How can flux-tower nets improve weather forecast and climate models?

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ERA-40 data: Pedro Viterbo

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Background references

- Betts, A. K., J.H. Ball, A.C.M. Beljaars, M.J. Miller and P. Viterbo, 1996: The land-surface-atmosphere interaction: a review based on observational and global modeling perspectives. *J. Geophys. Res.* **101**, 7209-7225.
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- Betts, A. K., R. Desjardins and D. Worth, 2004: Impact of agriculture, forest and cloud feedback on the surface energy balance in BOREAS. Submitted to *Agric. Forest Meteorol*.

- *Preprints: ftp://members.aol.com/akbetts*

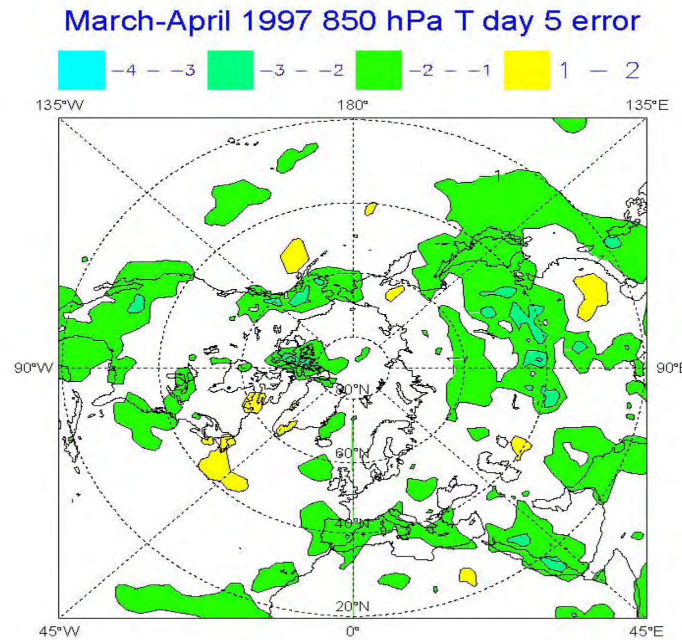
Climate and weather forecast models

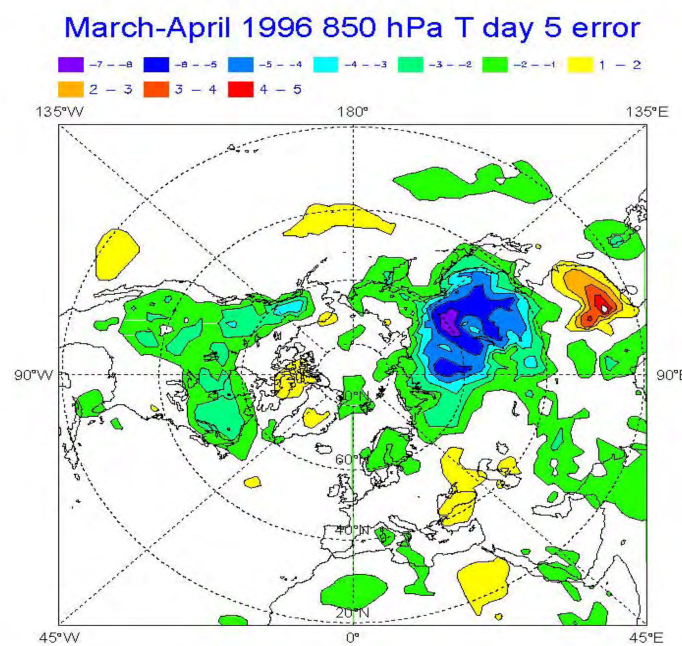
How well are physical processes represented?

- Accuracy of analysis: fit of model to data
  [analysis increments]
- Accuracy of forecast : growth of RMS errors from
  observed evolution
- Accuracy of model 'climate' : where it drifts to
  [model systematic biases]
- FLUXNET data can assess biases and poor representation of physical processes and their coupling

ECMWF forecast error in spring: 1996,1997

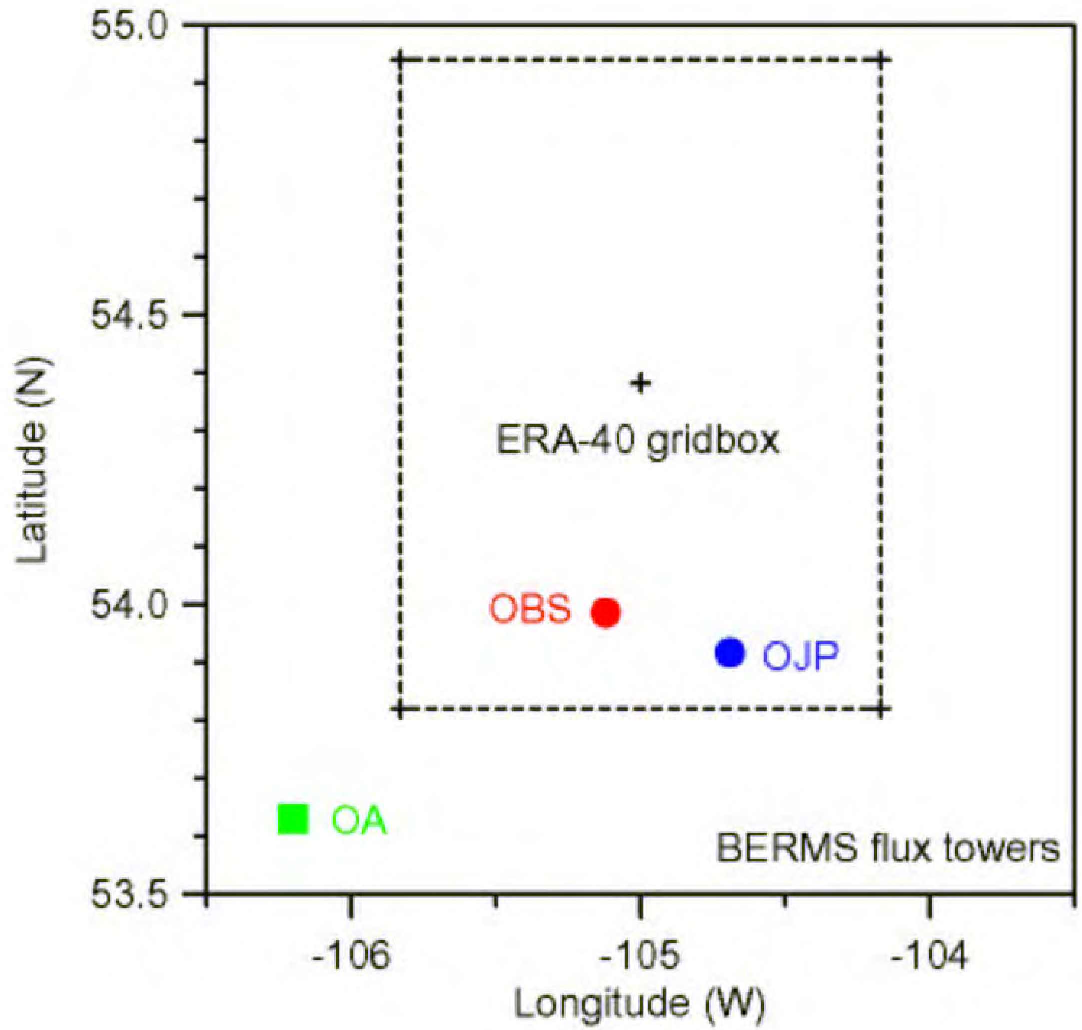
- Albedo of forest with snow reduced
- Removed 2-6K of cold bias over land in spring
- Improved NH forecasts for 3 months in spring



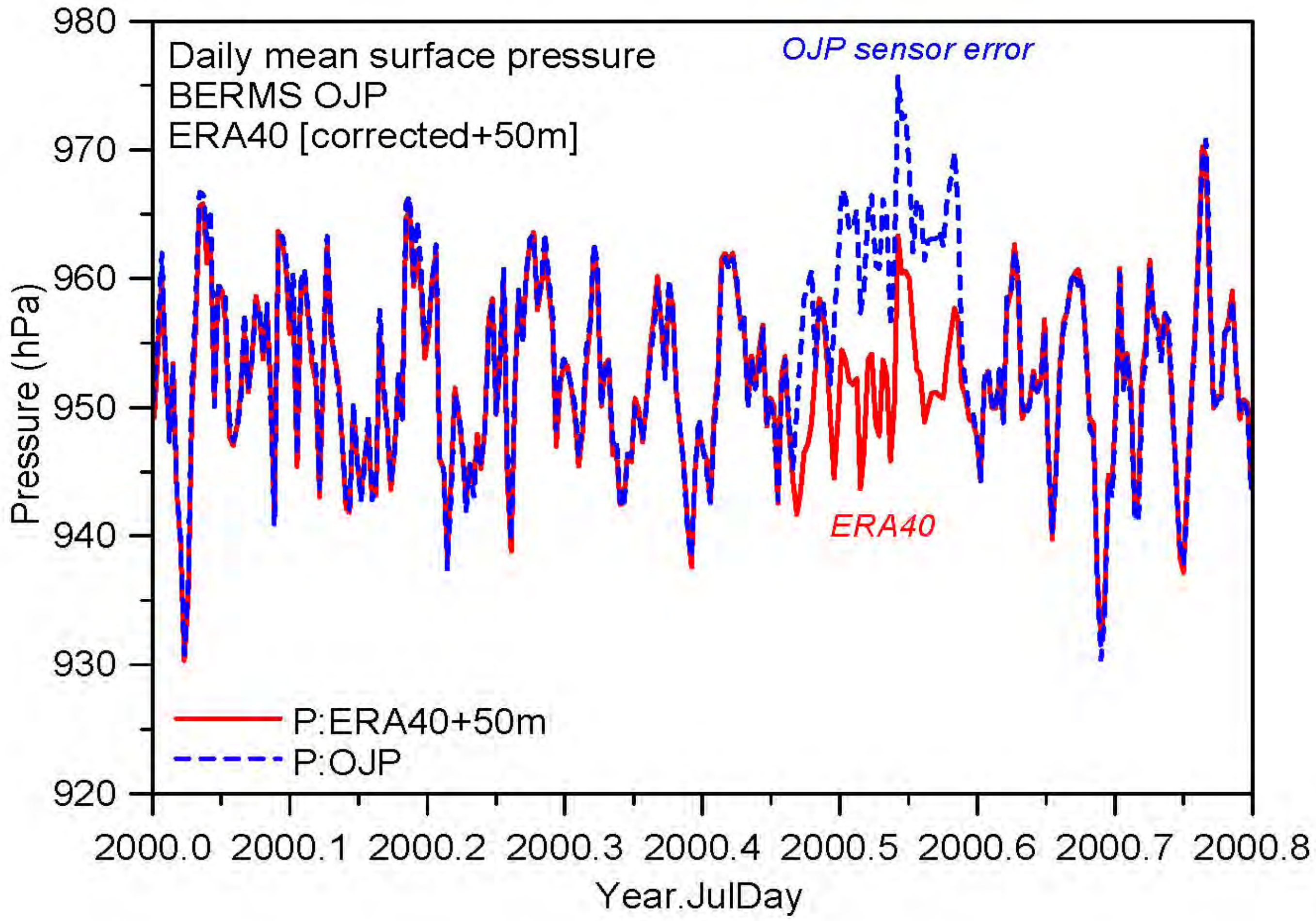


Compare ERA-40 with BERMS

- ECMWF reanalysis
- ERA-40 hourly time-series from single grid-box
- BERMS 30-min time-series from
  Old Aspen (OA)
  Old Black Spruce (OBS)
  Old Jack Pine (OJP)
- Daily Average



Model biases; data issues



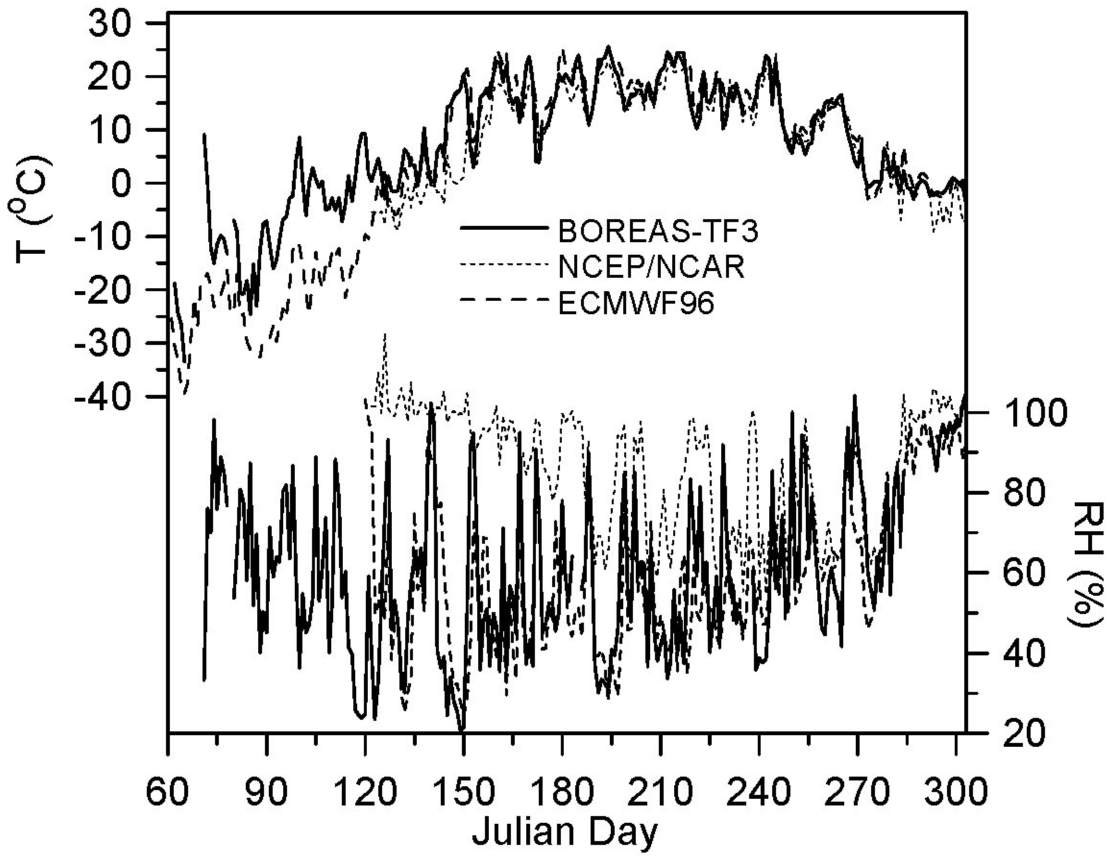
- Models can identify sensor issues and fill data

Large T, RH errors in 1996
- before BOREAS input

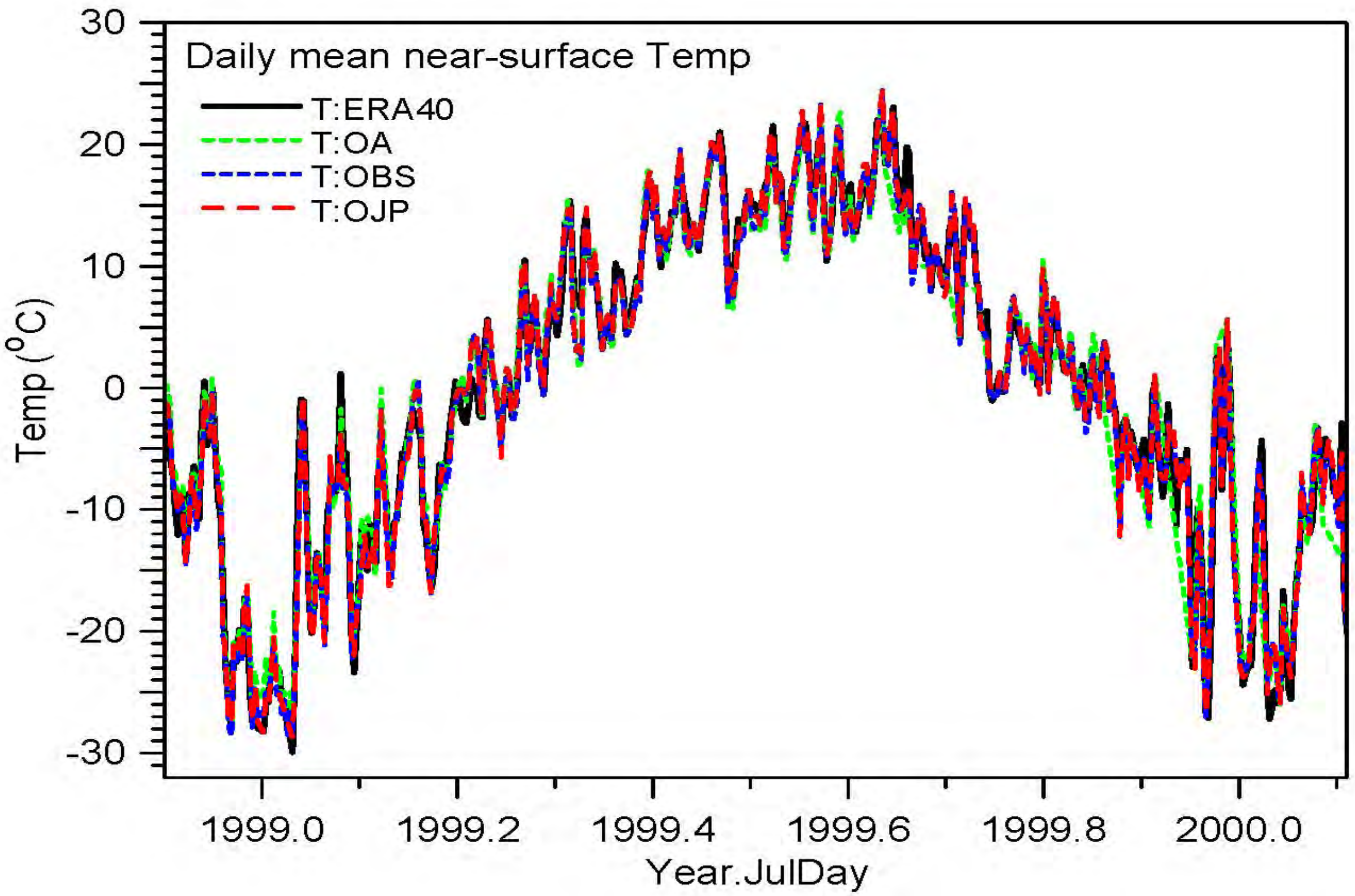
- -10K bias in winter

- NCEP/NCAR reanalysis saturates in spring

- *Betts et al. JGR, 1998*

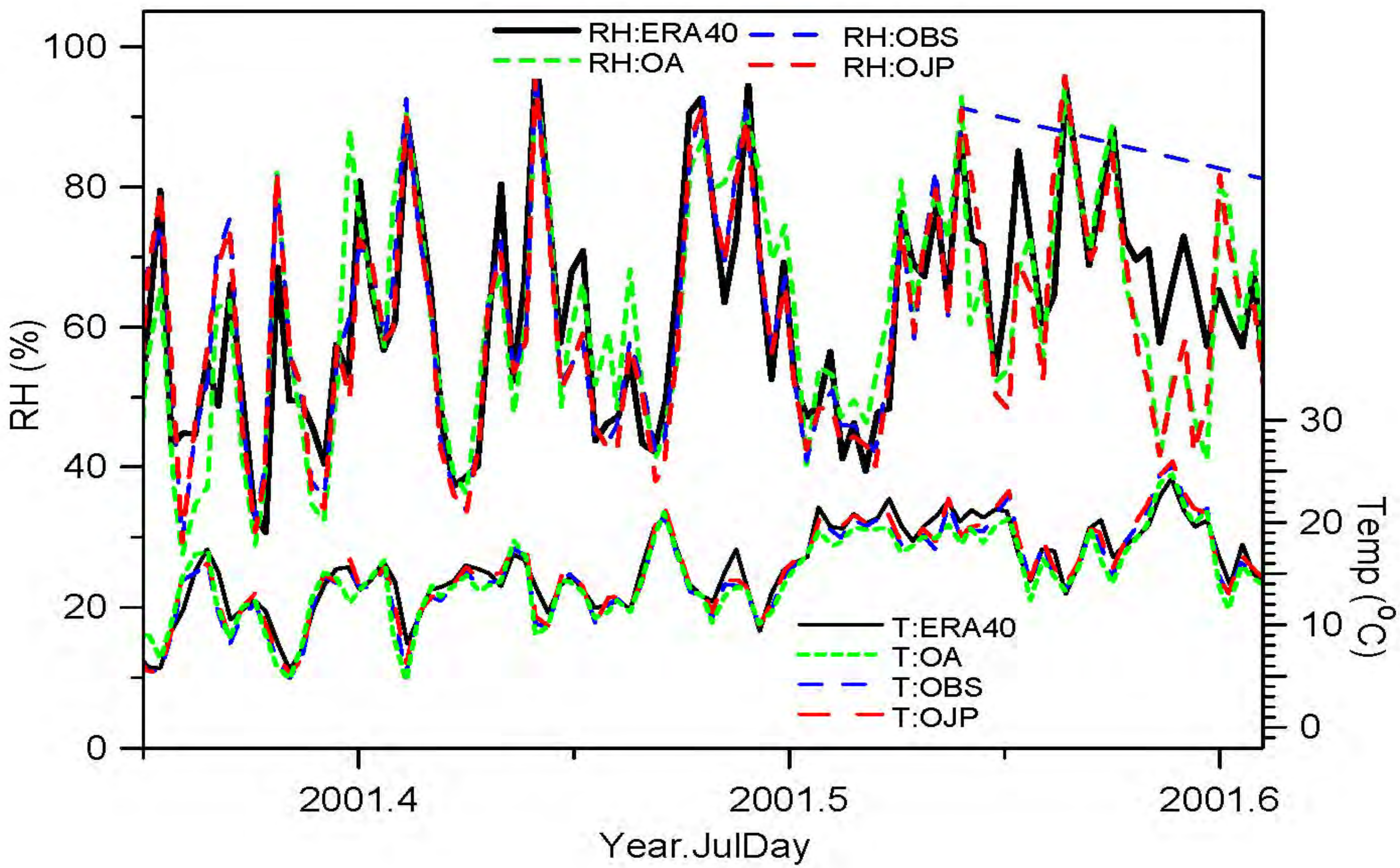


Global model improvements [ERA-40]



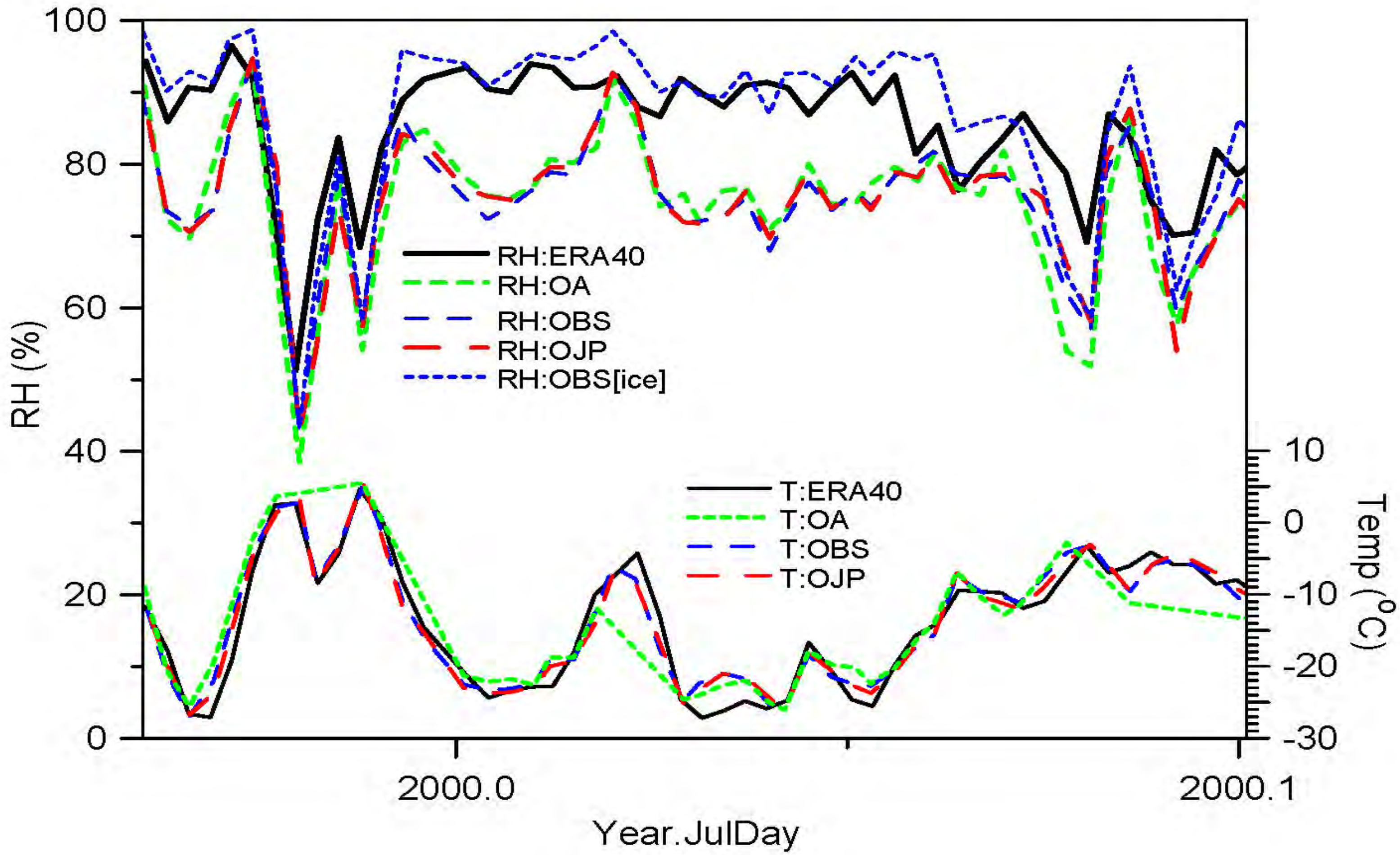
- ERA-40 land-surface model developed from BOREAS
- Reanalysis T bias of now small in all seasons
- BERMS inter-site variability of daily mean T is small

BERMS and ERA-40 - 2



- ERA-40 RH close to BERMS in summer

BERMS and ERA-40 - *3*



- RH difference when < -15°C in winter
- Model or RH sensors? No: RH_{ice} issue

Land-surface coupling

*Models differ widely**

Precip → SMI → λE → clouds → Precip

vegetation	*vegetation*	*BL param*	*dynamics*
soils		*RH*	*microphysics*
runoff			*Cu param*

LW,SW radiation

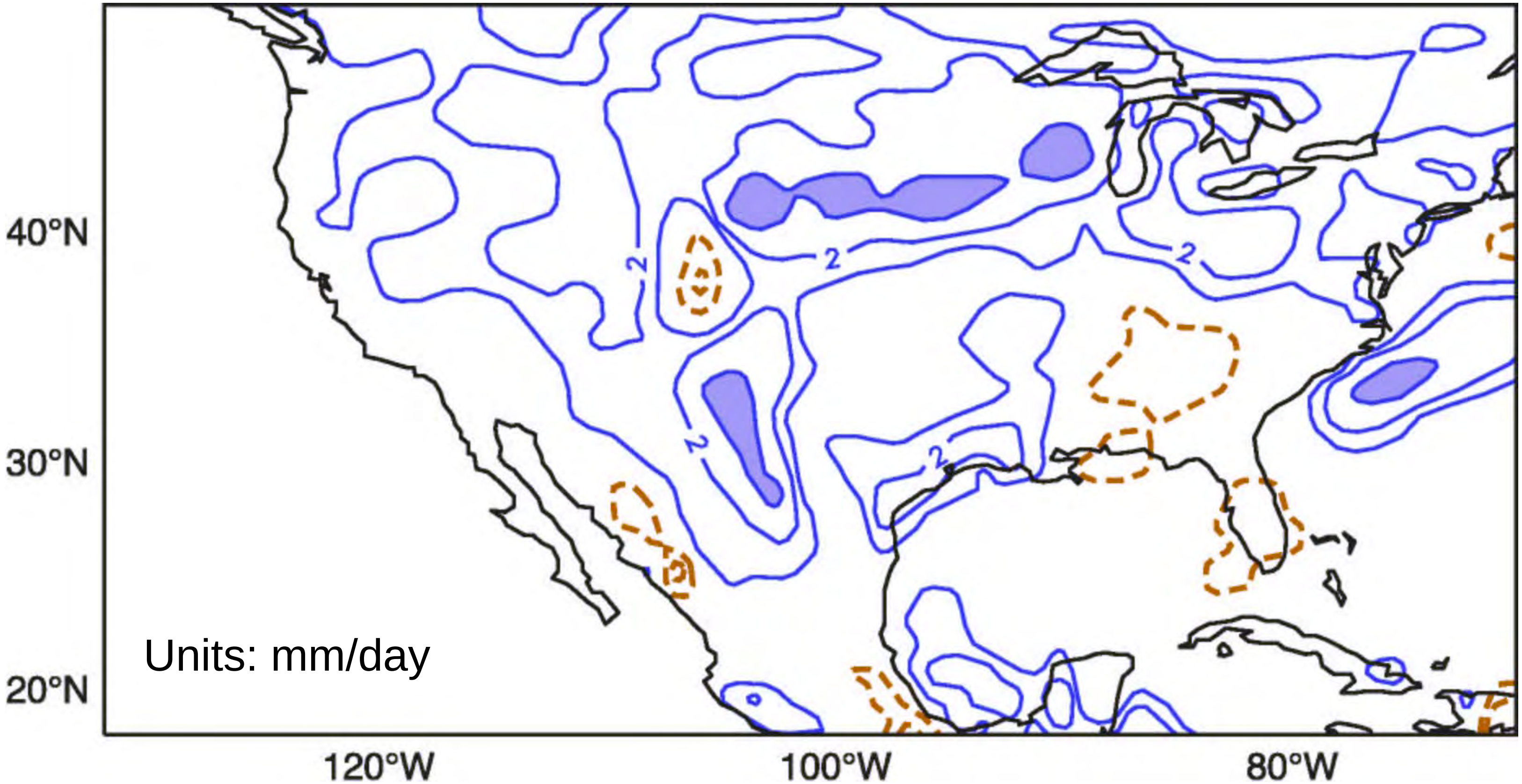
R_{net} *, H*

SMI : soil moisture index [0<SMI<1 as PWP<SM<FC]

*[*Koster et al., Science, 2004; Betts, BAMS, 2004]*

July 1993 Mississippi flood

ECMWF: 4-layer soil model [Viterbo and Beljaars, 1995]



- Sensitivity of one-month forecast to initial soil moisture : wet-dry soil
- July precipitation increased by > 120mm

Role of soil water, vegetation, LCL, BL and clouds in ‘climate’ over land

- SMI $\longrightarrow$ R_{veg} $\longrightarrow$ RH $\longrightarrow$ LCL $\longrightarrow$ LCC
- Clouds $\rightarrow$ SW albedo (α_{cloud}) at surface, TOA
- LCL + clouds $\longrightarrow$ LW_{net}
- Clouds $\rightarrow$ $SW_{net} + LW_{net} = R_{net} = \lambda E + H + G$
- Tight coupling of clouds means:

  - $\lambda E \approx$ constant

  - H varies with LCL and cloud cover

But are models right?? *[Betts et al. 2005]*

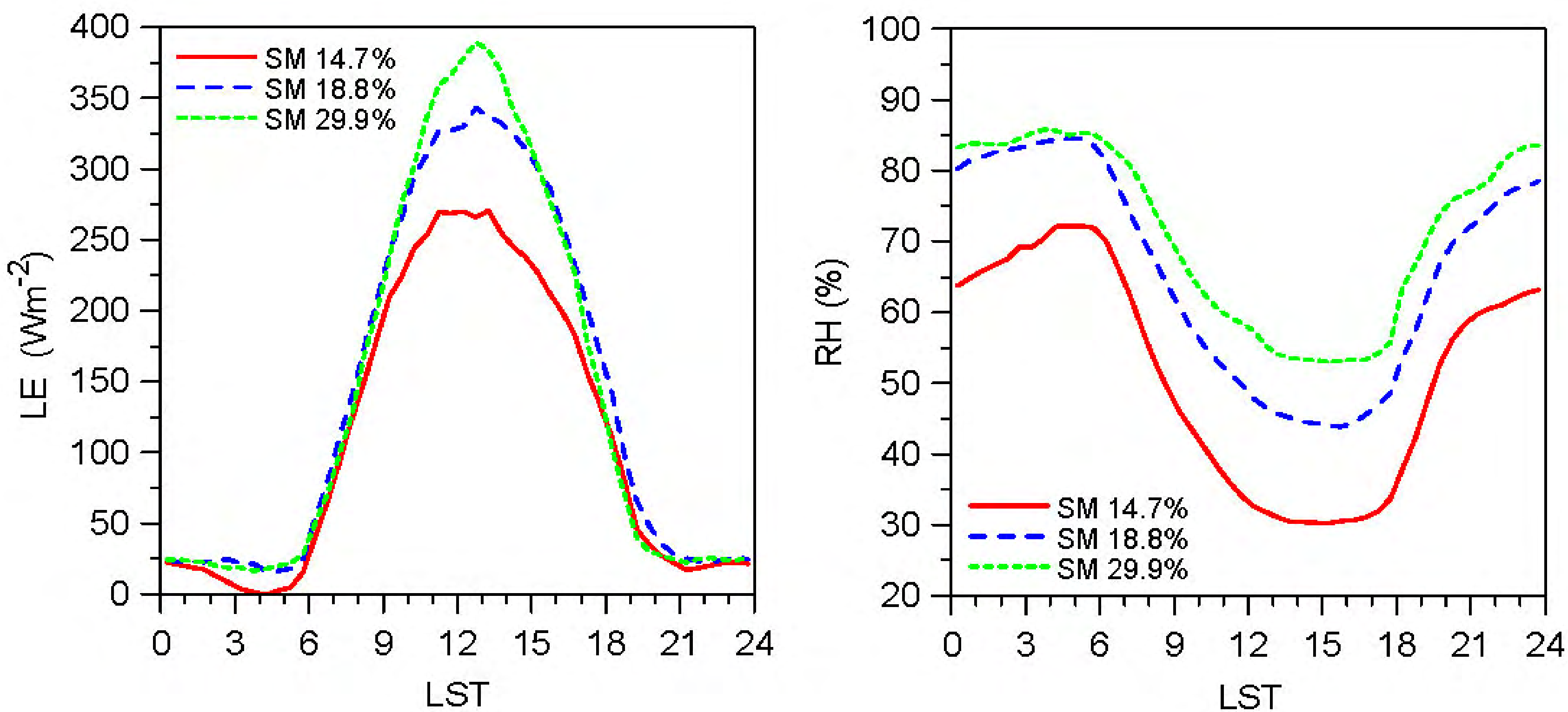
- DATA CAN TELL US

Daily mean fluxes give model ‘equilibrium climate’ state

- Map model climate state and links between processes using daily means
- Think of seasonal cycle as transition between daily mean states

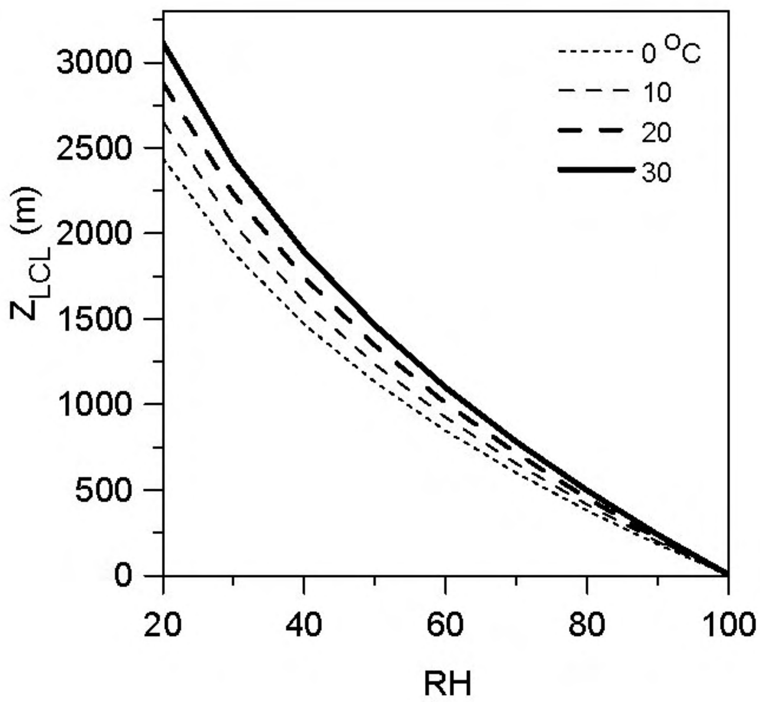
  + synoptic noise

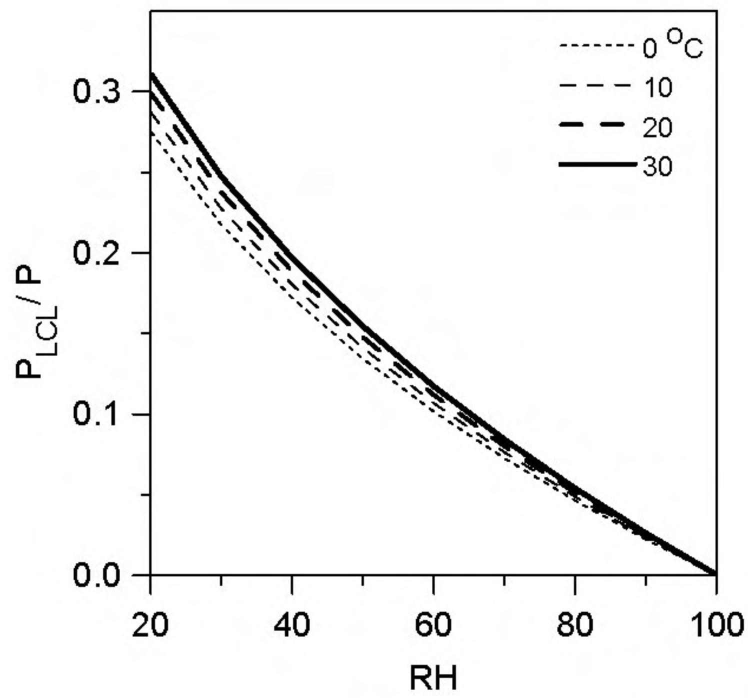
SMI → R_{veg} → RH → LCL → LCC



- FIFE grassland sunny days: sorted by soil moisture
- E and RH fall with SM

SMI $\longrightarrow$ R_{veg} $\longrightarrow$ RH $\longrightarrow$ LCL $\longrightarrow$ LCC





- RH gives LCL [largely independent of T]
- Saturation pressure conserved in adiabatic motion
- Think of RH linked to availability of water

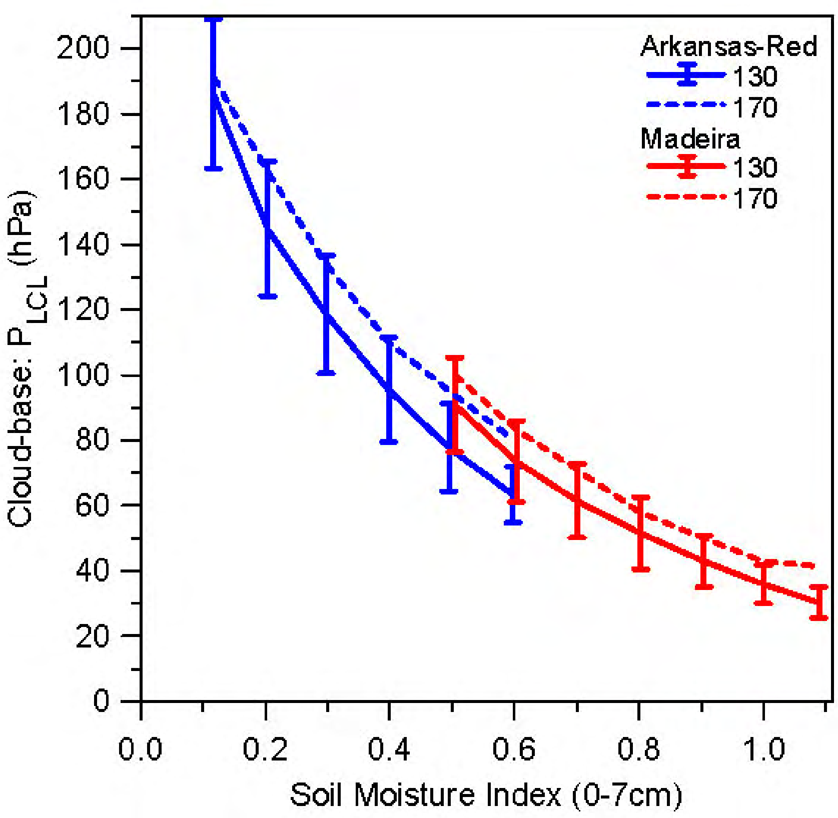
What controls daily mean RH anyway?

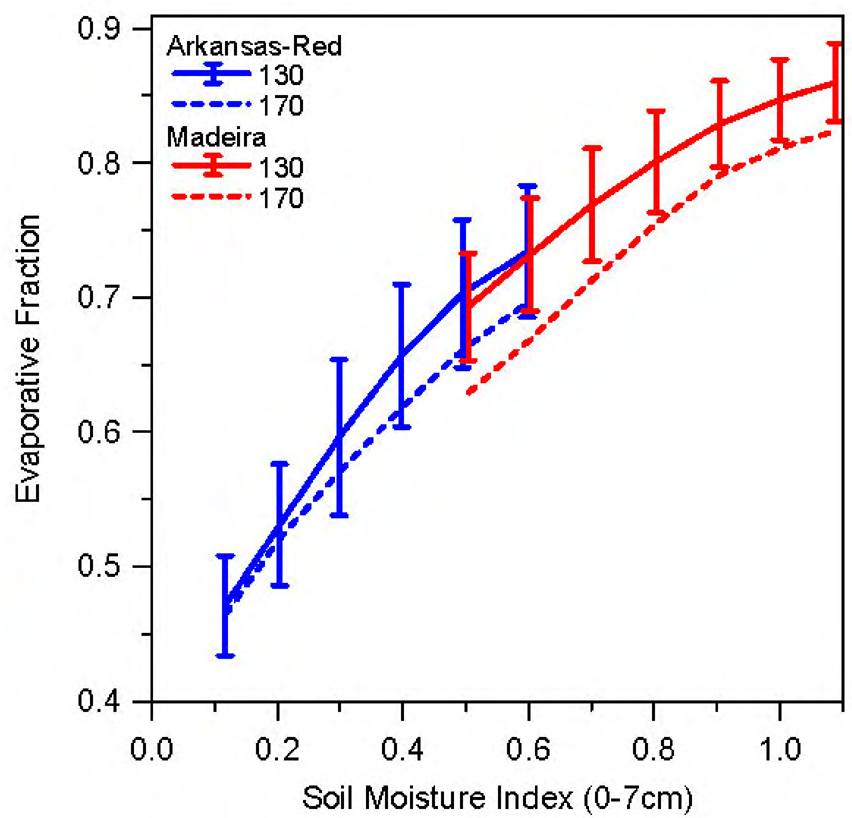
- RH is balance of subsidence velocity and surface conductance
- Subsidence is radiatively driven [40 hPa/day]
  + dynamical ‘noise’
- Surface conductance

  $G_s = G_a G_{veg} / (G_a + G_{veg})$

[30 hPa/day for $G_a = 10^{-2}$; $G_{veg} = 5.10^{-3}$ m/s]

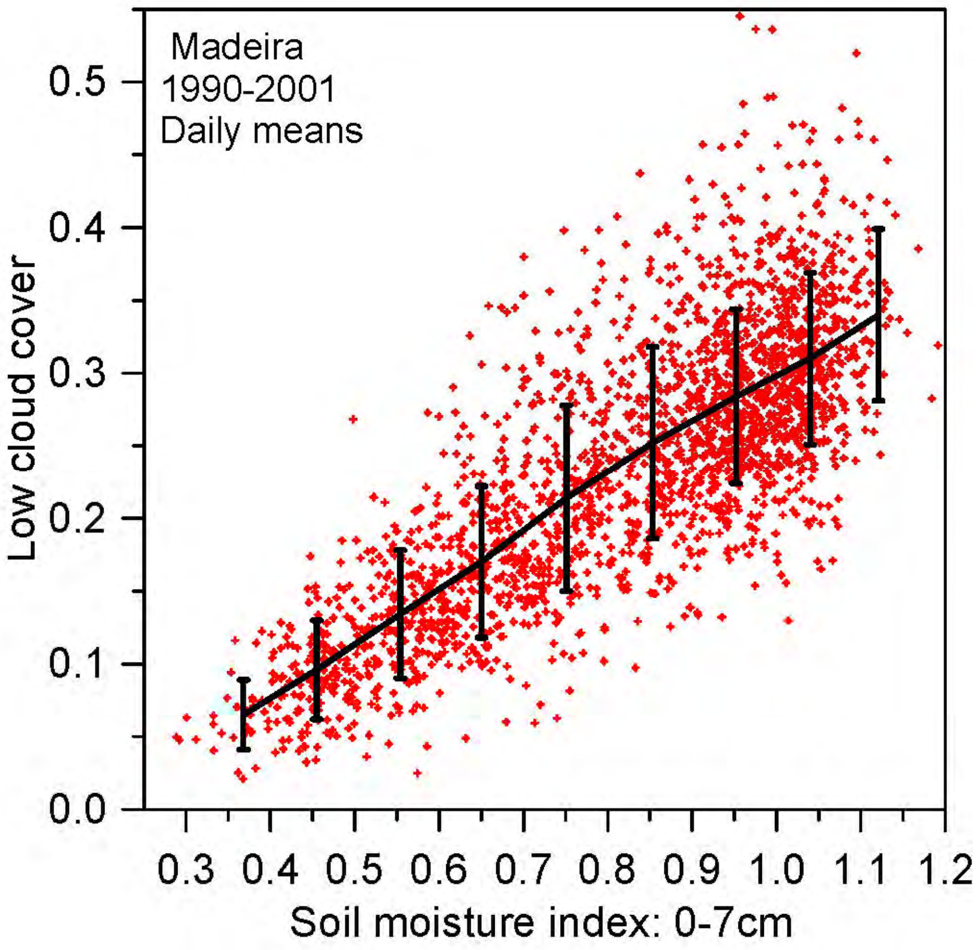
ERA40 ‘climate’ over land





- River basin daily means
- Binned by soil moisture and R_{net}

ERA40: SMI → Low cloud

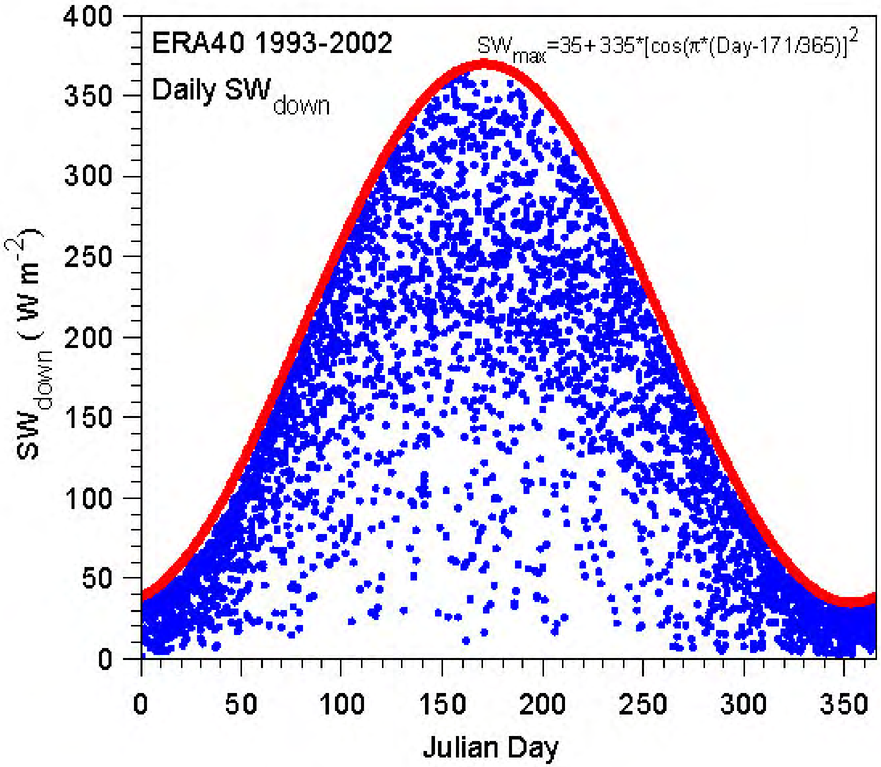


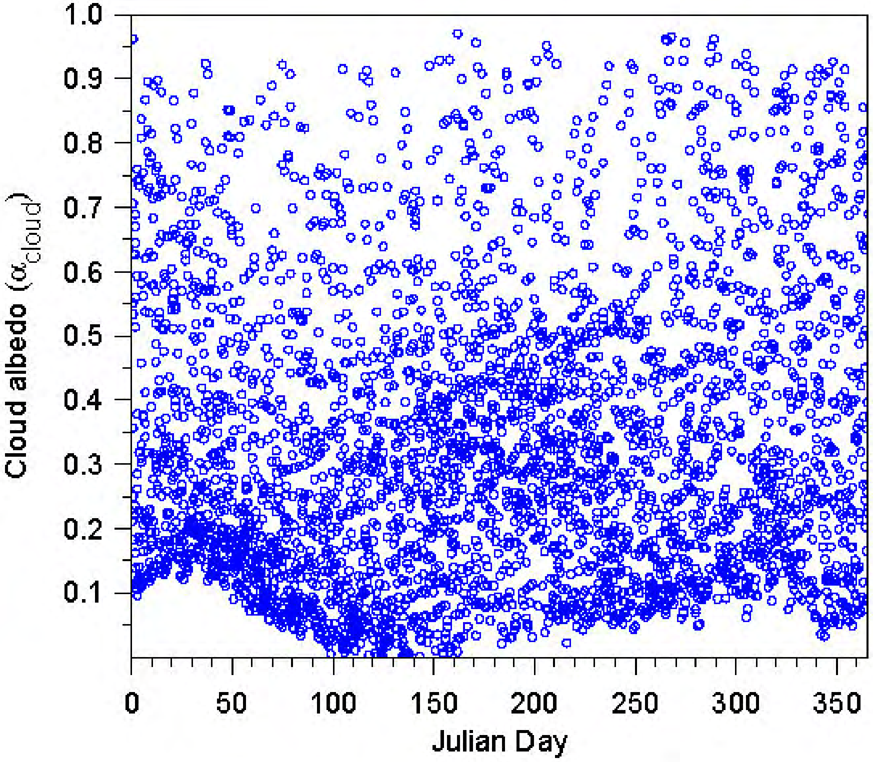
- Amazon: SMI linked to LCC in ERA40

Compare ERA-40 with 3 BERMS sites

- *Focus*: coupling of clouds to surface fluxes
- Define a 'cloud albedo' that reduces the shortwave (SW) flux reaching surface
- Basic 'climate parameter', coupled to surface evaporation [locally/distant]
- More variable than surface albedo

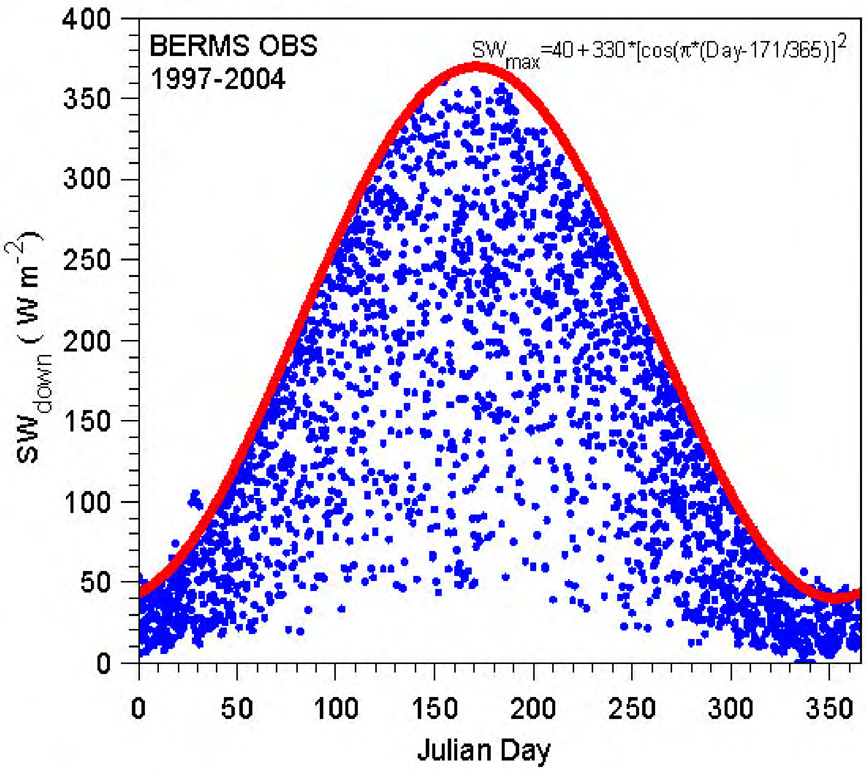
SW scaling: "Cloud albedo"

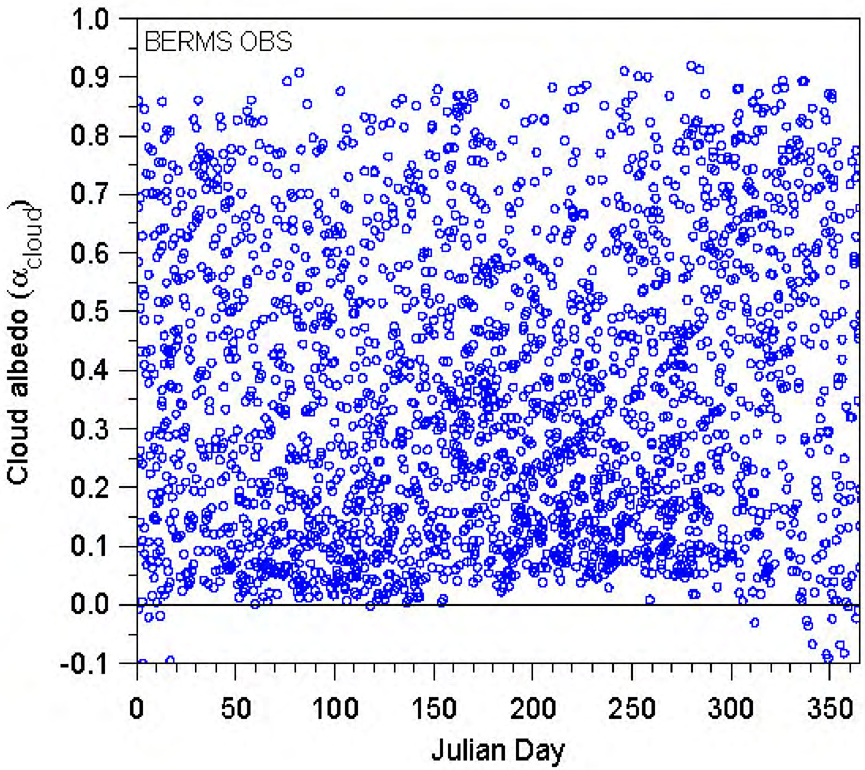




- Daily average fluxes
- 1- $SW_{down}/SW_{max} = \alpha_{cloud}$ [reflection+absorption]

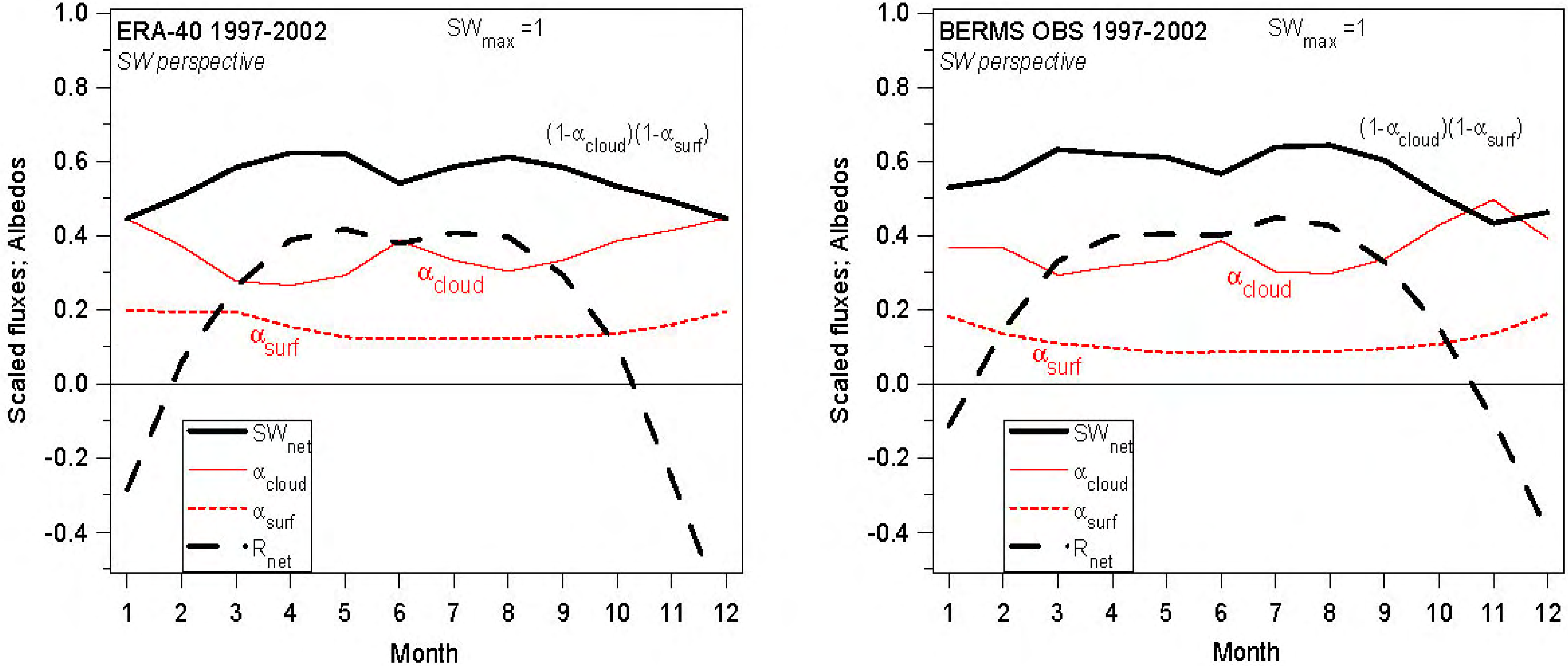
BERMS: Old Black Spruce





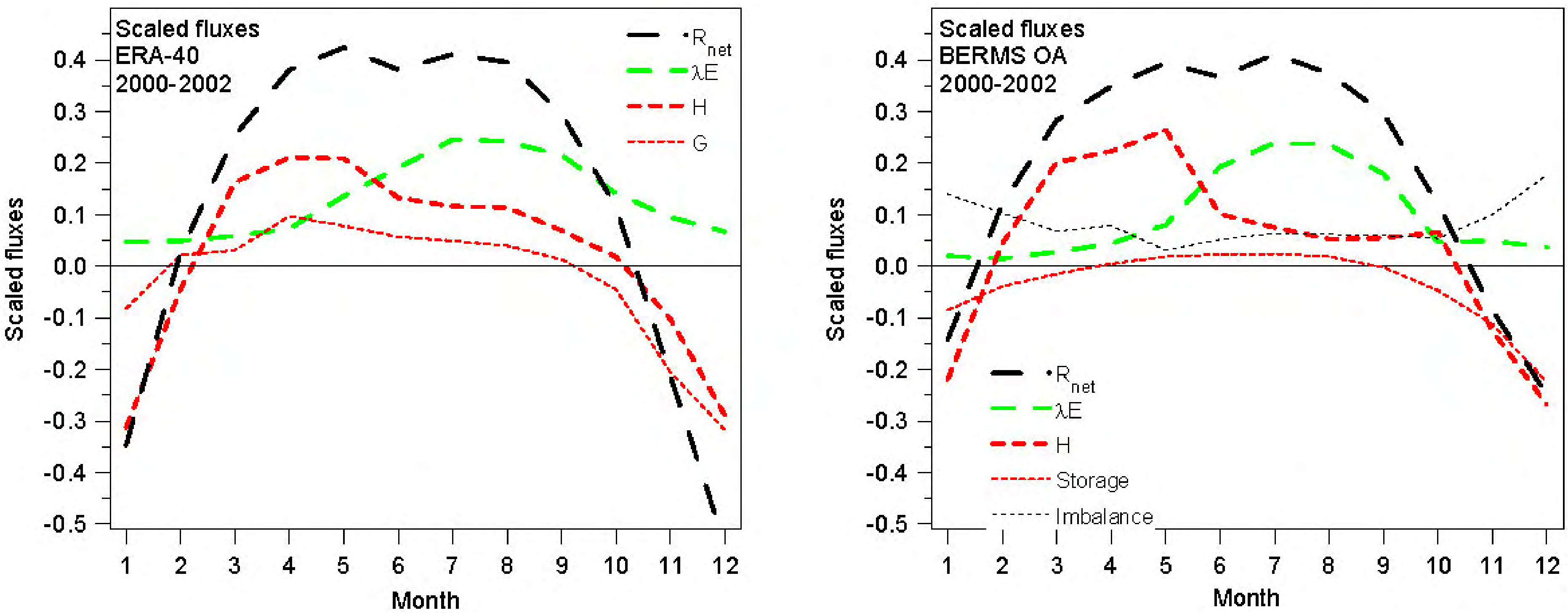
- Few spurious points in winter: snow/ice?
- Similar distribution to ERA-40

SW perspective



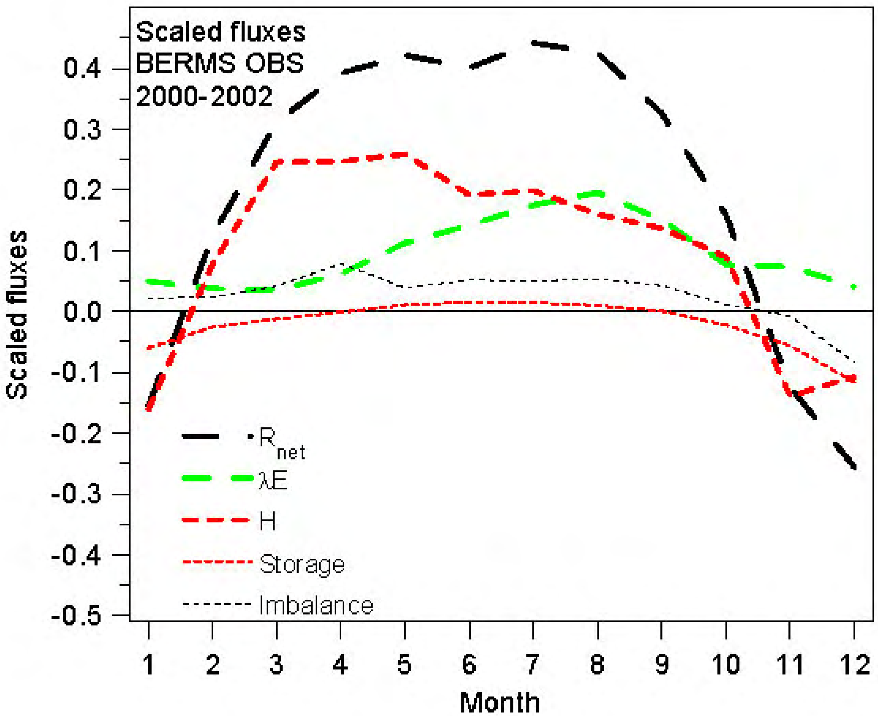
- α_{surf}, α_{cloud} give SW_{net}
- $R_{net} = SW_{net} - LW_{net}$

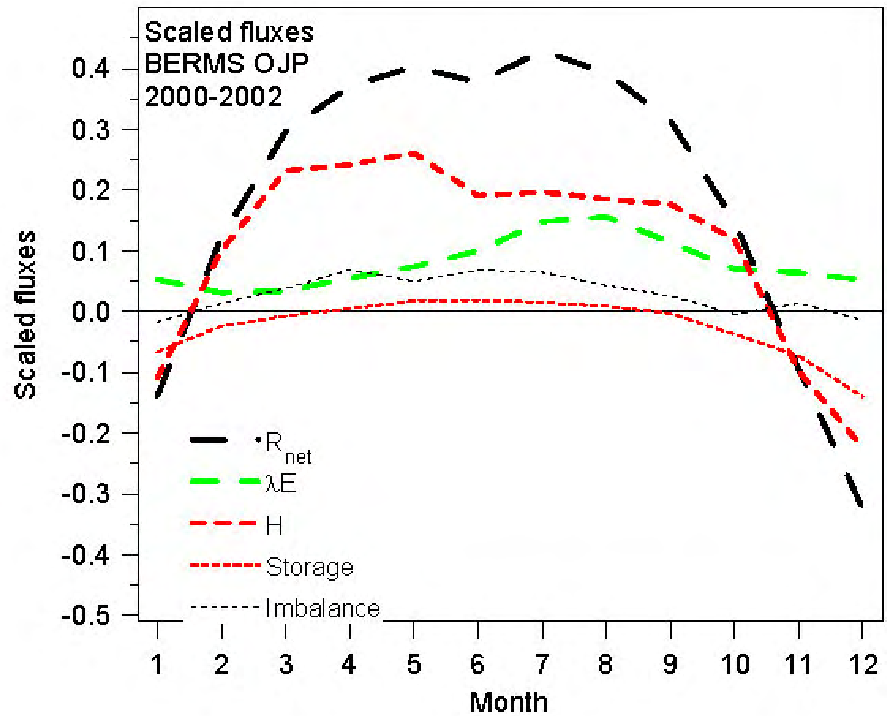
Fluxes scaled by SW_{max}



- Old Aspen has sharper summer season
- ERA-40 accounts for freeze/thaw of soil

Old Black Spruce and Old Jack Pine

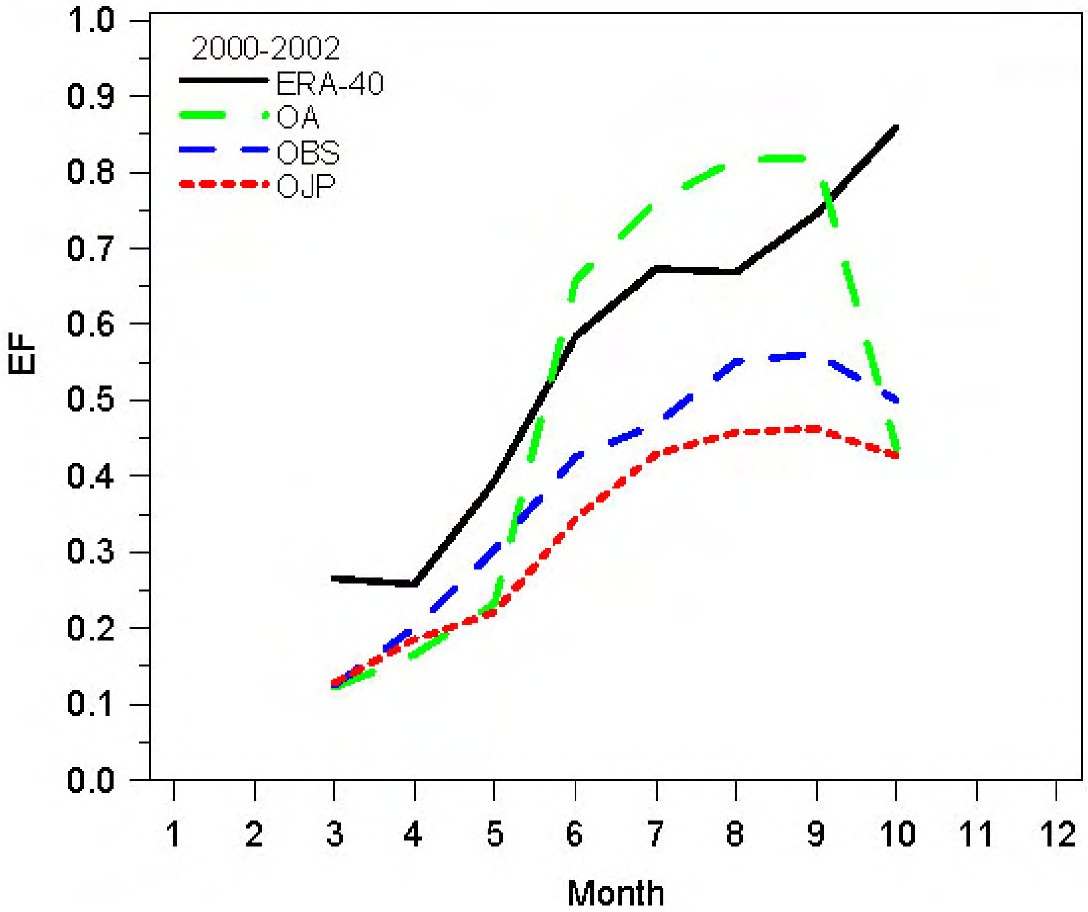




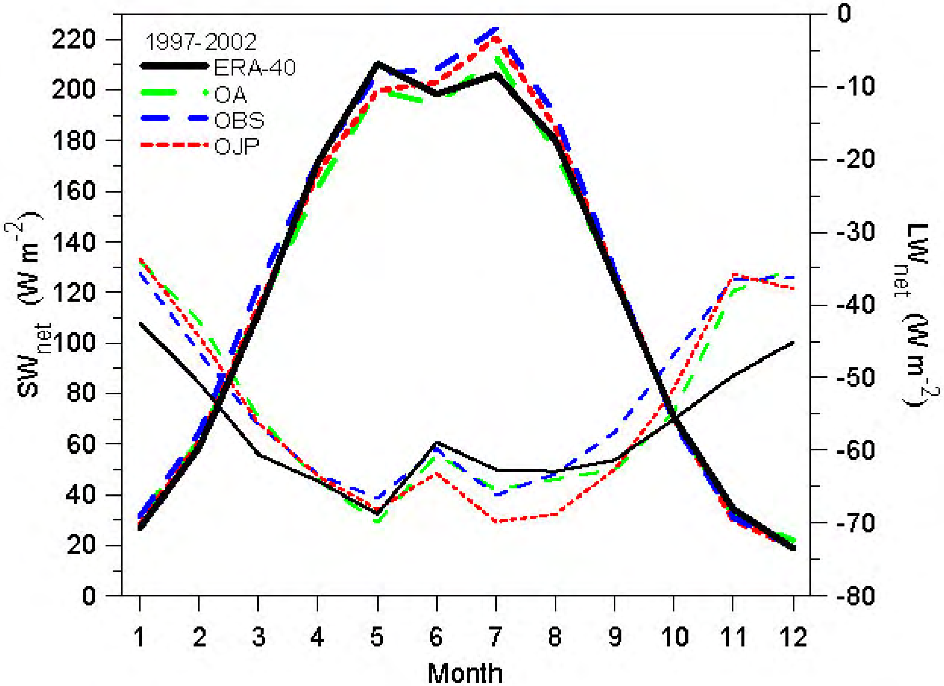
- Similar: λE greater at OBS
- Residual hints at spring thaw

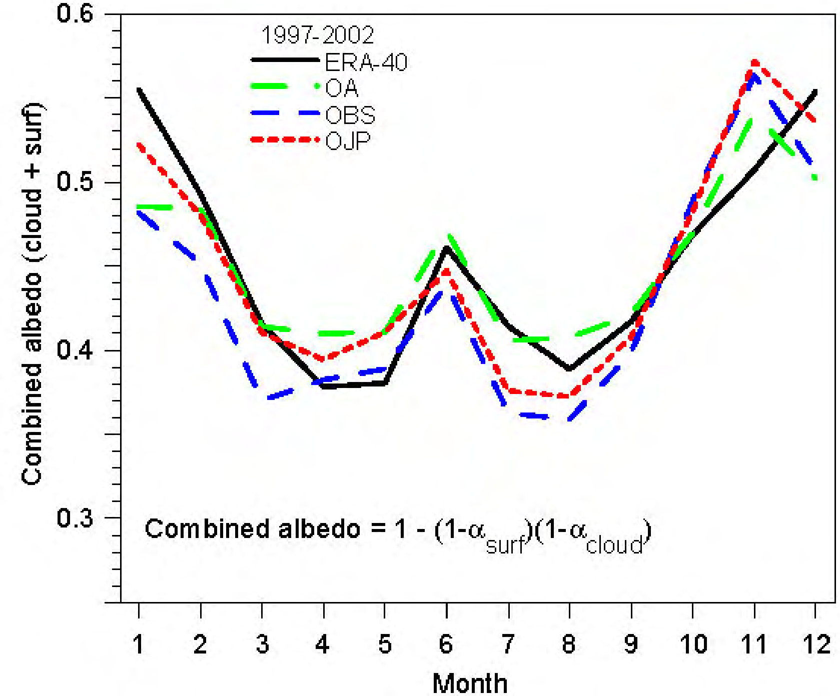
Seasonal Evaporative Fraction

- Data as expected
  OA>OBS>OJP
- ERA-40 too high in spring and fall
- Lacks seasonal cycle
- ERA a little high in summer?



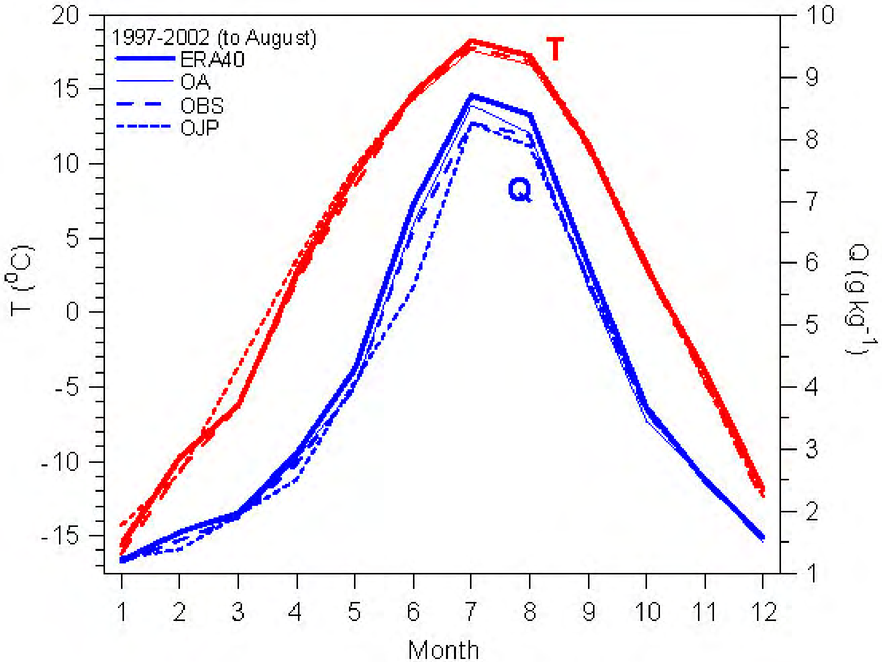
SW, LW and albedo comparison

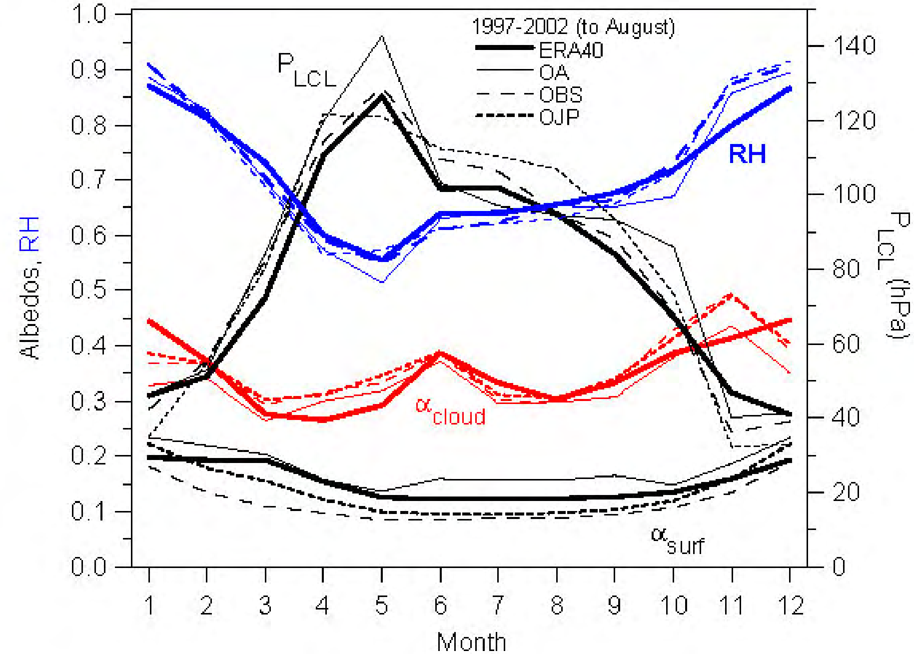




- SW_{net} related to combined albedo
- ERA-40 has LW_{net} bias in winter?

Comparison of T, Q, RH, albedos

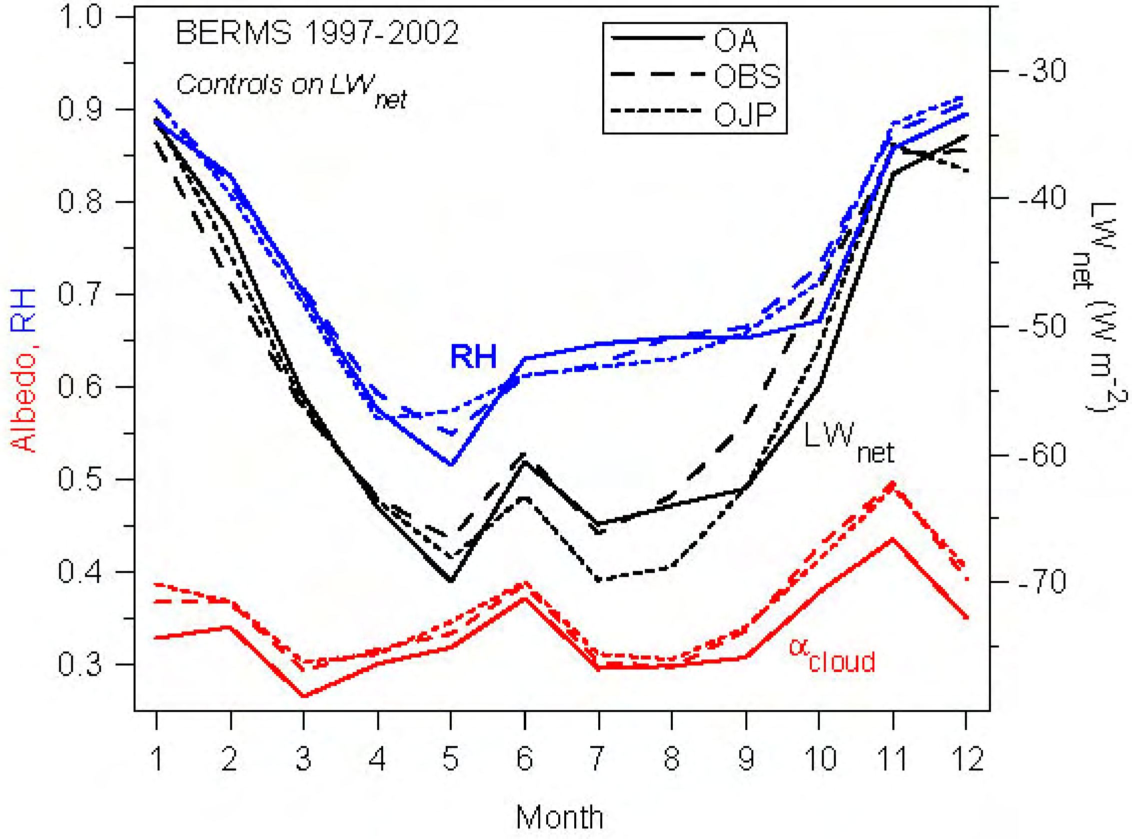




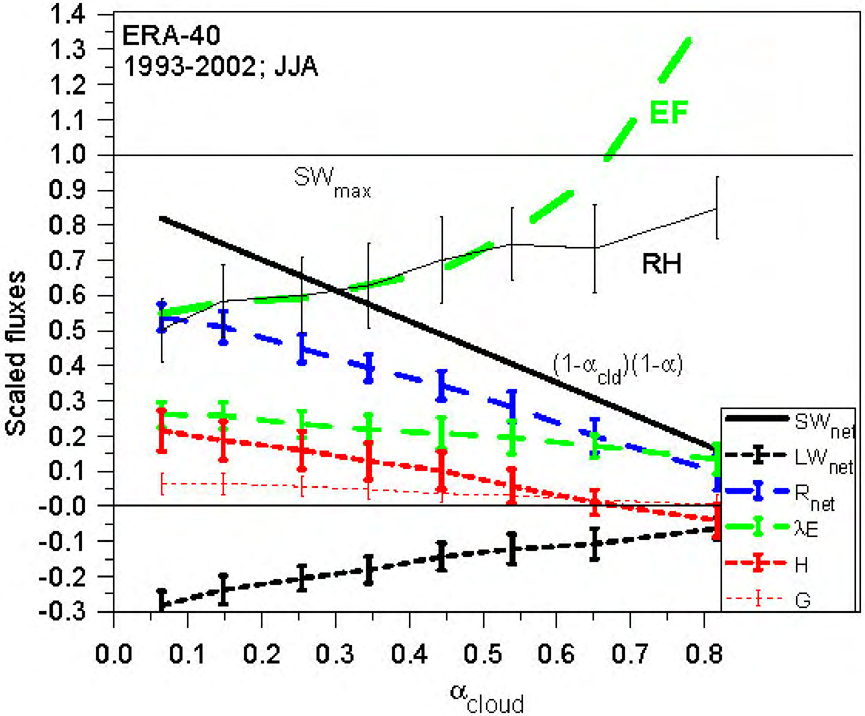
- ERA-40 has small wet bias
- α_{cloud} is BL quantity: similar at 3 sites
- RH, P_{LCL} also ‘BL’: influenced by local λE

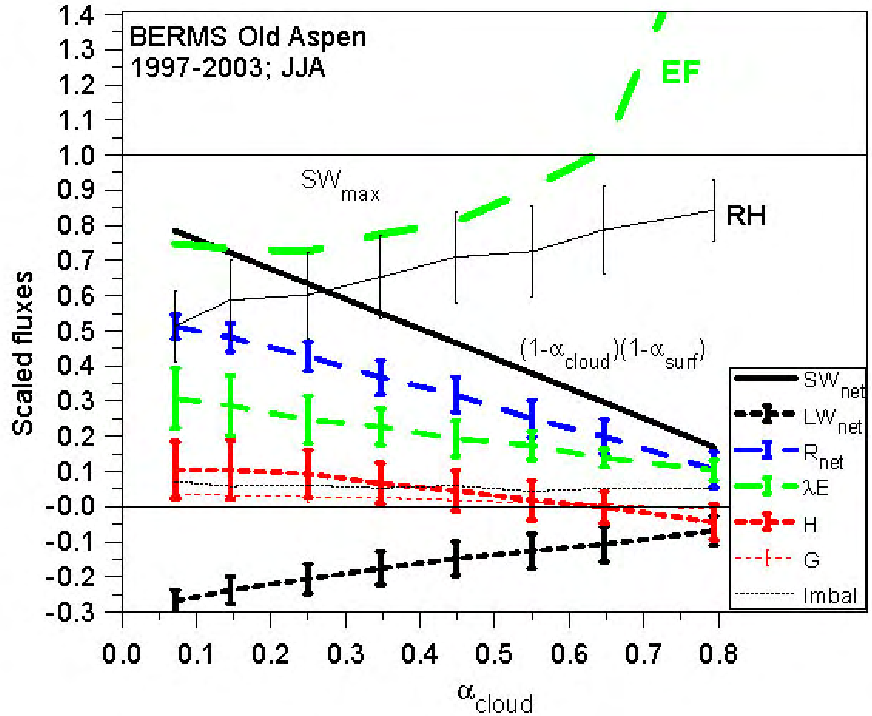
Controls on LW_{net}

- Depends on RH related to mean LCL
- Depends on cloud cover



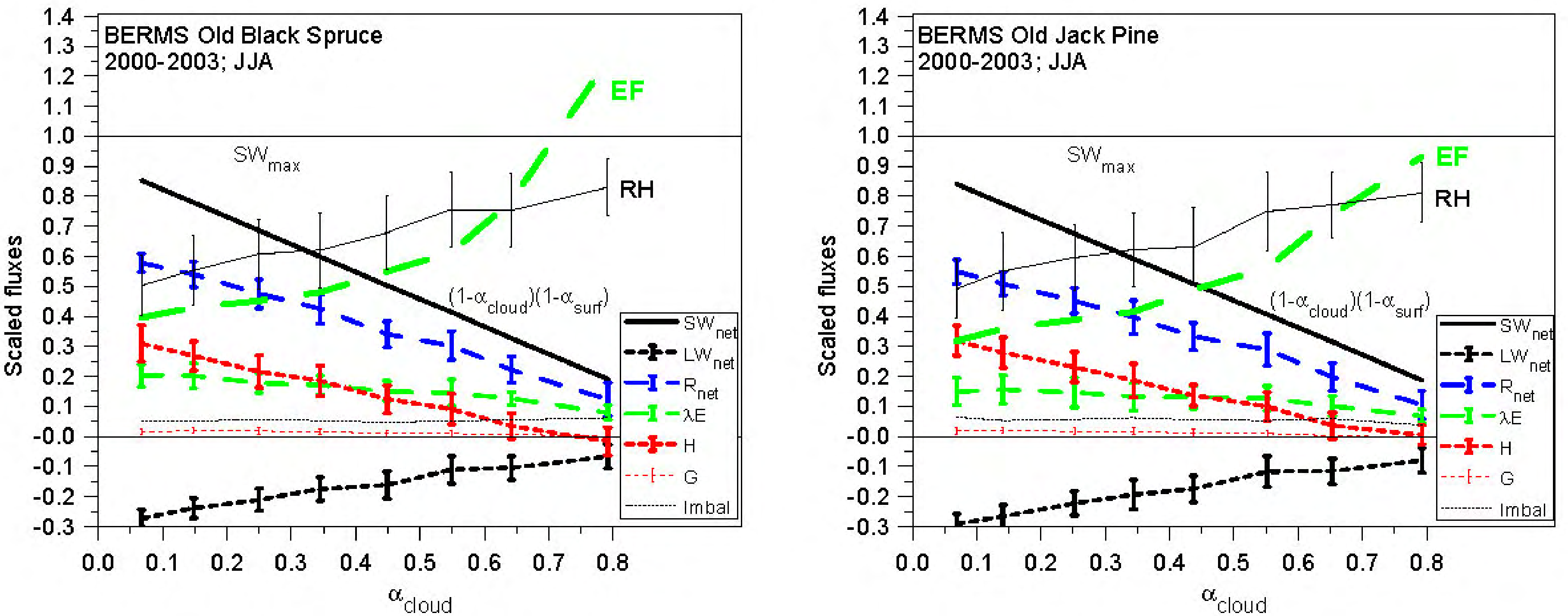
How do fluxes depend on cloud cover?





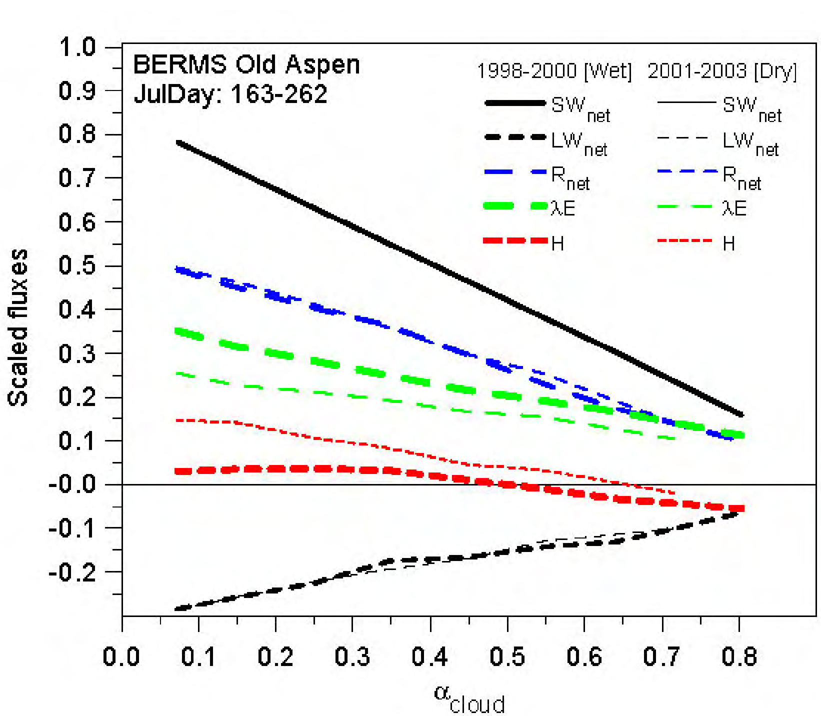
- Bin daily data by α_{cloud}
- Quasi-linear variation
- Evaporation varies less than other fluxes

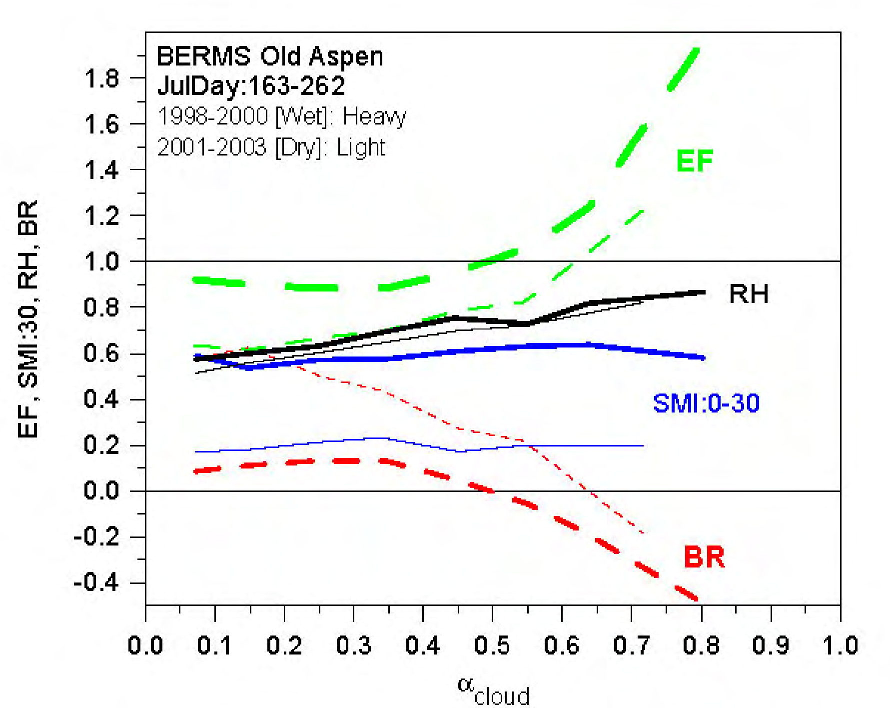
Conifer sites similar



- Evaporation flat, H parallel to R_{net}
- EF goes up with cloud cover

OA Summers 2001-2003 were drier than 1998-2000

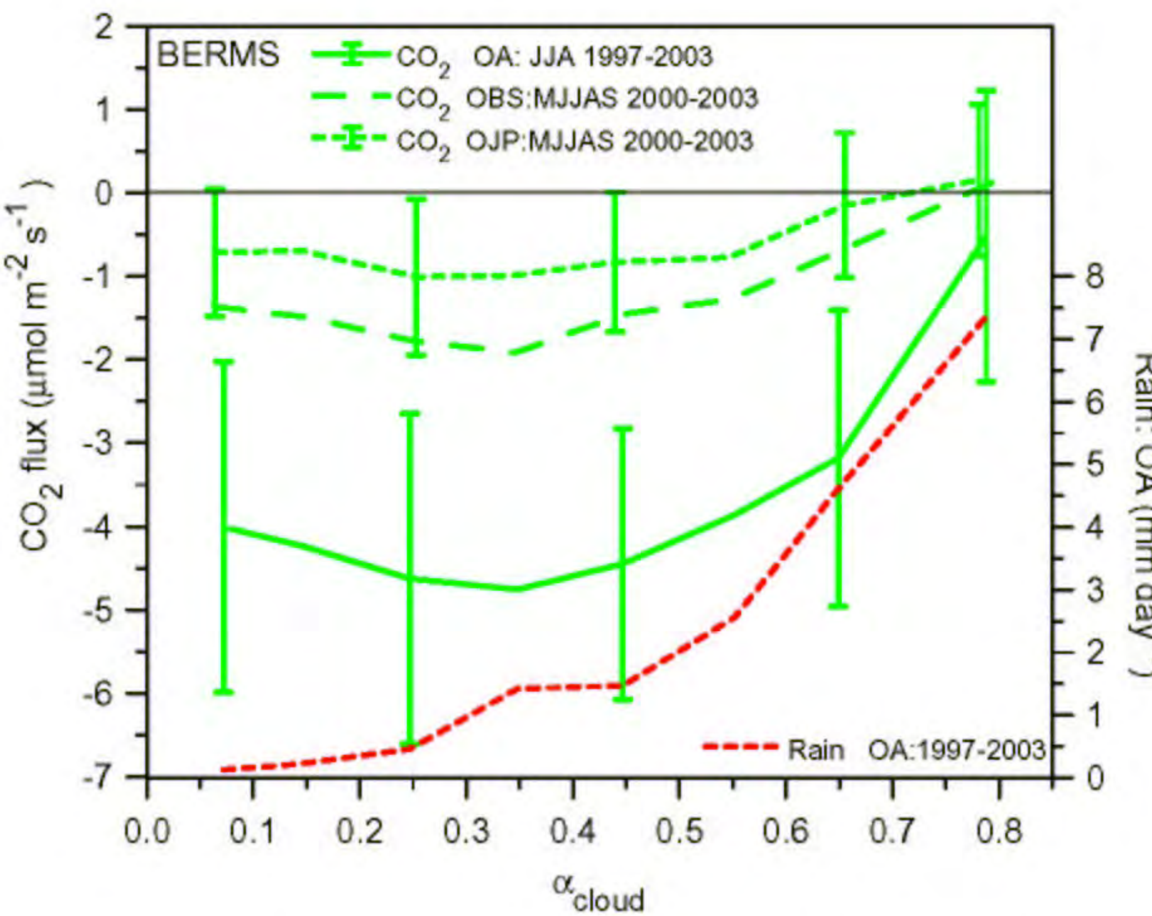




- Radiative fluxes same, but evaporation higher with higher soil moisture

CO_2 fluxes and clouds

- Flux progression from OJP,OBS to OA as expected
- Peak uptake at $\alpha_{cloud} = 0.35$



Conclusions -1

- Flux tower data have played a key role in improving representation of physical processes in forecast models
- Forecast accuracy has improved
- Mean biases have been greatly reduced
- Errors are still visible with careful analysis, so more improvements possible

Conclusions - 2

- Now looking for accuracy in key climate processes: will impact seasonal forecasts
- Are observables coupled correctly in a model?
- Key non-local observables:
  - BL quantities: RH, LCL
  - Clouds: reduce SW reaching surface, α_{cloud}

Conclusions - 3

- SW balance at surface
- Cloud albedo is as important as surface albedo [with higher variability]
- Clouds, BL and surface are a coupled system
- Models can help us understand the coupling of physical processes