Estimating evapotranspiration from weather station data

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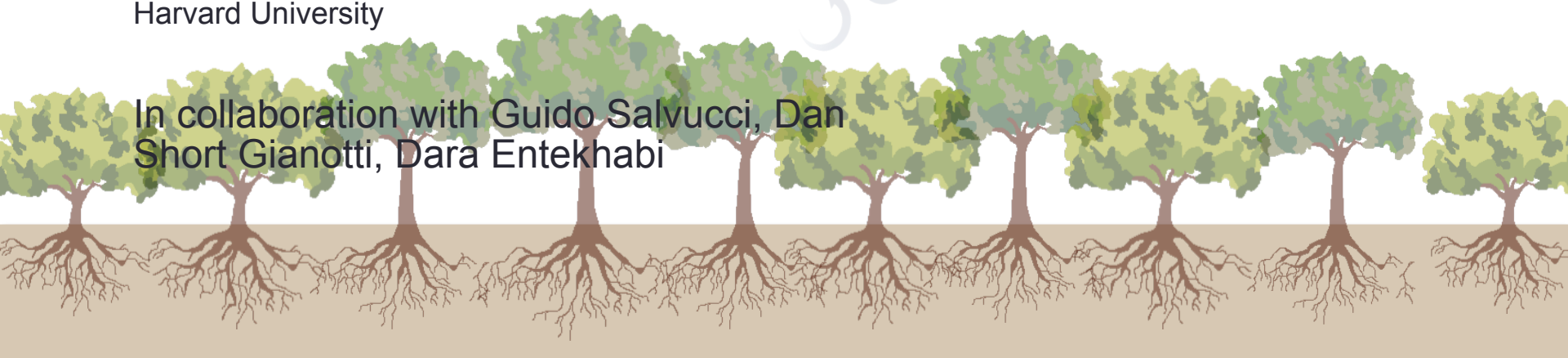
In collaboration with Guido Salvucci, Dan Short Gianotti, Dara Entekhabi



Presentation outline

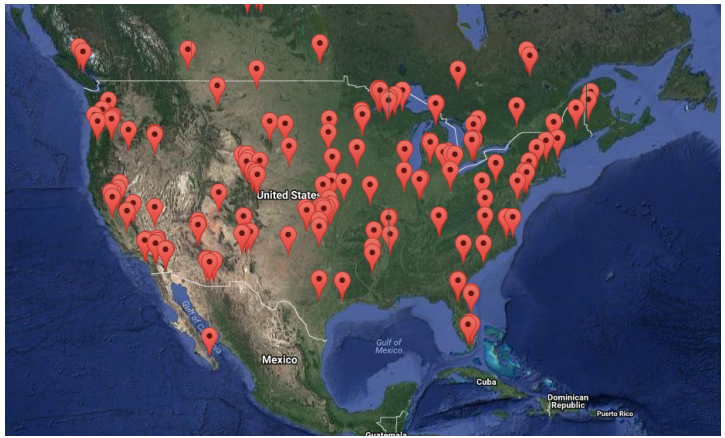
1. Evapotranspiration (ET) modeling framework

2. Utilizing data from AmeriFlux to parameterize and calibrate model sub-components and evaluate model output

3. Applications across the CONUS:
   - Comparing with water balance
   - Detecting and attributing trends
   - Partitioning ET to source components

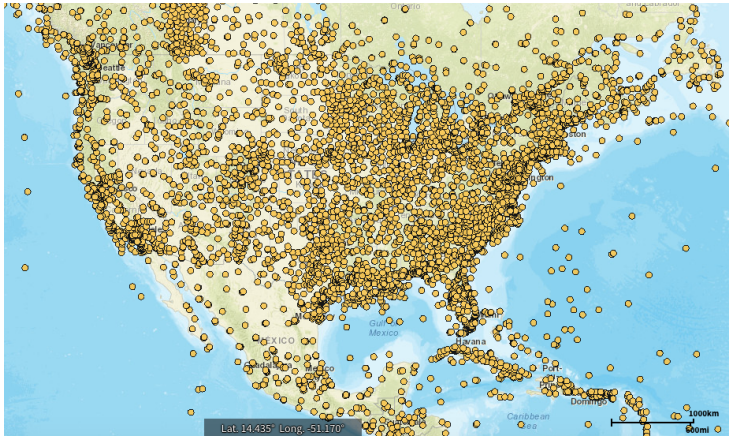
Primary goal: build a model to estimate ET from data collected at common weather stations

Eddy covariance sites
1991 (earliest) – present



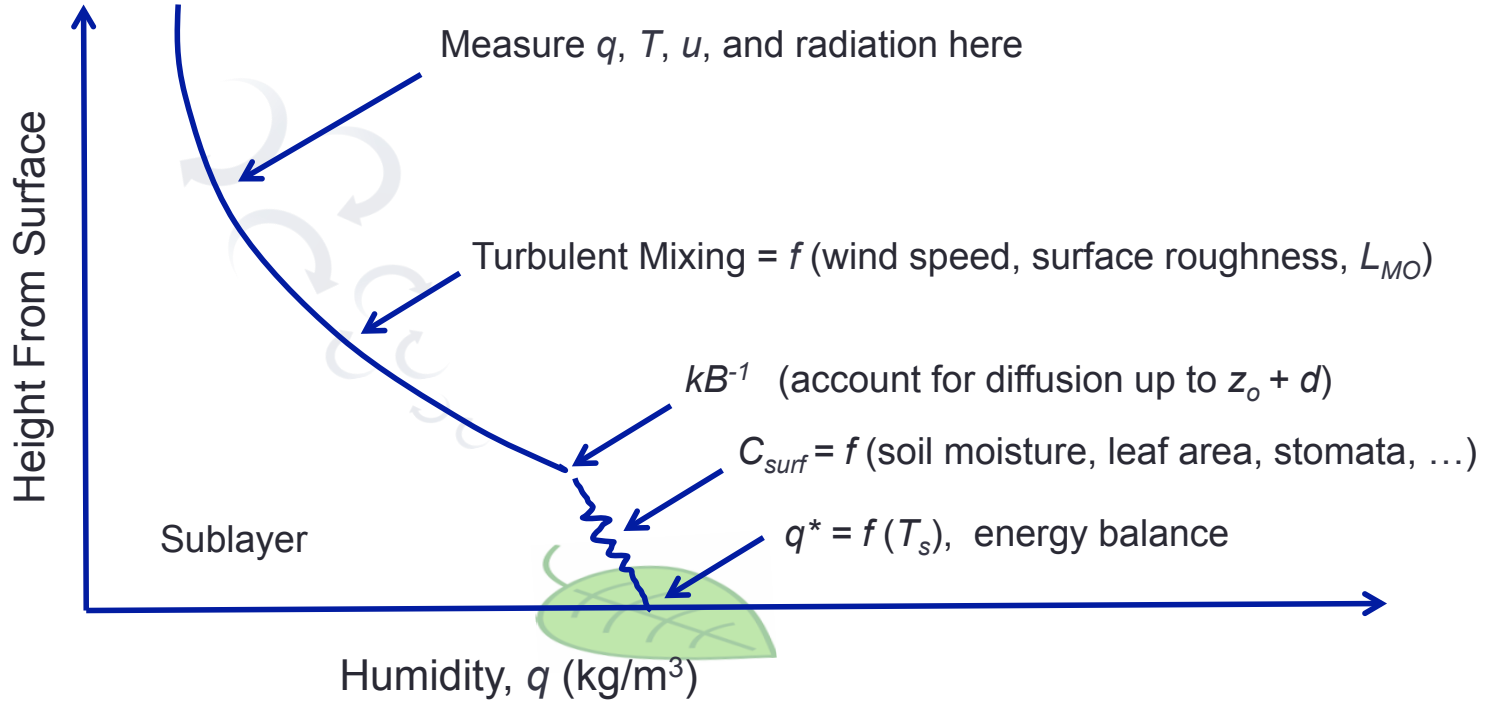
https://ameriflux.lbl.gov/sites/site-list-and-pages/

Weather station sites
Some in operation for >100 years



https://gis.ncdc.noaa.gov/maps/ncei/cdo/hourly

Modeling ET: rate-limited by mixing, energy supply, or surface state



Leverage relationship between temperature, humidity, and evapotranspiration

- ET is controlled by q and T in the boundary layer and land/canopy surface
- Traditional approach (e.g. Penman-Monteith) requires complex and calibrated parameterizations to account for the status of the land surface
- Since turbulent fluxes that balance radiative forcing in turn modify q and T in boundary layer, if the land and atmosphere are tightly coupled, we can reasonably expect relations between ET, q, and T….
- Instead of thinking of q and T as “drivers”, think of them as responses
- Use vertical profile of relative humidity as indicator of equilibrium

Approach: use vertical profiles of relative humidity to estimate a daily surface conductance

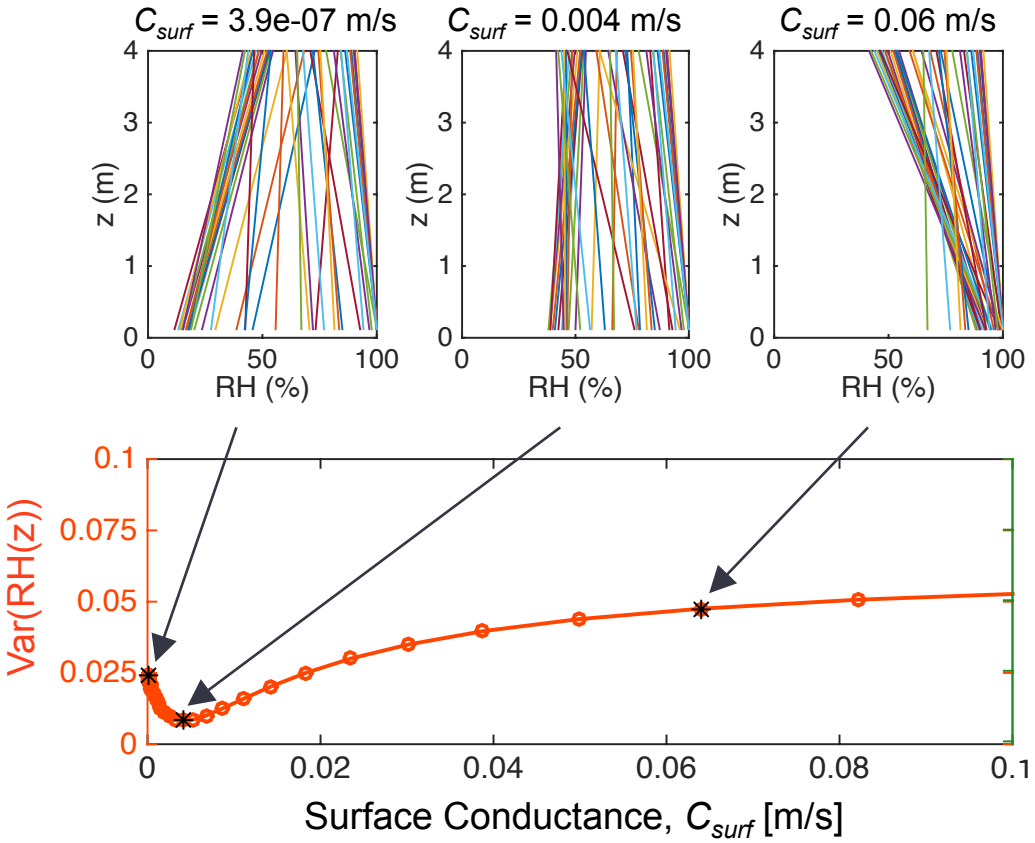
"ETRHEQ method"

Evapo**t**ranspiration from **R**elative **H**umidity in **Eq**uilibrium

Applying the method for one day at one site

STEP 1. Calculate vertical relative humidity (RH) profiles from the surface to z_m for a range of C_{surf} values

STEP 2. Average the vertical variance of RH, Var(RH(z)), for each C_{surf} value



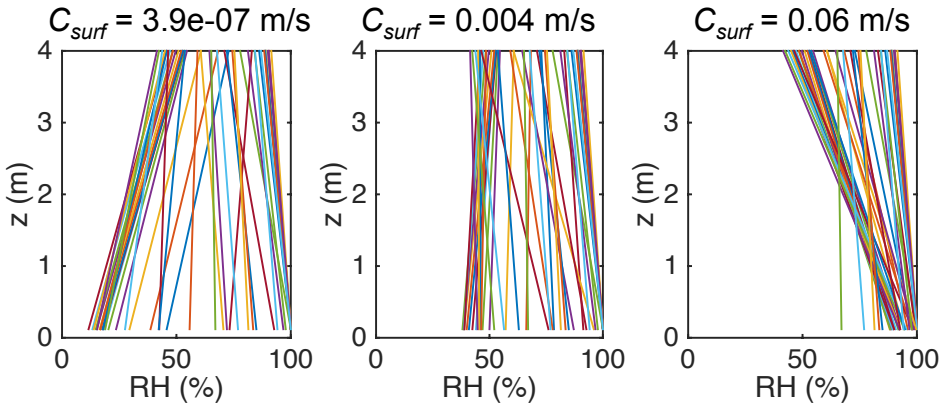
Note: Each colored line is one half hour profile during the day

Value of C_{surf} reflected in relative humidity profile

STEP 1. Calculate vertical relative humidity (RH) profiles from the surface to z_m for a range of C_{surf} values

STEP 2. Average the vertical variance of RH, Var(RH(z)), for each C_{surf} value

STEP 3. Hypothesis: the ET associated with the minimum Var(RH(z)) represents reality



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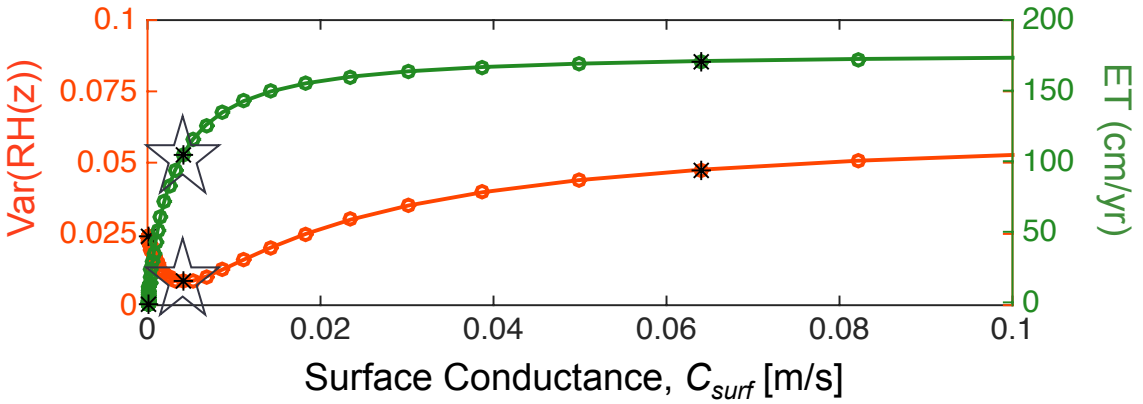


ETHEQ inputs and sub-models

- Meteorological inputs:
  - (1) temperature
  - (2) specific humidity
  - (3) wind speed
  - (4) pressure

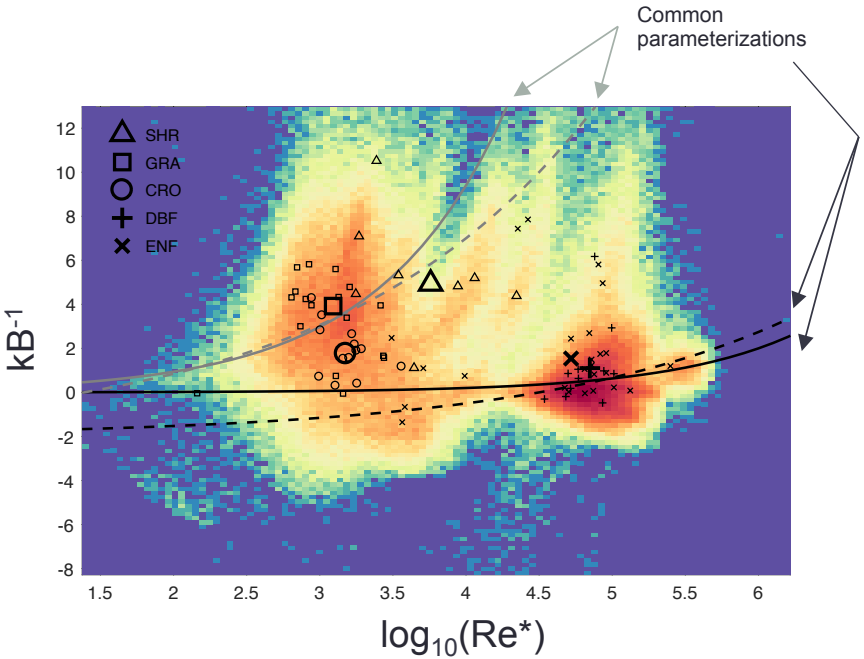
  } measured at weather stations

- Energy balance & roughness inputs:
  - Net solar radiation → reanalysis data
  - Incoming long wave → *f* (air temp, humidity, elevation)
  - Outgoing long wave → Stefan-Boltzmann (emissivity = 0.98)
  - Ground heat flux → Estimated from air temp using diffusion equation (thermal inertia of soil = 1300 $Jm^{-2}s^{-1/2}K^{-1}$)
  - Surface roughness → *f* (vegetation height)

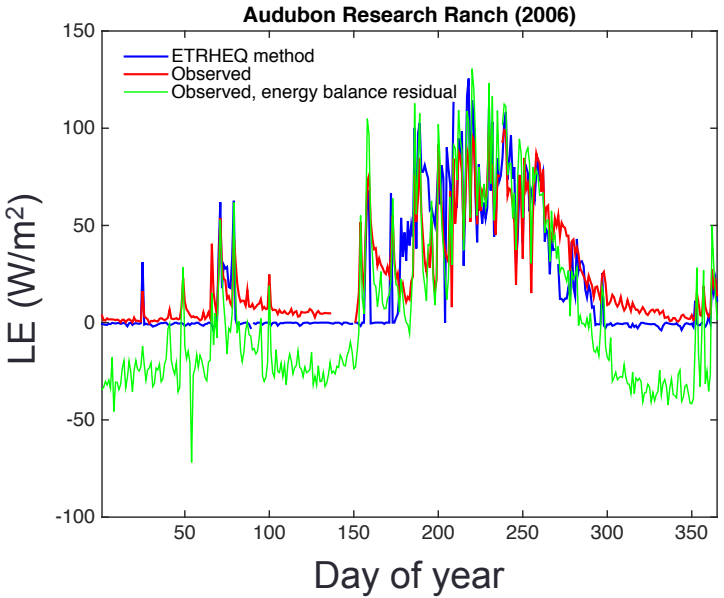
Determined global parameterization and calibration using AmeriFlux data

Parameterizing roughness lengths

- To calculate profiles of T and q, we need to estimate thermal roughness length
- No universal scaling and parameterization have been agreed upon
- We explored the diurnal and annual relationship between thermal roughness length (via kB^{-1}) and friction velocity using data from ~70 AmeriFlux sites
- Ultimately, in ETRHEQ: used constant kB^{-1} dependent on land cover type

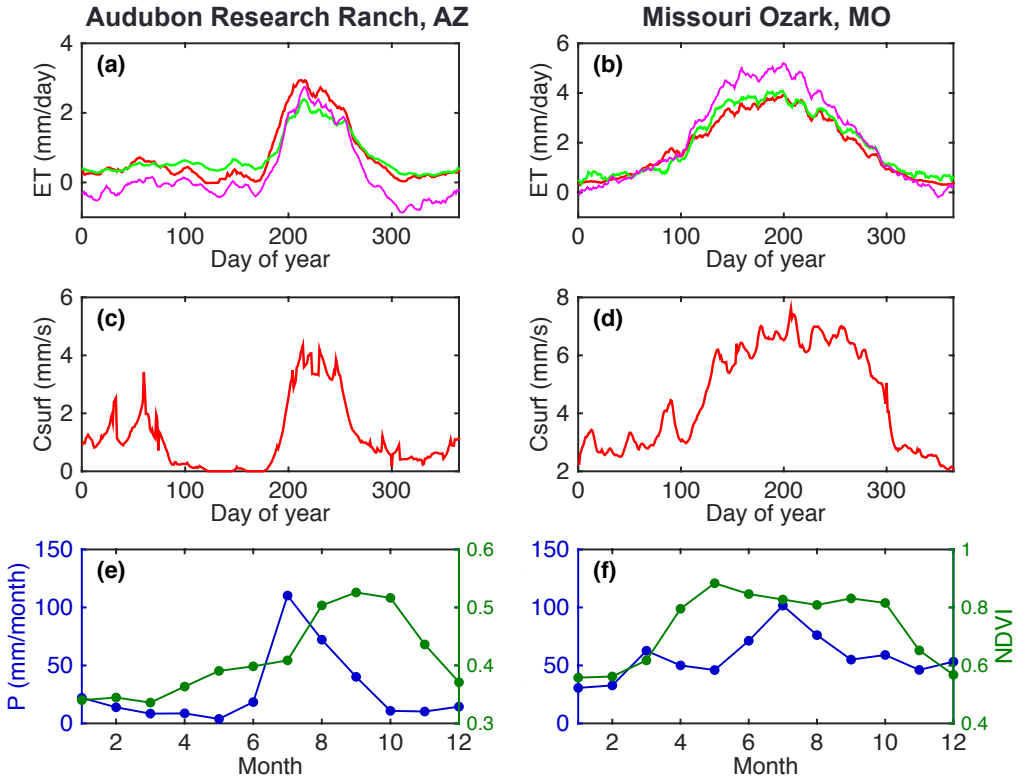


Example Matlab code on Github: https://github.com/AngelaRigden/ETRHEQ



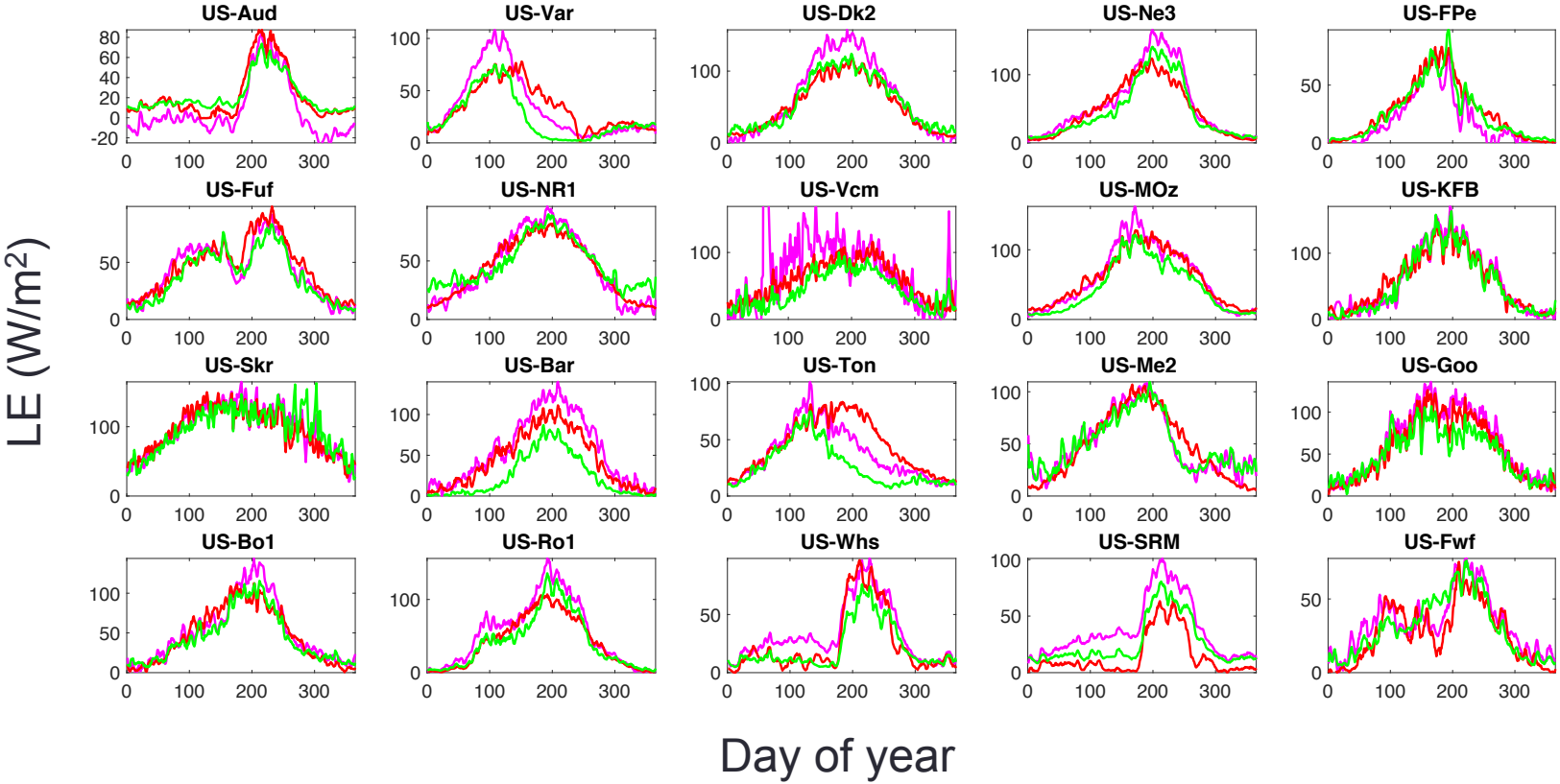
ETRHEQ evaluation: seasonal climatology

ETRHEQ ET
Measured ET
Energy balance residual ET (=Rn – SH – G)

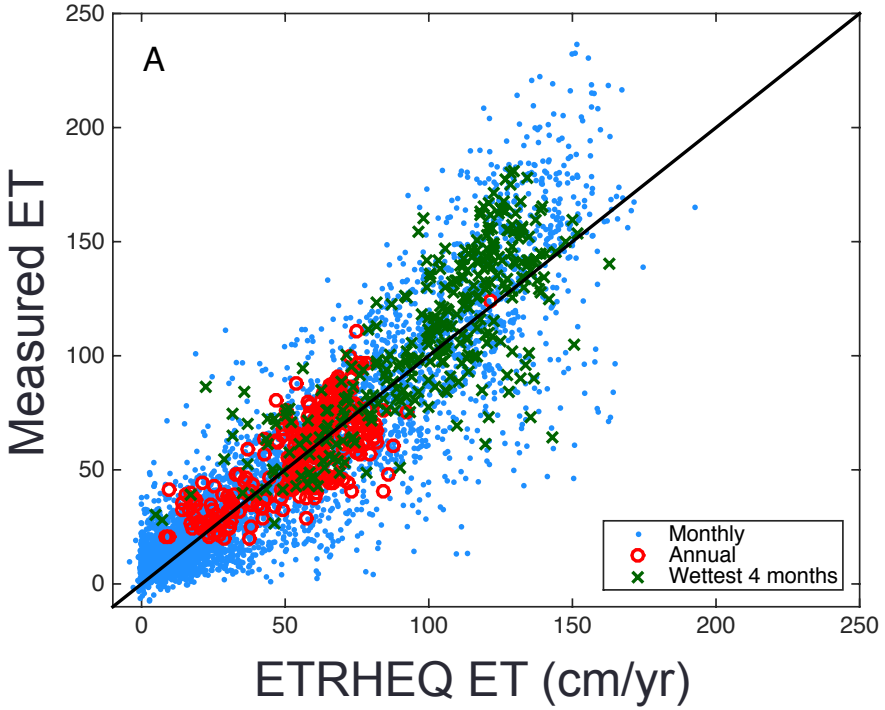


More seasonal climatology …

ETRHEQ ET
Measured ET
Energy balance residual ET



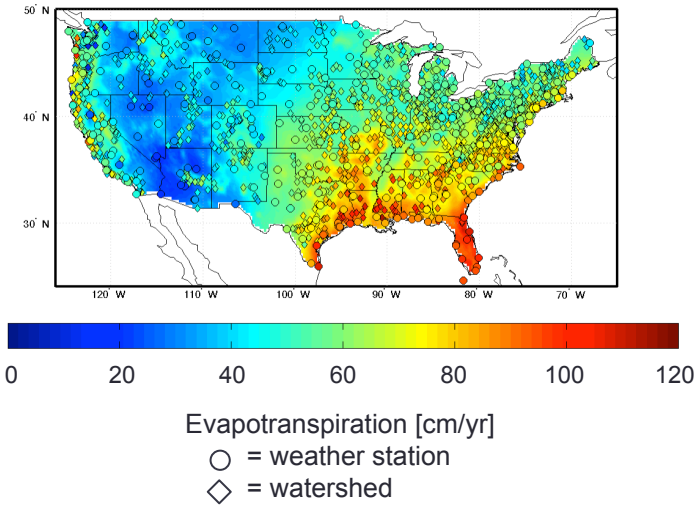
Tested at 62 AmeriFlux sites



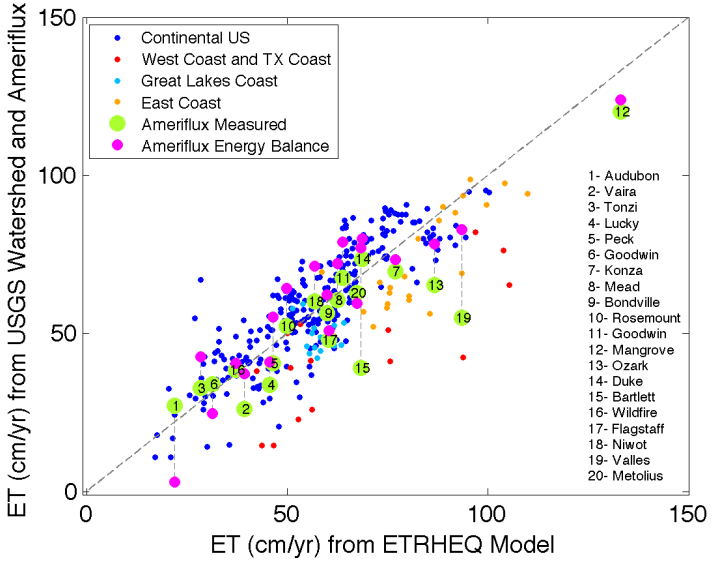
Monthly
Annual
Wettest 4 month

Annual climatology, with water balance ET

- Applied ETRHEQ at 305 weather stations over the CONUS from 1961 to 2014
- Evaluated climatological annual ET using USGS watershed data from 1168 watersheds
  [Sanford & Selnick, 2013]

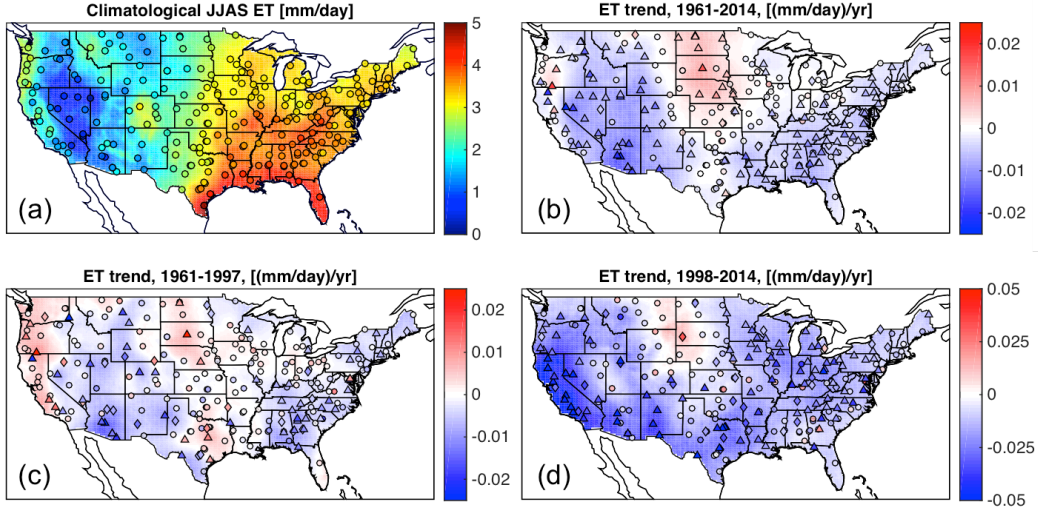


- ETRHEQ annual climatology agrees well with both eddy covariance data from AmeriFlux and watershed ET

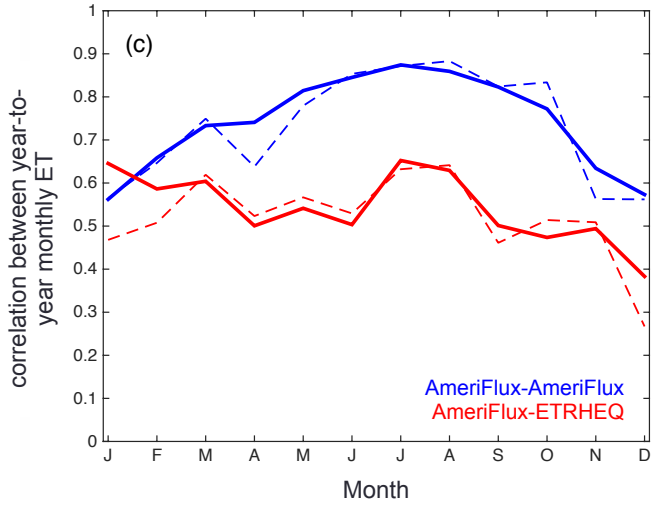


Trend detection and attribution

- Detected and attributed trends in ET at 236 (non-coastal) weather stations from 1961 to 2014 during the summertime (JJAS)
- Declines in ET → Declines C_{surf}



- Evaluated the ability of ETRHEQ to capture interannual variability using data from 62 AmeriFlux sites



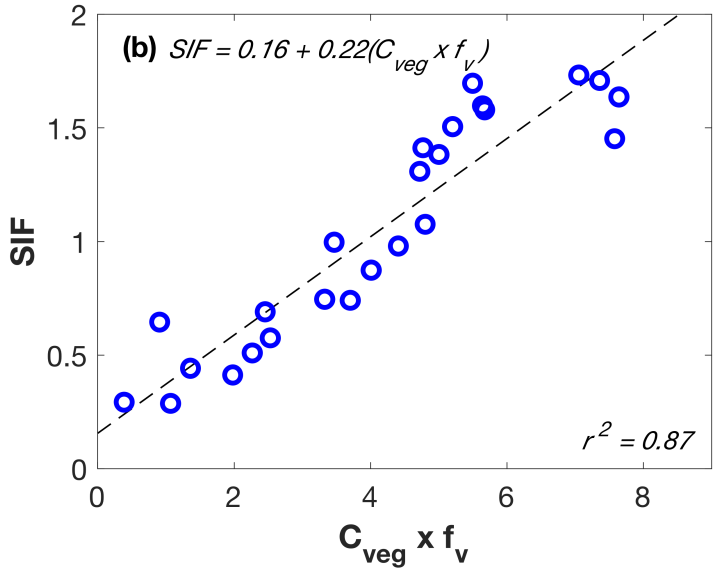
[*Rigden, Salvucci, Gianotti, & Entekhabi*, 2018, GRL]

Partitioning evapotranspiration

- Partitioned ETRHEQ inferred evapotranspiration into soil and vegetation components using satellite retrieved soil moisture (θ) from SMAP, an optimization model, and the following assumptions:

$$C_{surf} = f_v C_{veg}(\theta, VPD) + (1 - f_v) \times C_{soil}(\theta)$$

$$\frac{T}{ET} = \frac{f_v C_{veg}}{C_{surf}}$$



C_{surf} : surface conductance
C_{veg} : canopy conductance = *f(VPD,θ)*
C_{soil} : soil conductance = *f(θ)*
f_v : vegetation fraction
T/ET: fraction of evapotranspiration that is transpiration

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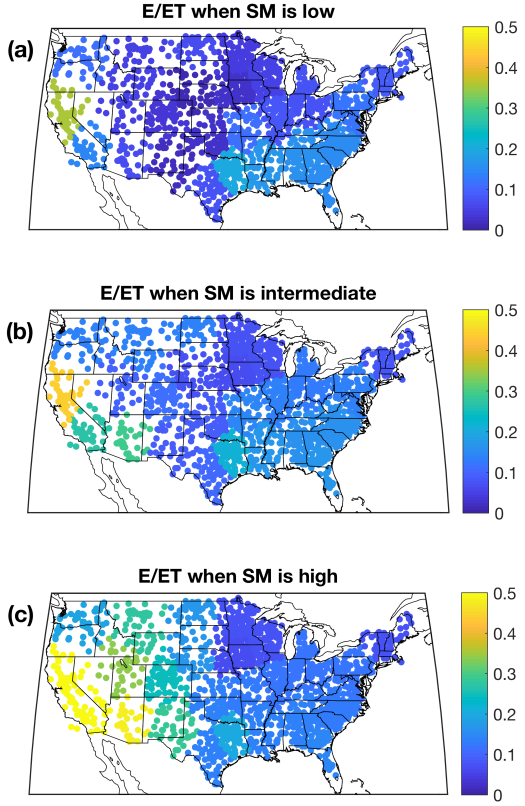

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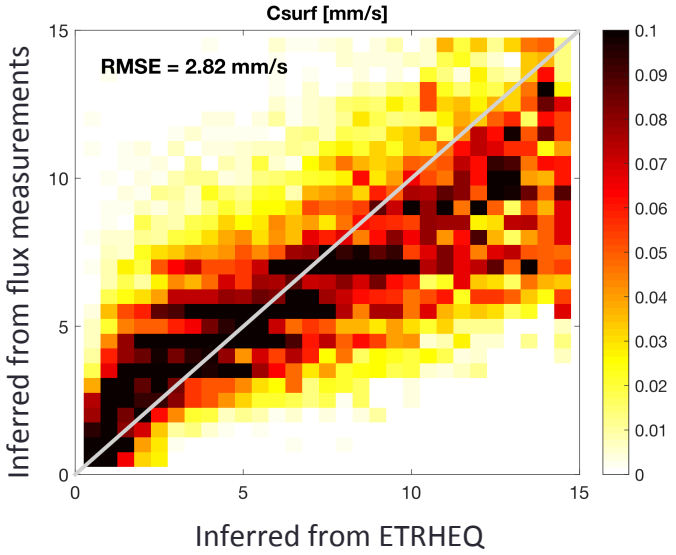
- Evaluated the ability of ETRHEQ to capture daily daytime C_{surf} using data from 48 AmeriFlux sites:



Summary

- ETRHEQ model works well across energy and water limitations, climates, and plant functional types
- So far we have utilized ETRHEQ to study trends and evapotranspiration partitioning across CONUS
- Exploration, model development, and model evaluation has been 100% enabled by flux observations– thank you!

Thanks! Questions?