Land-surface-atmosphere coupling

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Land-surface-atmosphere interaction

- Many interdependent processes
  - surface energy balance
  - shortwave and longwave fluxes: water vapor greenhouse & clouds
  - 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
- *Many, many people have contributed*
- Reflect my idiosyncrasies; and many aspects of the ECMWF model

References

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Themes

- *Land-surface climate; seasonal climate transitions*
- Evaluating models with data
- Surface albedo and effective cloud albedo
- *Cloud radiative impacts: SW and LW*
- Ice-albedo & water vapor greenhouse feedback
- Diabatic terms: precipitation and cloud forcing
- Evaporation-precipitation feedback
    - *Talk is mostly Figures: Betts, A. K. (2009) for details*
    - *Alanbetts.com for seasonal climate discussion -soon*

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

Clouds & 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*** ***[per unit area surface]***

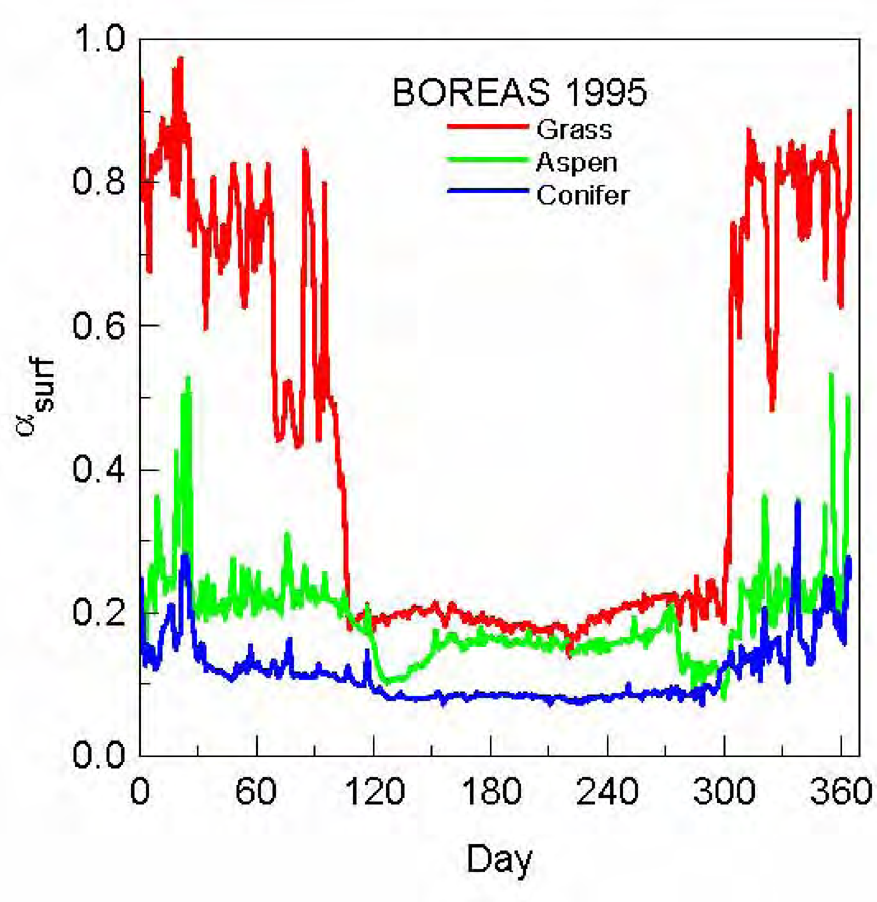
  - scaled surface **short-wave cloud forcing, SWCF**

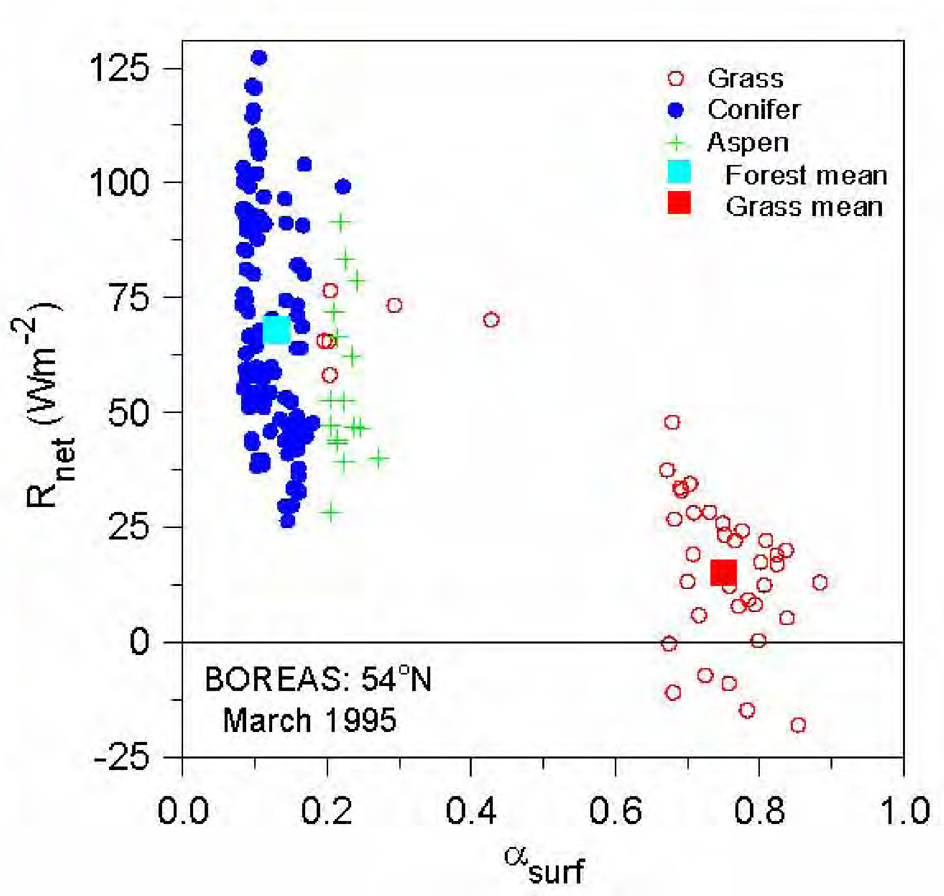
$$SWCF = SW_{down} - SW_{down}(clear)$$

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

[Betts and Viterbo, 2005; Betts, 2007]

Surface albedo

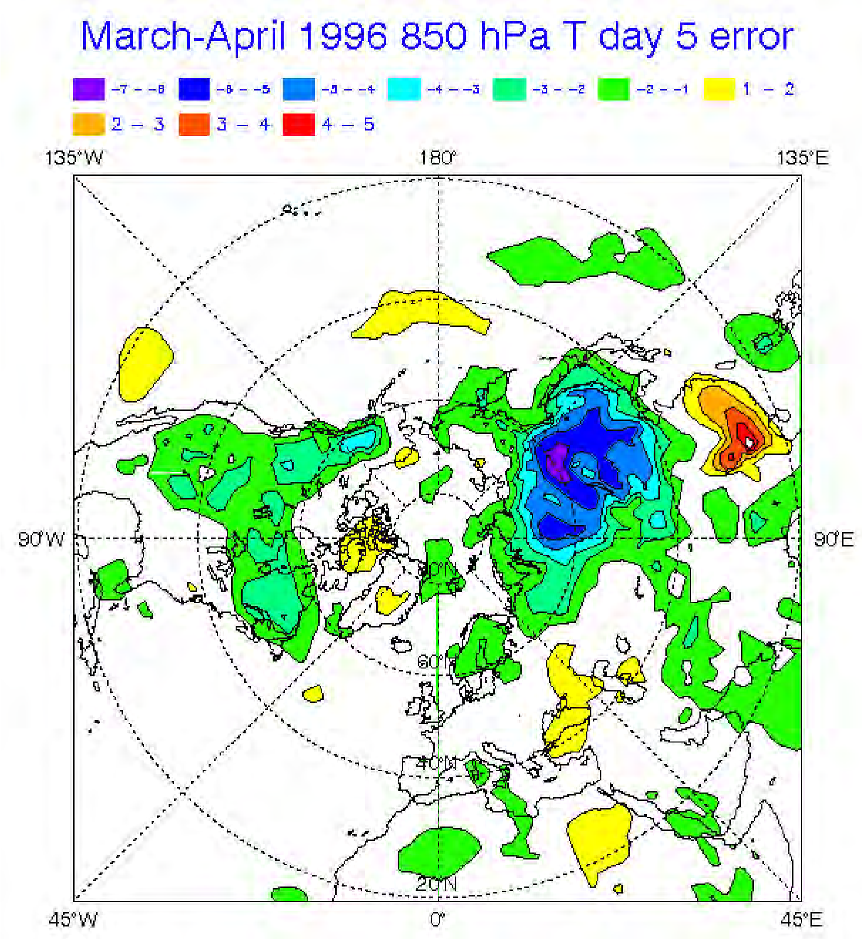




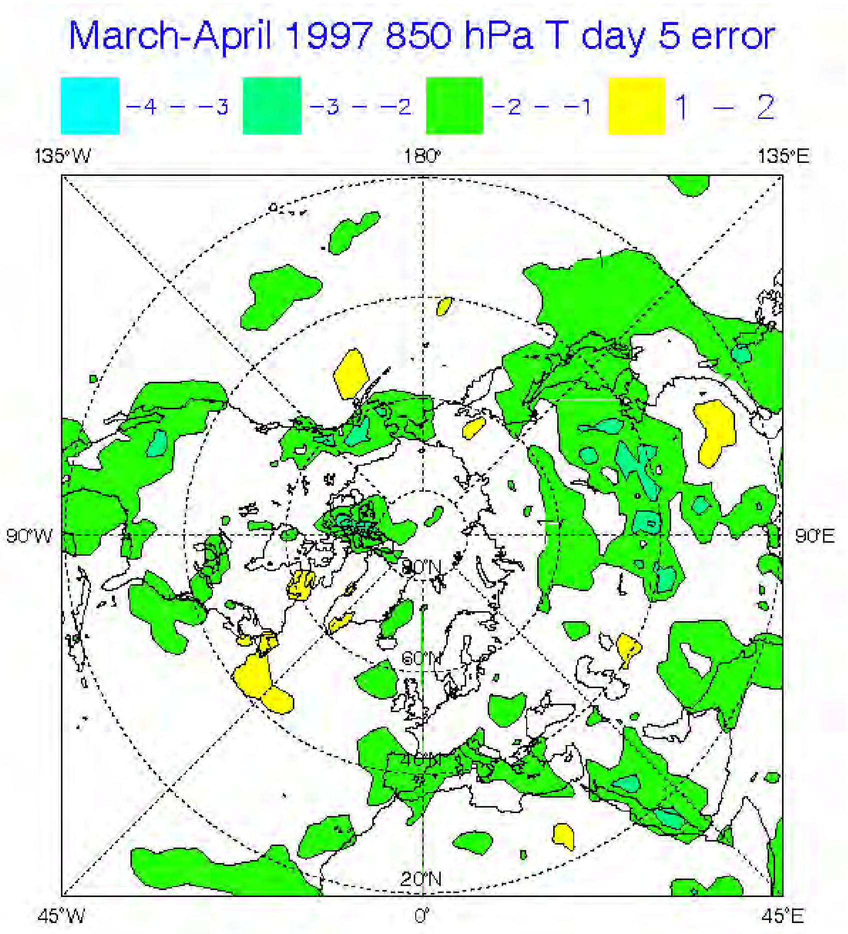
- Impact of landscape differences (forest/grass) on R_{net} are large in spring

Impact of reducing boreal forest

α_{surf} *from 0.8 to 0.2 (snow)*



March-April 1996 850 hPa T day 5 error



March-April 1997 850 hPa T day 5 error

- Large systematic bias reduction;
- NH 850 hPa T forecast skill improved Feb. to mid-May

Winter climate transition

- **Sun is low; and snow reflects sunlight, except where trees!**
- **R_{net} low, sublimation small, clear sky, outgoing LW_{net} large, gets colder**

Winter transition

- First heavy snow brings plunge of Temp. because reflection of sunlight drops net radiation below zero –
  [plus reduced water vapor greenhouse]
- Related to **snow/ice-albedo feedback** in climate system
- Related to accelerated warming & melting in the Arctic
- *Sublimation of snow by residual SW_{net} reduces surface solar heating to zero [& evaporation is reduced]*
- **Coupled to water vapor greenhouse feedback:** *evaporation falls with frozen temperatures & cloud decreases. Clear sky outgoing LW_{net} increases and locks in colder temperatures*

Rough Energetics

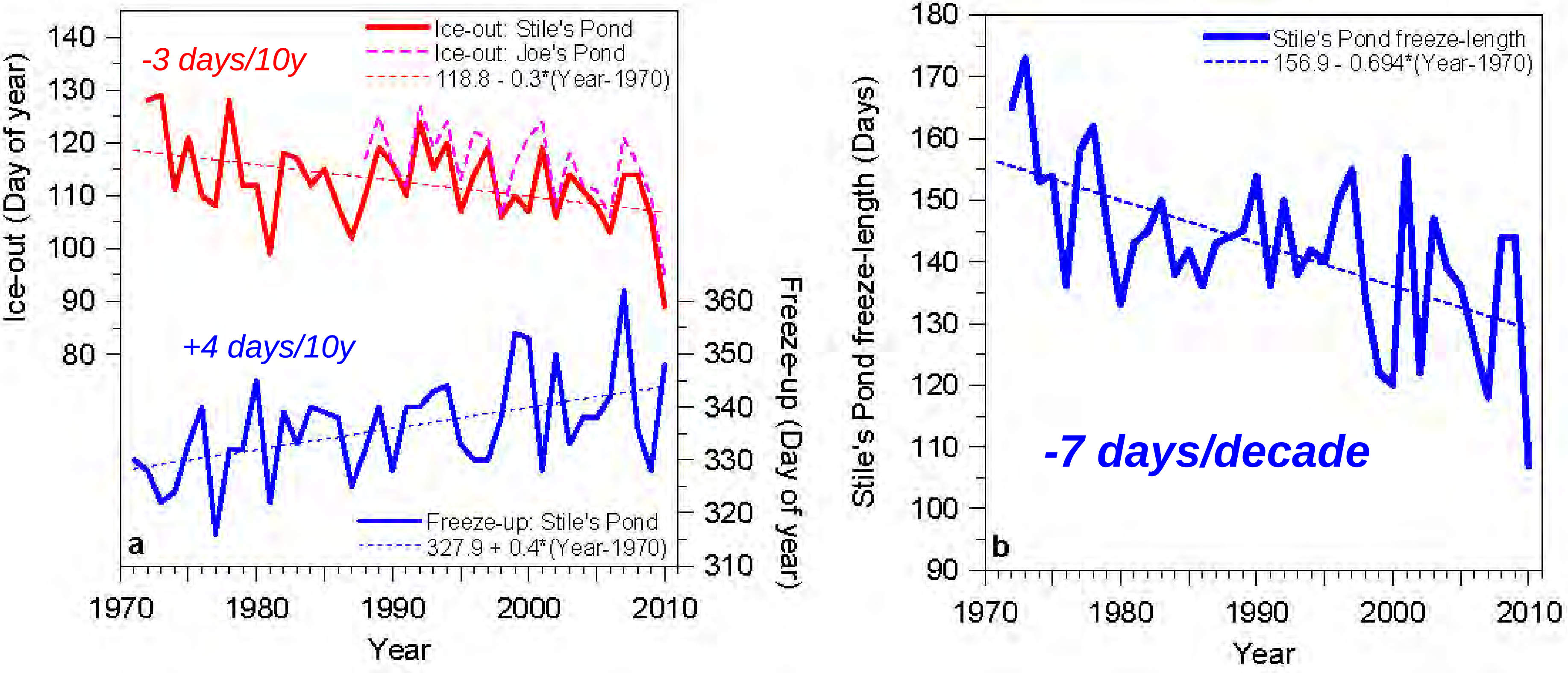
- Winter SW_{down}(clear) ≈ 130 Wm^{-2}
- 10cm fresh snow changes albedo from 0.15 to 0.75 & drops SW_{net} from 110 to 30 Wm^{-2}

- Residual 30 Wm^{-2} sublimes 1cm snow/day

- Snow loss increases as snow ages
  - snow lasts ≈ 5 days,
  - reducing solar heating to ≈ zero

Local Climate Indicators

Small lake freeze-up & ice-out

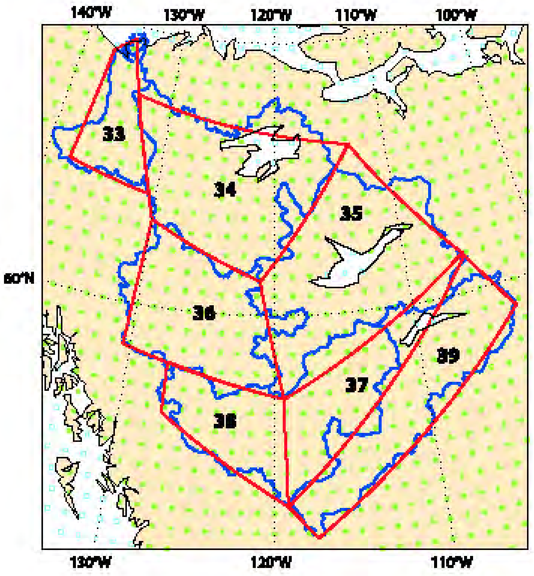


- **Small lakes are *climate indicators for the cold season* in Vermont.**
- Freeze-up depends on lake and air temperatures in the fall;
- Ice thickness depends on the severity of the winter,
- Spring melt/ice-out depends on ice thickness and air temperatures in spring.

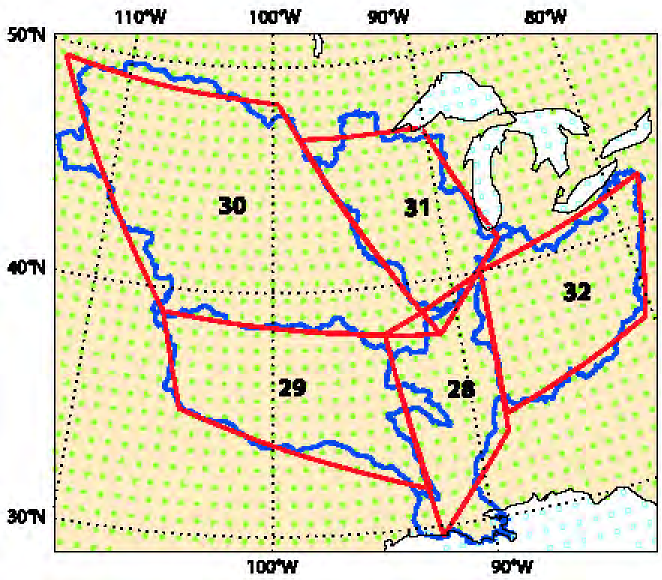
Aside

River basin archive

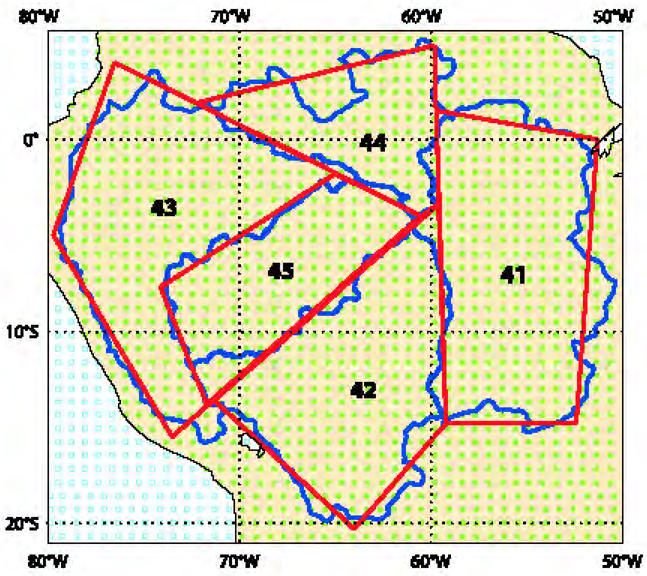
ERA-40 and ERA-Interim



Mackenzie



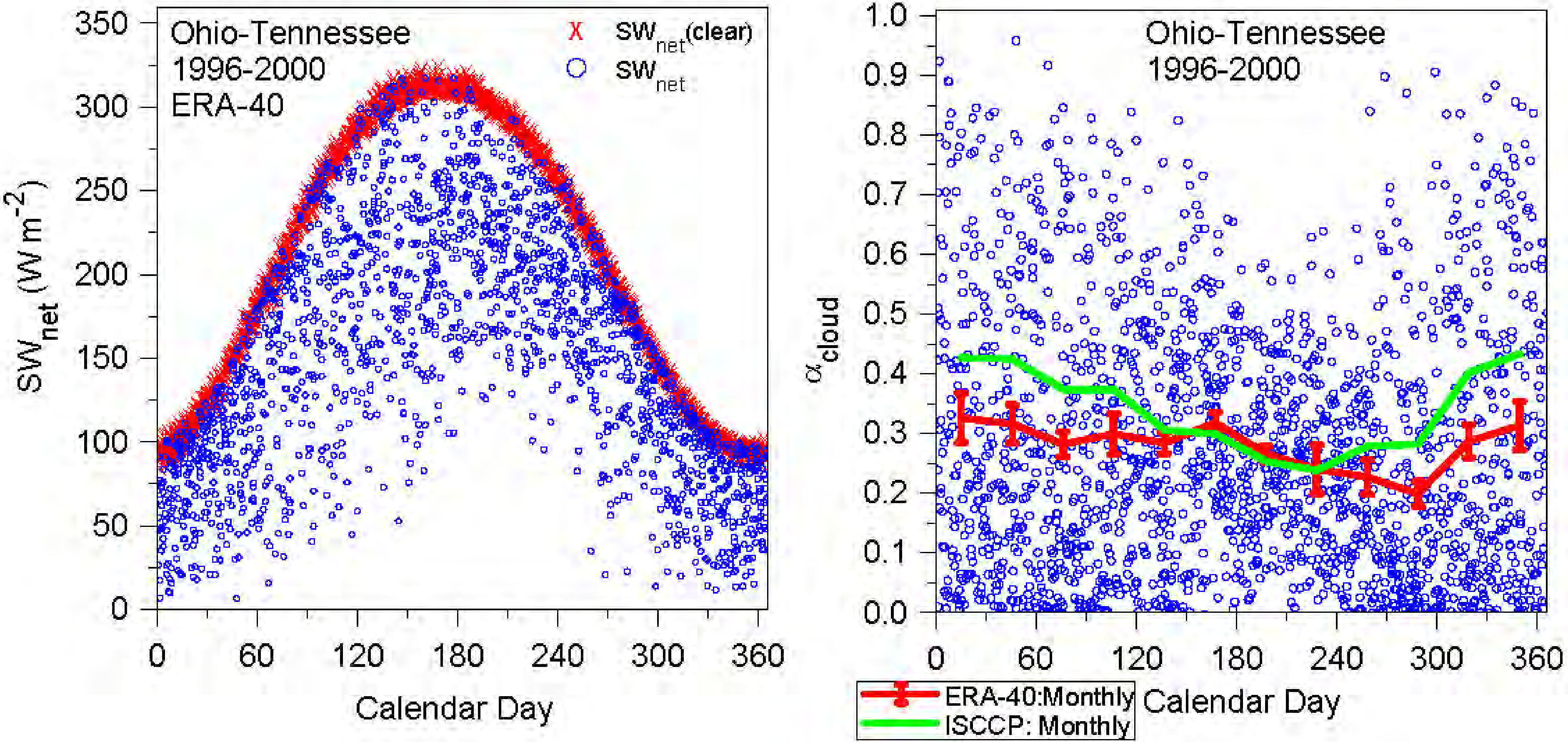
Mississippi



Amazon

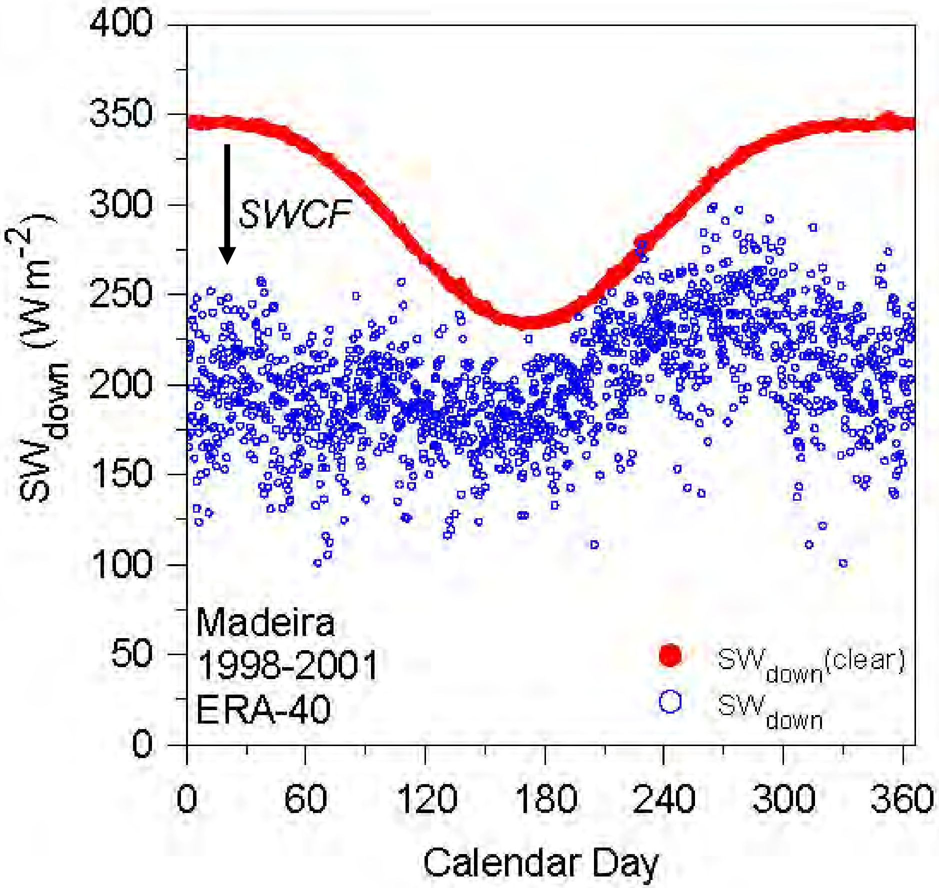
Evaluation on river basin scale, starting from **hourly archive**

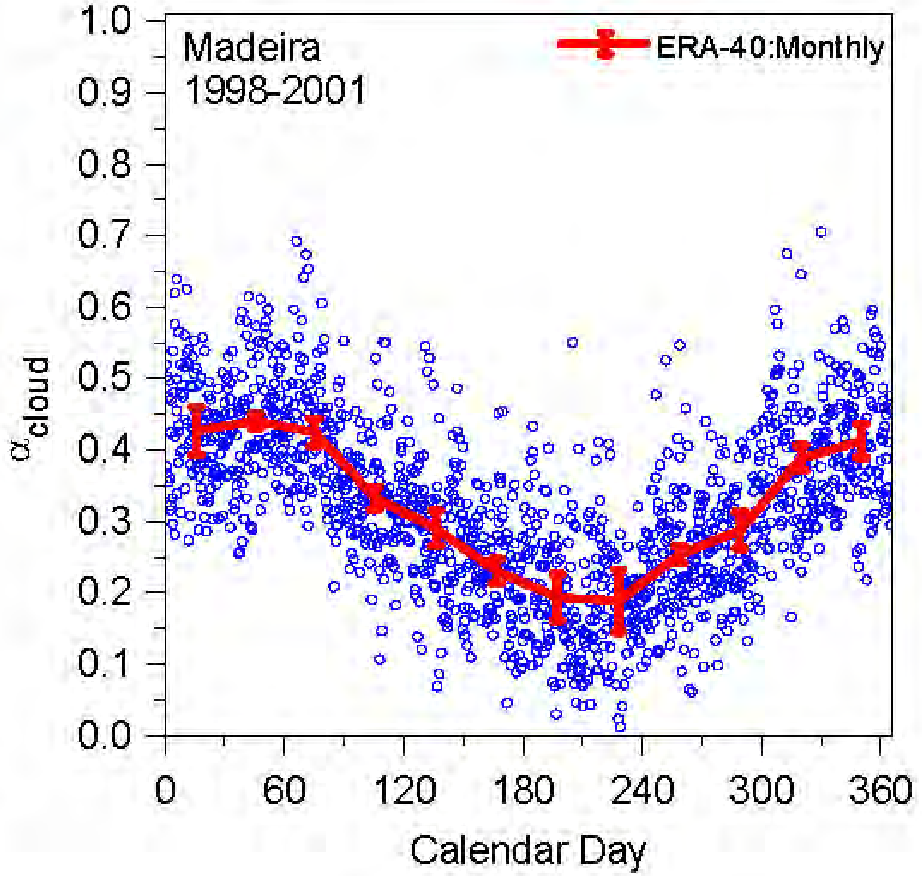
Effective Cloud albedo



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

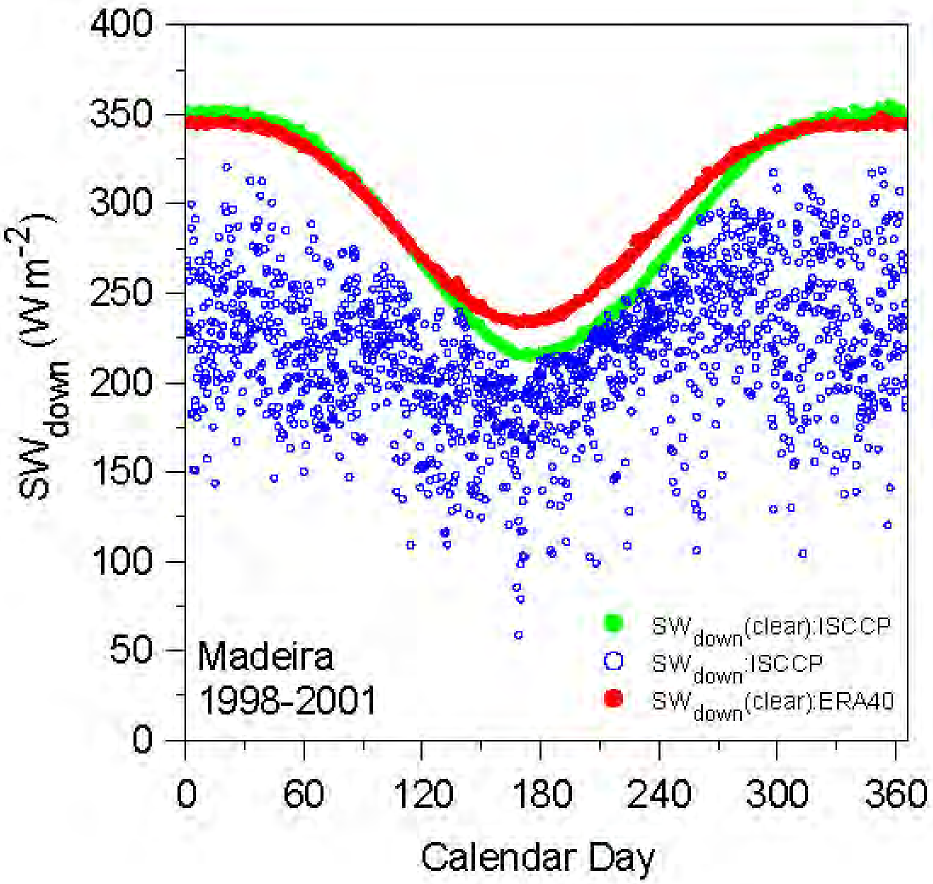
Eff. Cloud albedo: ERA-40 data

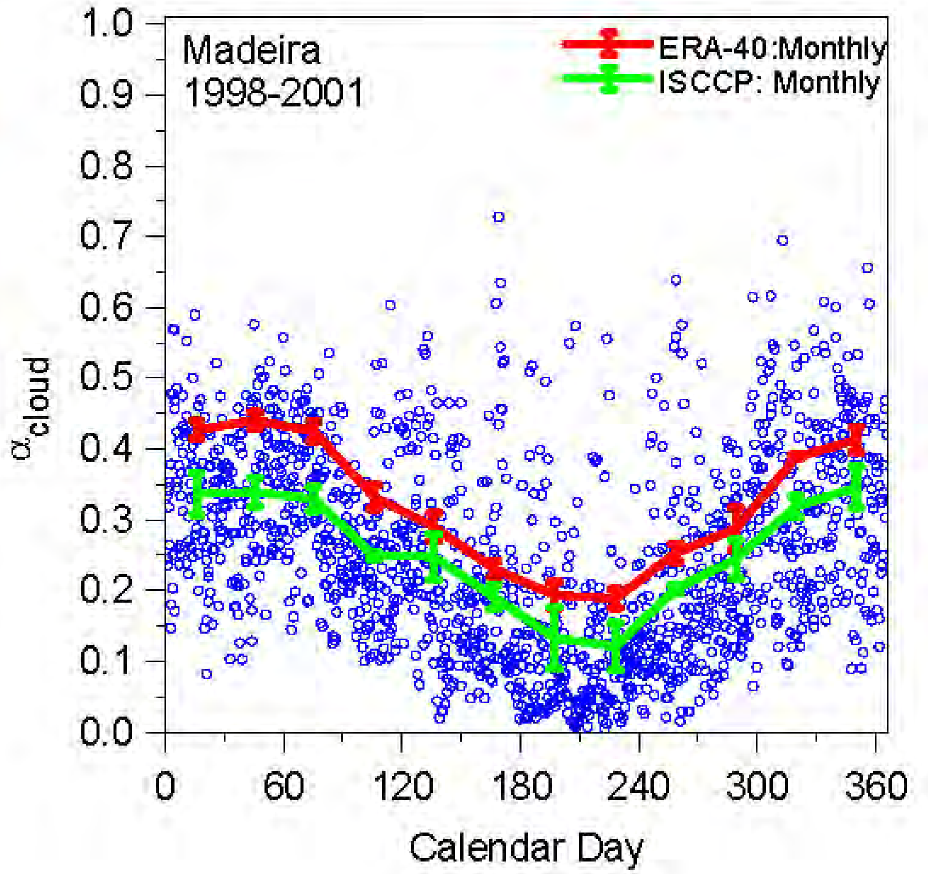




- Transformation of SWCF to α_{cloud}
- Seasonal cycle OK: small daily variability: biased???

Eff. Cloud albedo: ISCCP data

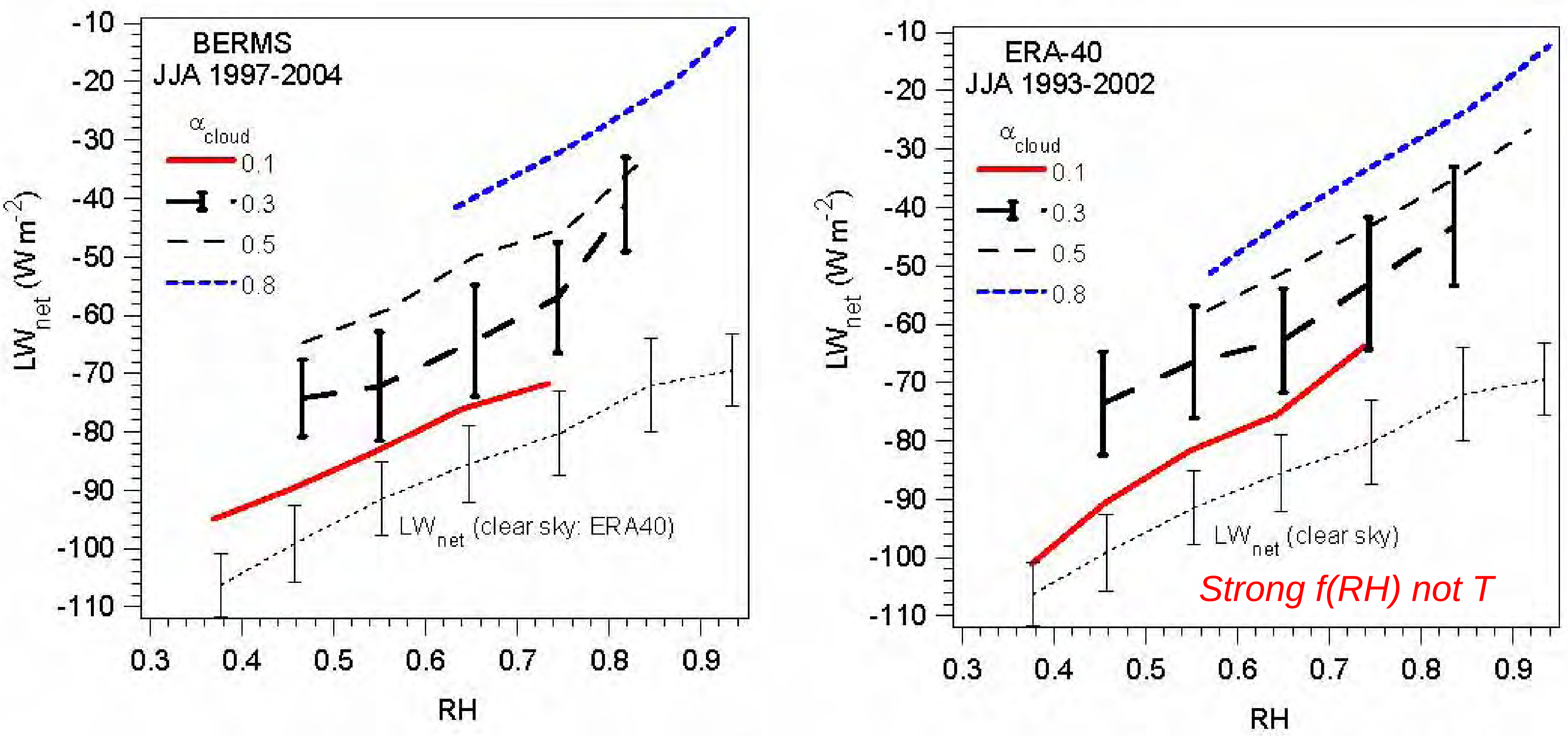




- Different clear-sky flux: Aerosol differences
- ERA-40 systematic high bias in α_{cloud} ≈ +7%
- ISCCP has more daily variability

Longwave

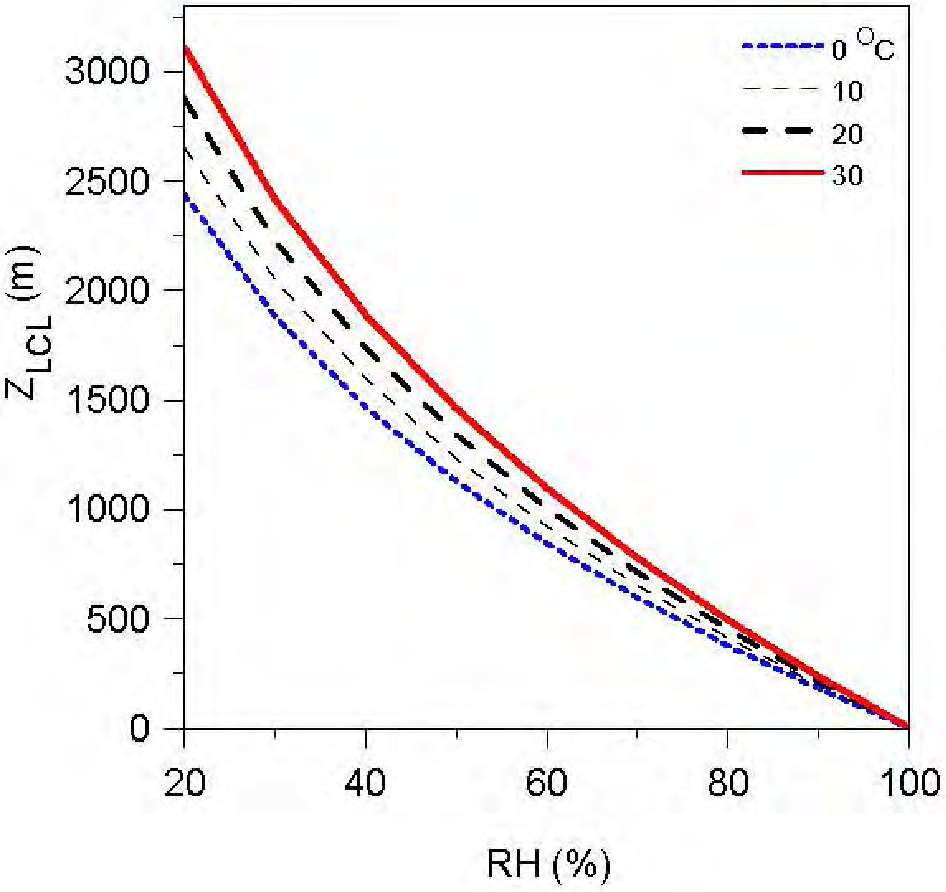
Surface LW_{net}

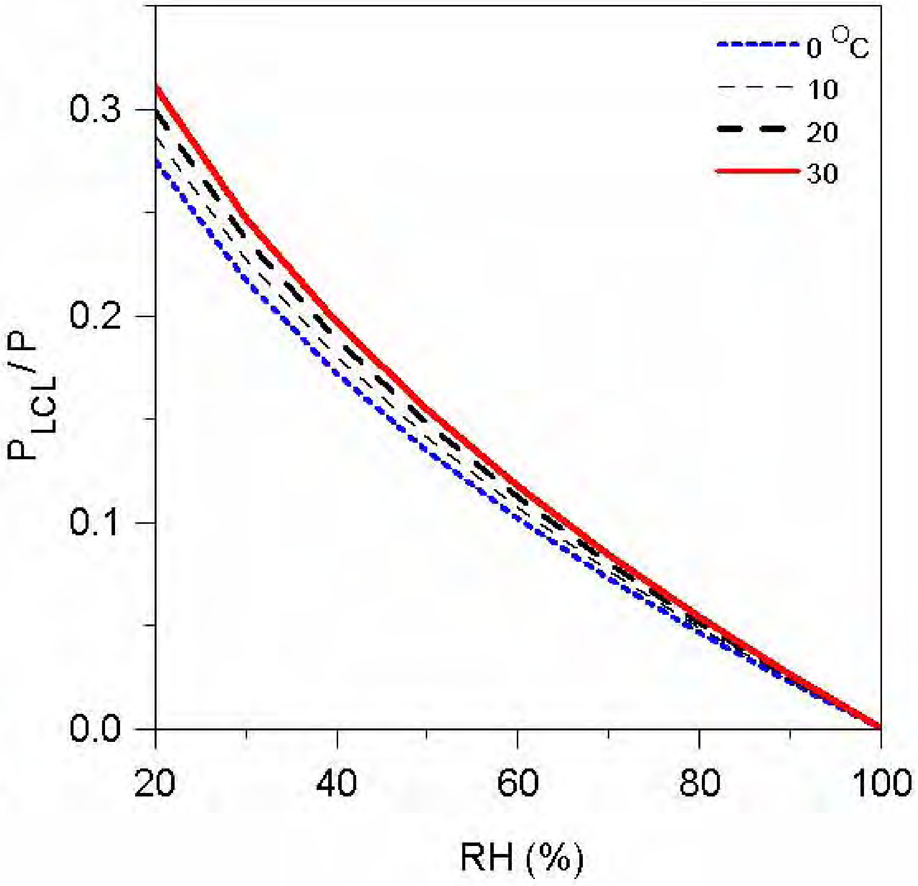


Strong f(RH) not T

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

Aside: Relation of RH to LCL





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

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

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

Define *diurnal temperature range*

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

Scale by 24h mean LW_{net}

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

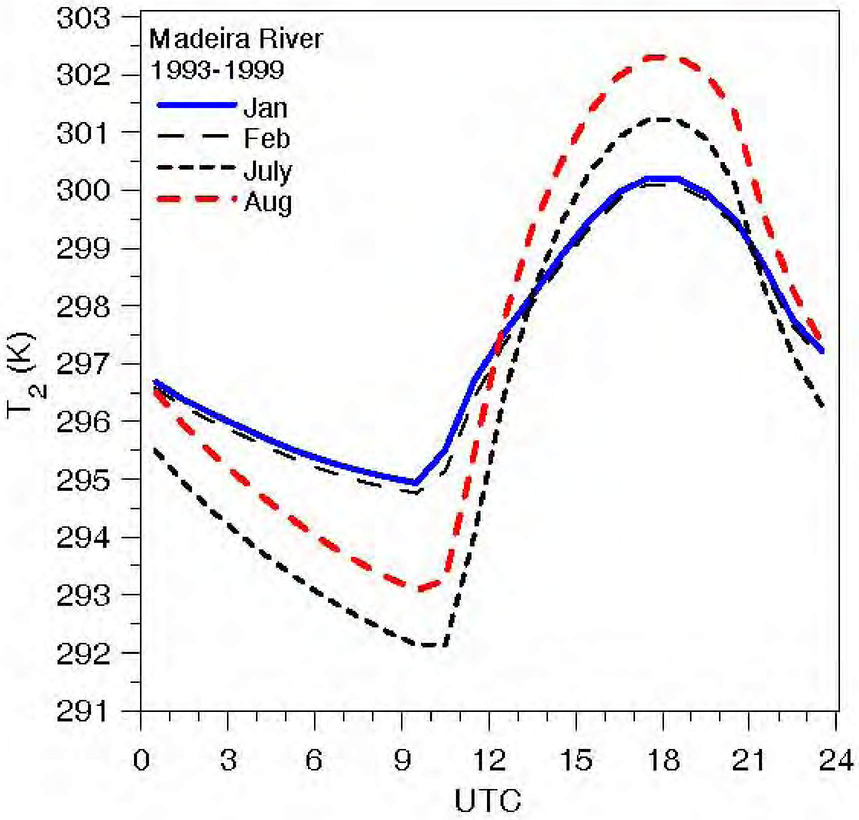
Slope Planck fn

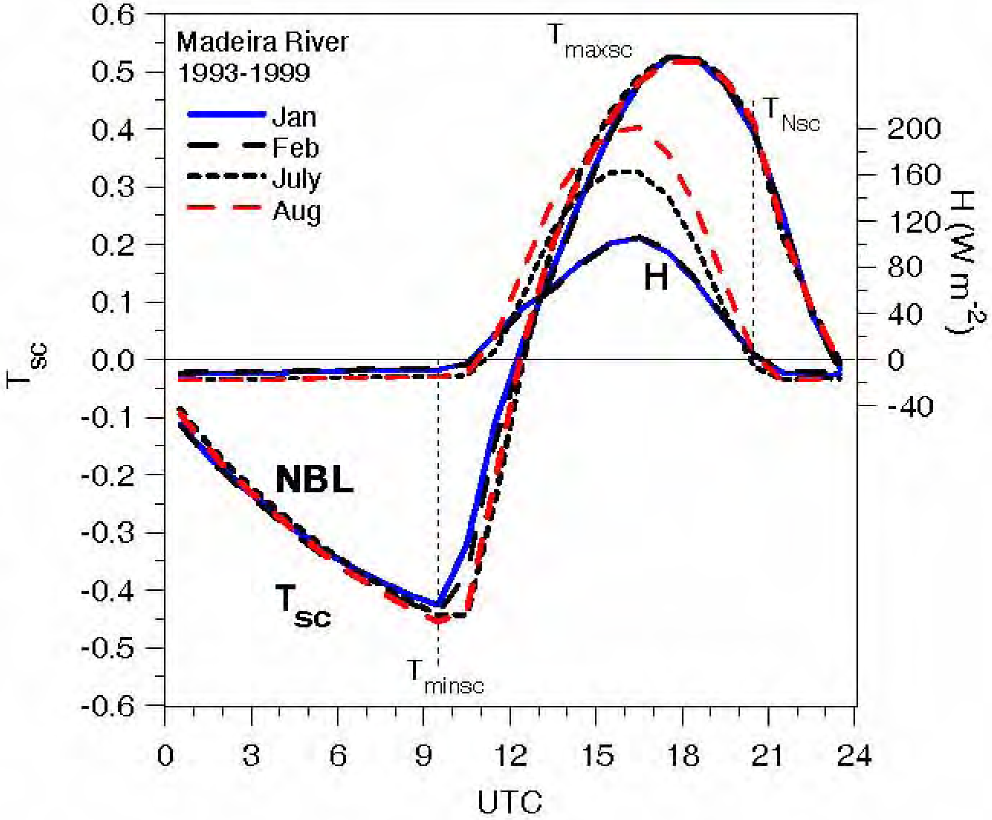
$T_{sc} = (T_2 - T_{24}) \,/\,)T_R$

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

[Betts, JGR, 2006]

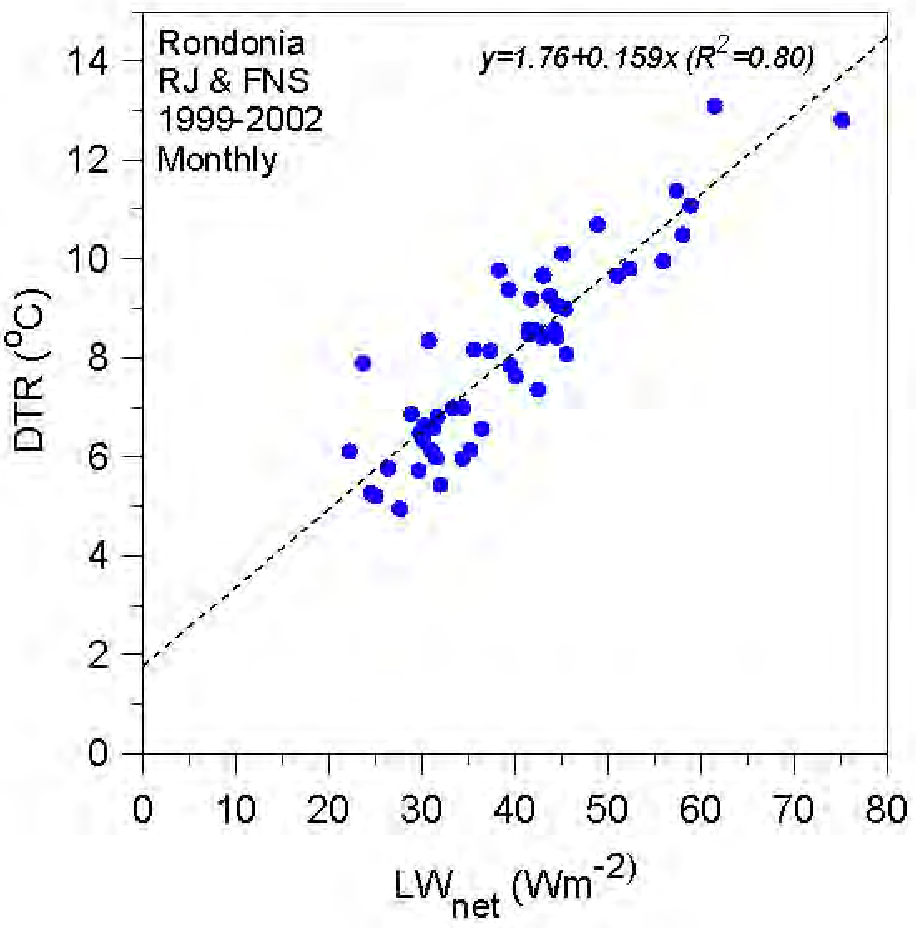
Mean diurnal cycle Madeira river

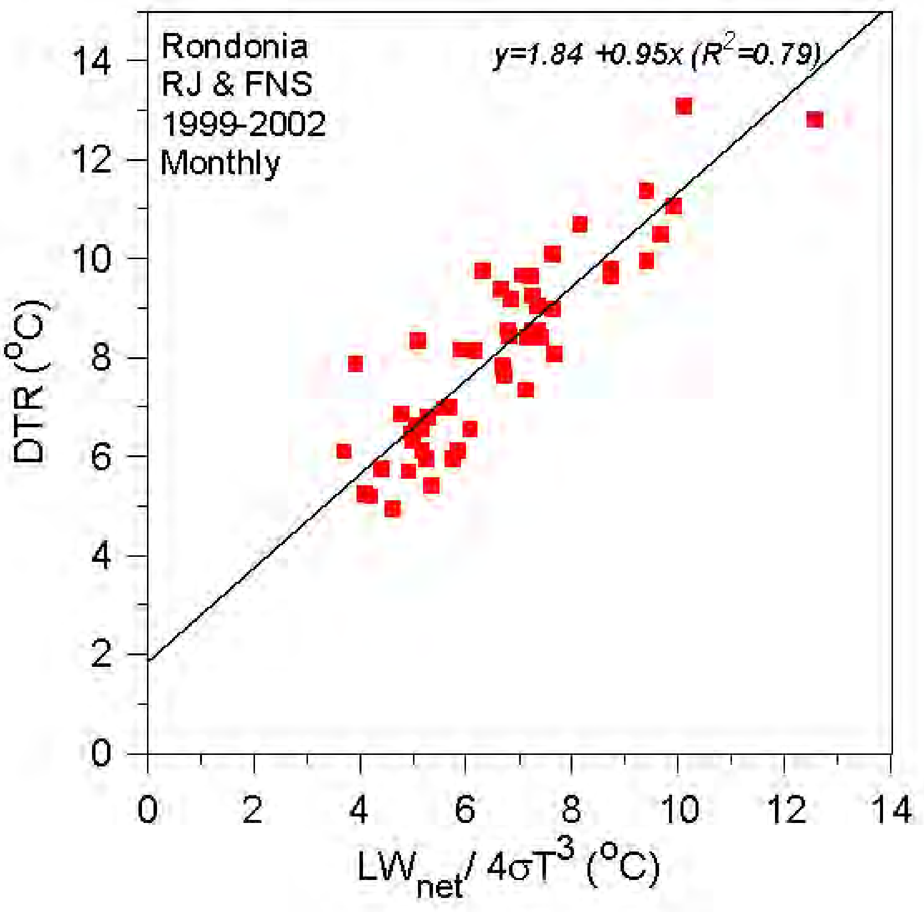




- DTR doubles in dry season (with LW_{net})
- $DTR_{sc} \approx 1$
- $\Delta T_{Nsc} = T_{Nsc} - T_{minsc} \approx 0.9\ DTR_{sc}$

LW_{net} and DTR – monthly mean data





- Mean LW_{net} and DTR correlated

[Betts: JGR, 2006]

Spring climate transition

- **Before leaf-out**

Little evaporation → Dry atmosphere, low RH

→ Deep dry BL

→ Large outgoing LW_{net}

Low water vapor greenhouse

→ Large DTR, warm days, cool nights

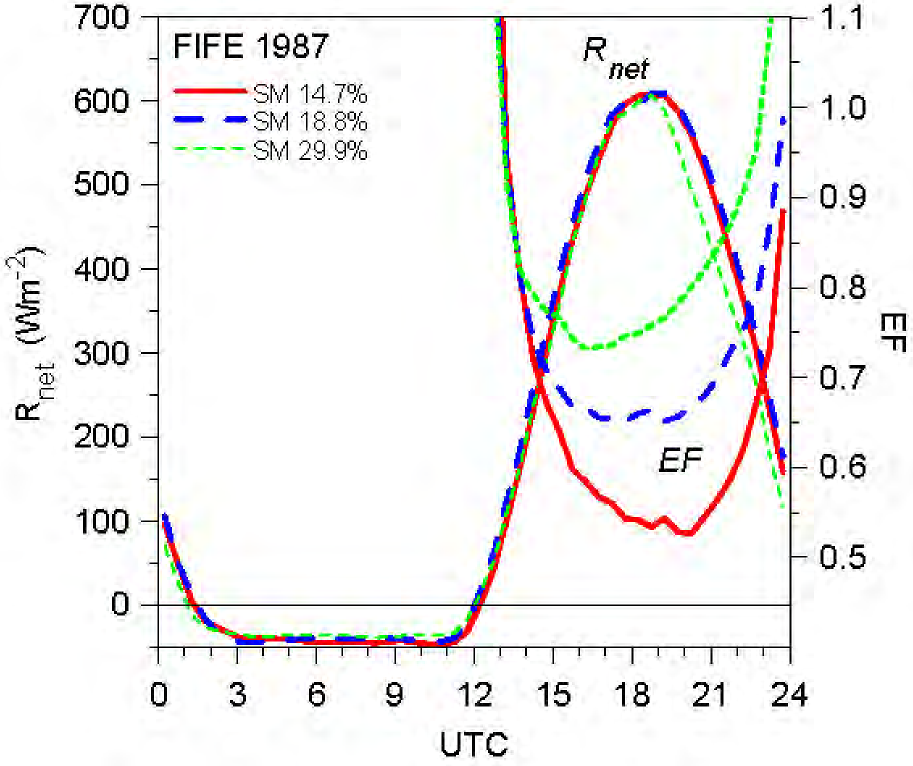
- **After leaf-out**

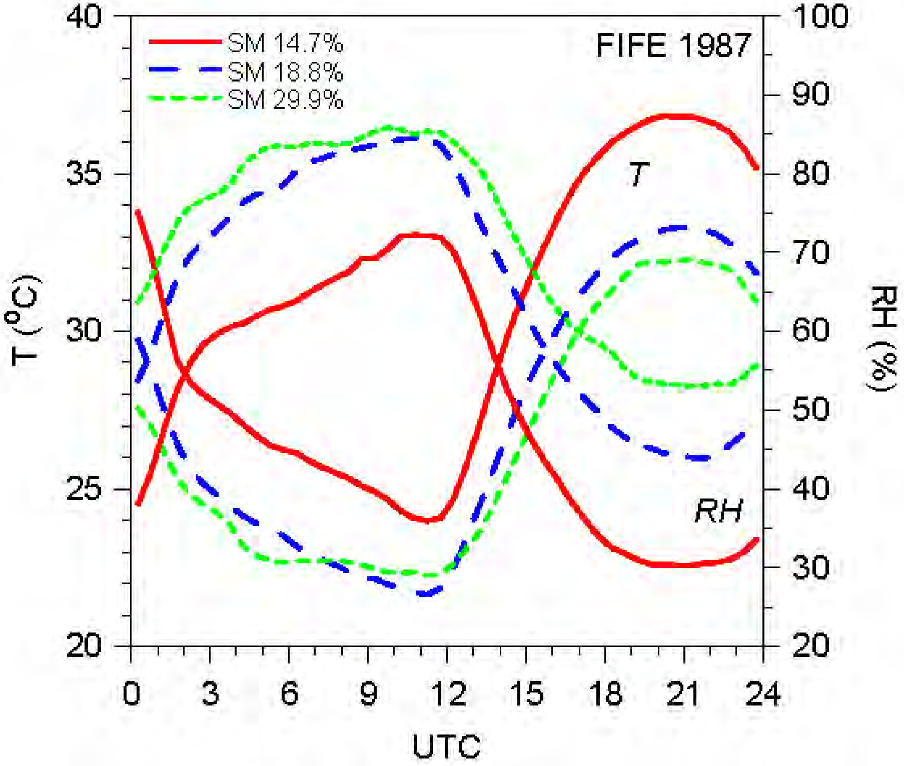
Large evaporation → Wet atmosphere, low cloudbase

→ Small outgoing LW_{net}

→ Reduced DTR, reduced T_{max}

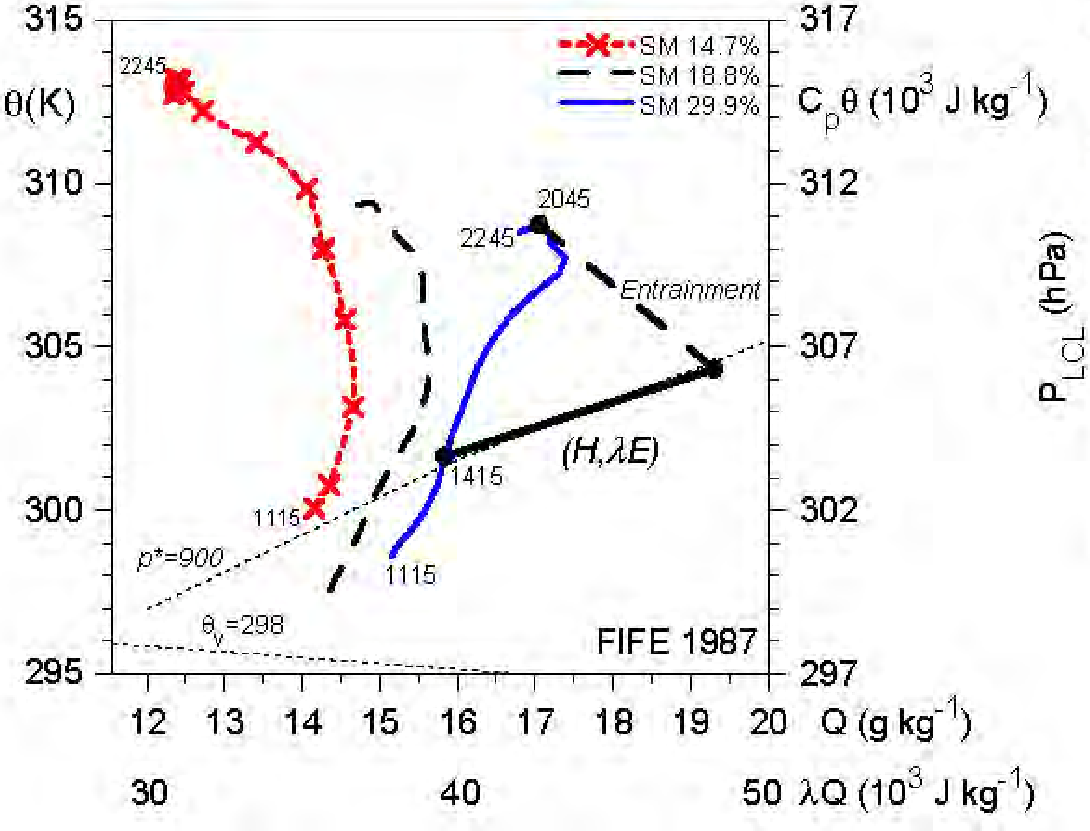
Water availability & the surface energy partition

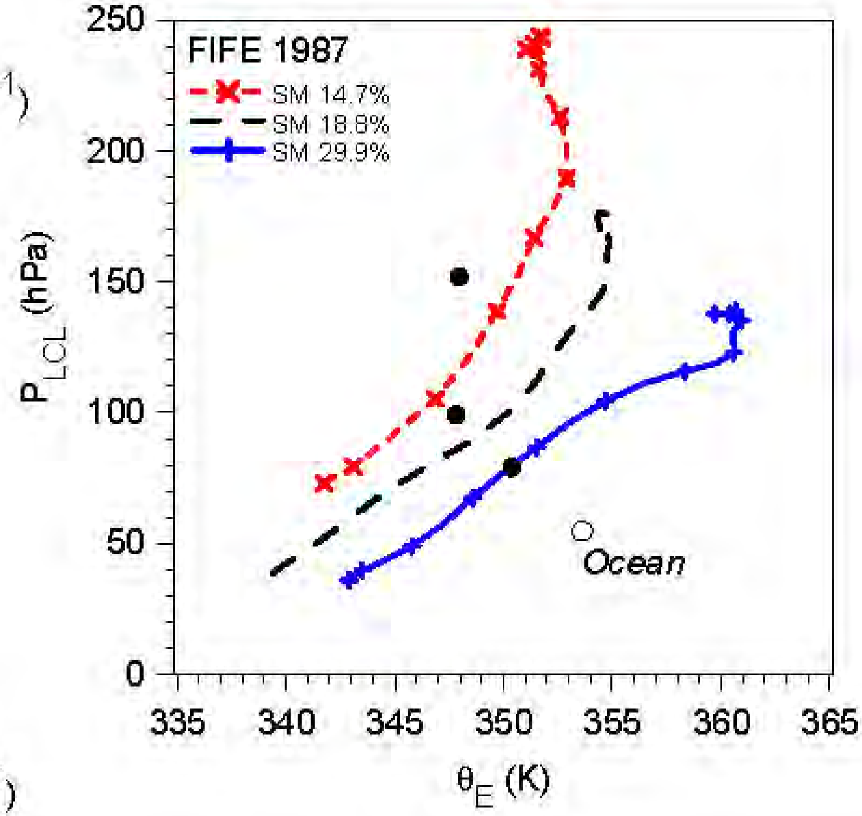




- FIFE grassland: partitioned by soil moisture
  - July & August; little cloud
- Evaporative fraction: EF = λE/(λE+H)

Diurnal cycle on vector diagrams

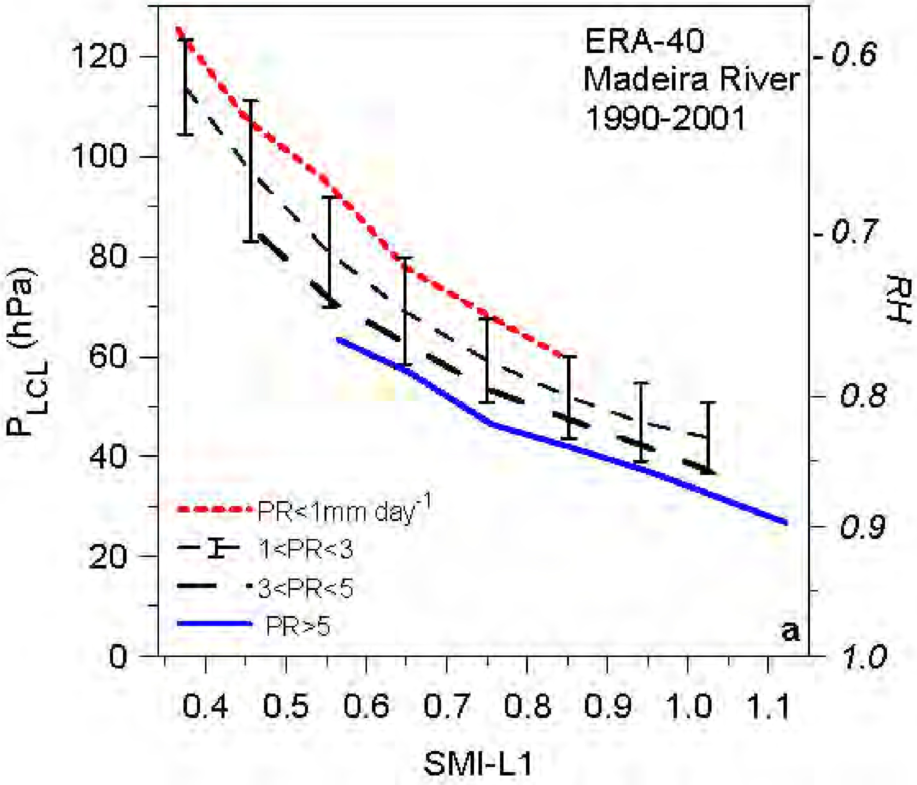


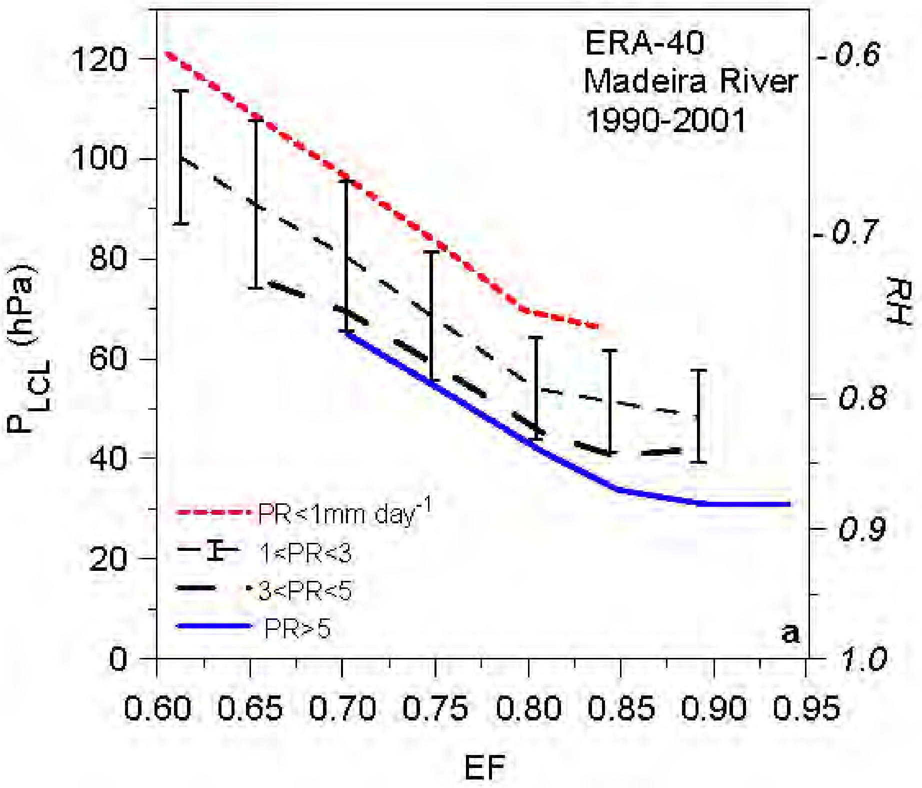


- $\Delta\boldsymbol{\xi}_{\mathbf{m}}/\Delta t = (\mathbf{F}_s - \mathbf{F}_i)/\ \rho\Delta Z_i$ where $\Delta\boldsymbol{\xi}_{\mathbf{m}}\ \mathbf{=}\ \Delta(C_p\theta, \lambda Q)_m$
- $(H, \lambda E) = \Omega\ \Delta(C_p\theta, \lambda Q)$ where $\Omega = \rho\Delta Z_i/\Delta t$

Fluxes *vector* *BL growth*

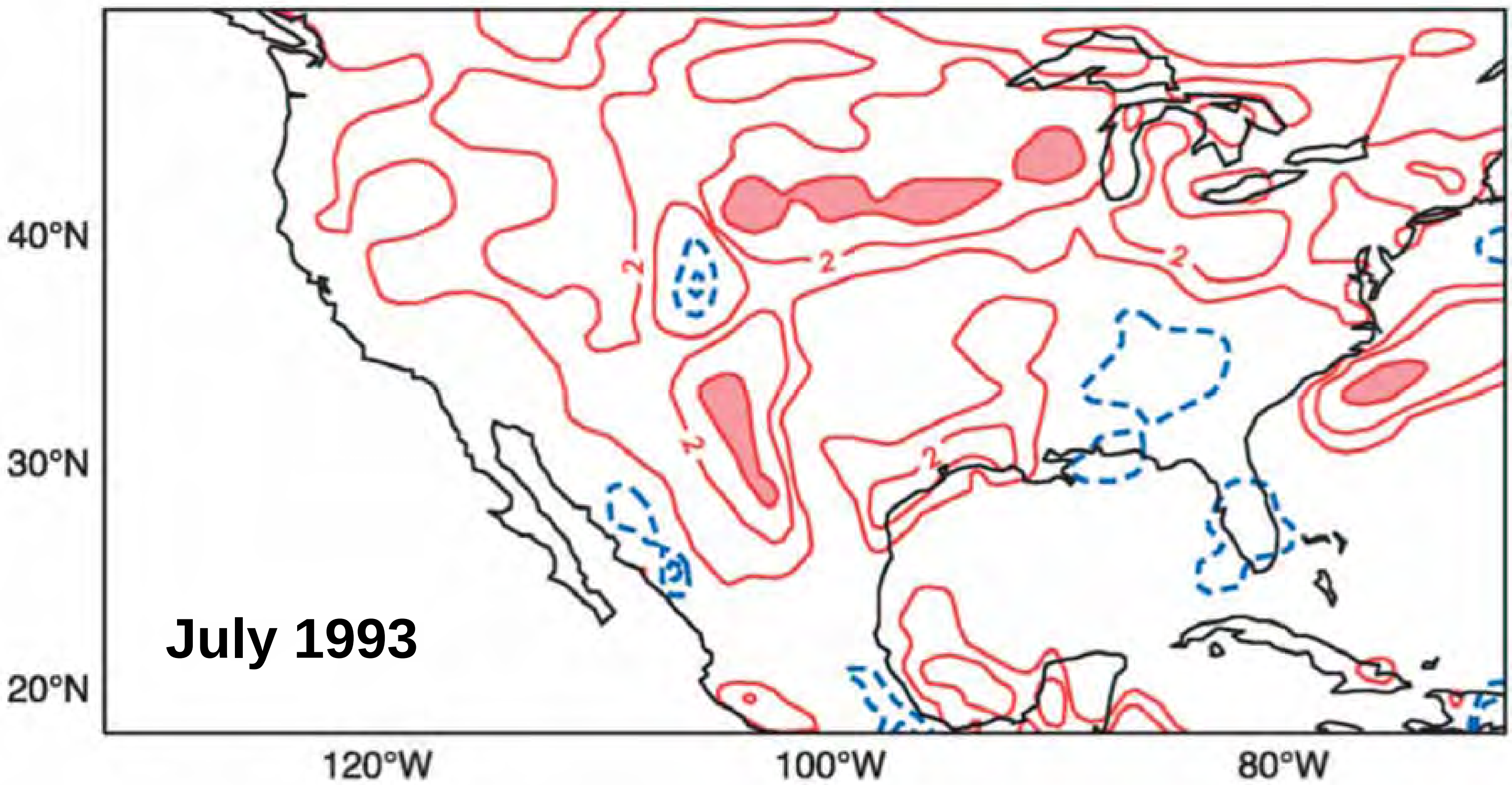
Land-surface-BL Coupling





- 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*

Evaporation-precipitation feedback

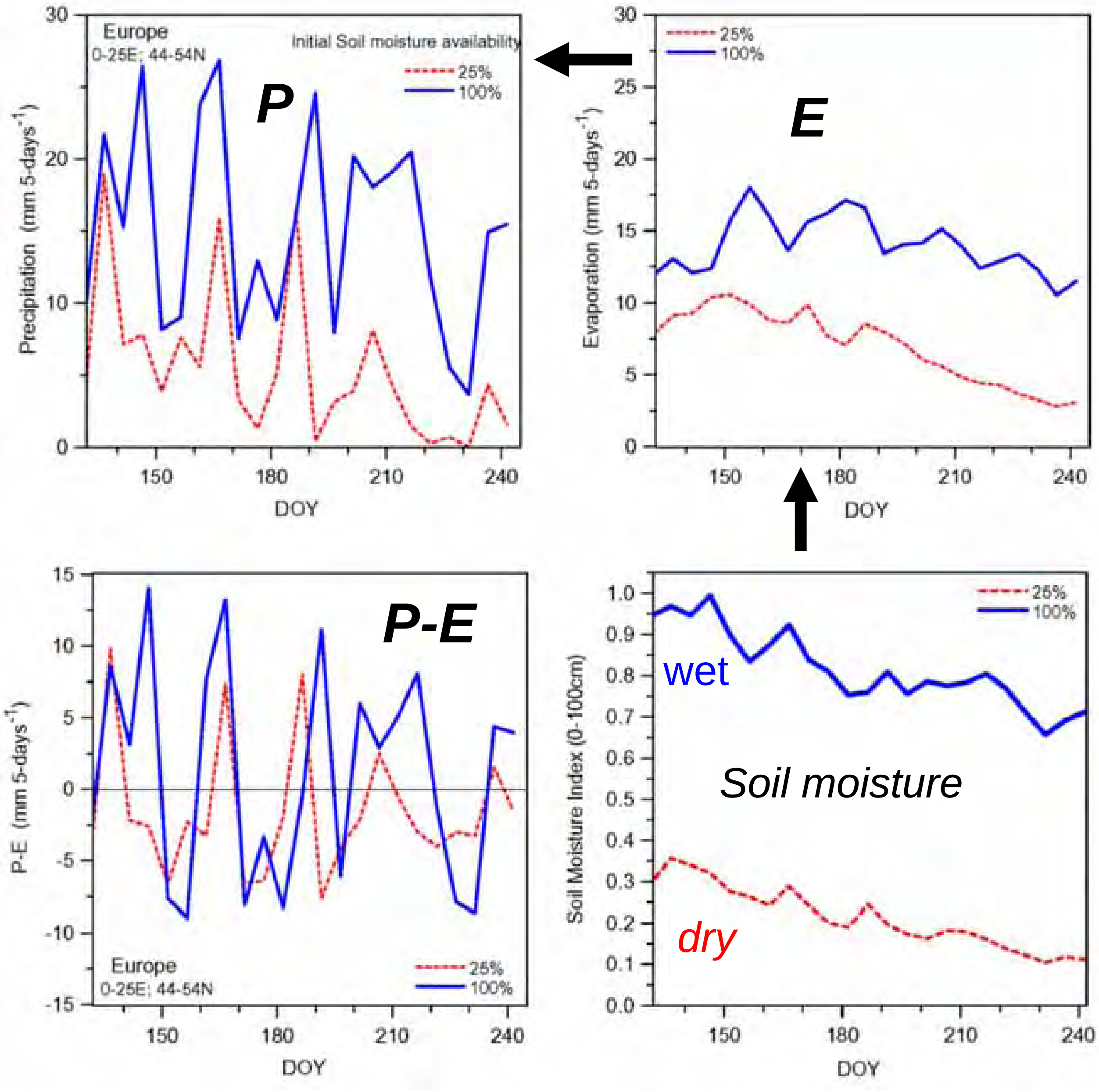


- *Difference* in monthly mean forecast precip. (in mm/day) starting with wet and dry soils *[Beljaars et al. 1996]*

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

[Betts 2004]



Is ERA-40 right?

Wet summers

- Both 2008 and 2009 were wet in Vermont!
- Direct fast evaporation off wet canopies
- Positive evaporation-precipitation feedback

Fall climate transition

- ***Mirror of Spring transition***

- **Vegetation delays first killing frost**

- Deciduous trees still evaporating, BL moist, BL cloud
- WV & cloud greenhouse reduces outgoing LW, reduces drop of T at night and prevents frost

- Till one night, dry air advection from north gives first frost, vegetation shuts down, frosts become frequent
- Dry atmos., large $LW_{net} \rightarrow$ large diurnal cycle

- Warm days and cool nights: ‘Indian summer’

Summary of Philosophy

- Evaluate models with observations
- Surface, BL, clouds and diabatic processes are tightly coupled: system observables?
- Understand processes globally and locally