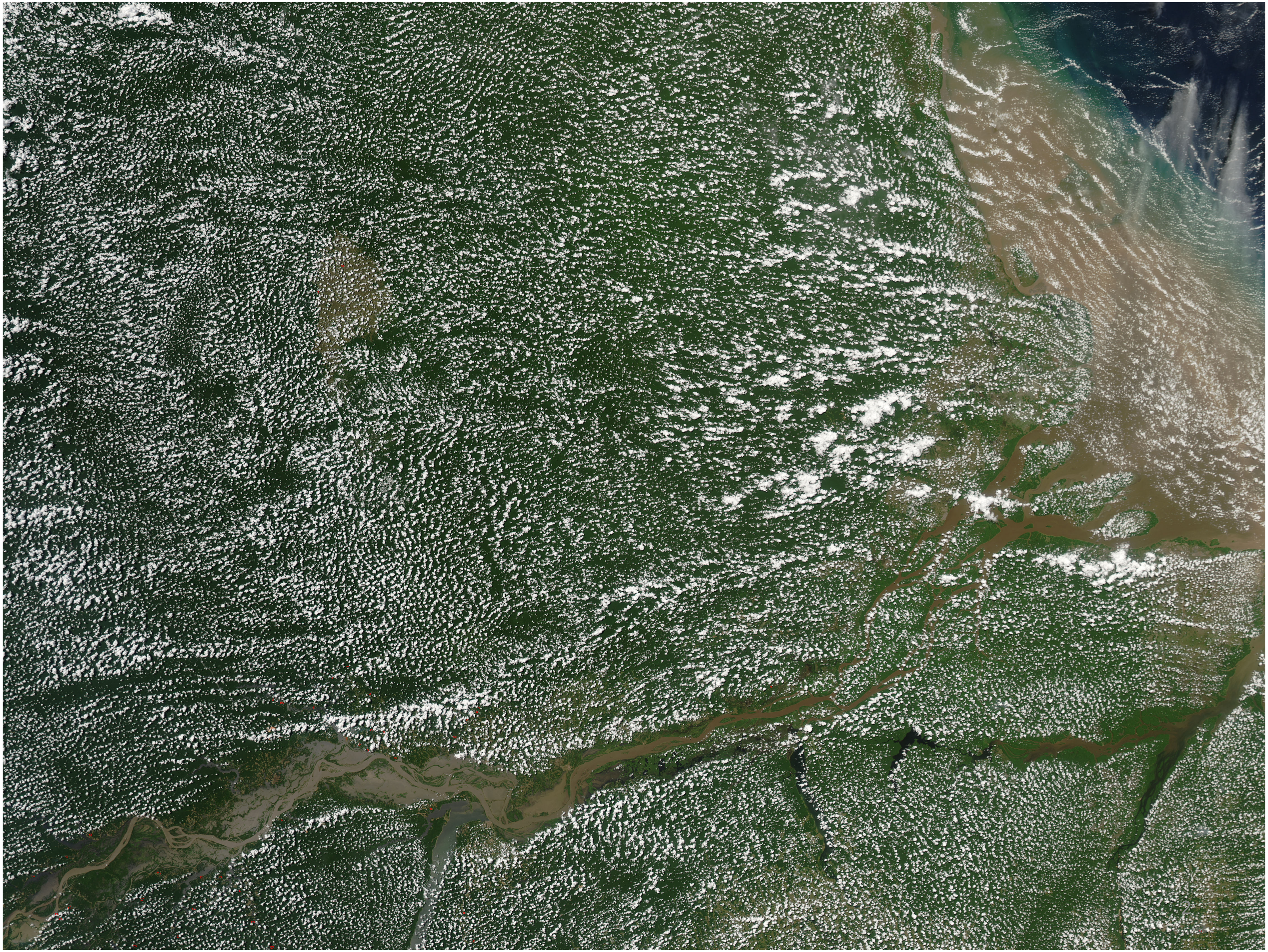
Nonlinearities and feedback in evapotranspiration in the land-atmosphere coupled system

Pierre Gentine

Columbia University

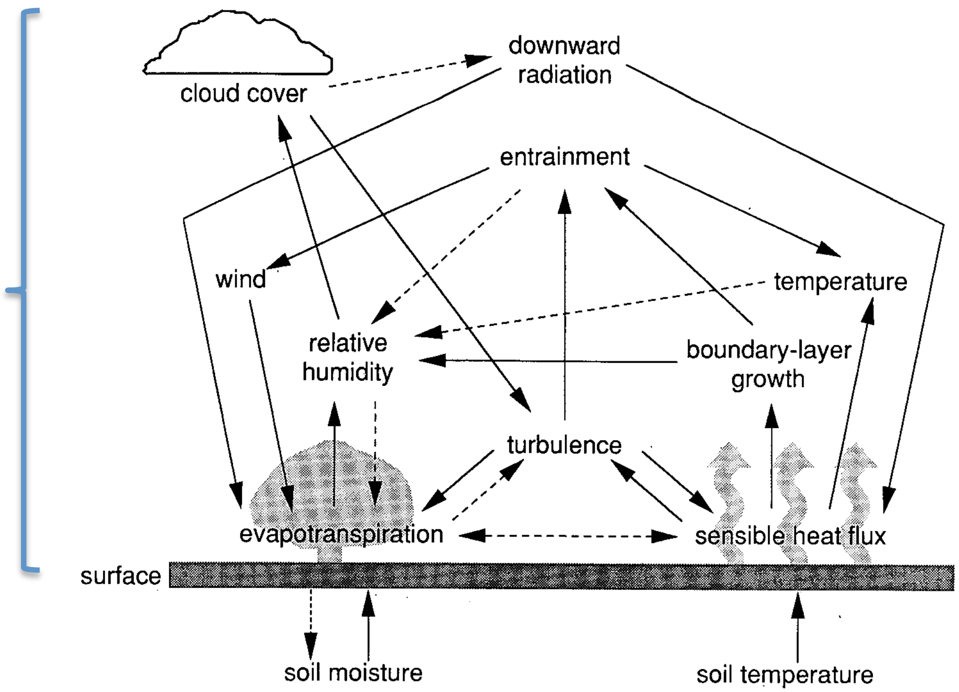
With:
Fabio D'Andrea, Kirsten Findell, Michael Ek, Ben Lintner, Bert Holtslag



Non-linear feedback in land-atmosphere interactions

Coupling in land-boundary layer interactions

Boundary layer
lower troposphere

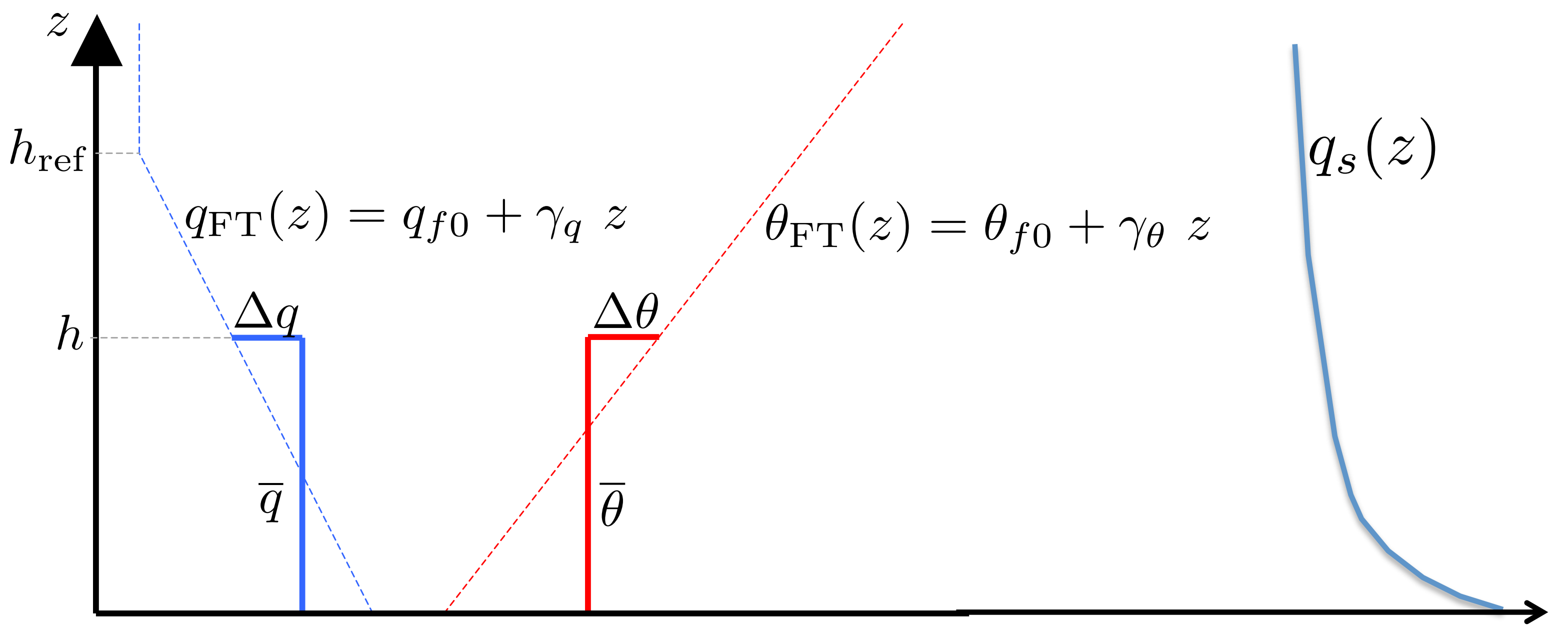


Ek and Mahrt (1994)

Some processes are missing: we will get back to this

Boundary layer humidity

Potential temperature $\theta = T\,(p_0/p)^{R_d/C_p}$

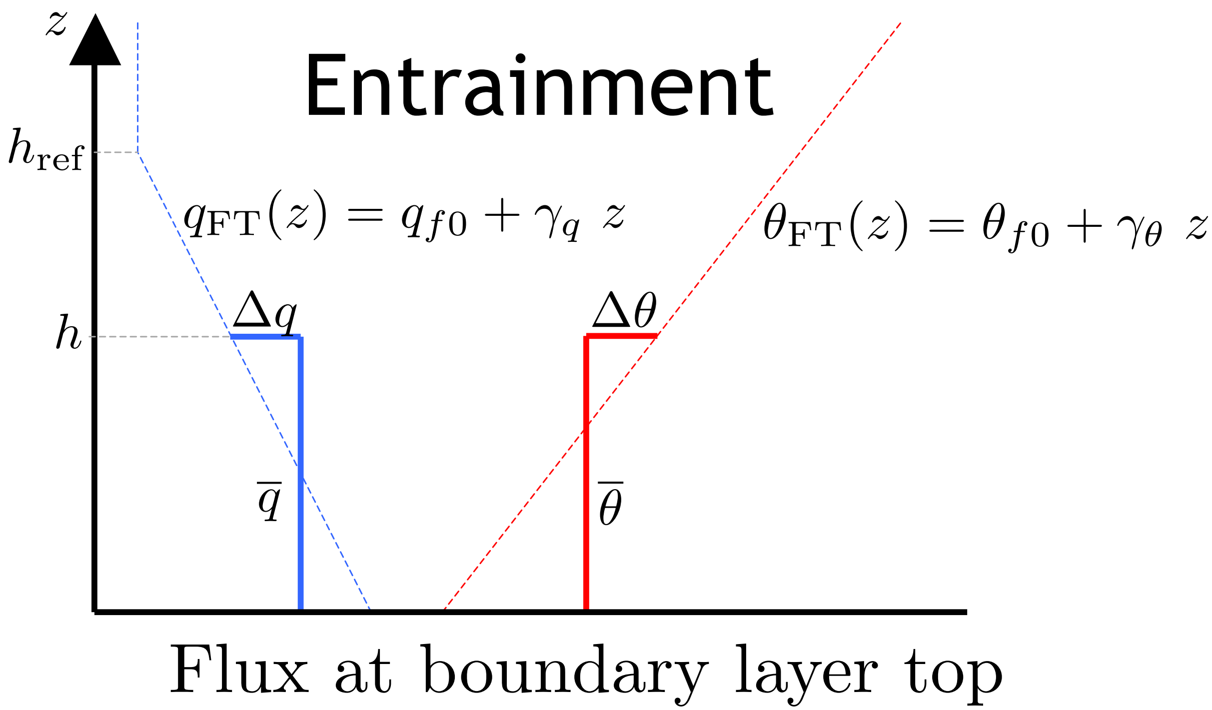


Cloud onset when relative humidity is 100%

$$RH = \frac{q}{q_s(T,P)} = \frac{q}{\epsilon e_s(T)/P}$$

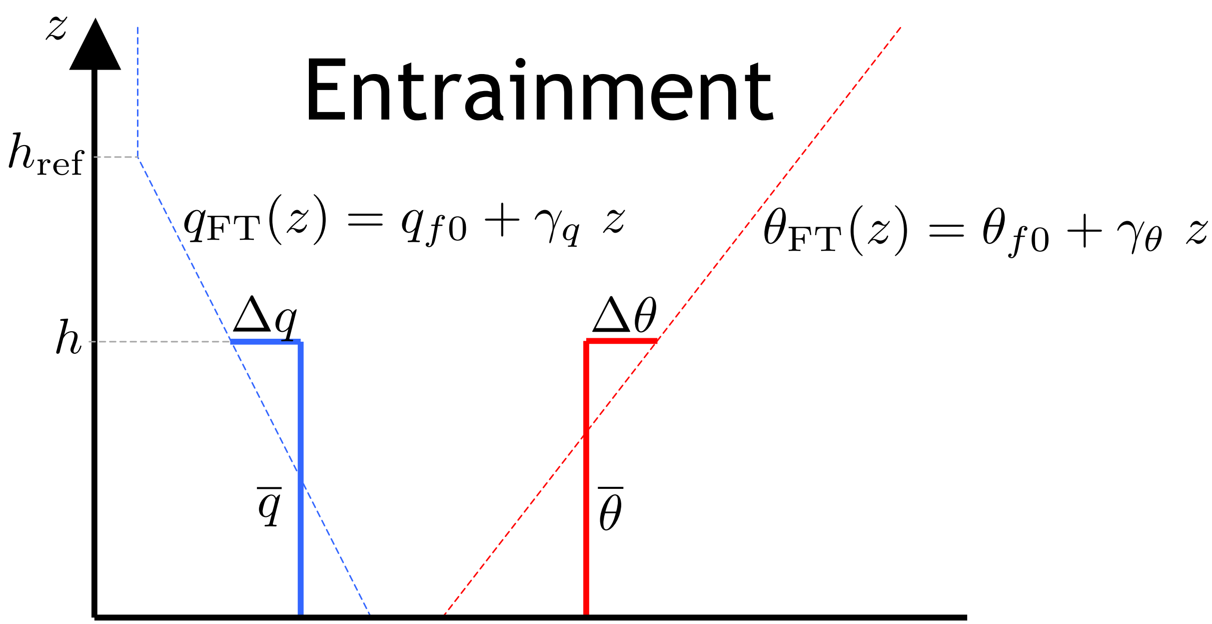
Conserved

Boundary layer humidity



Potential temperature	$\overline{w'\theta'} = w_e \Delta\theta$	Warming (in θ)
Specific humidity	$\overline{w'q'} = w_e \Delta q$	Drying (in q)

Boundary layer humidity



$$\frac{dz_i}{dt} = w_e$$

Closure $\overline{w'\theta_v'}(z_i) = -\beta\overline{w'\theta_v'}(0) = -w_e\Delta\theta$

Does the boundary layer moisten or dry up?

In terms of specific humidity:

Inversion Bowen ratio (Betts 1992)

$$B_{\text{inv}} = -\frac{C_p \gamma_\theta}{L_v \gamma_q} > 0$$

Critical EF

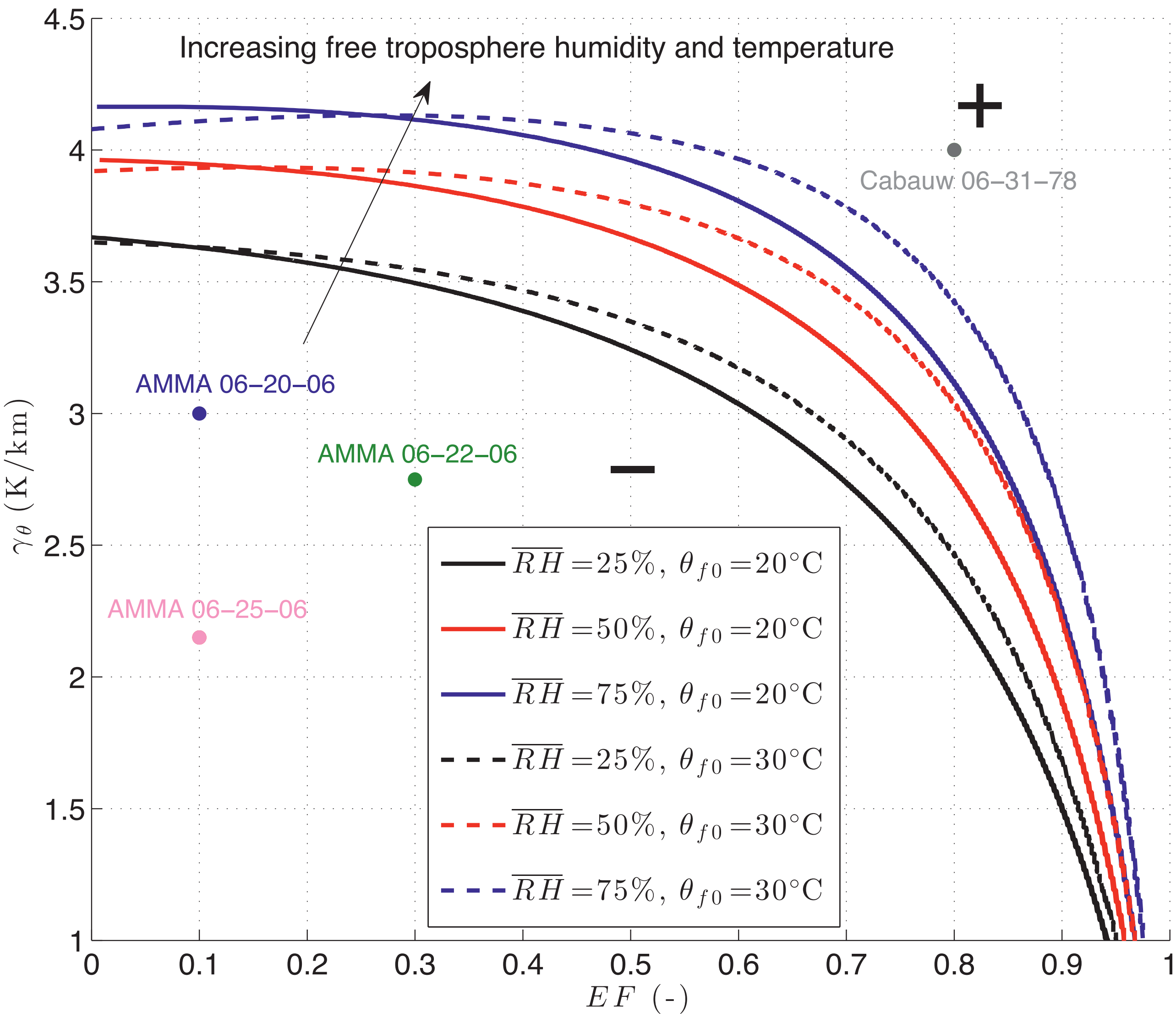
$$EF_c = 1 - \frac{1}{1 + 2\beta + B_{\text{inv}}} < 1$$

When *EF>EFc* => moistening of the boundary layer in q but not necessarily in RH.

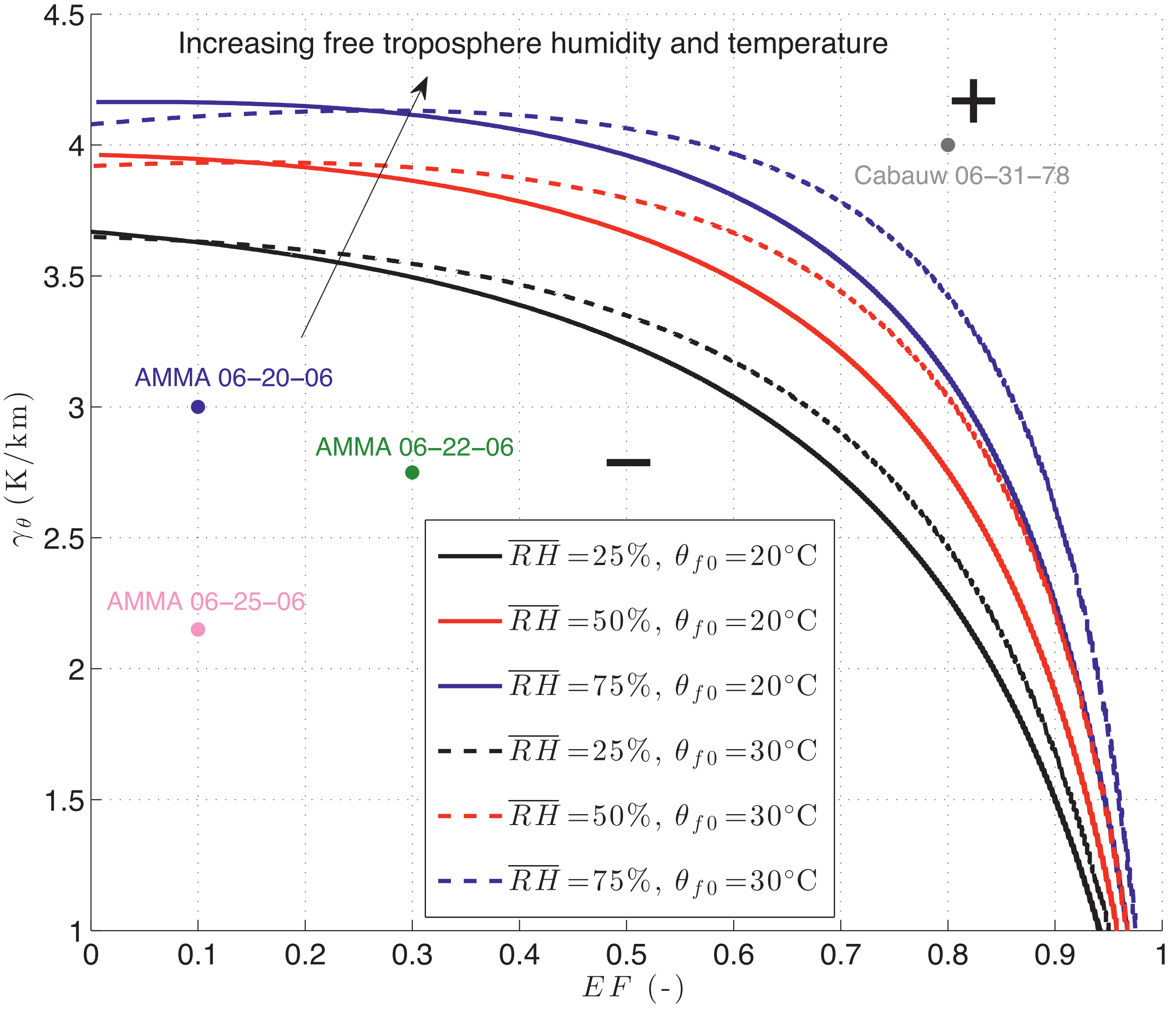
$$RH = \frac{q}{q_s(T,P)} = \frac{q}{\epsilon e_s(T)/P}$$

Not a conserved variable.

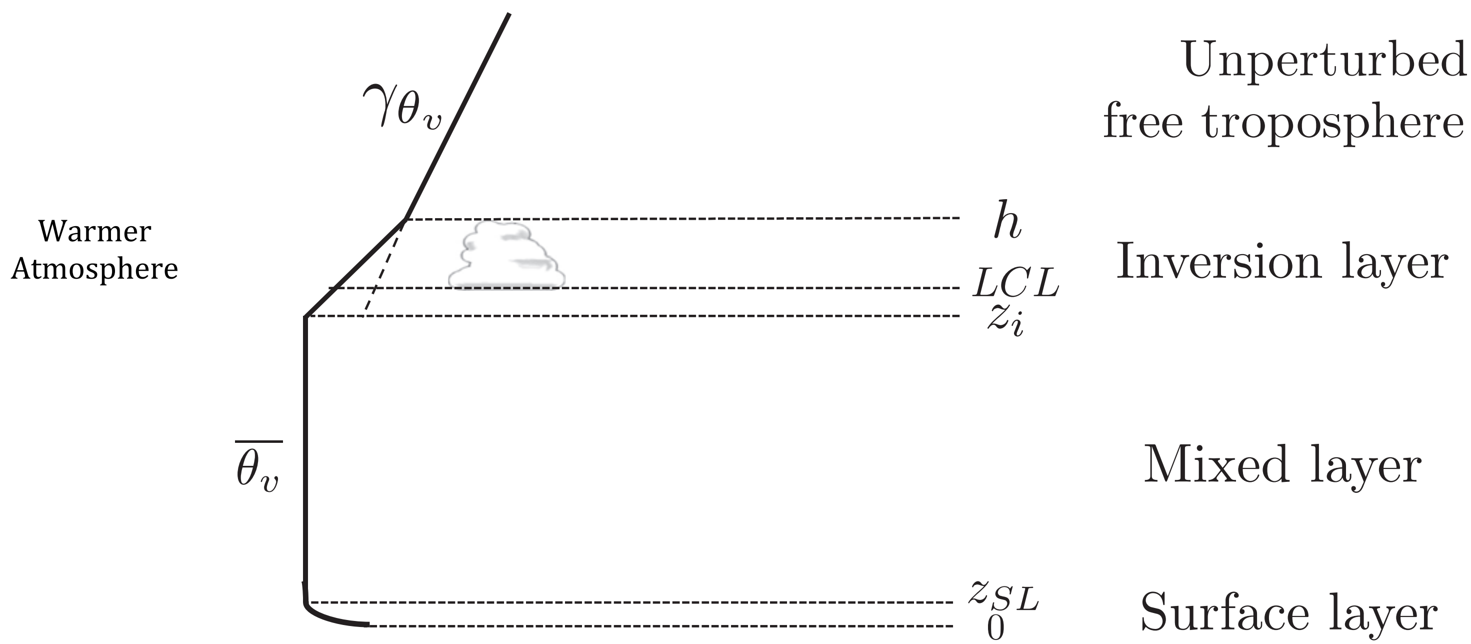
What about RH(zi)?



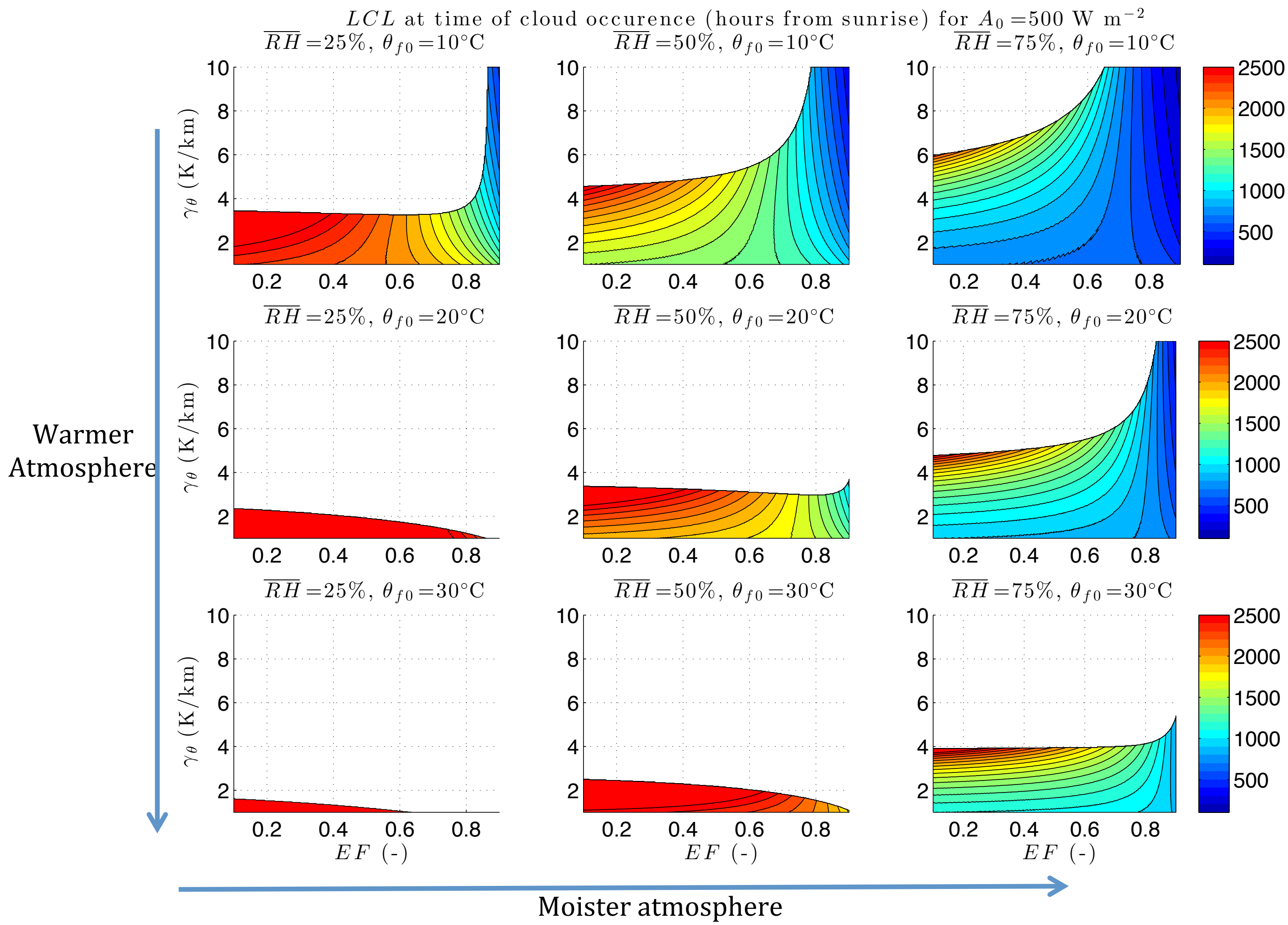
What about RH(zi)?



Time of cloud occurence



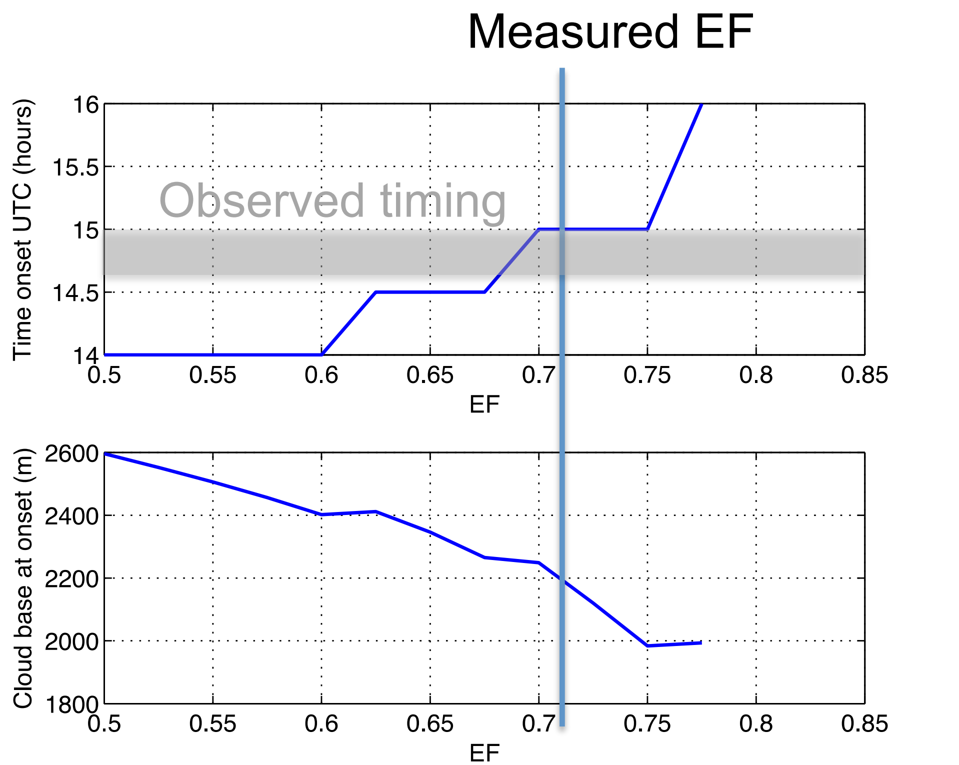
Cloud base at cloud occurence



Gentine, P., A. A. M. Holtslag, F. D'Andrea, and M. Ek (2013), Surface and atmospheric controls on the onset of moist convection over land, *J Hydrometeorol*, 130211131121003, doi:10.1175/JHM-D-12-0137.1.

Evaporative Fraction from clouds

Entrainment is the only unknown:
better than high number of parameters in land surface models.



We can get timing and timing estimate from remote sensing
-> could be used in data assimilation
The highest the temporal resolution, the better

Gentine, P., C. R. Ferguson, and A. A. M. Holtslag (2013), Diagnosing evaporative fraction over land from boundary-layer clouds, *J Geophys Res-Atmos*, *118*, 1–12, doi: 10.1002/jgrd.50416.

New method to estimate evapotranspiration

Background:
Penman-Monteith equation:

$$ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{e^*(T_a) - e_a}{r_a}}{\Delta + \gamma\left(1 + r_s/r_a\right)}$$

R_n can be obtained from satellites
e_a, $e^*(T_a)$: observed from weather stations
r_a can potentially be estimated

Problems:
G: ground heat flux, hard to measure and generally unavailable
r_s is unknown (in fact it is the most important parameter!)

Salvucci, G. D., and P. Gentine (2013), Emergent relation between surface vapor conductance and relative humidity profiles yields evaporation rates from weather data, *Proc Natl Acad Sci U S A*, –, doi:10.1073/pnas.1215844110.

New method to estimate evapotranspiration

To alleviate stomatal resistance parameterization:

Priestley-Taylor equation:

$$ET = \alpha \frac{\Delta(R_n - G) + \rho_a c_p \frac{e^*(T_a) - e_a}{r_a}}{\Delta + \gamma}$$

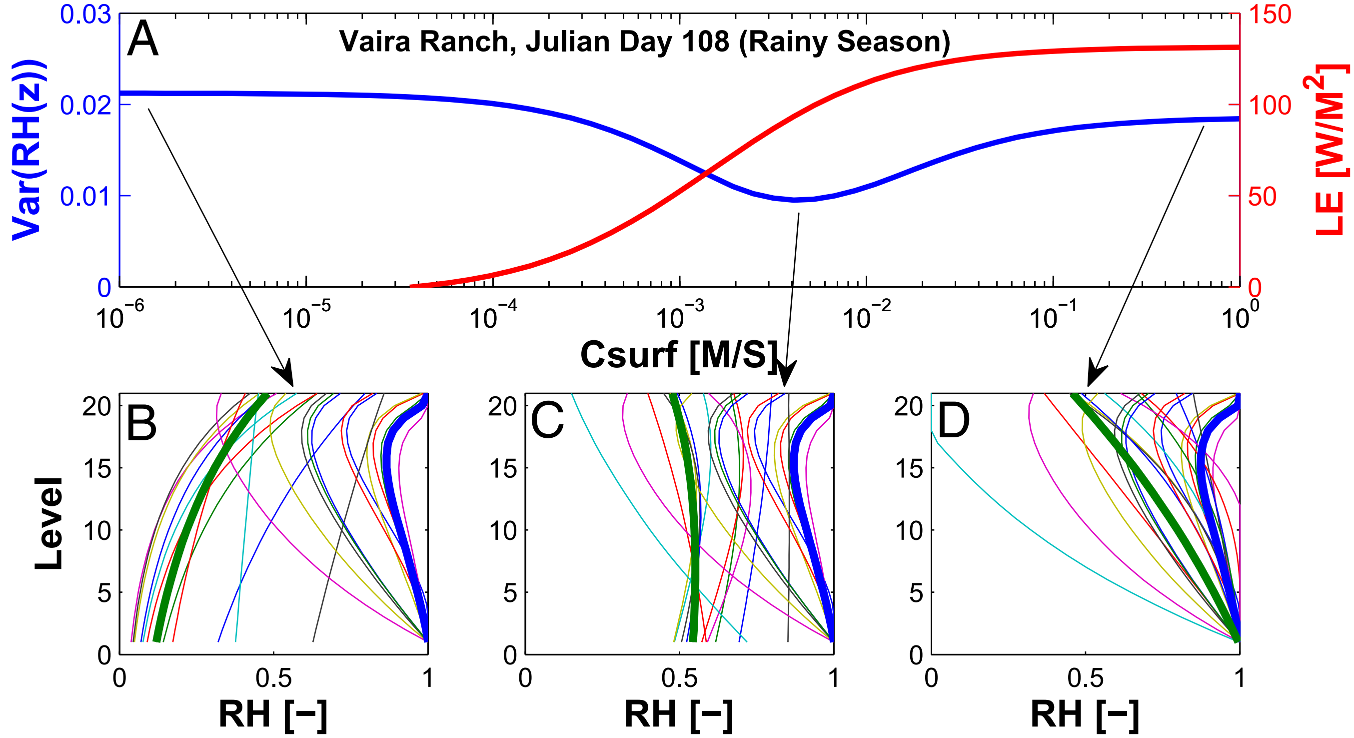
α: empirical coefficient (=1.26) assumed to be relatively constant in various conditions because of land-atmosphere coupling.

In reality it is far from being constant e.g. heterogeneous landscape (T_a is near constant).

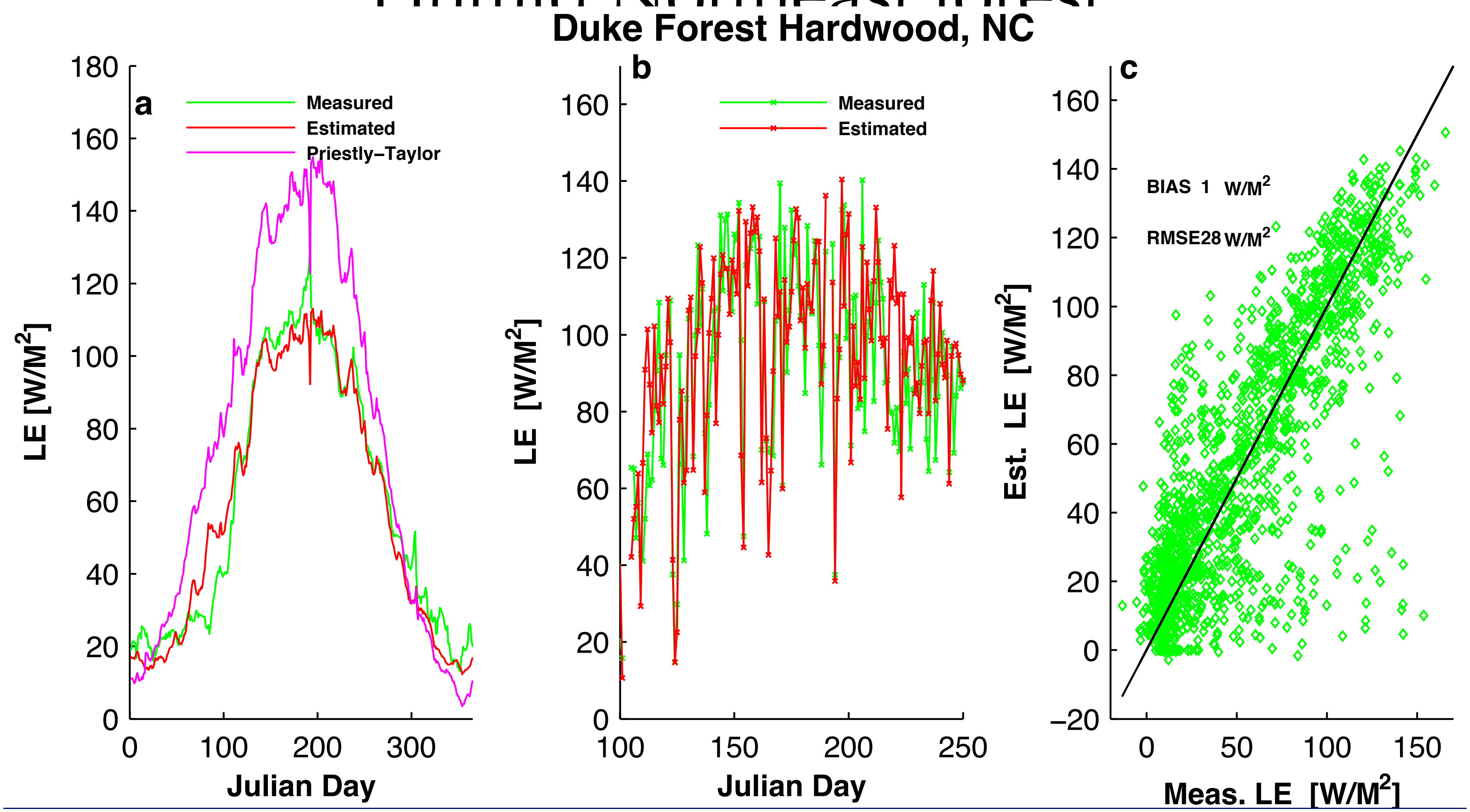
New method to estimate evapotranspiration

Actual stomatal resistance minimizes daily relative humidity profile variance (near surface)

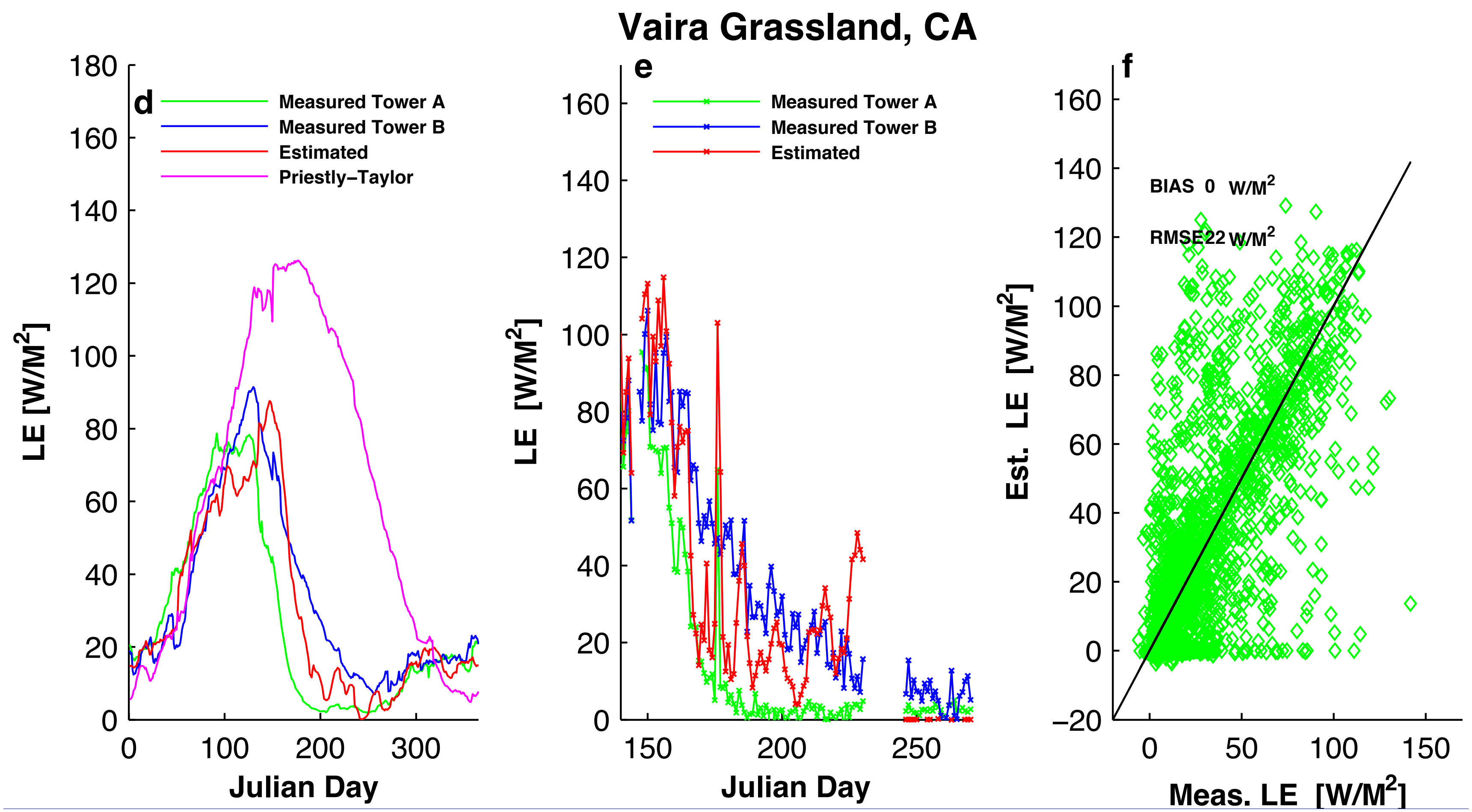
Salvucci and Gentine 2013 PNAS



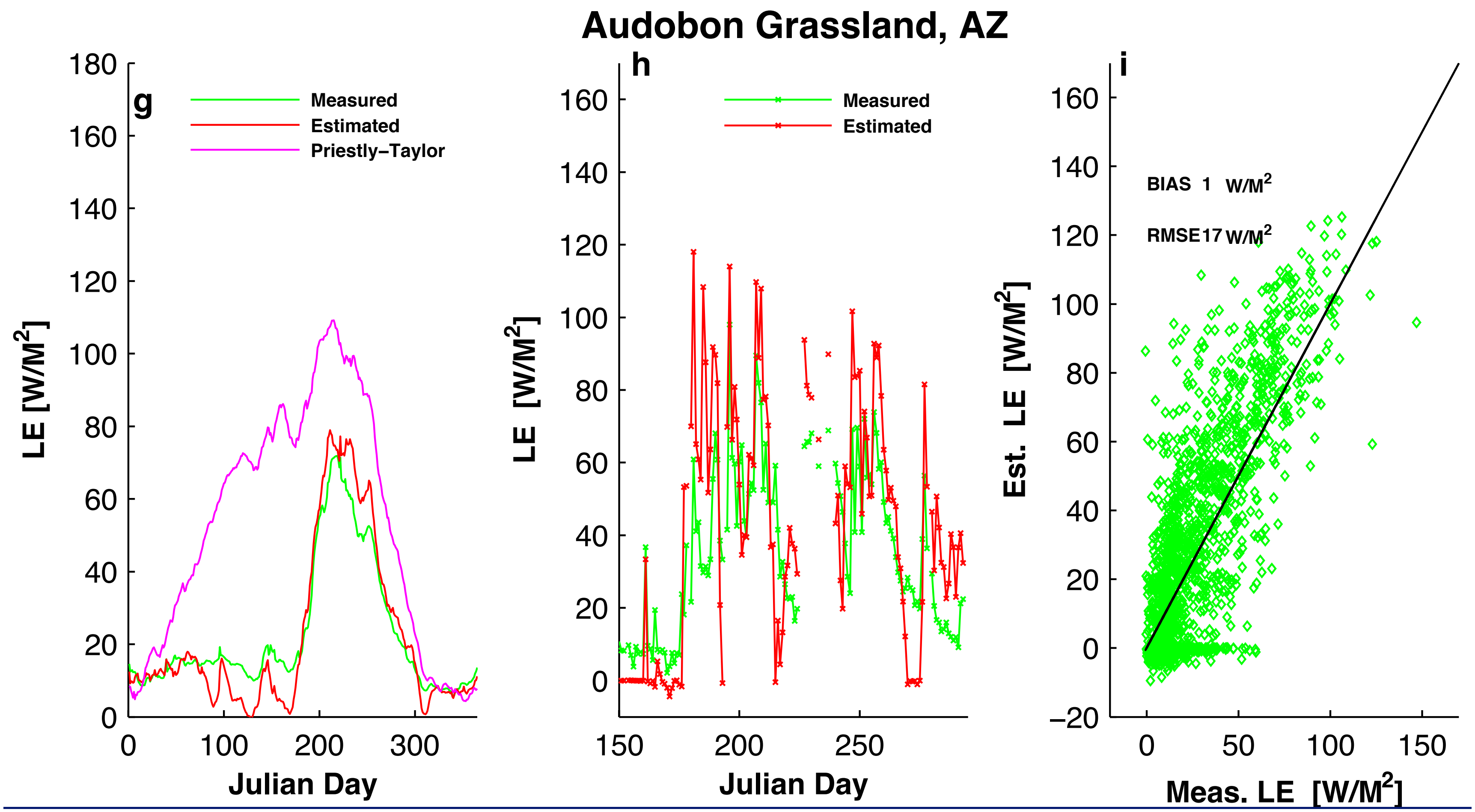
Minimum variance
Humid Northeast forest



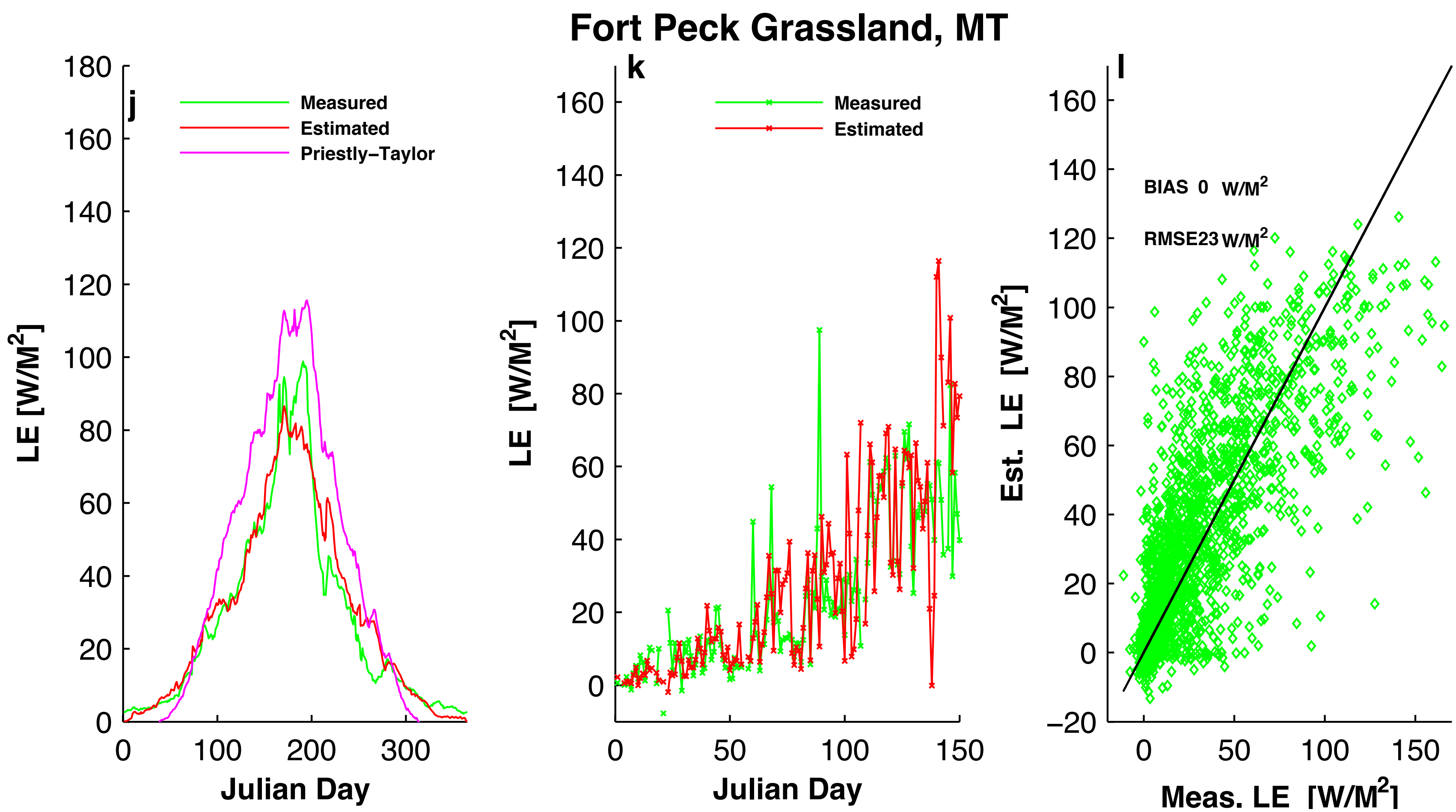
Minimum variance Mediterranean climate



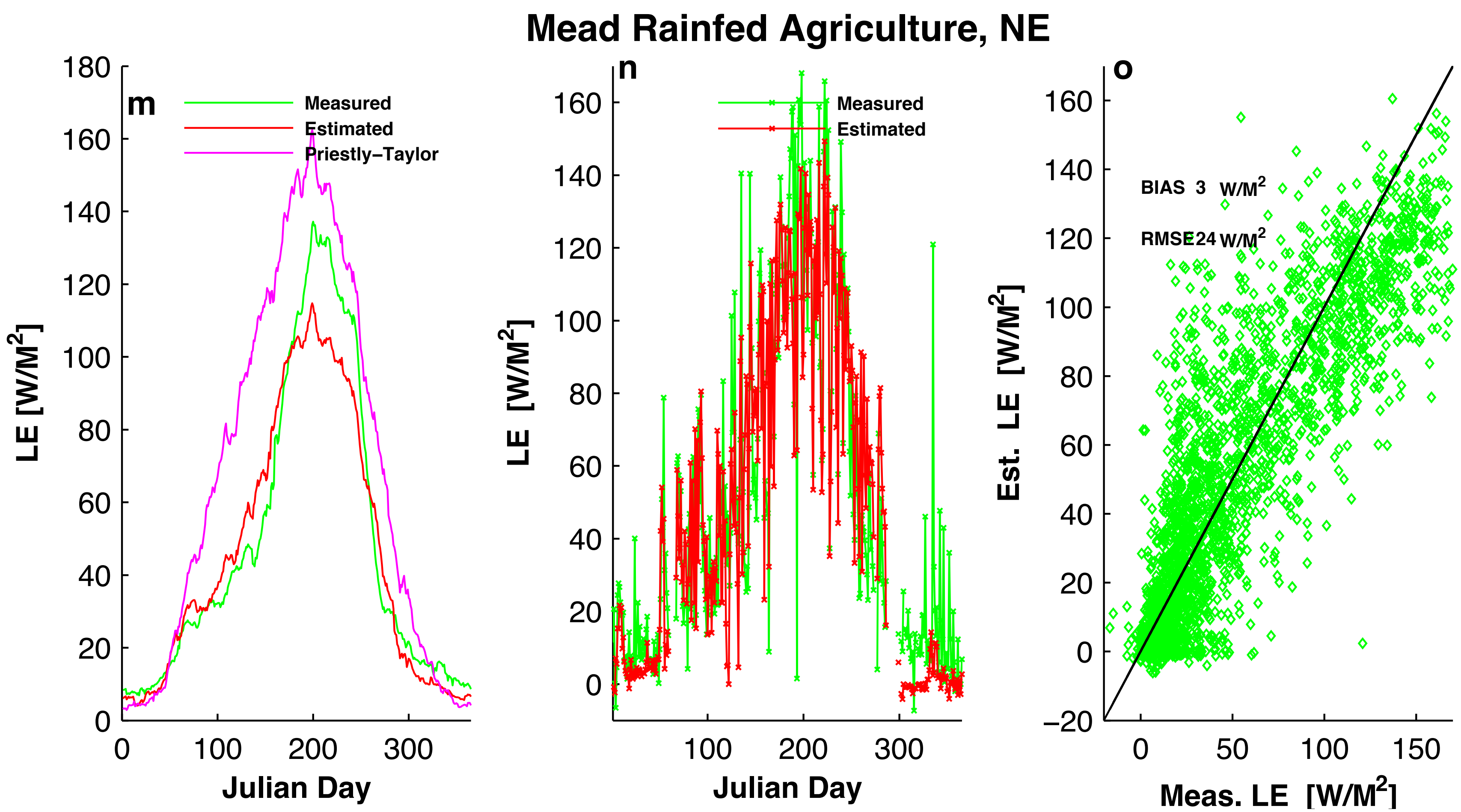
Minimum variance
Arid southwest



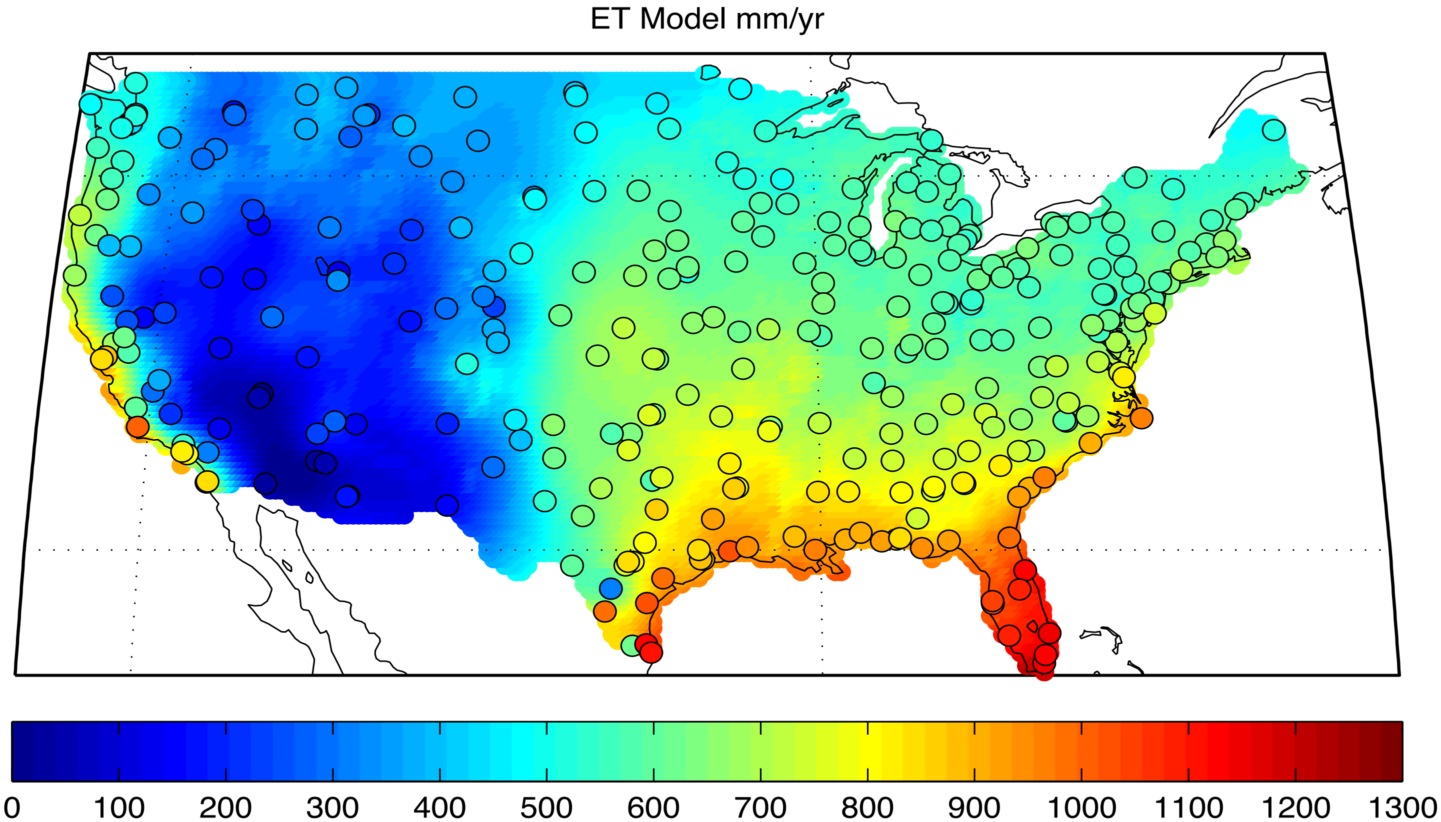
Minimum variance
Northern Great Plains



Minimum variance
Rainfed agriculture



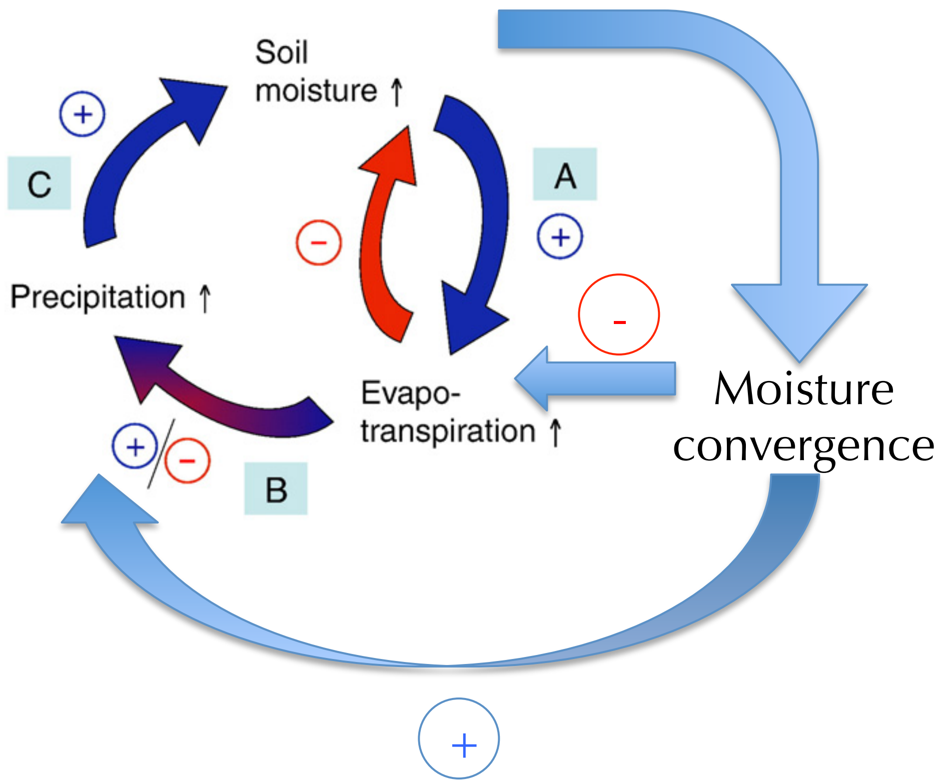
Now 40 years 3hr/daily data over the US



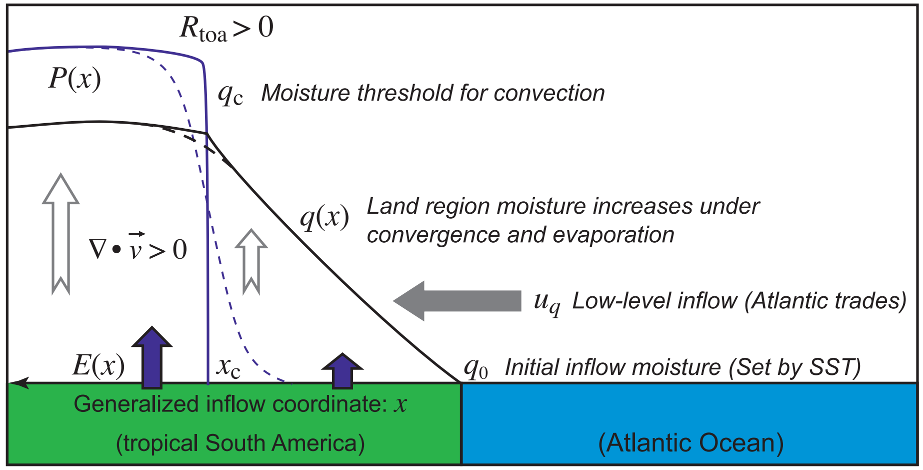
Rigden, Salvucci

Soil moisture-*ET*-precipitation feedbacks

Seneviratne et al. 2010



Large-scale prototype of LA interactions



Vertically-averaged atmospheric heat and moisture budgets

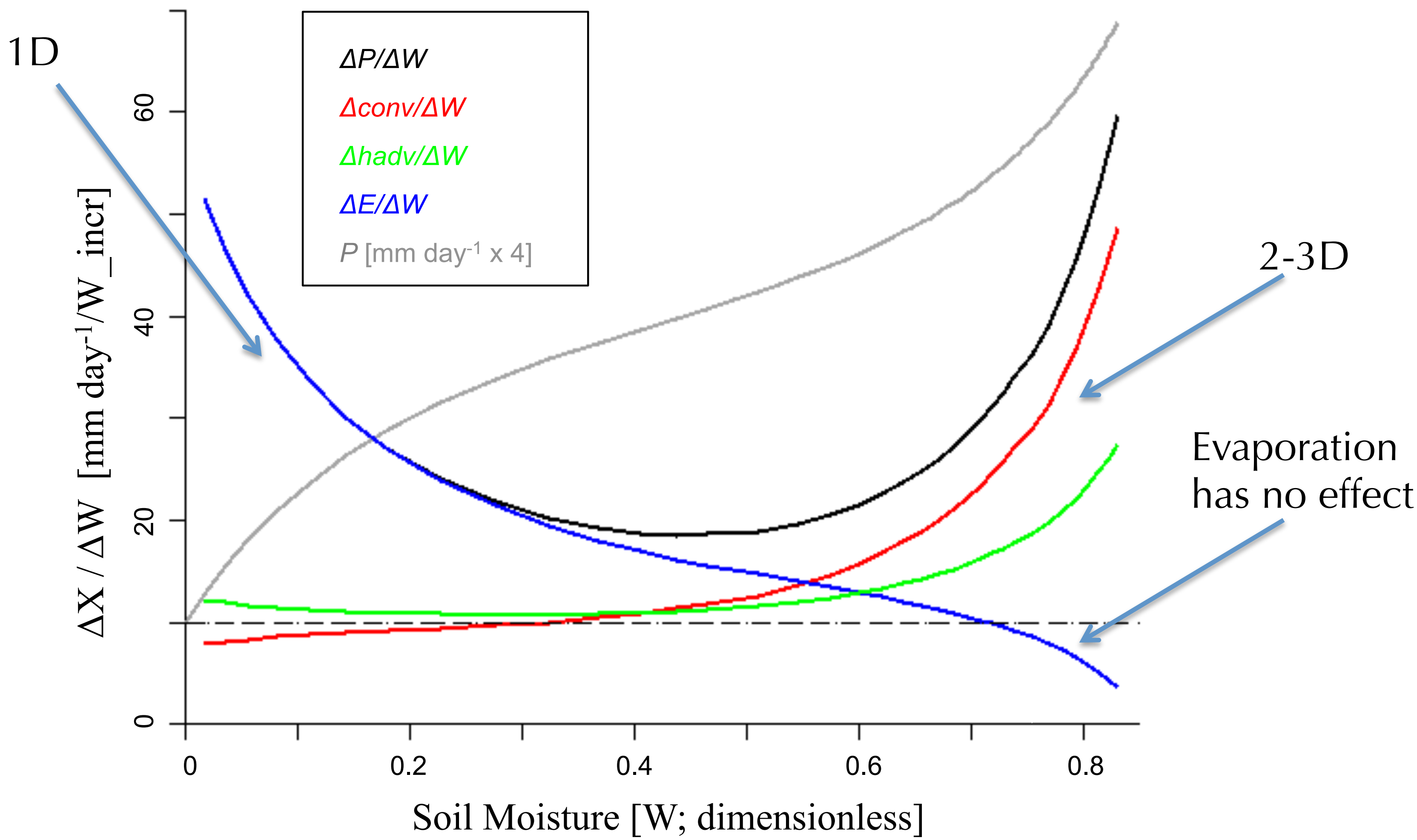
$$\frac{\partial T}{\partial t} = -M_s \nabla_H \cdot \mathbf{v} + P + R_n + H_{surf} - \mathbf{v}_T \cdot \nabla_H T$$

$$\frac{\partial q}{\partial t} = M_q \nabla_H \cdot \mathbf{v} - P + E - \mathbf{v}_q \cdot \nabla_H q$$

Advection is imposed at the ocean-land interface

Lintner et al. J Climate 2012

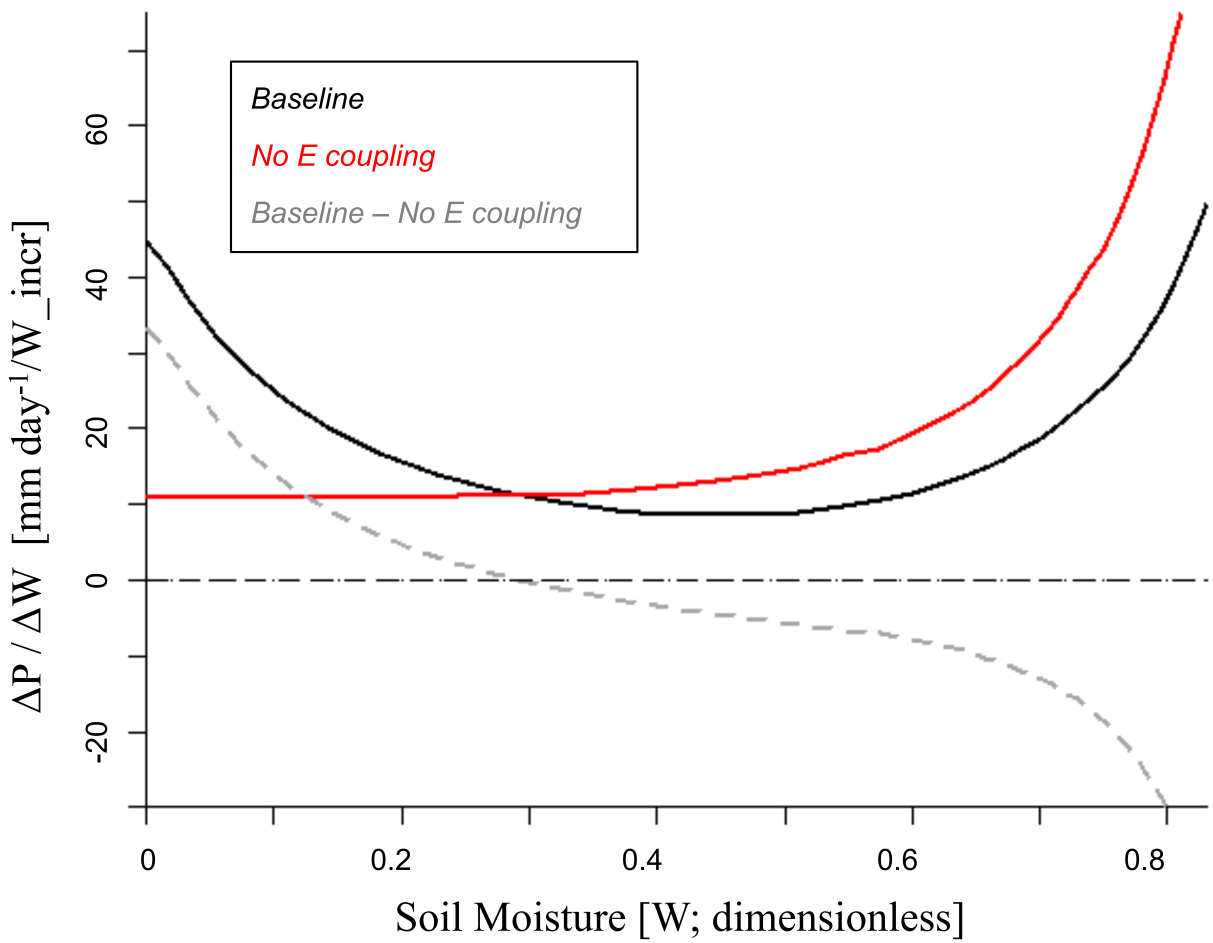
Moisture Convergence



Lintner, B. R., P. Gentine, K. L. Findell, F. D'Andrea, and A. H. Sobel (2013), An Idealized Prototype for Large-Scale Land–Atmosphere Coupling, *Journal of Climate*, 121031110523000, doi:10.1175/JCLI-D-11-00561.1

Moisture Convergence

If we shut down dependence of E(W): only surface hydrology



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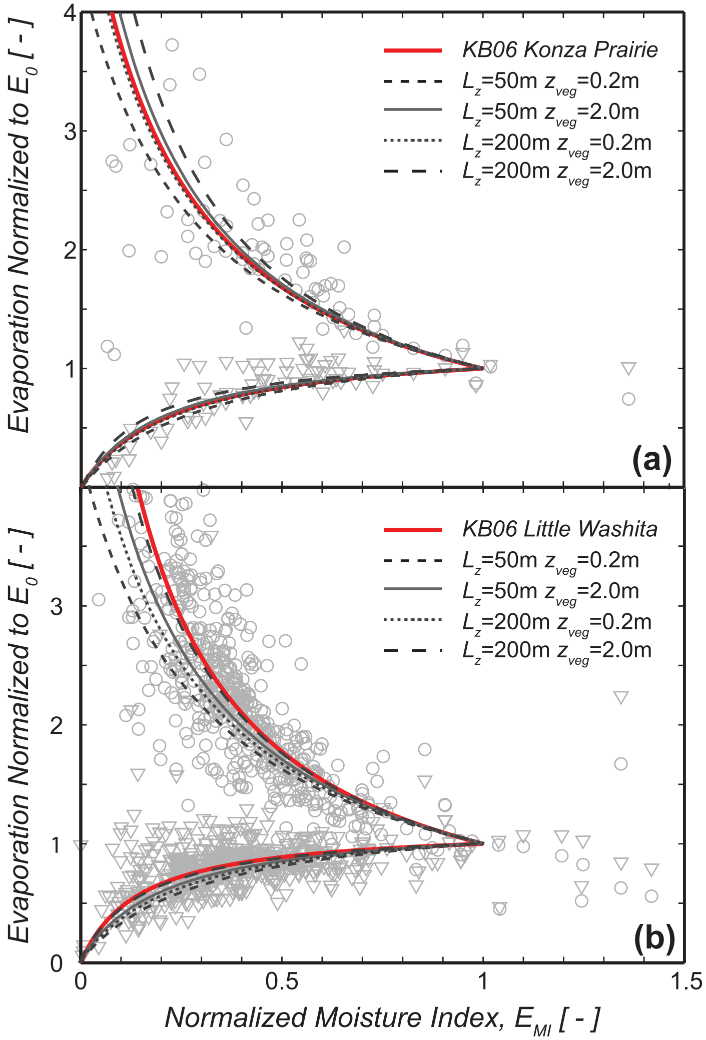
Outcome: complementary relationship

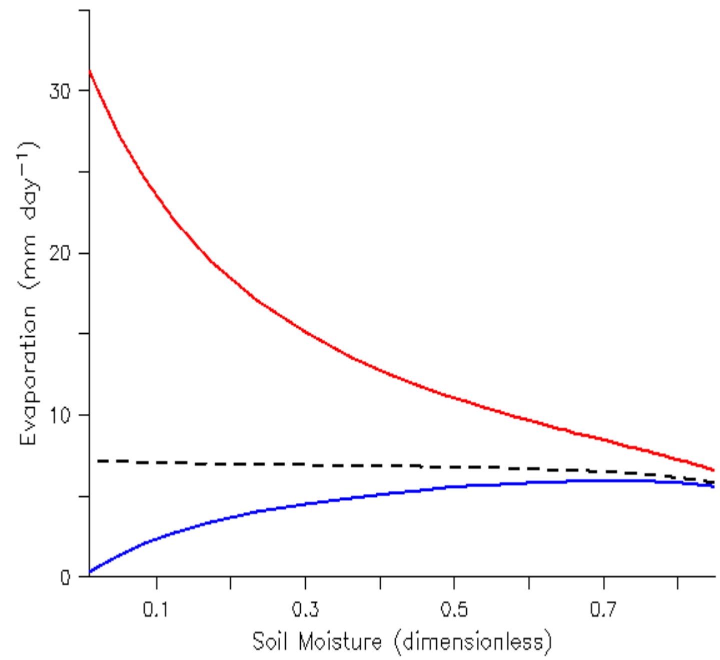


Petitjohn and Salvucci 2009

$$ET = \beta(\text{moisture})E_p$$

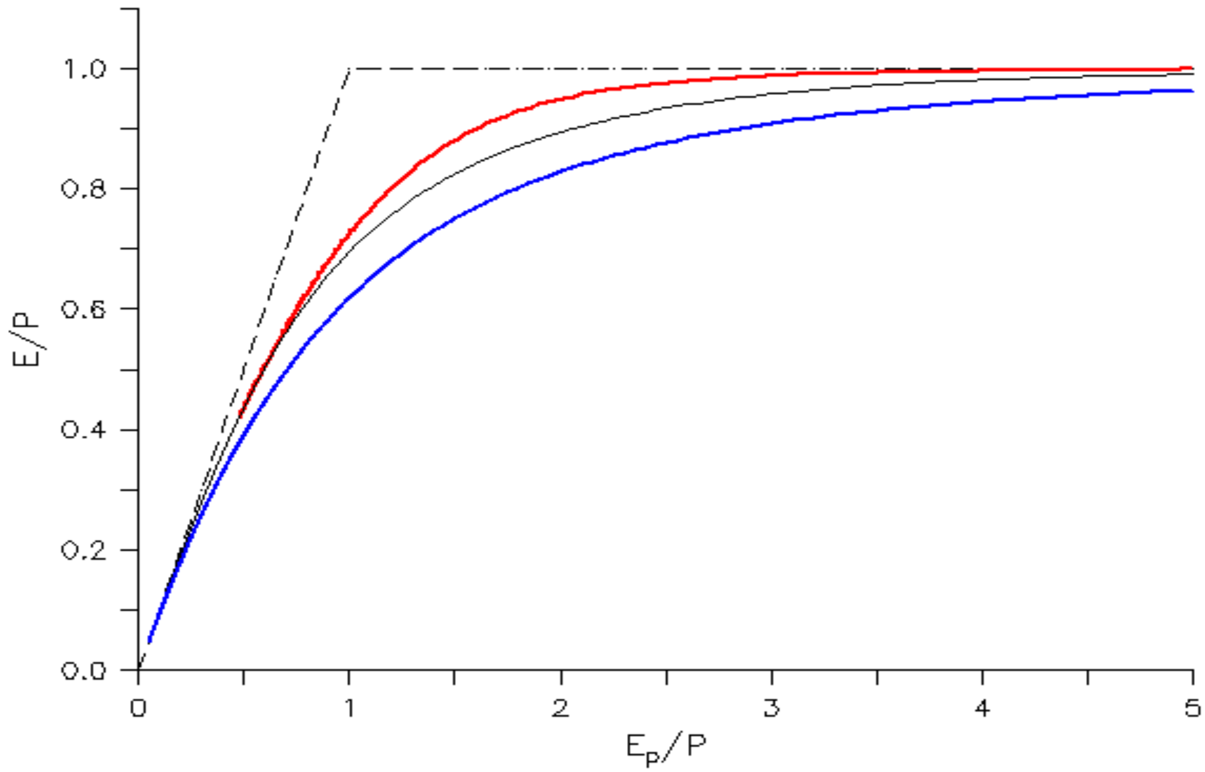
coupled

Results from synoptic model:
Effect of convergence on the RHS



Lintner et al. 2013 HESS in preparation

Outcome: Budyko curve



Blue: $ET=s^2\ E_p$
Red: $ET=s^4\ E_p$
Gray: Original Budyko curve

Overall shape is well described through land-atmosphere coupling.