Physical relations in observations and models

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ECMWF Semina

'The parametrization of sub-grid processes and their interaction with the dynamics'

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Land-surface-atmosphere interaction

- Many interdependent processes
  - surface energy balance
  - shortwave and longwave fluxes
  - night-time boundary layer
  - role of water in the surface energy partition
  - vector methods
  - coupling between surface, boundary layer, precipitation
  - evaporation-precipitation feedback.
  - partition of moisture convergence into TCWV, cloud & precipitation
  - ratio of diabatic terms: cloud forcing to precipitation

- Adapted from papers of past 10-15 years

- Reflect my idiosyncrasies; and many aspects of the ECMWF model
  - *Many, many people have contributed*

References

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- Betts, A. K., M. Köhler and Y-C. Zhang, 2008: Comparison of river basin hydrometeorology in ERA-Interim and ERA-40 with observations. *J. Geophys. Res.* (submitted). tm568.pdf

Themes

- Evaluating models with field data
- FIFE (grassland);
- BOREAS/BERMS (boreal forest)
- GEWEX (river basins)
- ERA-40 river basin & grid-point comparisons
- Diurnal, daily mean, annual cycle
- *Land-surface climate*
- *Precipitation, evaporation, dynamics*
- *Cloud radiative impacts*

  – *Talk is mostly Figures: text has details*

Surface Energy Balance

$$R_{net} = SW_{net} + LW_{net} = H + \lambda E + G$$

- the split between surface processes and atmospheric processes
- the split between SW and LW processes
- the partition between clear-sky and cloud processes in the atmosphere
- the partition of the surface R_{net} into H and λE, which is controlled largely by the availability of water for evaporation and by vegetation

Surface SW_{net}

$$SW_{net} = SW_{down} - SW_{up} = (1-\alpha_{surf})(1-\alpha_{cloud})\, SW_{down}(clear)$$

- *surface albedo*

$$\alpha_{surf} = SW_{up} / SW_{down}$$

- *effective cloud albedo*
  - a scaled surface short-wave cloud forcing, SWCF

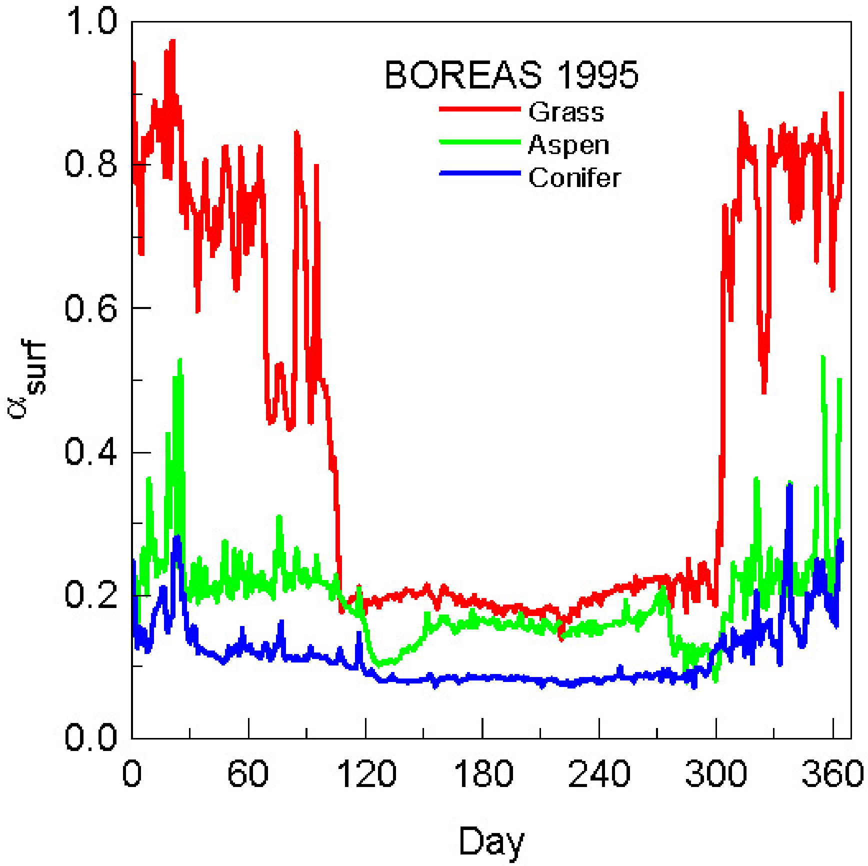
$$\alpha_{cloud} = -\, SWCF / SW_{down}(clear)$$

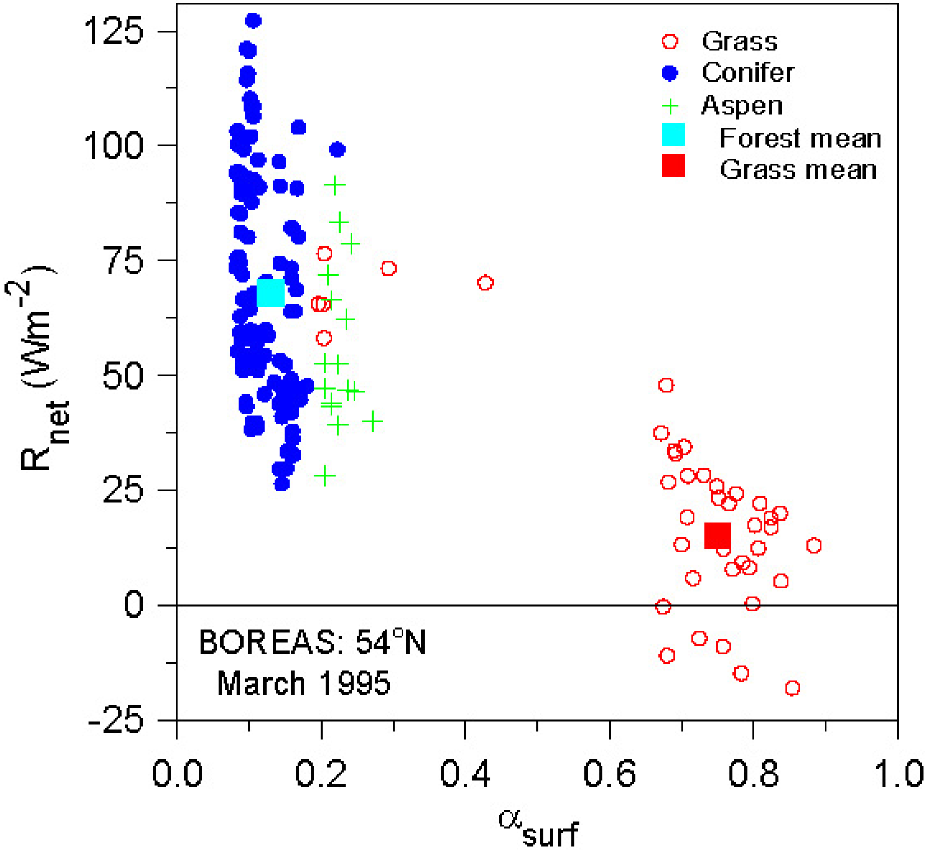
where

$$SWCF = SW_{down} - SW_{down}(clear)$$

[Betts and Viterbo, 2005; Betts, 2007]

Surface albedo

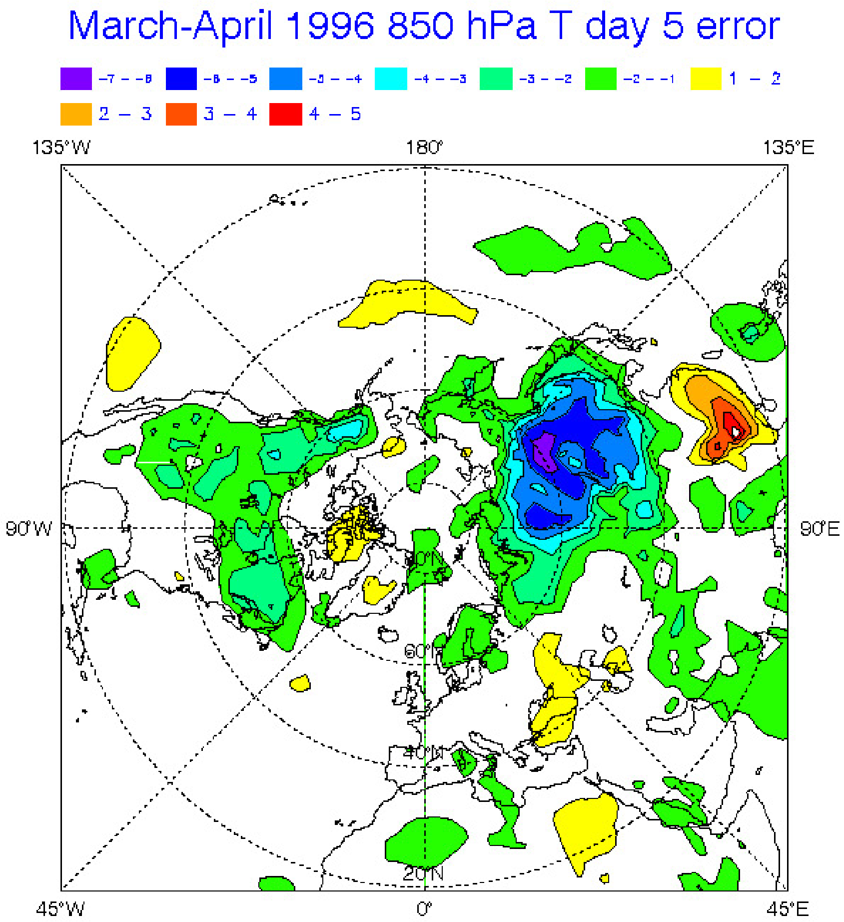


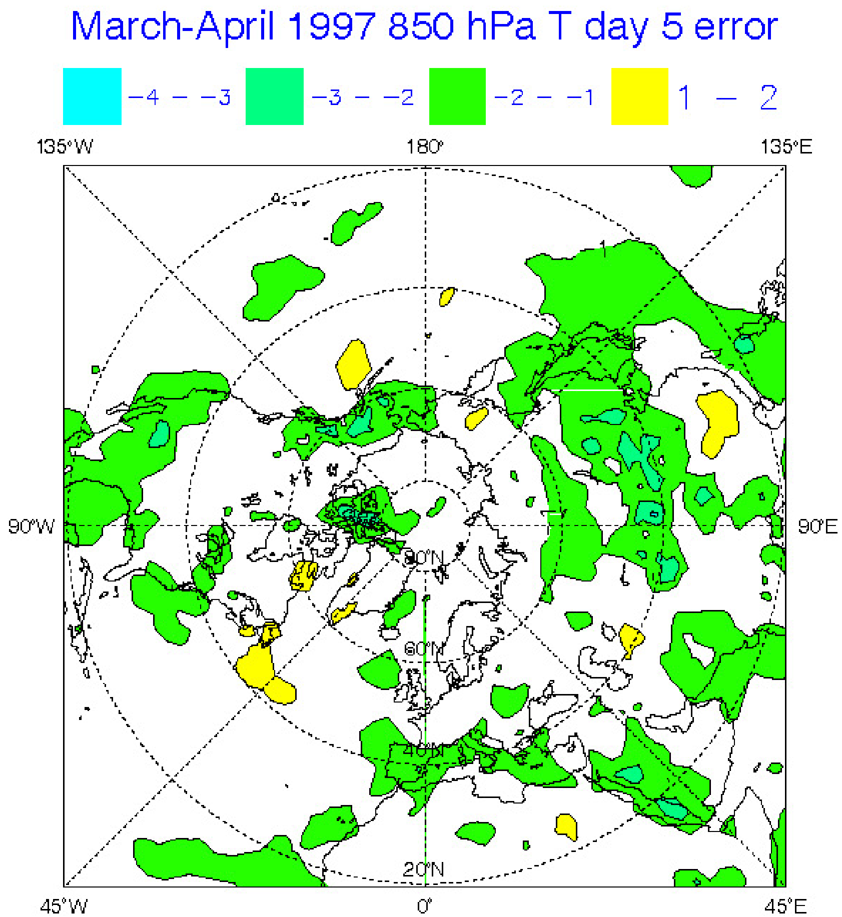


- Impact of landscape differences (forest/grass) on R_{net} are large in spring

Impact of reducing boreal forest

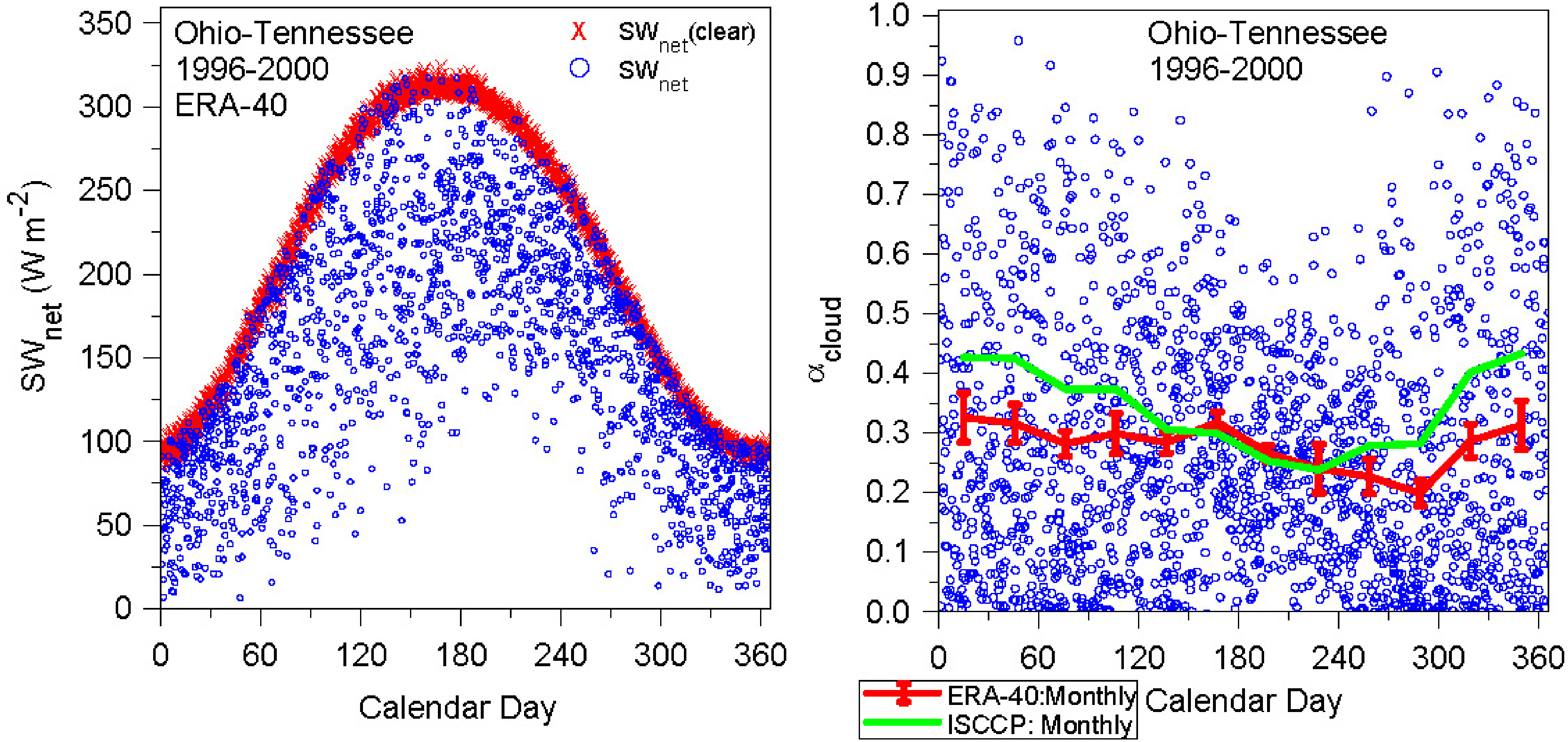
α_{surf} from 0.8 to 0.2





- Large systematic bias reduction; NH forecast skill improved

Cloud albedo



- Transformation of SWCF to α_{cloud}
- Large variability: 10% low bias in winter

Aside on ‘*River basin archive*’

ECMWF Comparison of river basin hydrometeorology in ERA-Interim and ERA-40 with observations

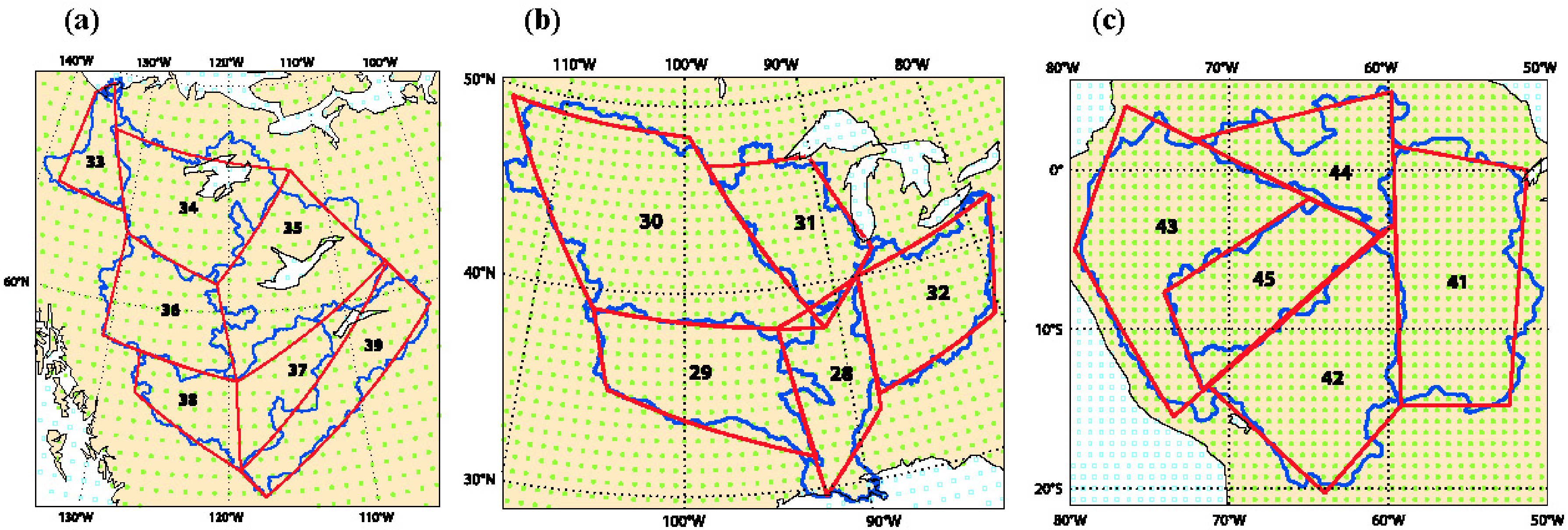
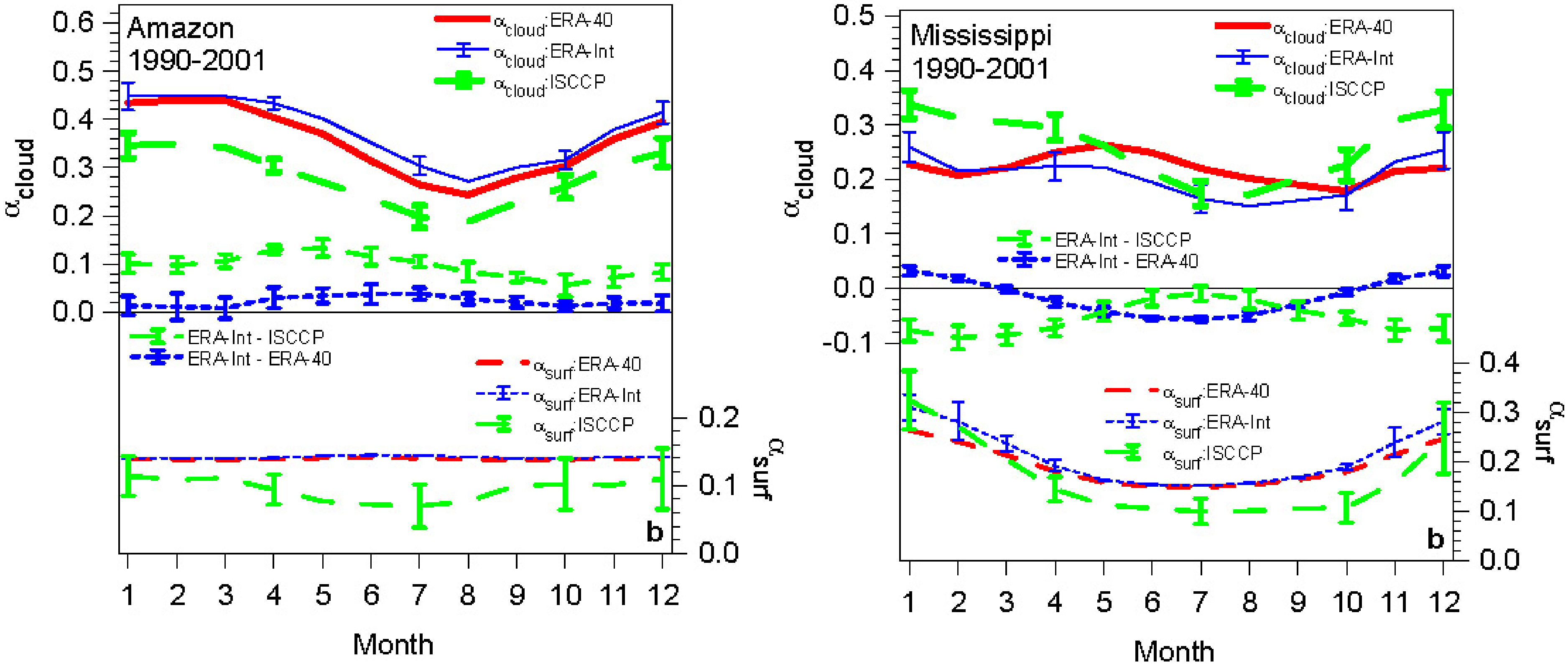


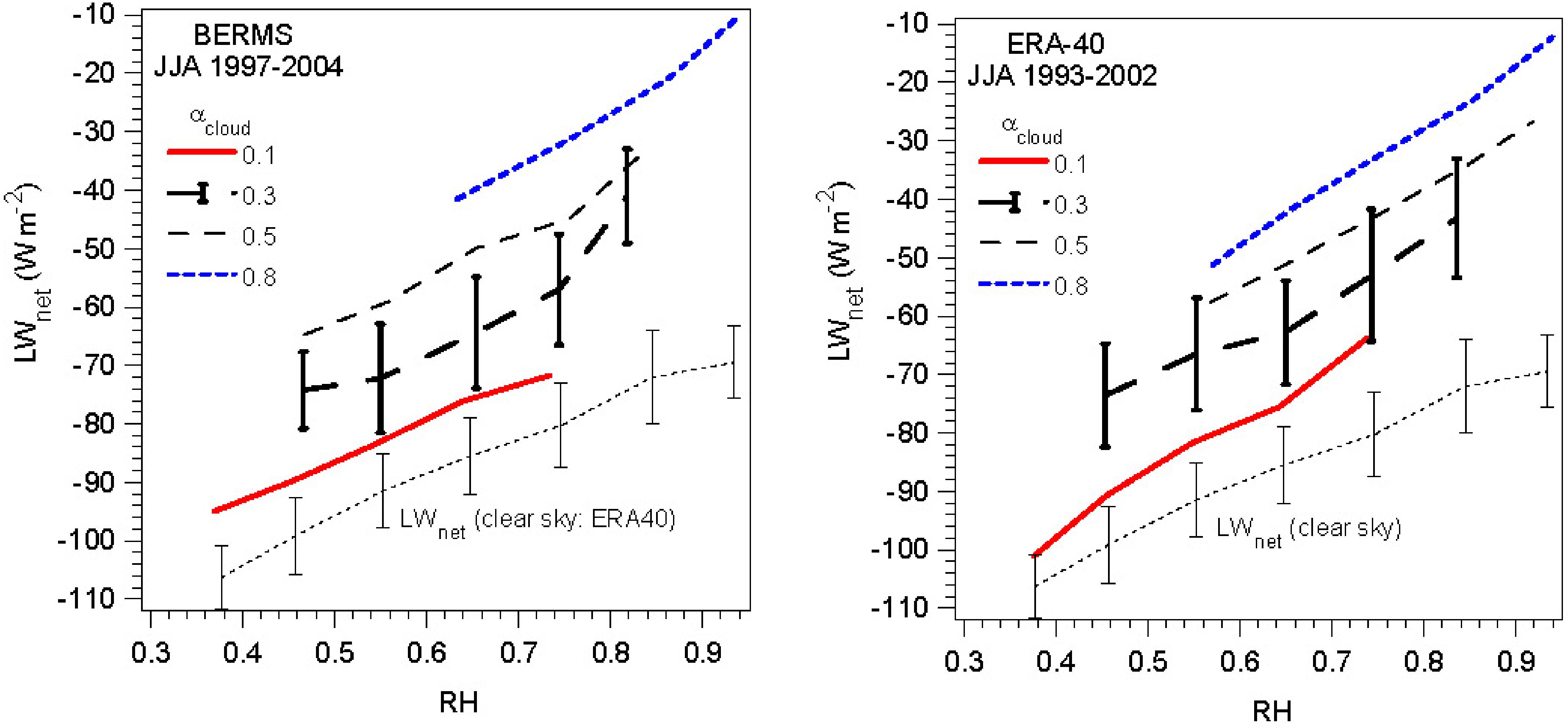
Figure 1: Mackenzie (a), Mississippi (b) and Amazon (c) river basins selected from ERA-40 and ERA-Interim hourly archives. [Betts et al. 2008: TM568]

ERA-40, Interim & ISCCP



- Amazon: reanalyses α_{cloud} biased high
- Mississippi: different bias signature
- ISCCP α_{surf} biased & noisy

Surface LW_{net}



- Point comparison: stratified by RH/LCL & α_{cloud}
- Quasilinear clear-sky and cloud greenhouse effects
- Amazon similar

Coupling of LW_{net} with diurnal temperature range and NBL

Define

$DTR = T_{max} - T_{min}$

Scale by 24h mean LW_{net}

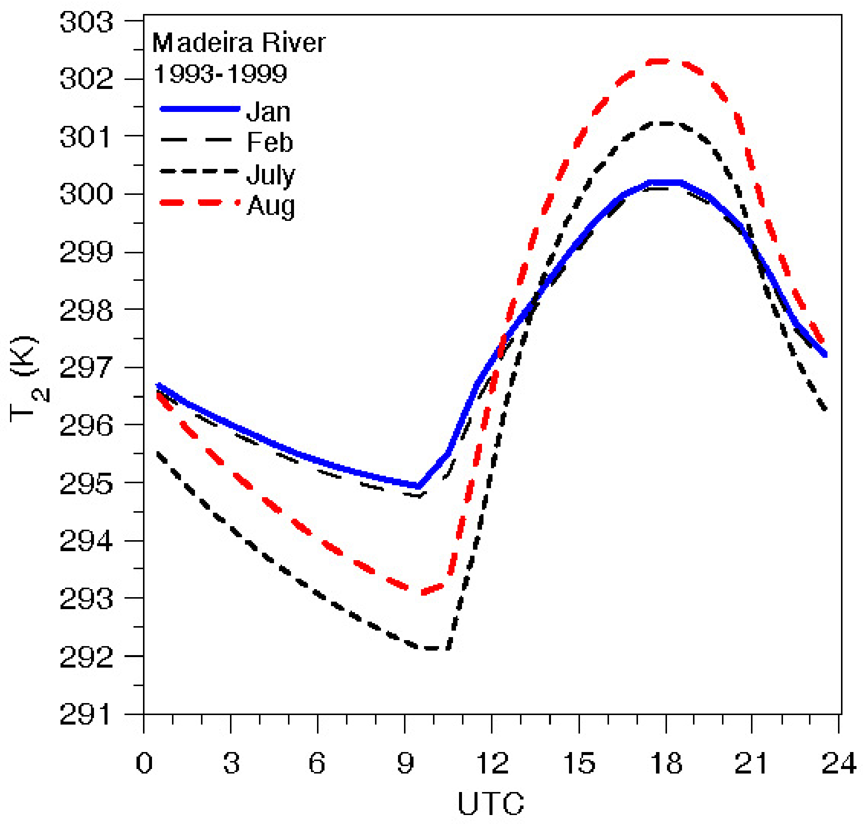
$\Delta T_R = -\lambda_0 \, LW_{net24}$ where $\lambda_0 = 1/(4\sigma T^3)$

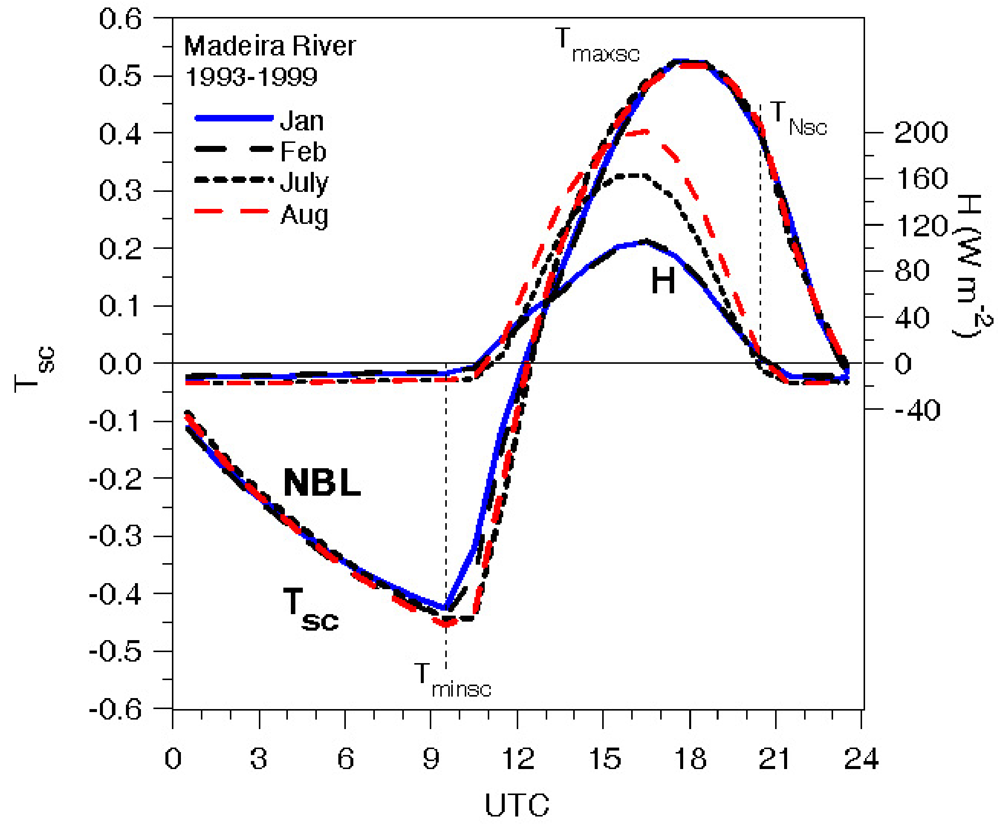
$T_{sc} = (T_2 - T_{24}) \, / \,)T_R$

$DTR_{sc} = T_{maxsc} - T_{minsc} \approx 1$ (Amazon)

[Betts, JGR, 2006]

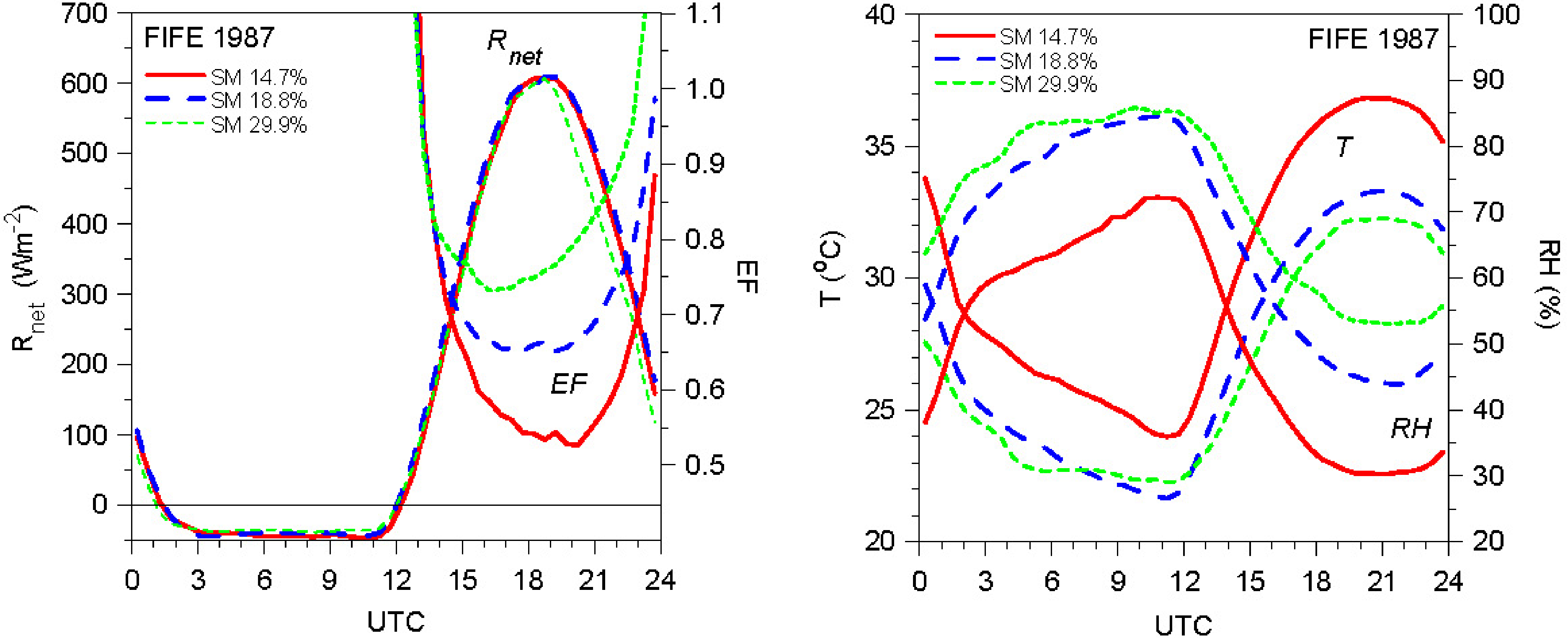
Mean diurnal cycle Madeira river





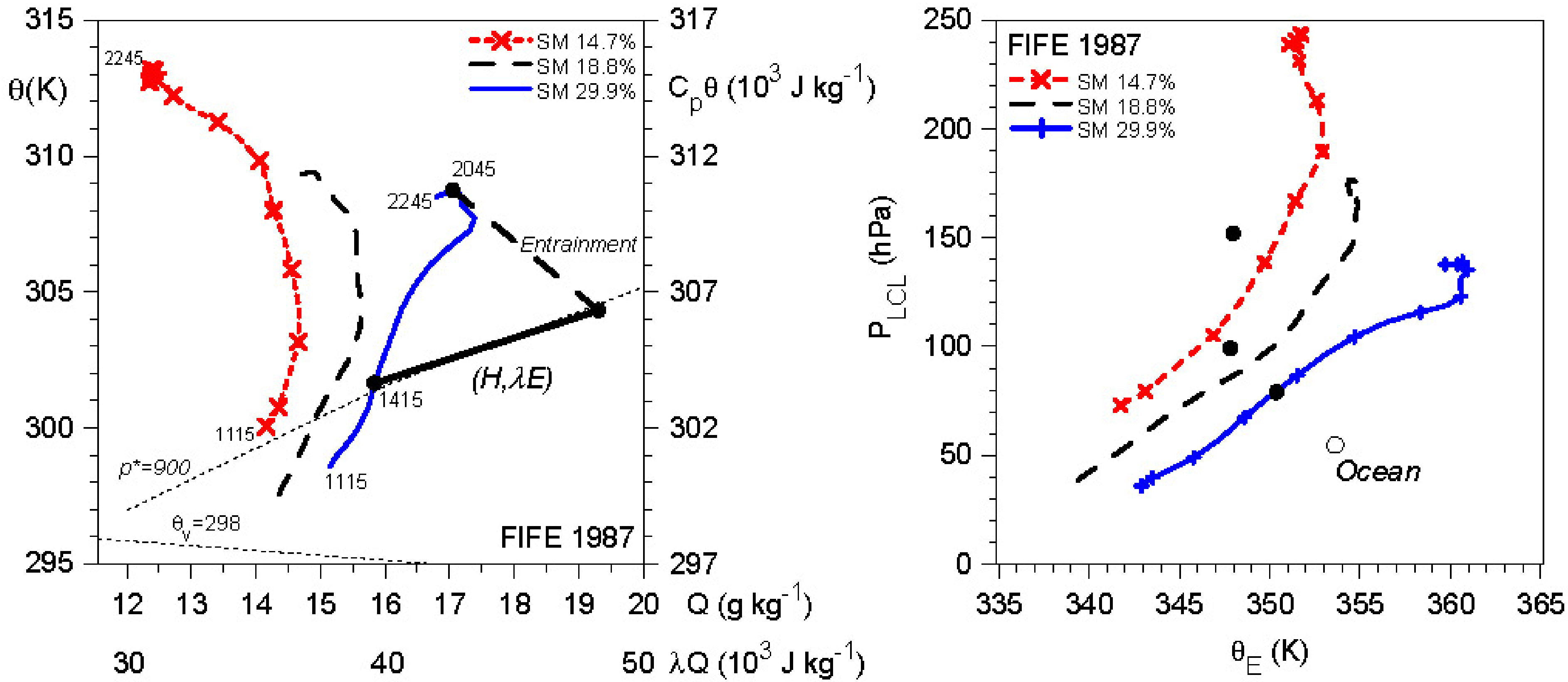
- DTR doubles in dry season (with LW_{net})
- $DTR_{sc} \approx 1$
- $\Delta T_{Nsc} = T_{Nsc} - T_{minsc} \approx 0.9\ DTR_{sc}$

Water availability & the surface energy partition



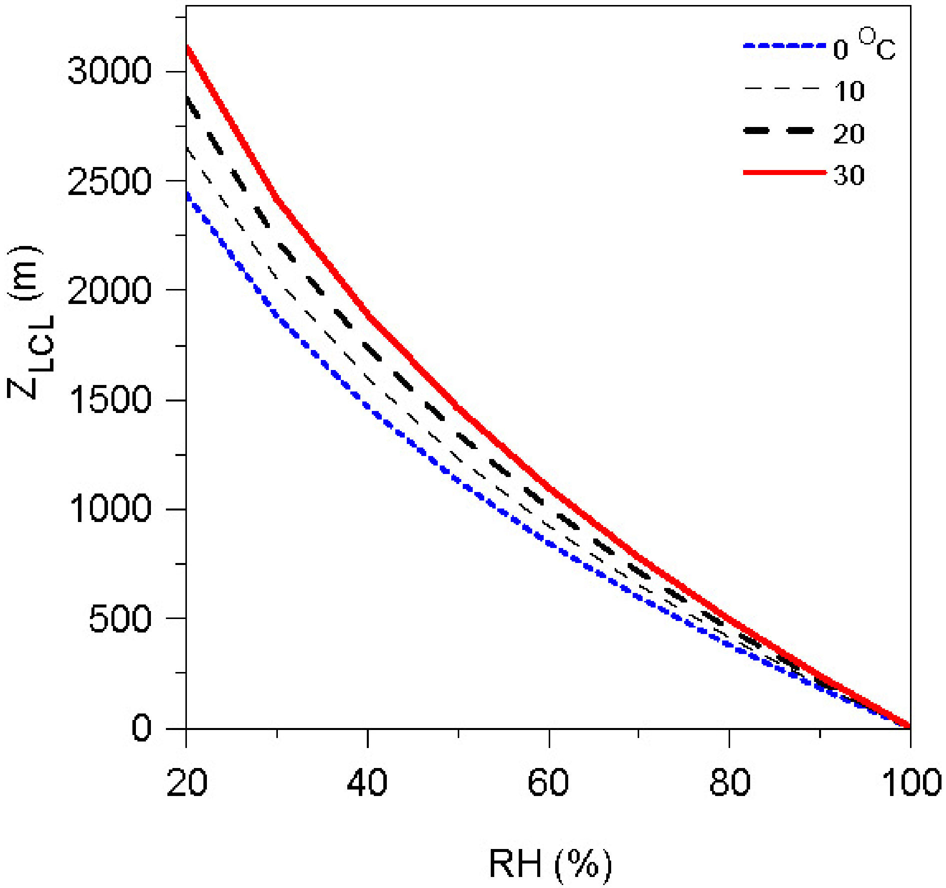
- FIFE grassland: partitioned by soil moisture
  - July & August; little cloud
- Evaporative fraction: EF = λE/(λE+H)

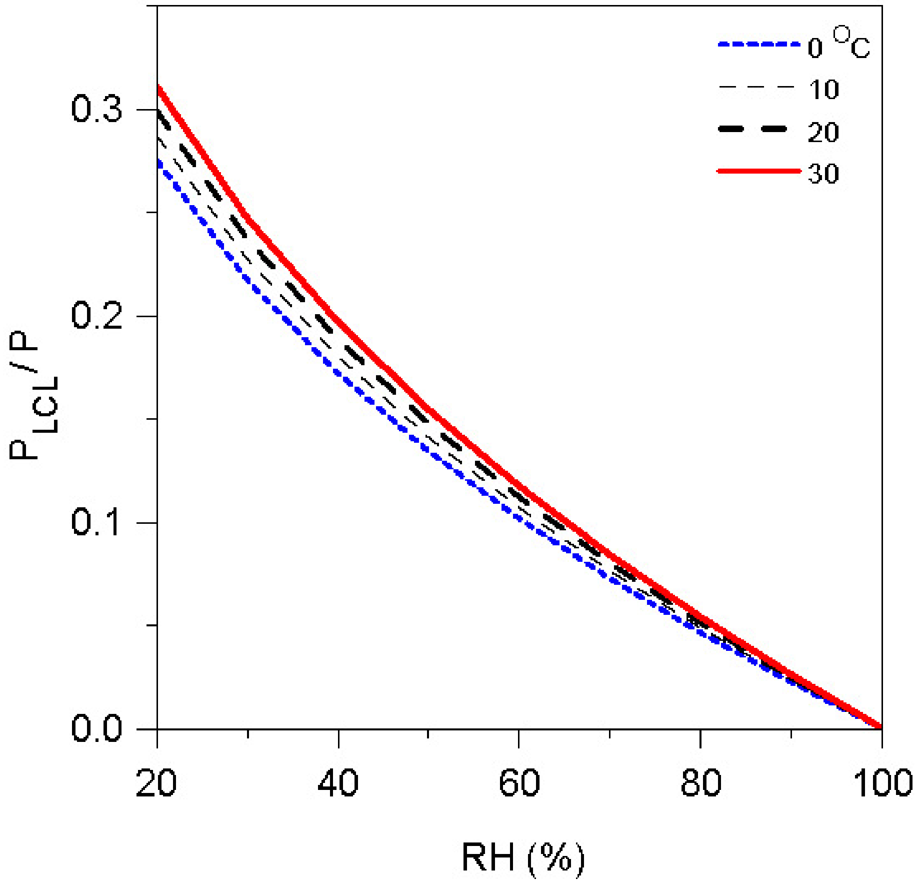
Diurnal cycle on vector diagrams



- $\Delta\boldsymbol{\xi}_m/\Delta t = (\mathbf{F}_s - \mathbf{F}_i)/\ \rho\Delta Z_i$ where $\Delta\boldsymbol{\xi}_m = \Delta(C_p\theta, \lambda Q)_m$
- $(H, \lambda E) = \Omega\ \Delta(C_p\theta, \lambda Q)$ where $\Omega = \rho\Delta Z_i/\Delta t$

Aside: Relation of RH to LCL

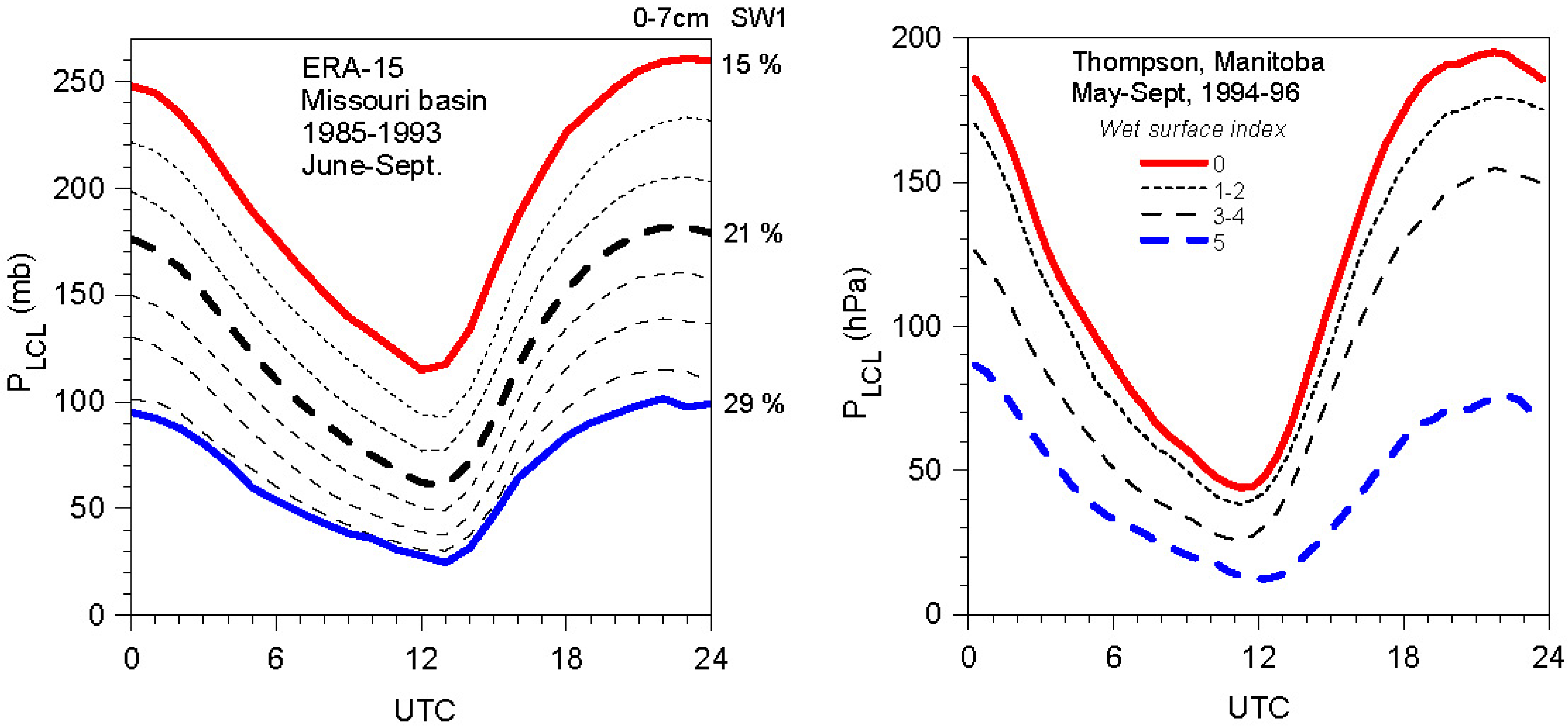




- Z_{LCL} is fn(T) but not p

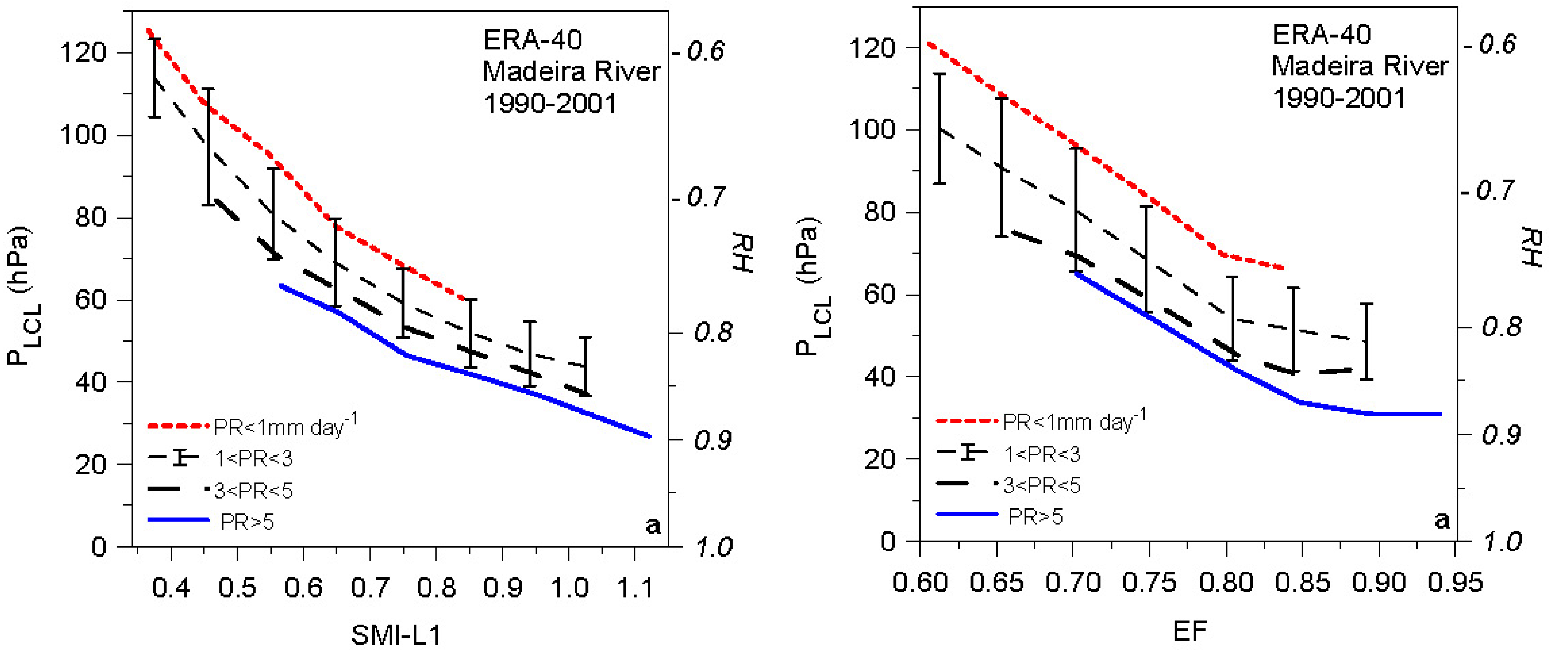
P_{LCL}/p is weak fn(T)

Water availability, Evaporation and LCL



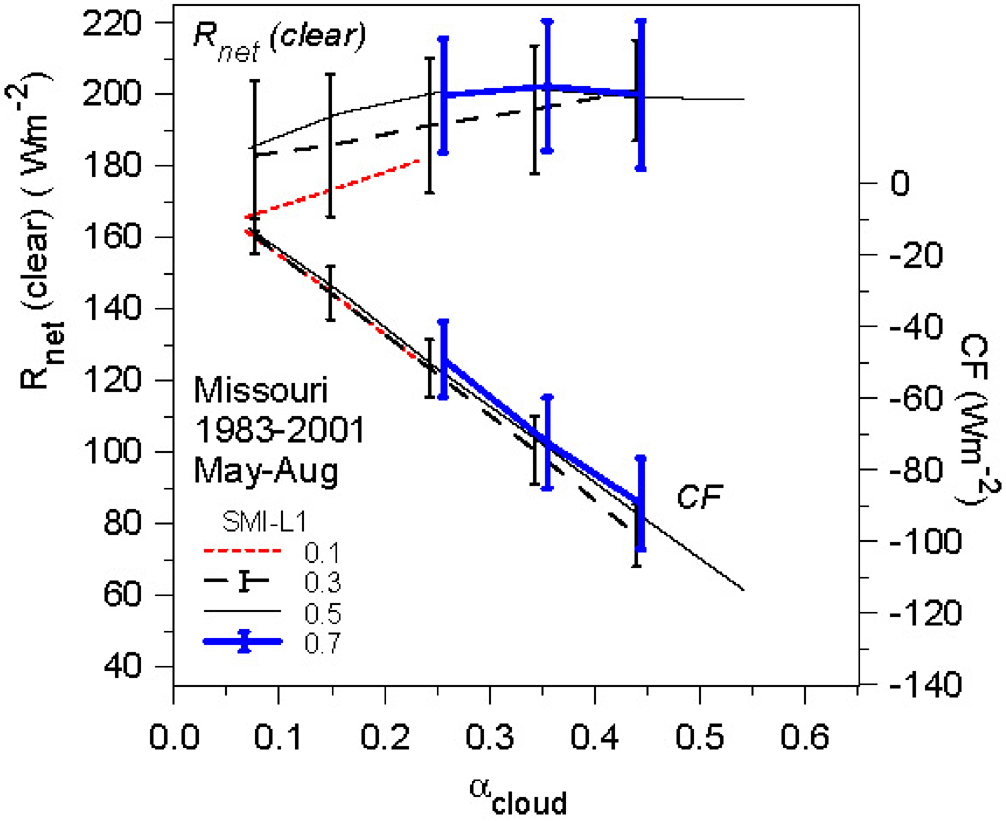
- ERA-15: SW-L1 Boreal forest & moss
- Resistance to evaporation gives RH drop and LCL rise

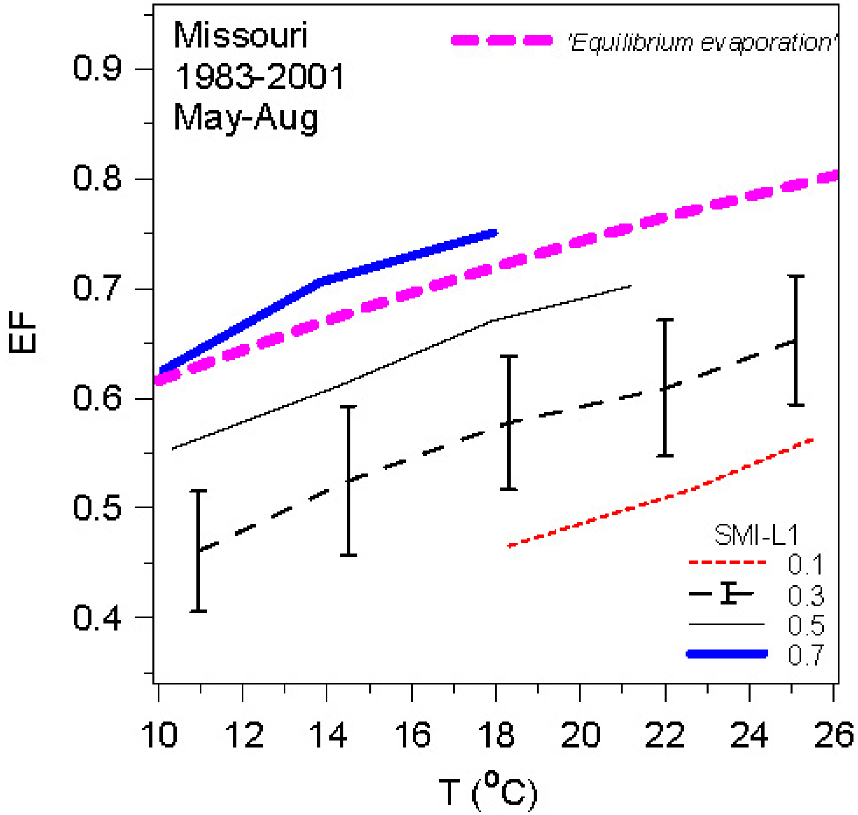
Land-surface-BL Coupling



- SMI-L1 = (SM- 0.171)/(0.323-0.171)
- P_{LCL} stratified by Precip. & SMI-L1 or EF
- Highly coupled system: only P_{LCL} *observable*

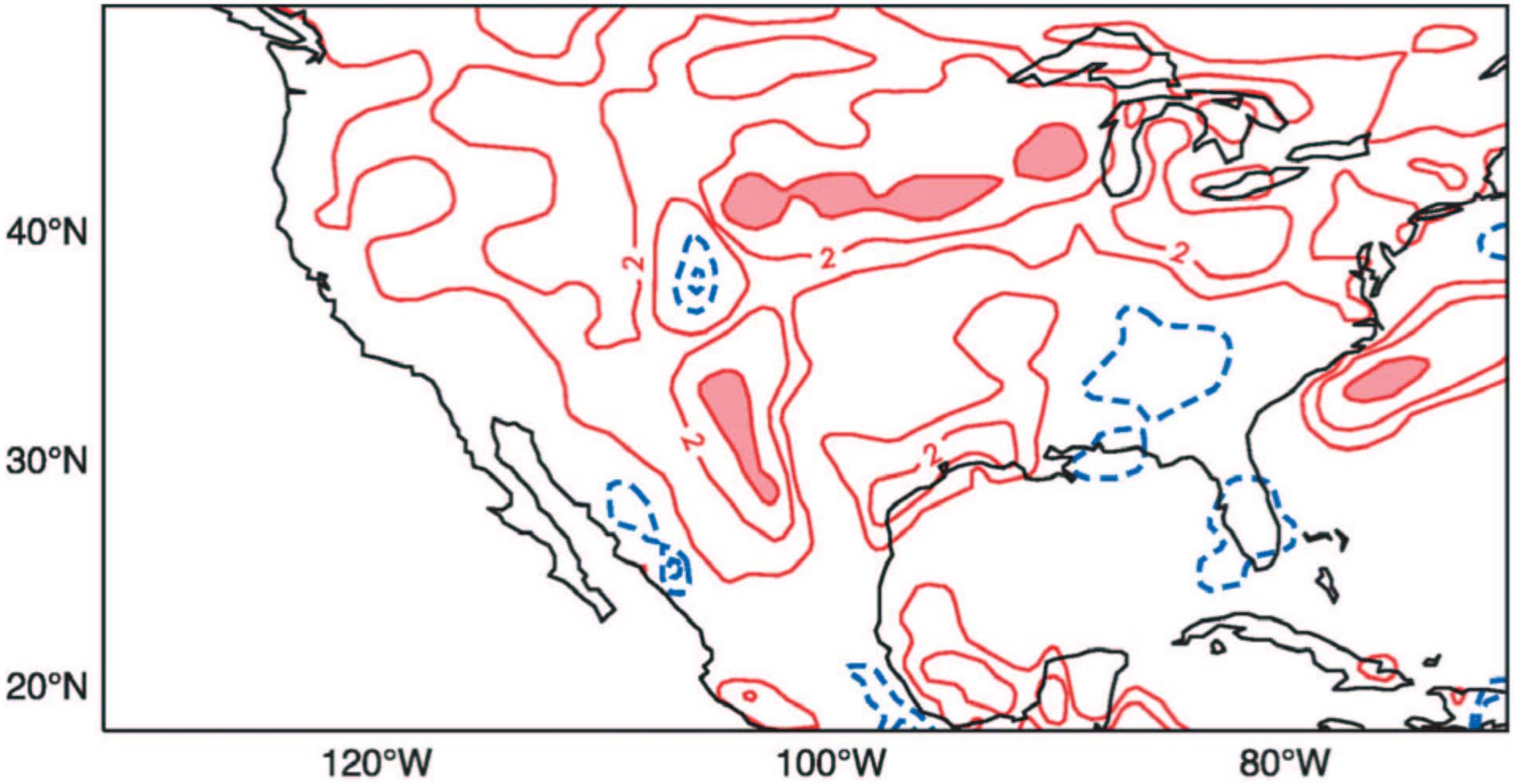
Separating cloud and surface controls on the SEB and EF





- R_{net} depends on cloud cover
- EF depends on T and soil moisture

Evaporation-precipitation feedback

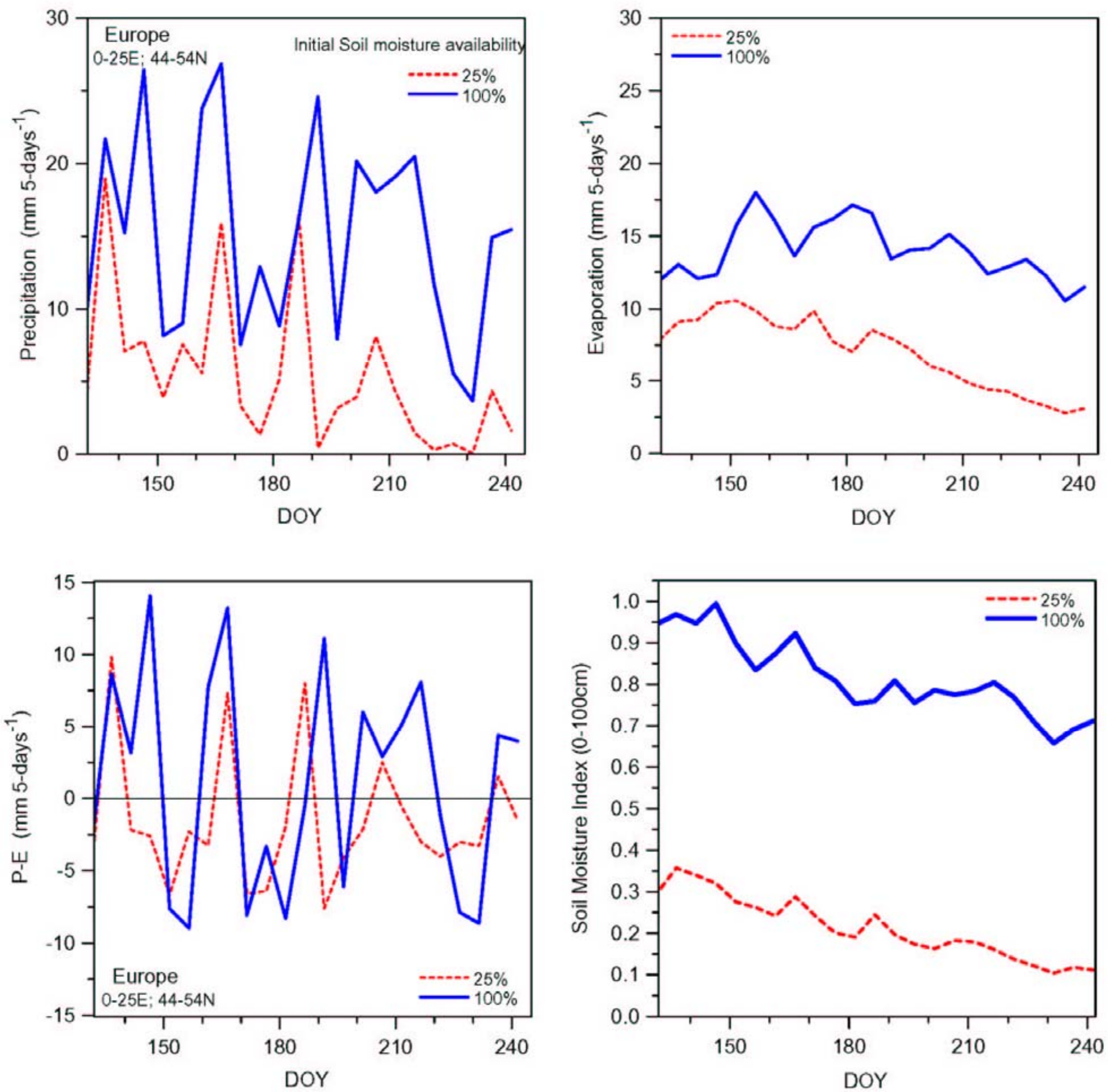


- Difference in monthly forecast precip. (July 1993) starting with wet and dry soils

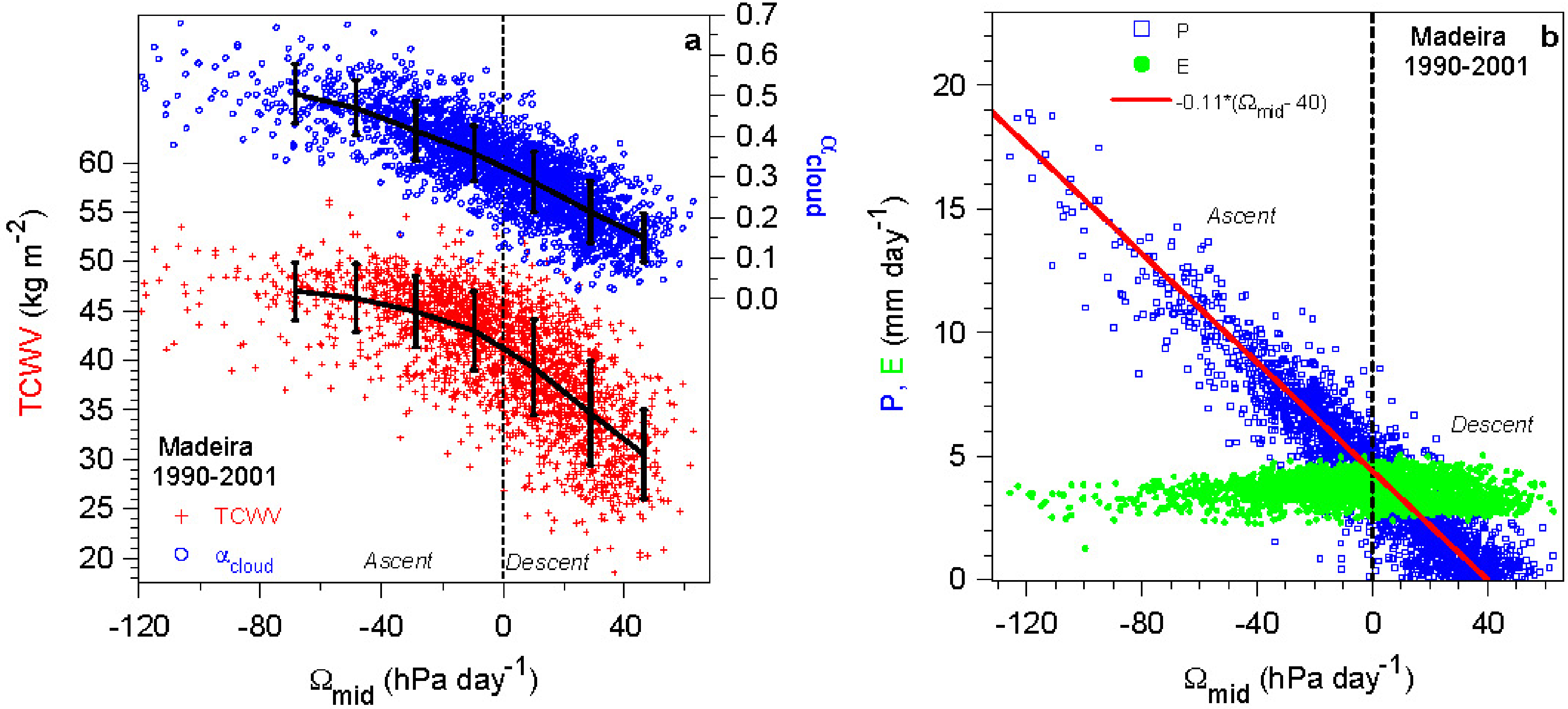
[Beljaars et al. 1996]

Evaporation-precipitation feedback in ERA-40

- Two 120-day FX from May 1, 1987, initialized with wet and dry soils
- Memory lasts all summer
- E and P fall with dry soil
- E-P changes little; variability drops

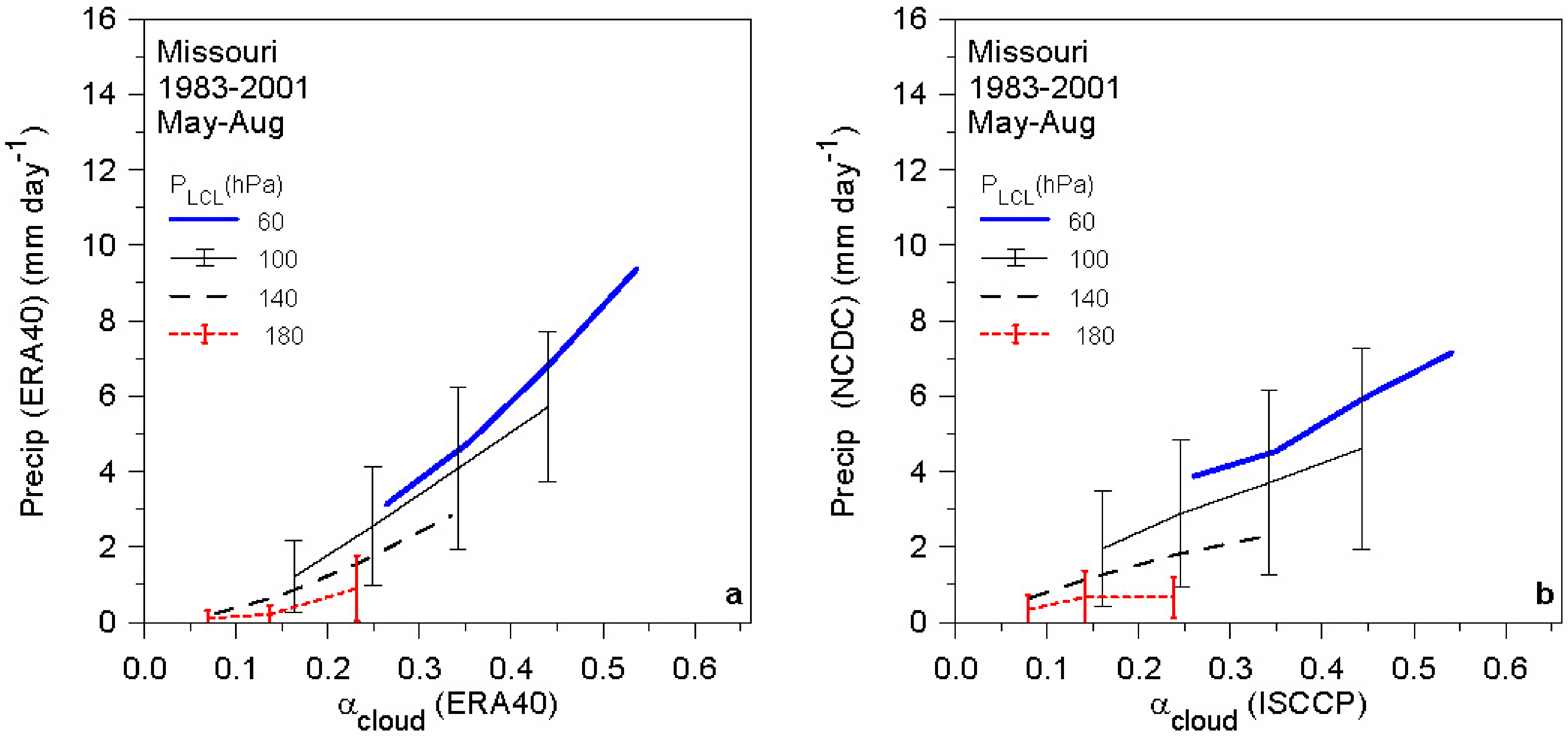


Precipitation and cloud coupling to vertical motion



- Partition of moisture convergence into TCWV, α_{cloud}, and precipitation

Cloud forcing to Precipitation



- SWCF/precip less in ERA-40 (0.48) than *observed (0.74)*
- Cloud radiative & diabatic forcing *comparable*
- *And closely coupled on all timescales in atmosphere*

Summary/Philosophy

- Look for relationships and information in the coupling of processes/ observables
- Models have only limited value without deep understanding of the coupling of processes
- Observations important for evaluation & to suggest processes that are simply missing
- Every model cycle needs analysis of relationships, diurnal, daily mean and seasonal, for both wet and dry seasons (or disturbed/suppressed conditions) against observations for tropical and mid-latitude climate regimes
- A challenge: but tractable as both global, regional and point time-series datasets improve