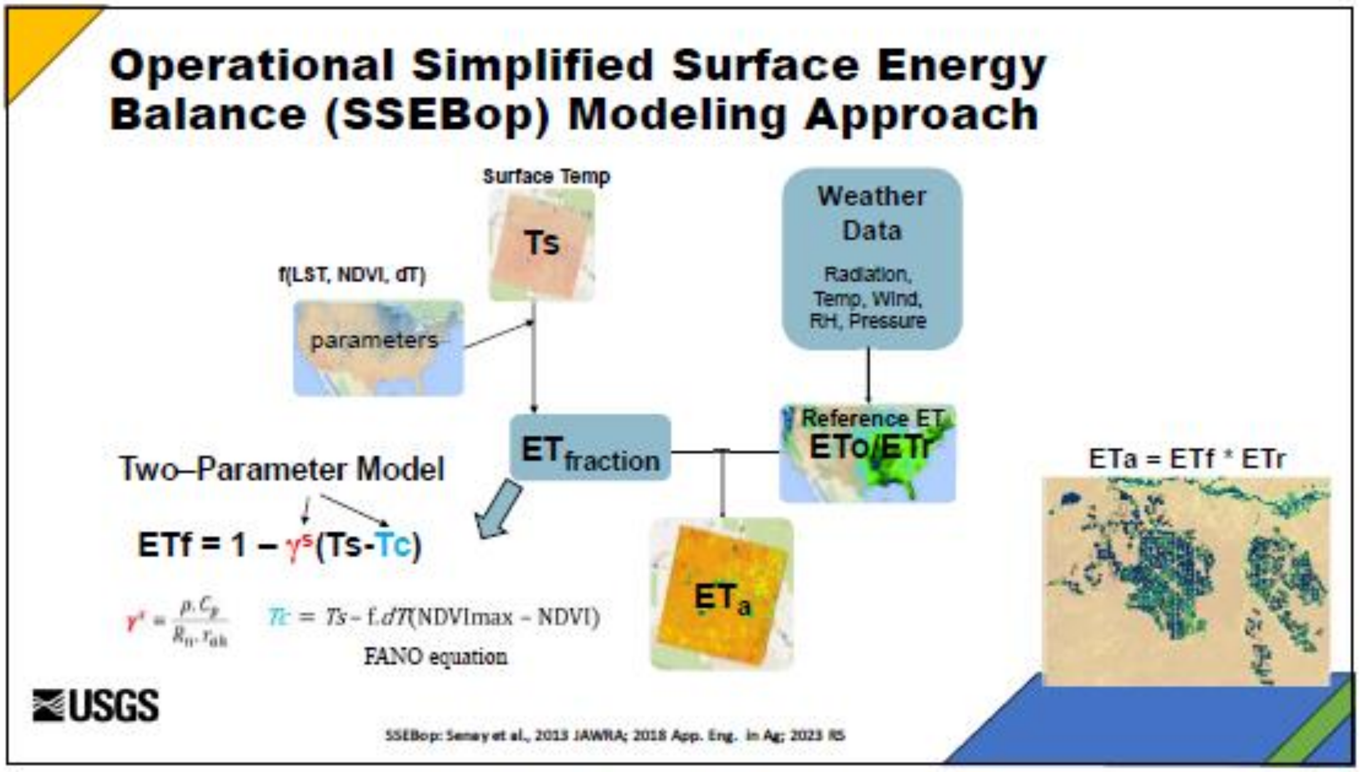
Ferrel, W.M. (1886); Allen et al. (1998)


Operational Simplified Surface Energy Balance (SSEBop) Modeling Approach
Surface Temp
Ts
f(LST, NDVI, dT)
parameters
Weather Data
Radiation, Temp, Wind, RH, Pressure
Reference ET
ETo/ETr
ETfraction
Two–Parameter Model
ETf = 1 – γˢ(Ts-Tc)
Tc = Ts – f.dT(NDVImax – NDVI)
FANO equation
ETa
ETa = ETf * ETr
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SSEBop: Senay et al., 2013 JAWRA; 2018 App. Eng. in Ag; 2023 RS

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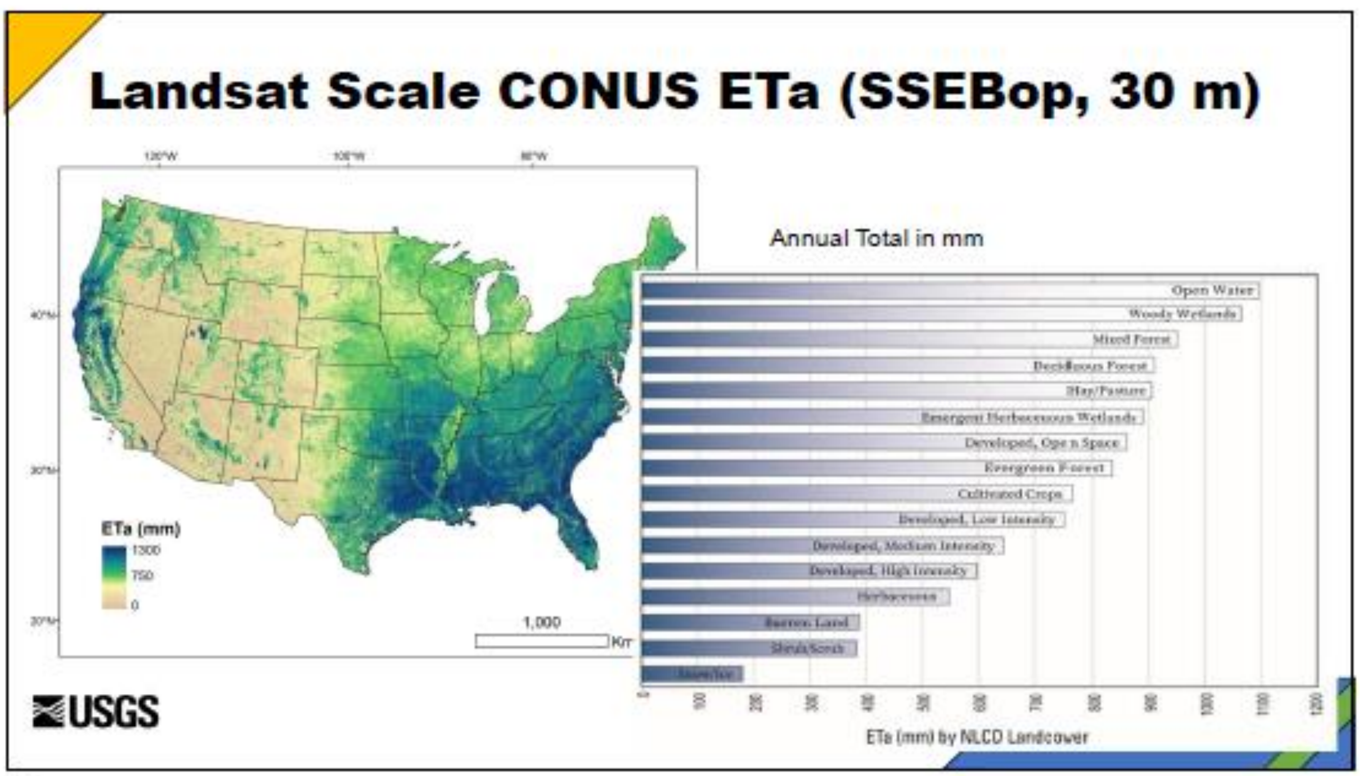
Landsat Scale CONUS ETa (SSEBop, 30 m)
ETa (mm)
1300
750
0
1,000
Km
Annual Total in mm
Open Water
Woody Wetlands
Mixed Forest
Deciduous Forest
Hay/Pasture
Emergent Herbaceous Wetlands
Developed, Open Space
Evergreen Forest
Cultivated Crops
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Herbaceous
Barren Land
Shrub/Scrub
Snow/Ice
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
ETa (mm) by NLCD Landcover
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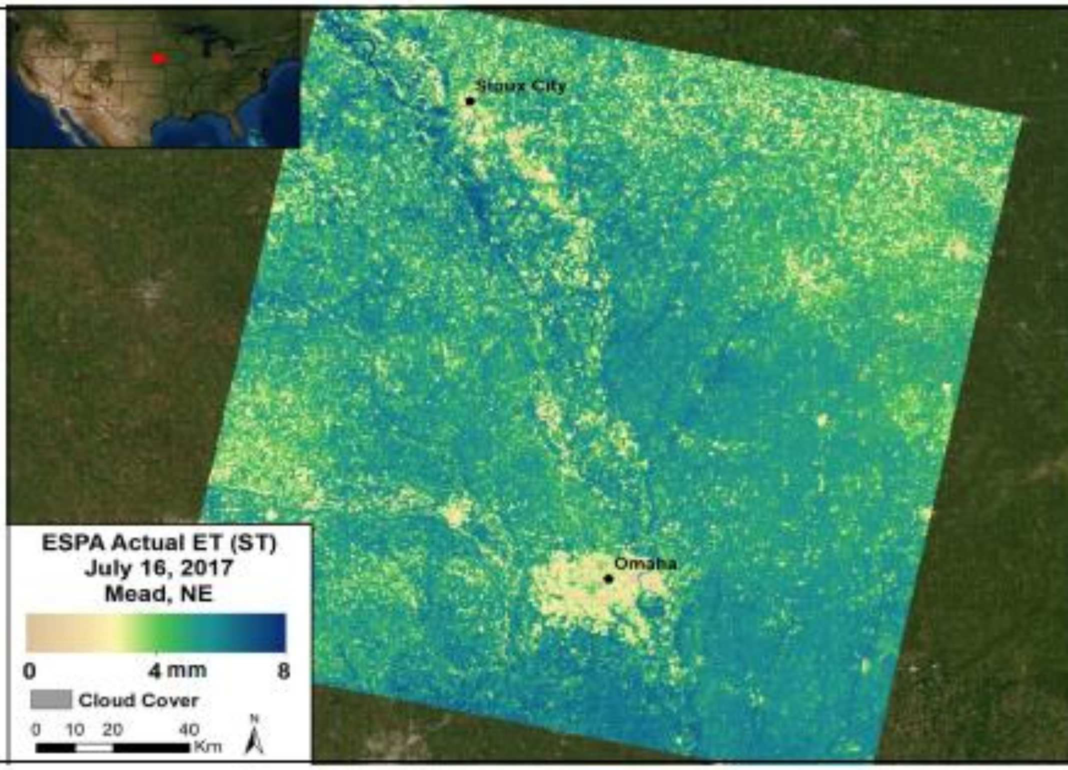
ESPA-based
SSEBop ETa
July 16, 2017



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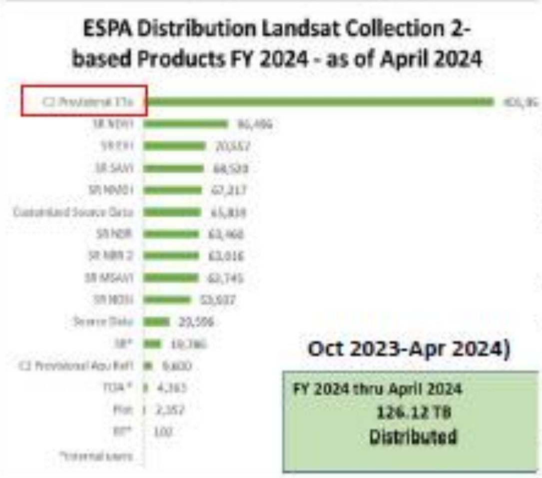
ESPA ET download stats vary by month…



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Model Performance Evaluation…

- Visual, qualitative spatial patterns
- EC (Eddy covariance) Flux Tower
- Basin Water Budget

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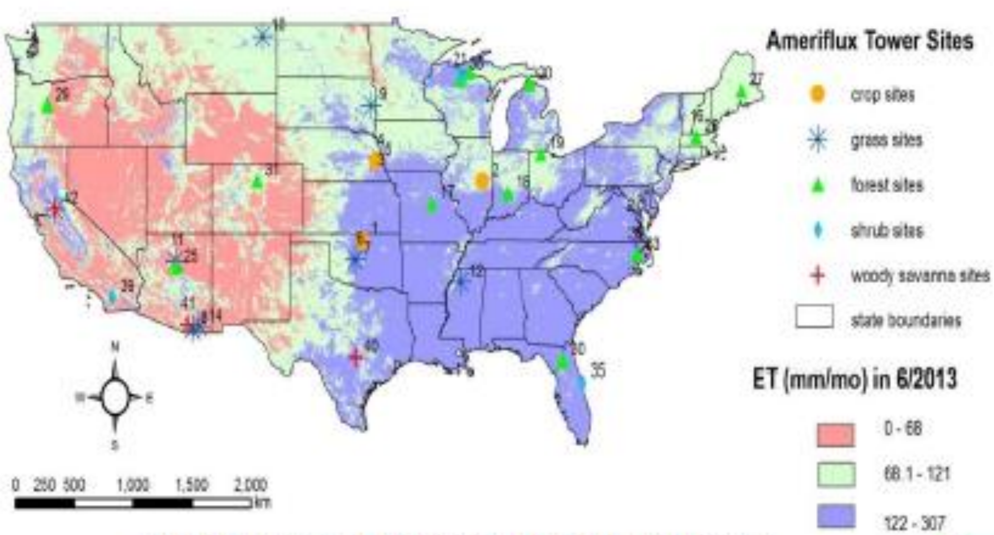
Validation with EC Flux Towers



42 Ameriflux tower stations (2001-2007) with five land cover types—crop, grass, forest, shrub and woody savanna. The background color represents the ET range for June 2013.

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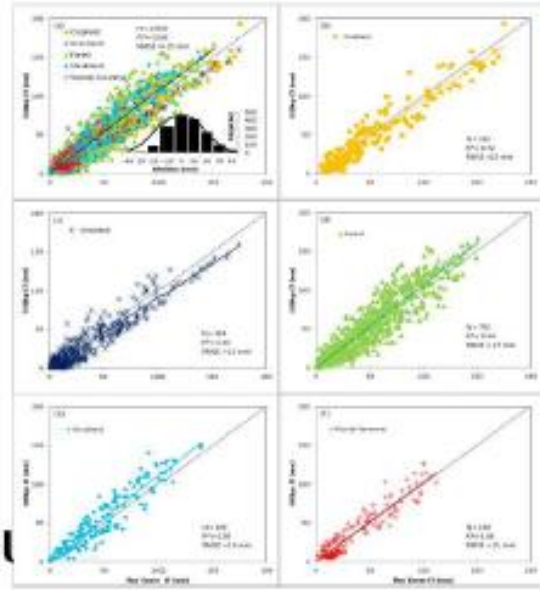
Model validation with EC Flux Towers by cover type



MODIS-based

Comparison scatterplot between monthly ET (mm month^{-1}) from the SSEBop and the ET measurements by eddy covariance method across 42 Ameriflux tower sites during 2001 - 2007.

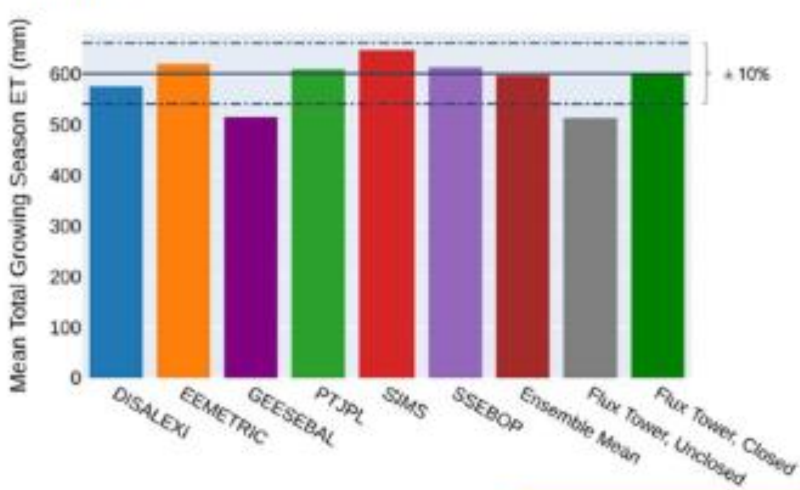
Overall model uncertainty is around 20% for monthly.

Chen et al., 2016 Journal of Hydrology

OpenET Phase I : Model Intercomparison

15 EC Flux Towers over Croplands

Total growing season weighted mean ET (n = 15 sites with 40 total growing seasons) for 6 satellite-driven ET models, the ensemble mean ET, and ET calculated from the closed and unclosed energy balances at each flux tower site.



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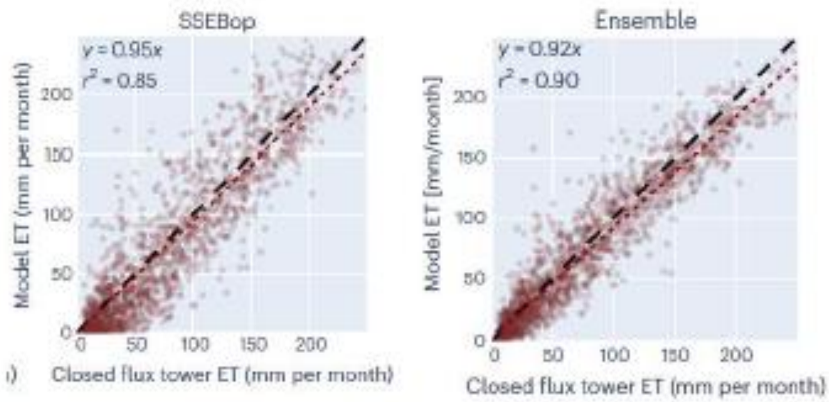
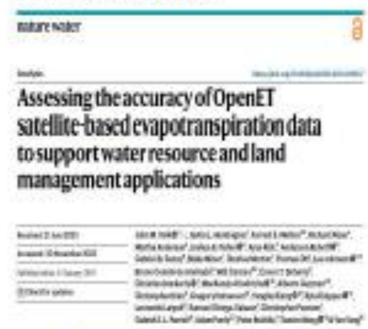
OpenET Phase II : SSEBop Evaluation with 53 Cropland EC Sites in CONUS



Volk et al., 2024. Nature Water.



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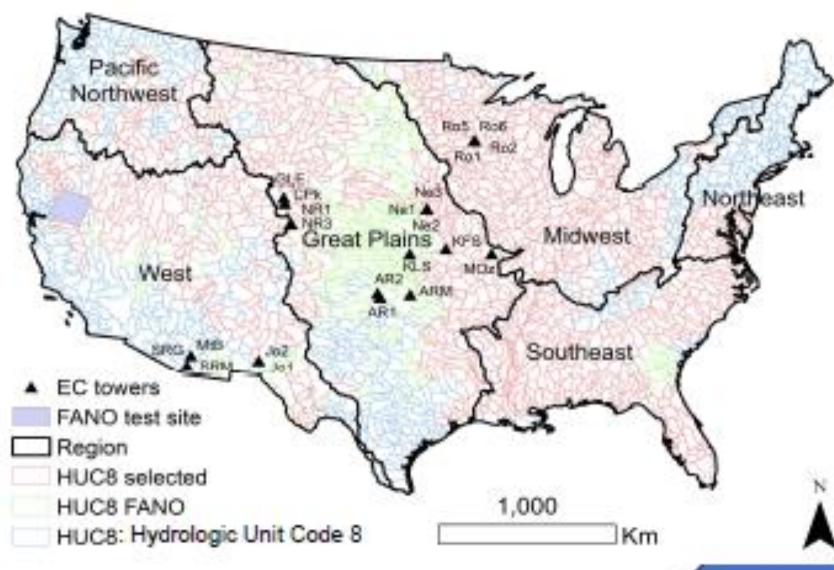
Water Balance ET Evaluation (HUC-8 Basins) grouped by 6 Regions



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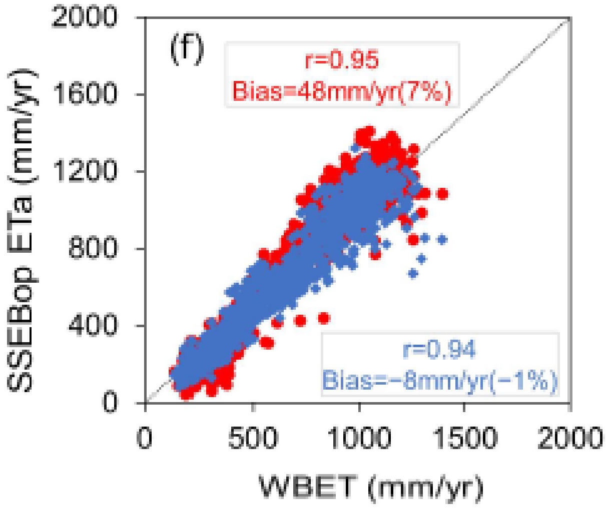
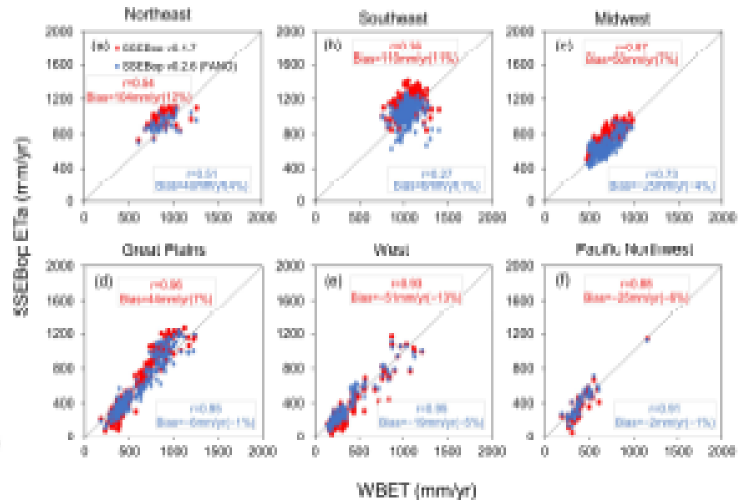
Water Balance ET Evaluation (continued)





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Summary

- (Provisional) Landsat ETa is useful for field-scale water use mapping and historical (1982-present) analysis.
- Bias Correction: one-time bias correction using locally available observed data (water balance, EC flux tower) will improve the absolute accuracy.
- Operational global SSEBop ET is being generated using thermal imagery (MODIS/VIIRS/Landsat) and gridded weather datasets.

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