An index of maximal land-atmosphere coupling and its use in estimating evaporative fraction across a range of Ameriflux sites

Guido D. Salvucci

Boston University Department of Earth and Environment

Pierre Gentine

Columbia University Department of Earth and Environmental Engineering

Background & Assumptions

- Through diffusion and energy balance, ET is controlled by the humidity (q) and temperature (T) in the surface layer, and the moisture and temperature of the surface.
- The turbulent fluxes that balance radiative forcing in turn modify q and T in boundary layer
- If tightly coupled, we can reasonably expect relations between ET, humidity, and temperature, independent of the surface

Examples

- *Prietsley-Taylor & Equilibrium Evaporation:* exploit constraints on q and T profiles due to $q^*(T)$.
- *Bouchet-Morton*: measures deviation from equilibrium conditions through heightened potential evaporation under hot and dry conditions, implying lower actual evaporation.
- These ideas have attracted Brutsaert's (and students) attention over the years in a series of papers (e.g. Brutsaert &Stricker (79), Parlange&Katul (92), Brutsaert&Parlange (98), Qualls, Crago…

Focus of Talk: Exploring Evidence for Coupling in Relative Humidity Profiles

Ameriflux Data

- In place of profile data, estimate specific humidity (q) and temperature (T) profiles from effective surface "zo+d" to measurement height using simple (neutral) log profiles in the constant flux layer (steady state assumed).

Modelling

- Represent soil moisture/vegetation controls on ET with canopy resistance (r_{can}) added to atmospheric resistance (r_{at})

Exploring RH(z,t)

METHODS

- Solve energy balance for observed radiative forcing, wind speed, T_{air} and q_{air}, and nominal roughness parameters (Z_{veg}/10; 0.7*Z_{veg}), surface emissivity, and (r_{can})
- Repeat for each half-hourly observation, for a range of r_{can}
- RESULT: Diurnal energy balance partition (LE, H, G, R_{lup}), q(z,t), T(z,t) and lots of inferred RH(z,t) profiles

Expression for RH Gradient

- For RH=q/q*:

$$\frac{\partial RH}{\partial z} = \frac{\partial}{\partial z}\left(\frac{q}{q^*(T)}\right) = -q \bullet \left(q^*\right)^{-2}\frac{\partial q^*}{\partial z} + \left(q^*\right)^{-1}\frac{\partial q}{\partial z}$$

- With chain rule and $\Delta \equiv \frac{\partial q^*}{\partial T}$:

$$\frac{\partial RH}{\partial z} = -RH \bullet \left(q^*\right)^{-1}\Delta\frac{\partial T}{\partial z} + \left(q^*\right)^{-1}\frac{\partial q}{\partial z}$$

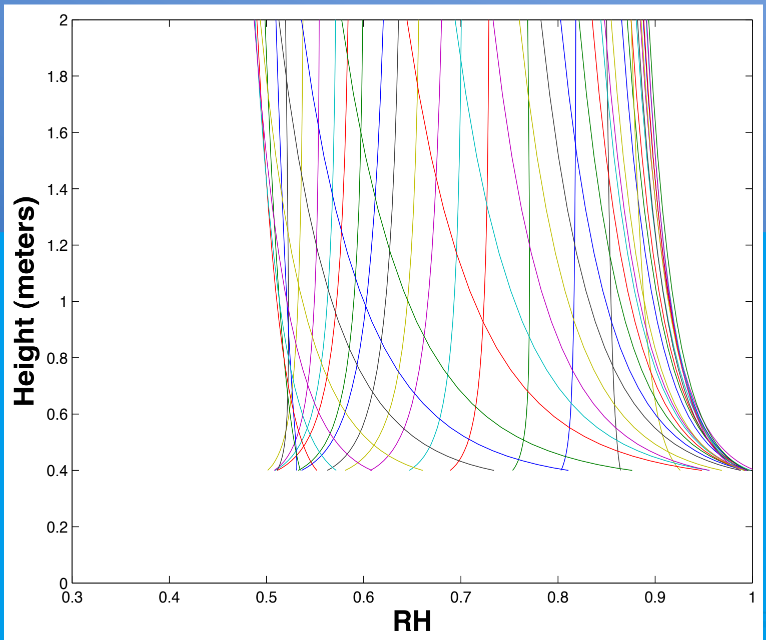
Expression for RH Gradient

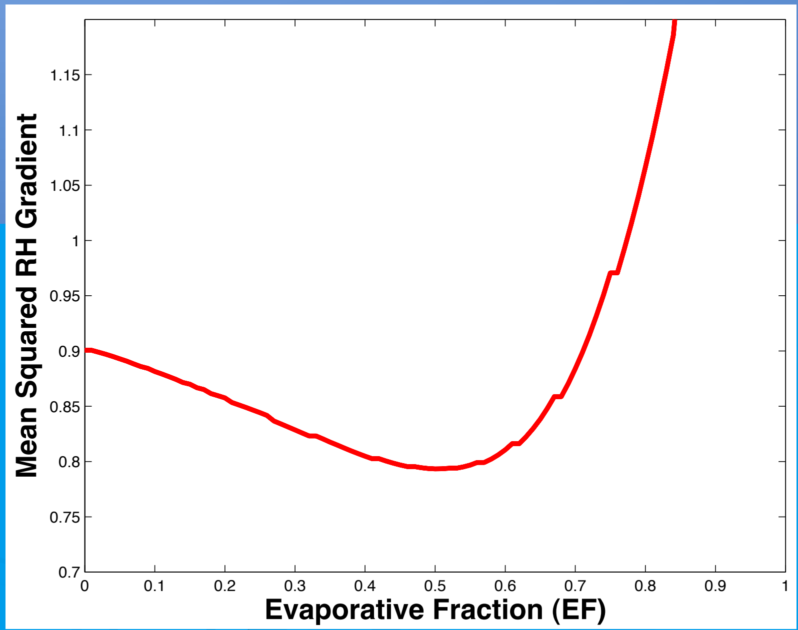
- With the Bowen ratio: $\frac{\partial q}{\partial z} = \beta^{-1} \frac{c_p}{\lambda} \frac{\partial T}{\partial z}$
- And Clausius Clayperon : $K \equiv \frac{q^*}{\Delta} = \frac{R_d \bullet T^2}{\varepsilon \lambda} \cong 16$
- And gradient flux: $H = -c_p \kappa \rho u^* \left(h - d\right) \cdot \frac{\partial T}{\partial z}$
- Yields RH grad at z=h in terms of fluxes:

$$\frac{\partial RH}{\partial z} = \frac{1}{K} \cdot \left(\frac{1}{c_p \kappa \rho u^* \left(h - d\right)} \right) \cdot \left(\left(H \cdot RH\right) - \left(\frac{c_p LE}{\lambda \Delta} \right) \right)$$

A Strange Observation

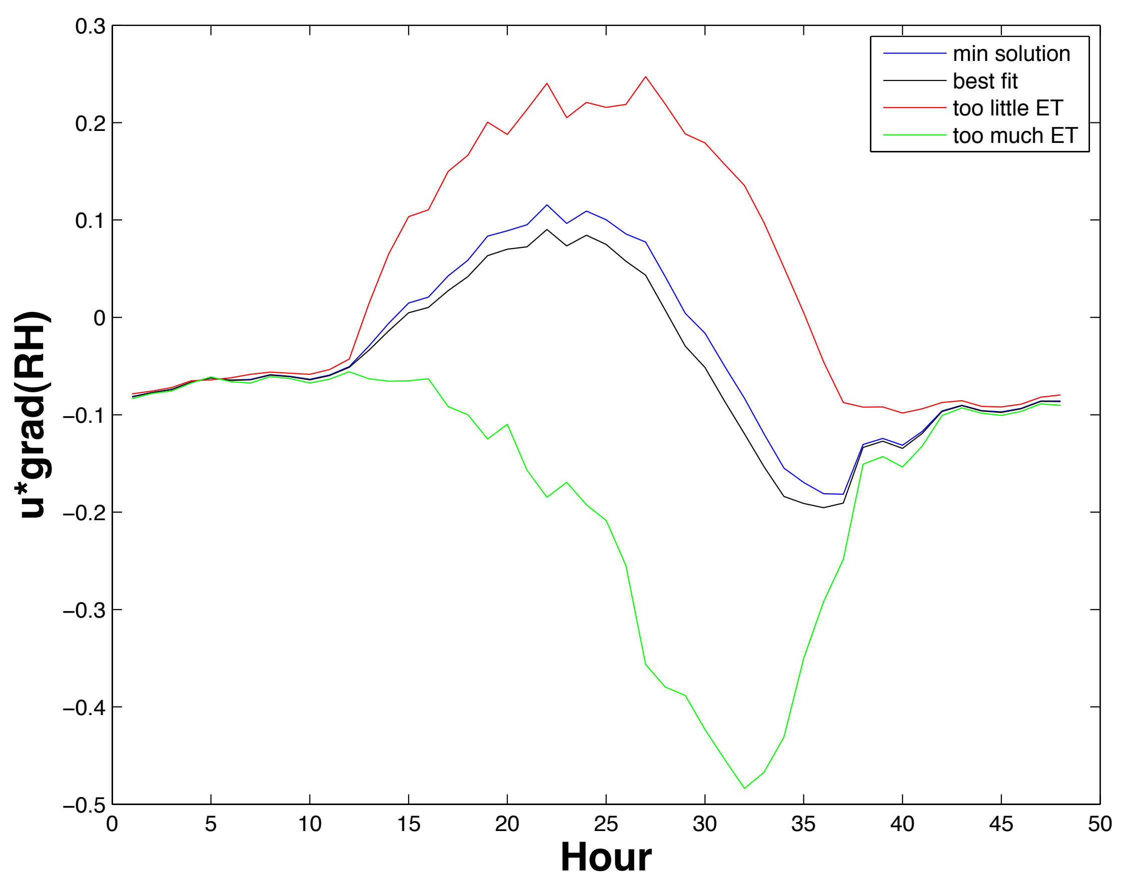
On any given day, a specific value of r_{can} (associated with a specific LE(t) and H(t)) ***minimizes*** the mean squared RH gradient over the day, e.g.:



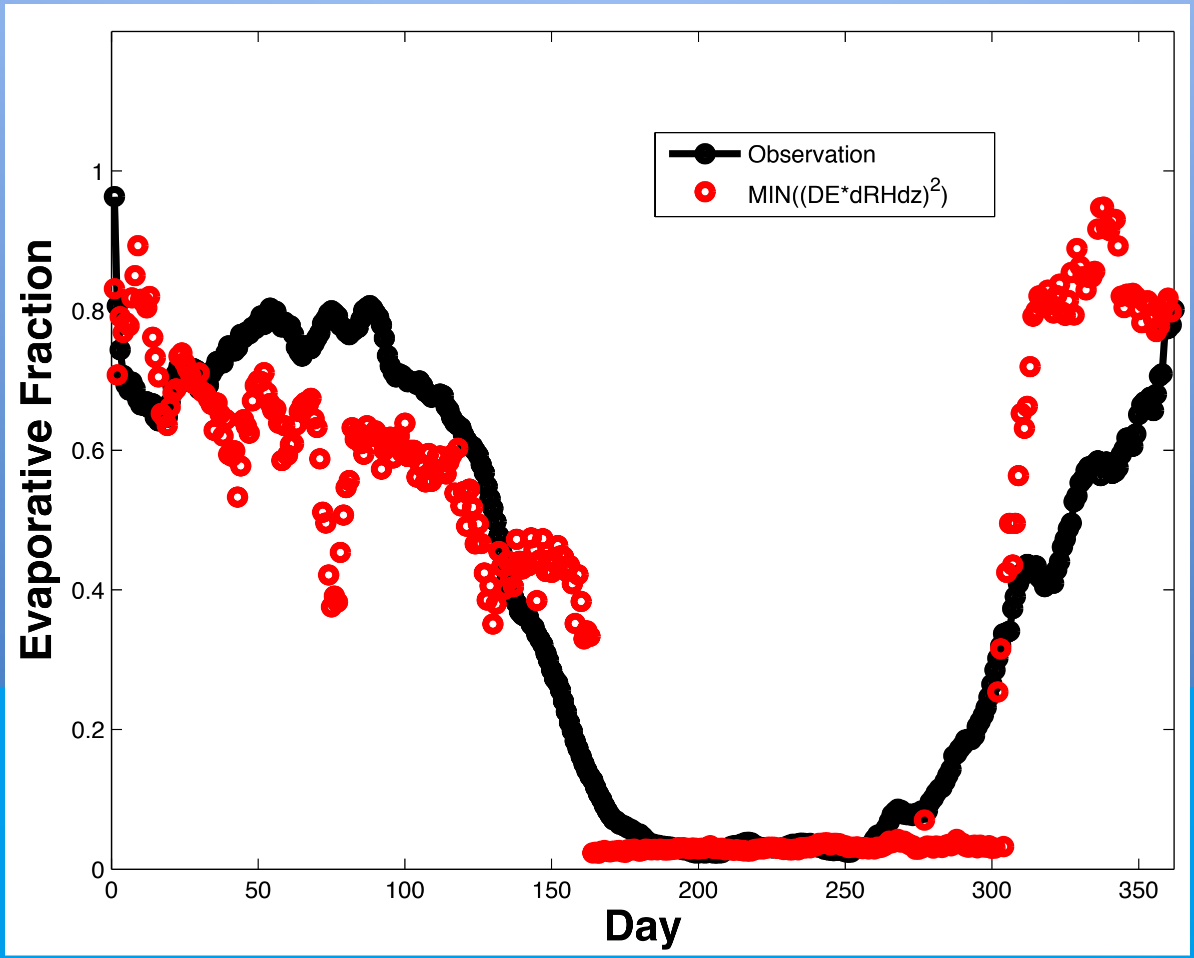


An Emergent Behavior ?

Examples that follow show that: *the value of r_{can} that yields RH profiles with minimum u*-weighted mean squared gradient at the surface predicts LE remarkably well !*



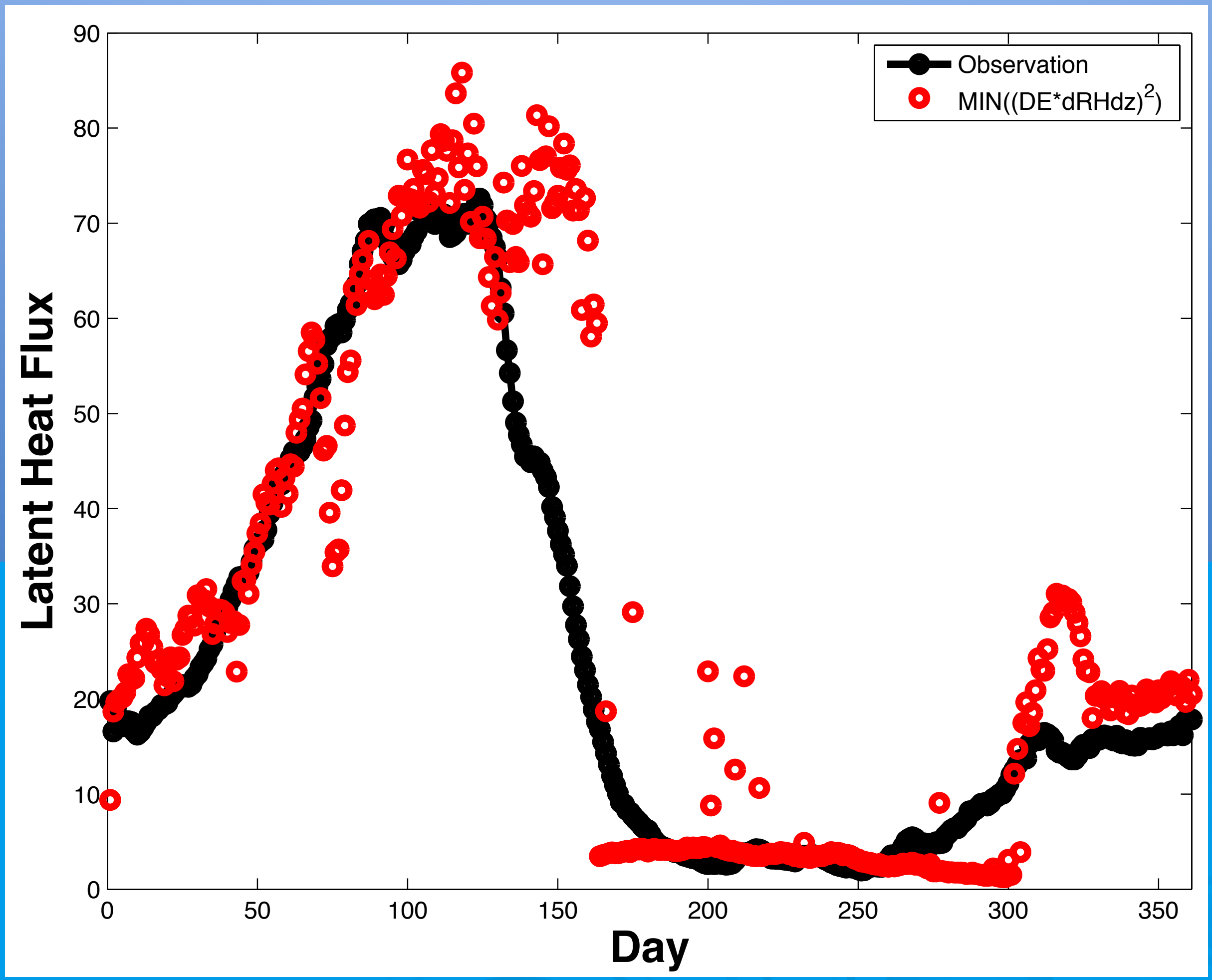
Example at Vaira Ranch CA (seasonal avg)



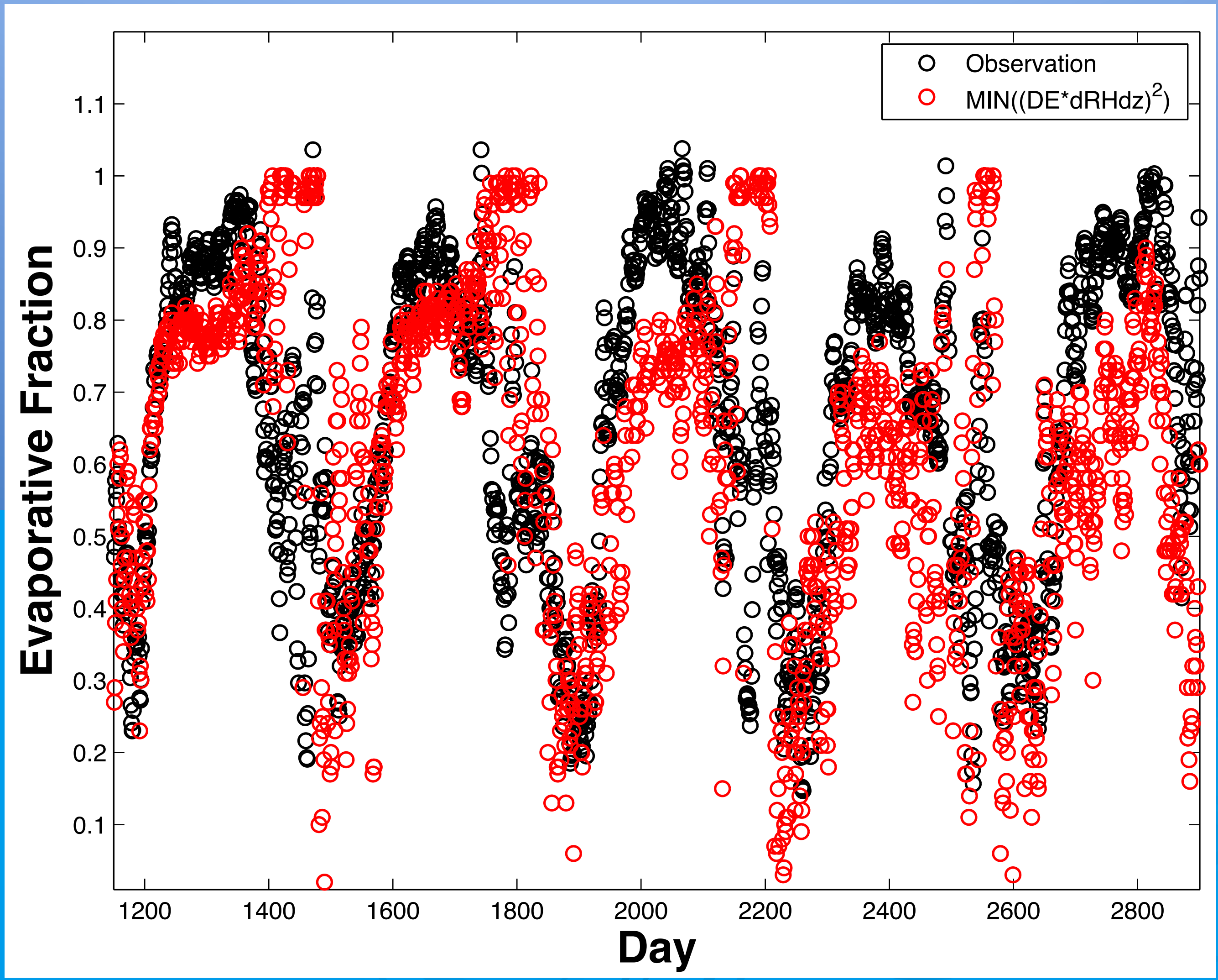
EF = LE/(LE+H)

Strong summer drydown captured well

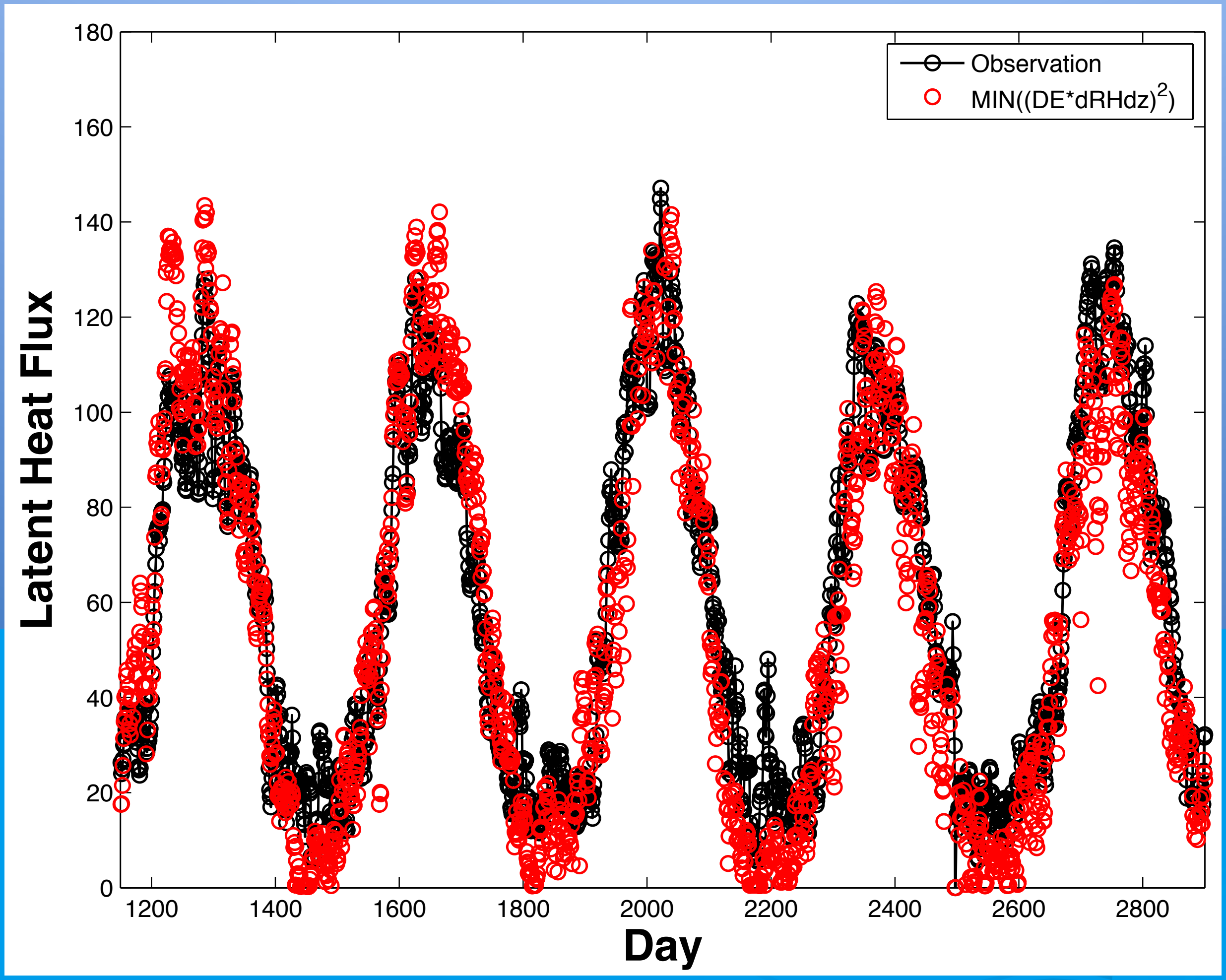
Example at Vaira Ranch CA (seasonal average)



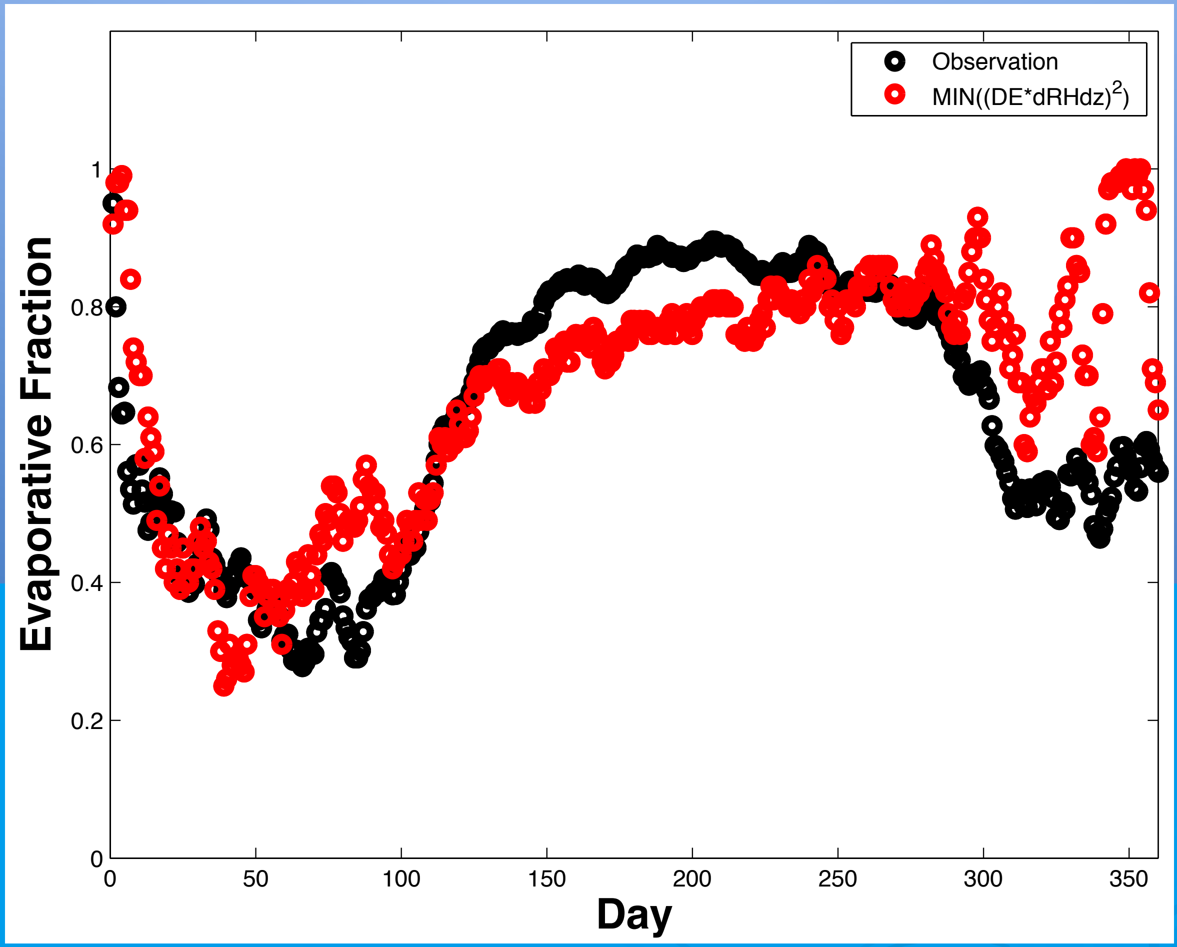
Example at Duke Forest (HW) (10 day filter)



Example at Duke Forest (HW) (10 day filter)



Example at Duke Forest (HW) (seasonal avg)



Summary

1) Similar results at other Ameriflux sites

2) Appears that fluxes of heat and moisture between land and boundary layer tend to minimize RH gradient at the surface, but *WHY* ? *Measure of maximum coupling* ?

3) Possibilities:

*role of thermodynamic potential $R_v T \cdot \log(RH)$?

*entropy production ? (appears not to be, though RH does appear in the entropy equation for moist air)

*a fluke (unlikely, but maybe… *I hope not*)

Summary

4) For better or worse, very sensitive to details, e.g.

**must* evaluate at zo+d (if higher e.g. at screen height, predictions are terrible),

*diurnal cycle impt (can’t daily avg)

*must minimize mean square (not variance, and not mean)

*issue is gradient (or “flux”) , not just RH (i.e. not min var (RH))

Summary

5) Practical implication: Estimate soil-limited ET *without* measurement of soil moisture/vegetation stress, i.e.:

if min grad(RH) is an intrinsic property of the coupled system, then you can calibrate r_{can} *to satisfy it*

6) Future work: See if same behavior emerges in free-running land-atmosphere model (i.e., without specified temp, humidity, radiation etc). Trying simplified single-column radiation/convection model… but many devils in details.