Land-surface-BL-cloud coupling

Alan K. Betts
Atmospheric Research, Pittsford, VT
akbetts@aol.com

Co-investigators
BERMS Data: Alan Barr, Andy Black, Harry McCaughey
ERA-40 data: Pedro Viterbo

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Background references

- Betts, A. K., 2004: Understanding Hydrometeorology using global models. *Bull. Amer. Meteorol. Soc*., **85**, 1673-1688.
- Betts, A. K and P. Viterbo, 2005: Land-surface, boundary layer and cloud-field coupling over the Amazon in ERA-40. *J. Geophys. Res*., in press
- Betts, A. K., R. Desjardins and D. Worth, 2004: Impact of agriculture, forest and cloud feedback on the surface energy balance in BOREAS. *Agric. Forest Meteorol*., in press

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

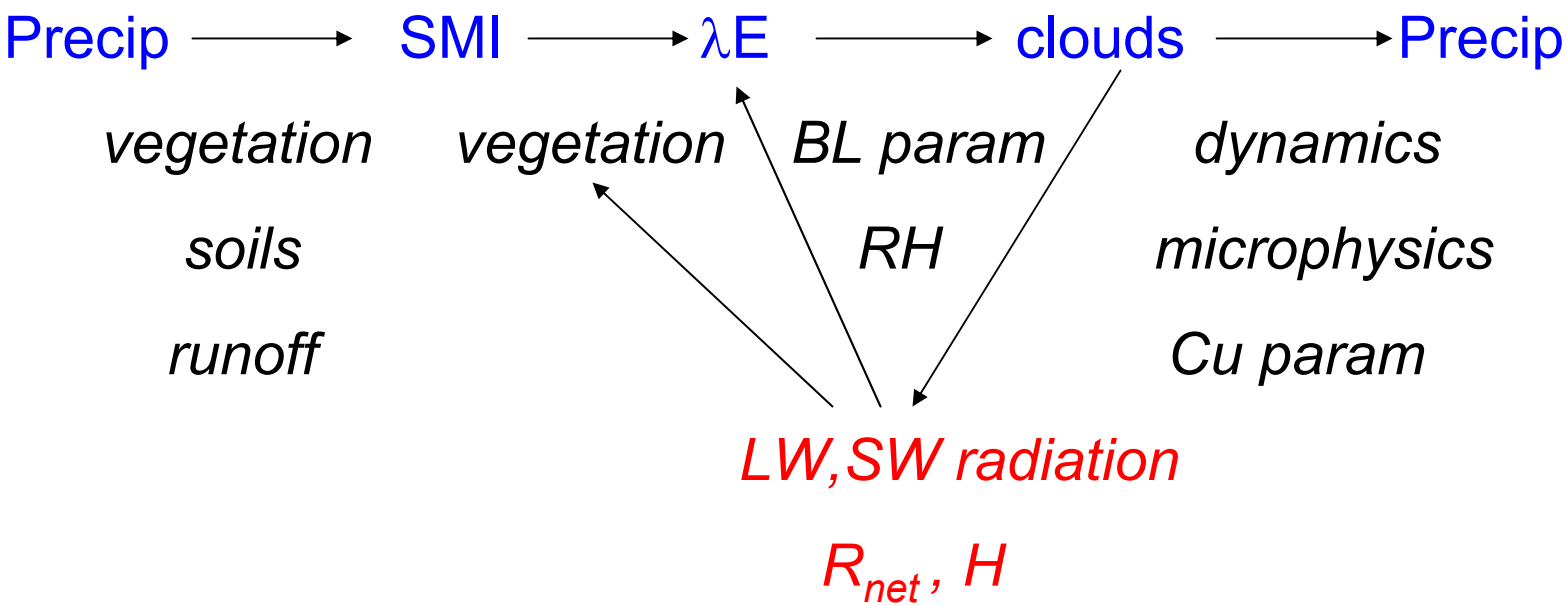
Climate and weather forecast models

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

Land-surface coupling

Models differ widely *[Koster et al., Science, 2004]*



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

α_{cloud}: 'cloud albedo' viewed from surface

[*]

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 and Viterbo, 2005]*

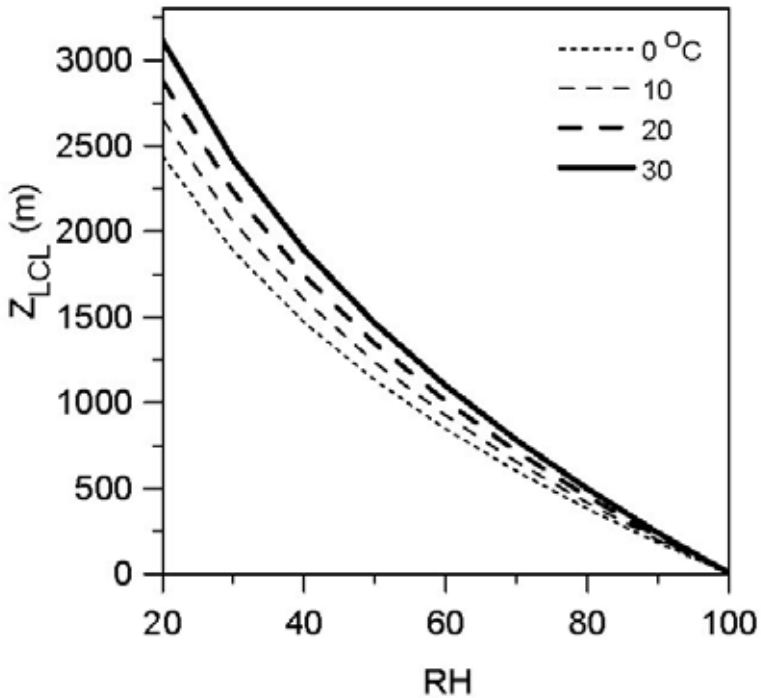
- DATA CAN TELL US

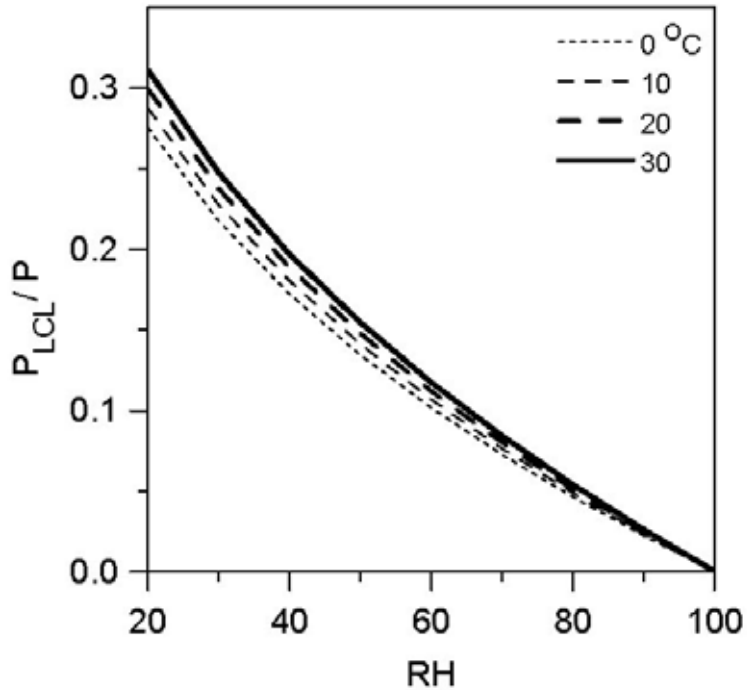
Daily mean fluxes give model 'equilibrium climate' state

- 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





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

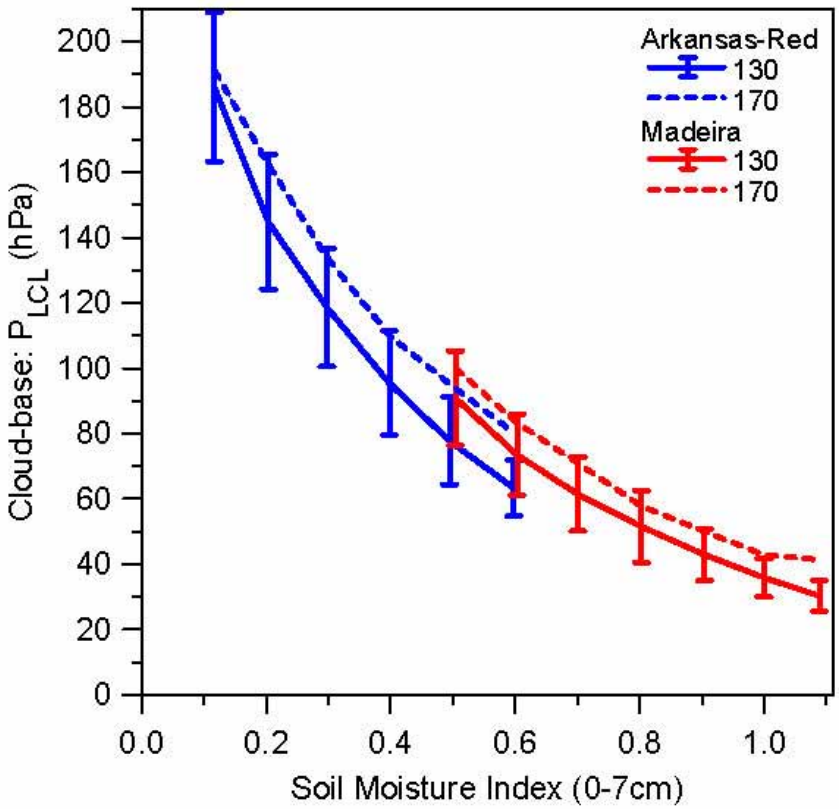
What controls daily mean RH anyway?

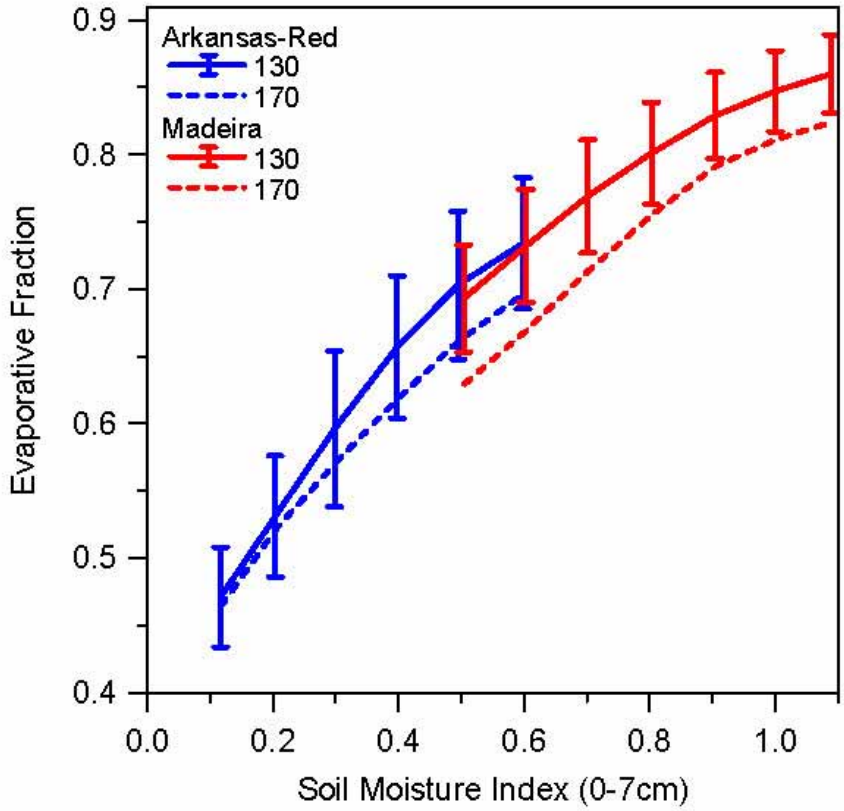
- RH is balance of subsidence velocity and surface conductance
- Subsidence is radiatively driven [40 hPa/day]
  + dynamical 'noise'
- Surface conductance

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

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

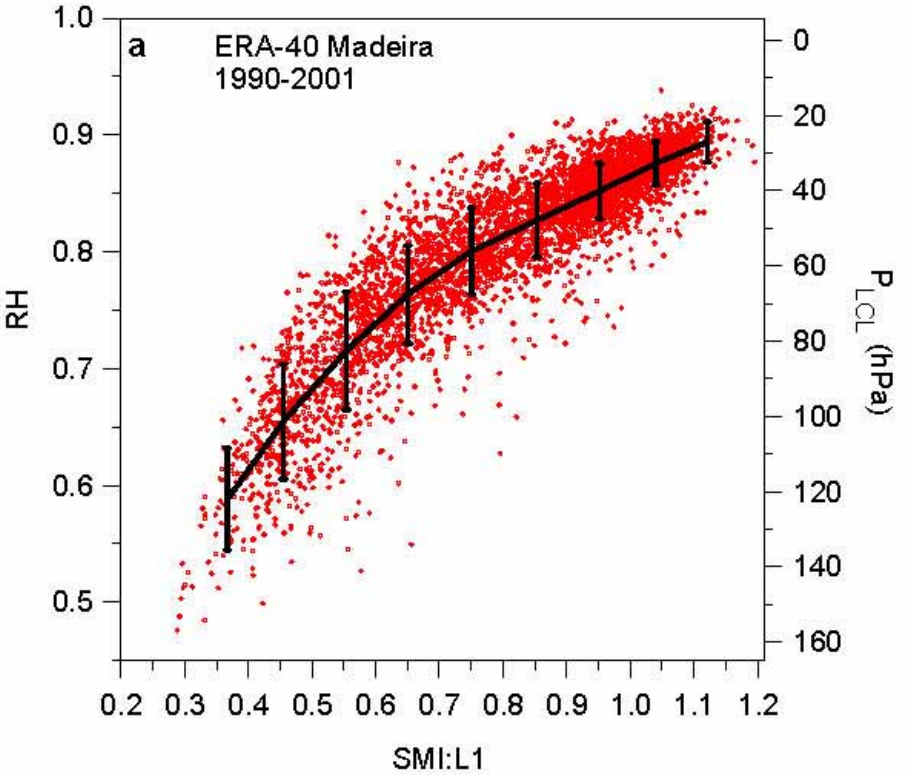
ERA40: soil moisture → LCL and EF

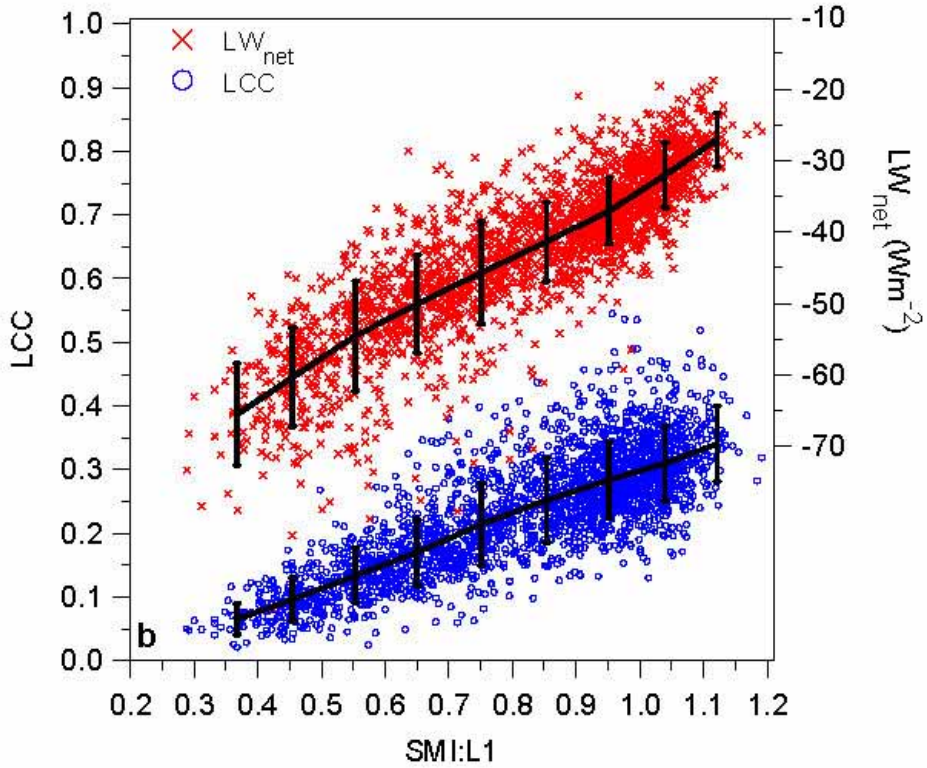




- River basin daily means
- Binned by soil moisture and R_{net}

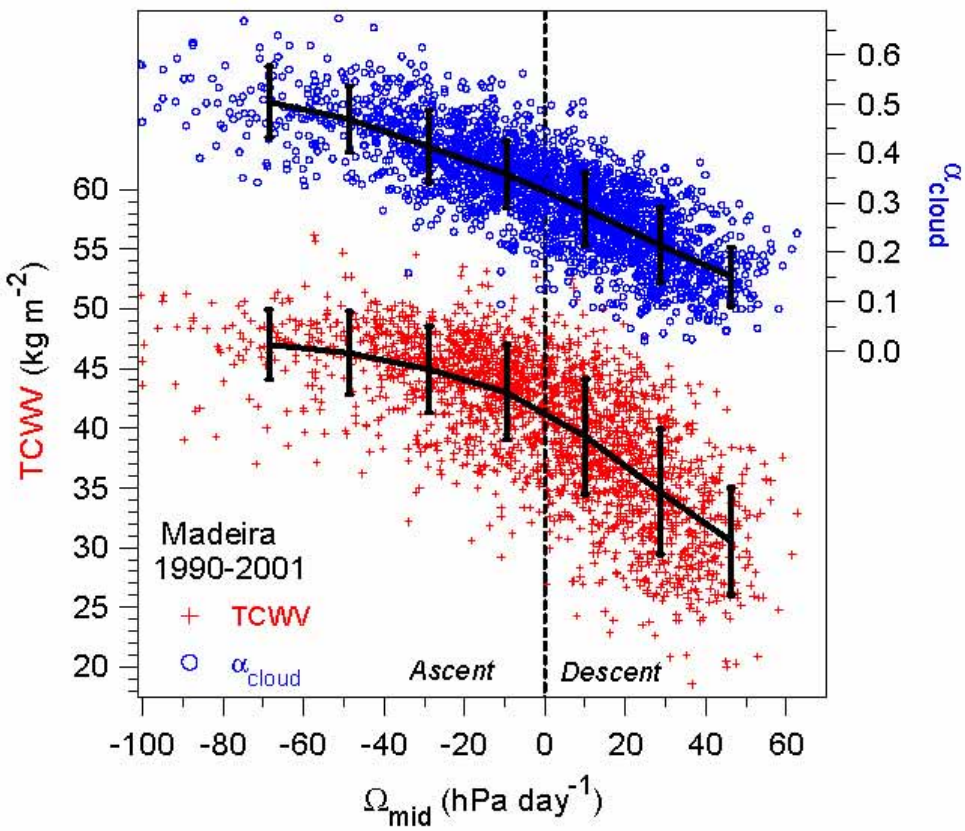
ERA40: Surface 'control'

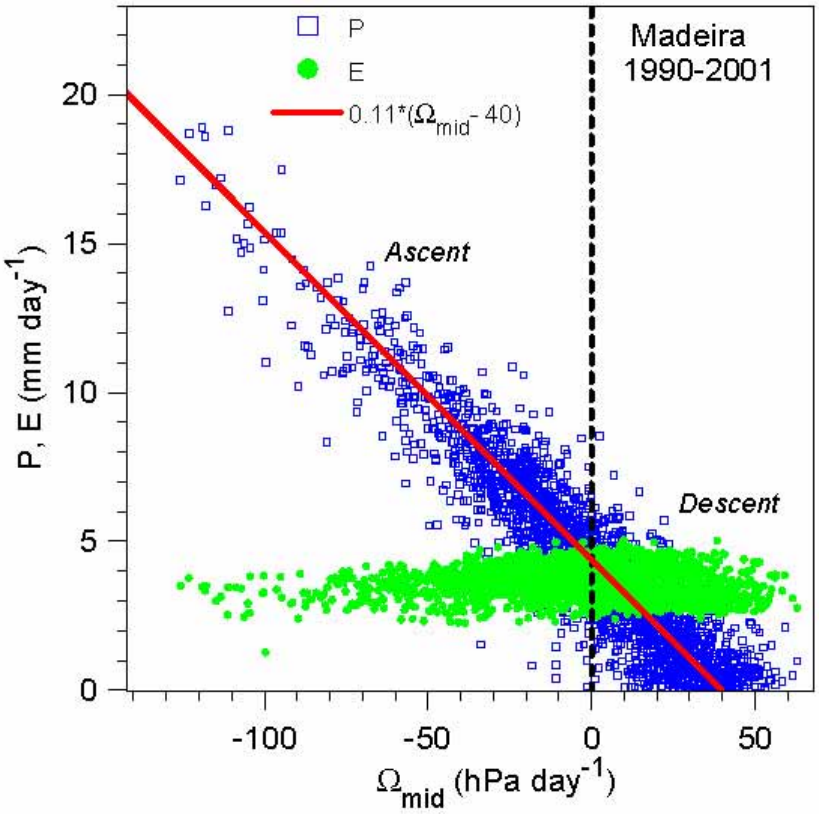




- Madeira river, SW Amazon
- Soil water ⟶ LCL, LCC and LW_{net}

ERA-40 dynamic link (mid-level omega)





- Ω_{mid} → Cloud albedo, TCWV and Precipitation

Compare ERA-40 with 3 BERMS sites

Focus:

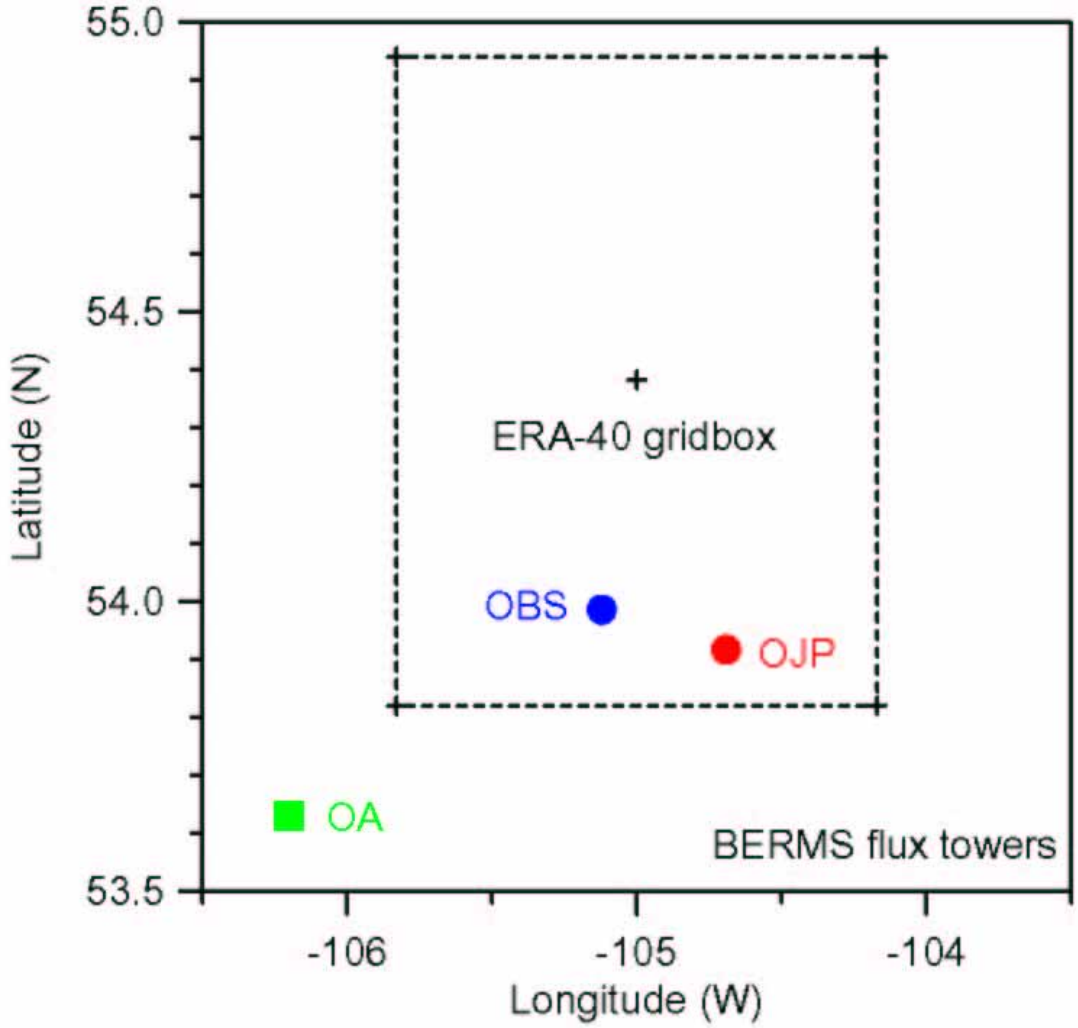
- Coupling of clouds to surface fluxes
- Define a 'cloud albedo' that reduces the shortwave (SW) flux reaching surface

  - Basic 'climate parameter', coupled to surface evaporation [locally/distant]

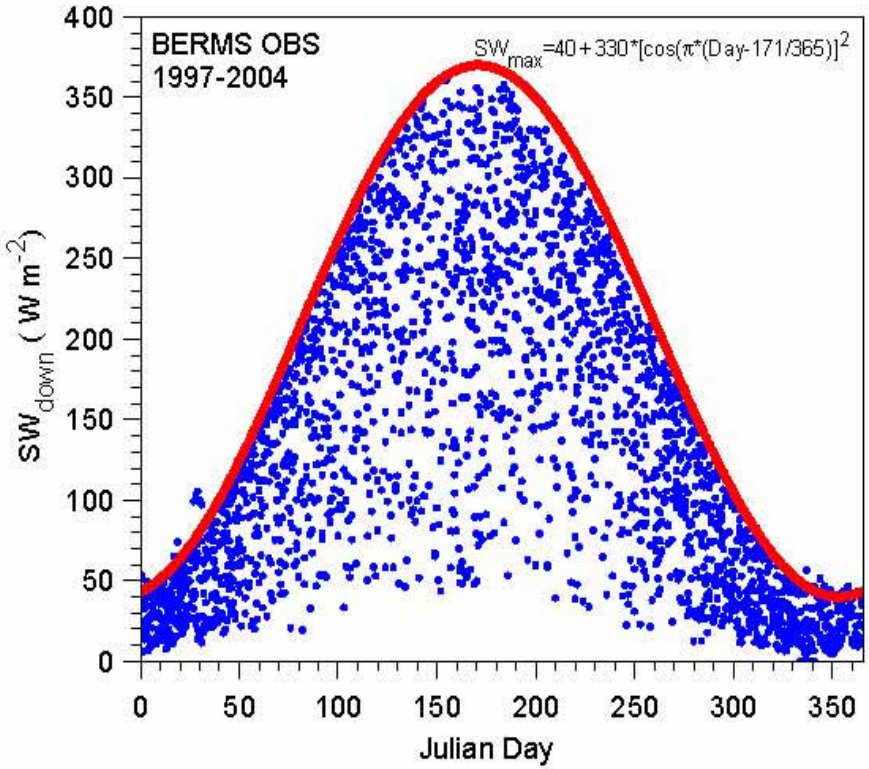
  - More variable than surface albedo

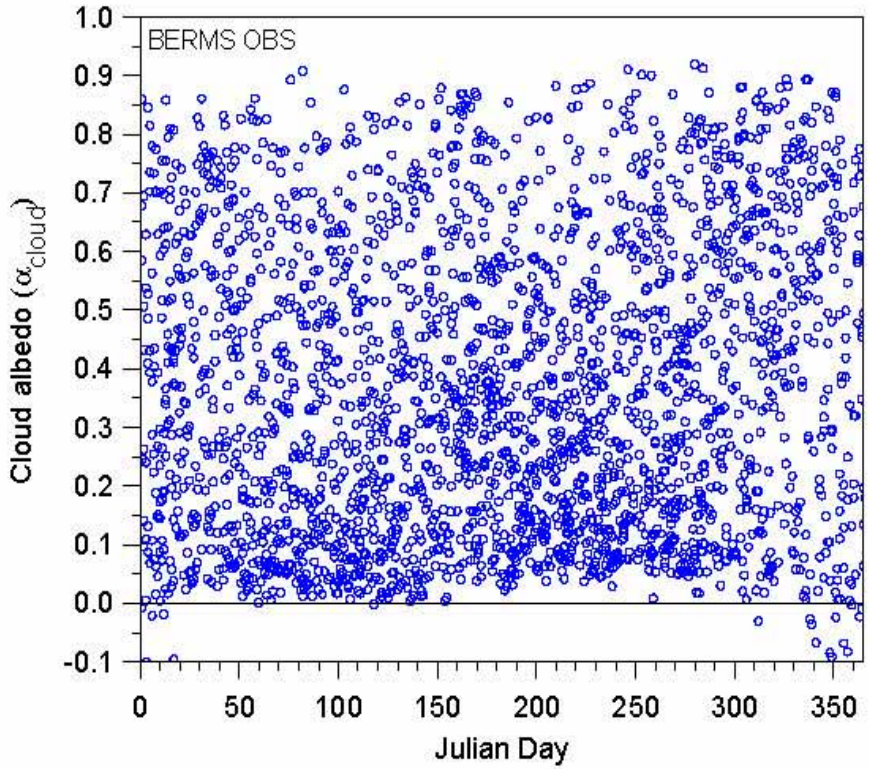
Compare ERA-40 with BERMS

- 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



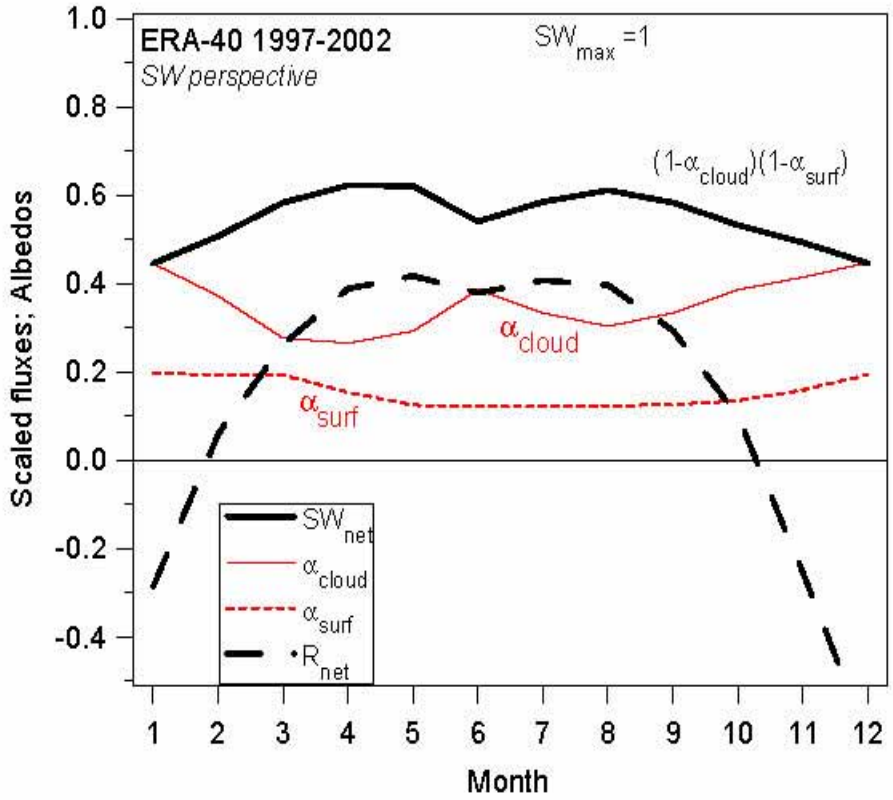
BERMS: Old Black Spruce

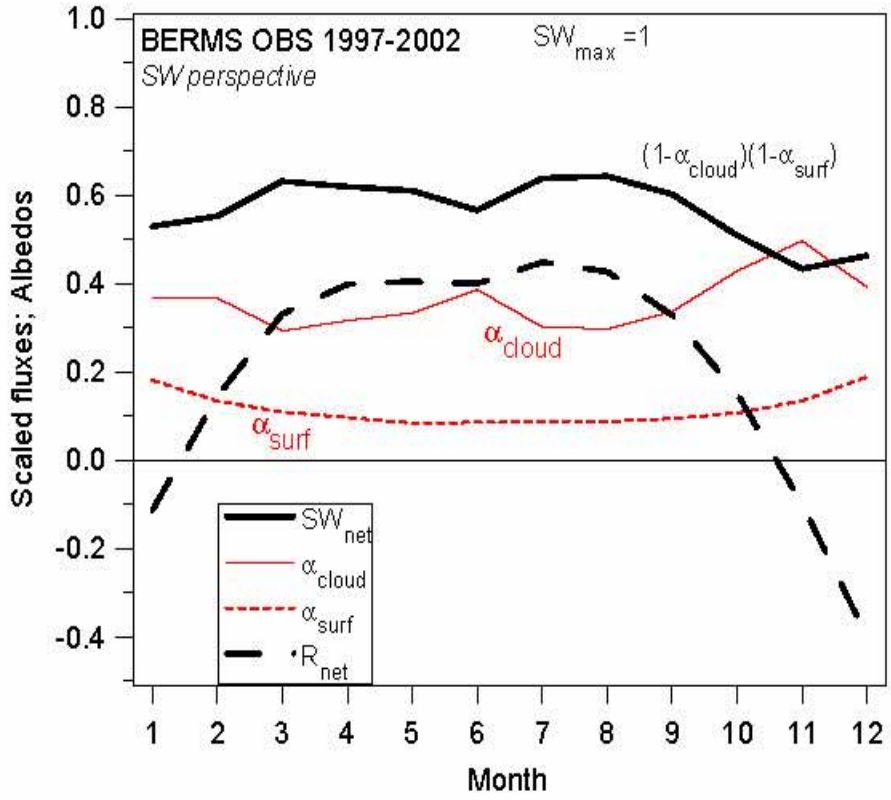




- Cloud 'albedo': $\alpha_{cloud} = 1 - SW_{down}/SW_{max}$
- Similar distribution to ERA-40

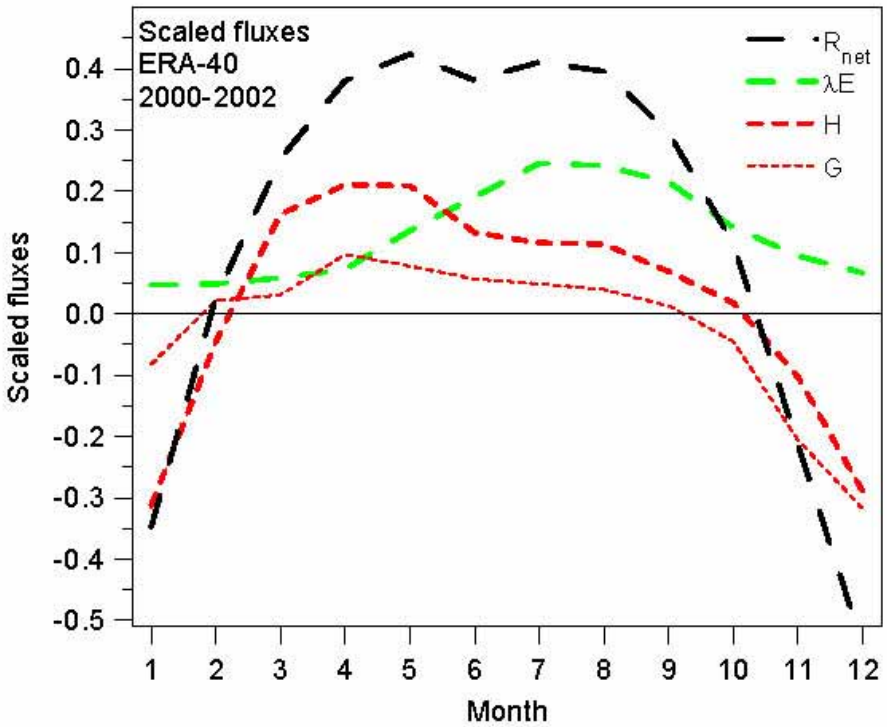
SW perspective: scale by SW_{max}

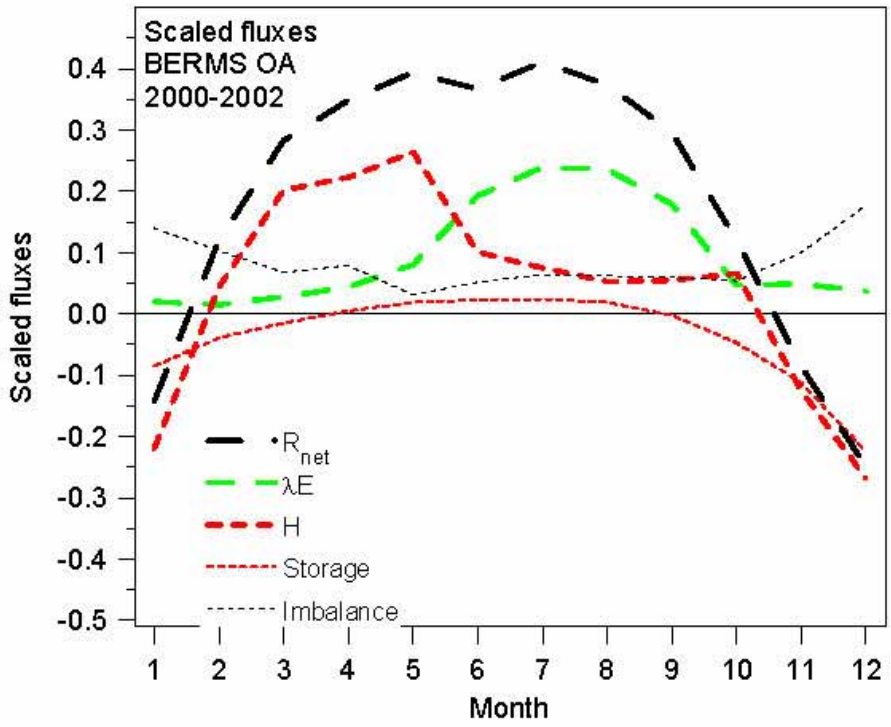




- α_{surf}, α_{cloud} give SW_{net}
- $R_{net} = SW_{net} - LW_{net}$

Fluxes scaled by SW_{max}

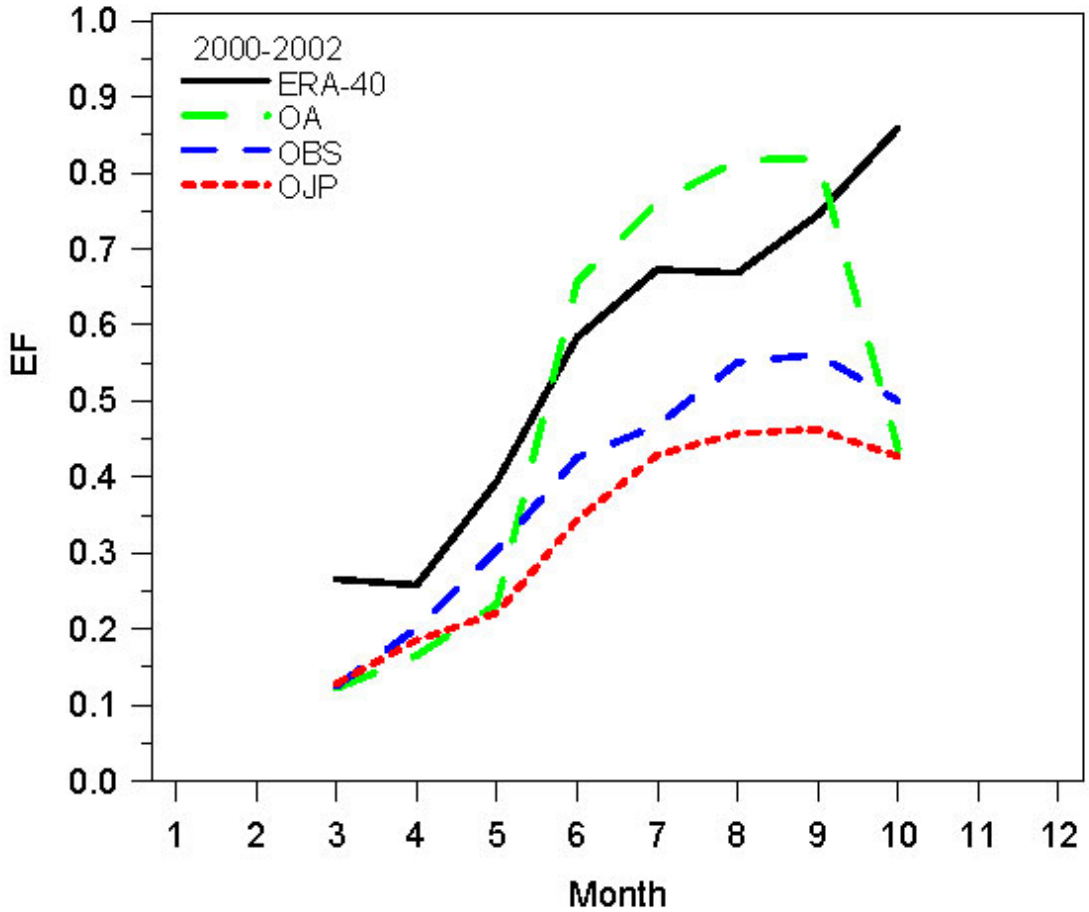




- Old Aspen has sharper summer season
- ERA-40 accounts for freeze/thaw of soil

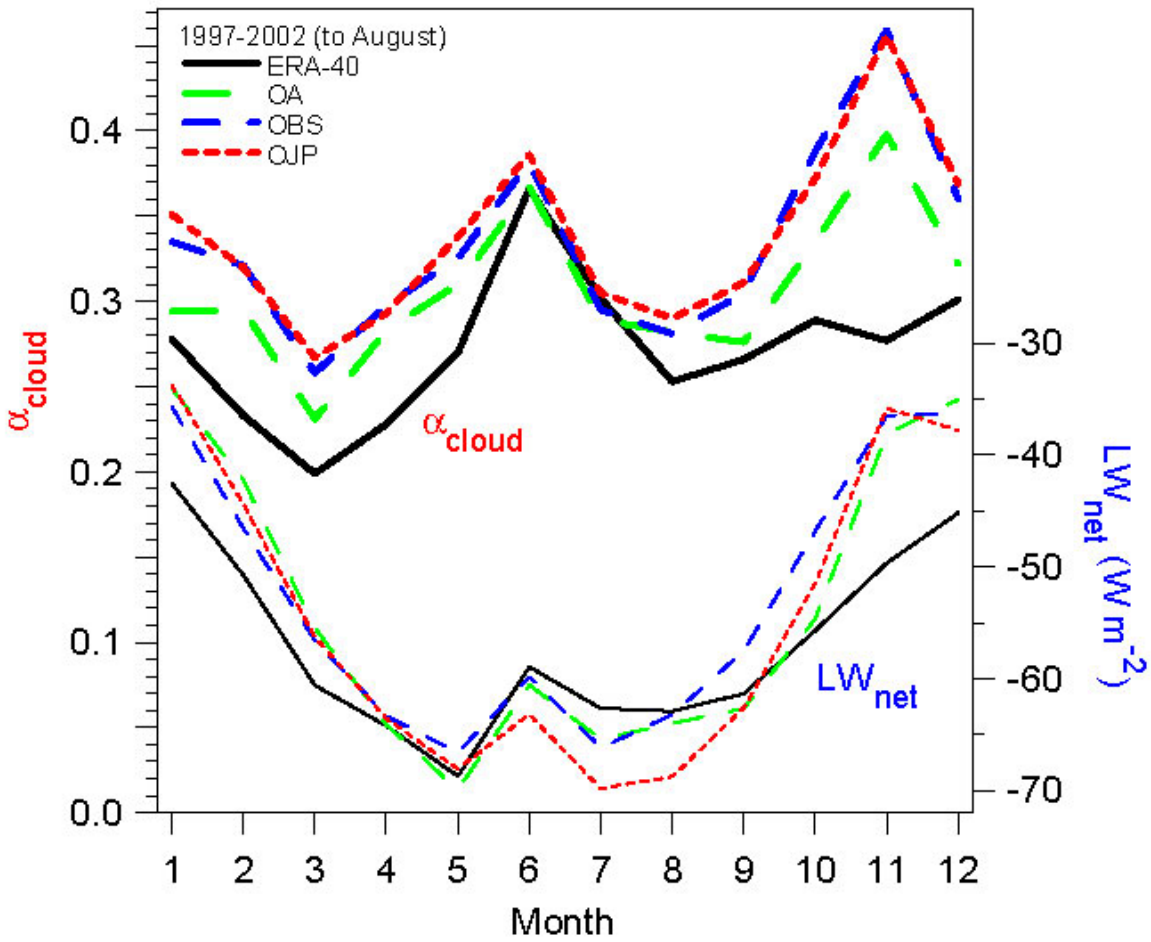
Seasonal Evaporative Fraction

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

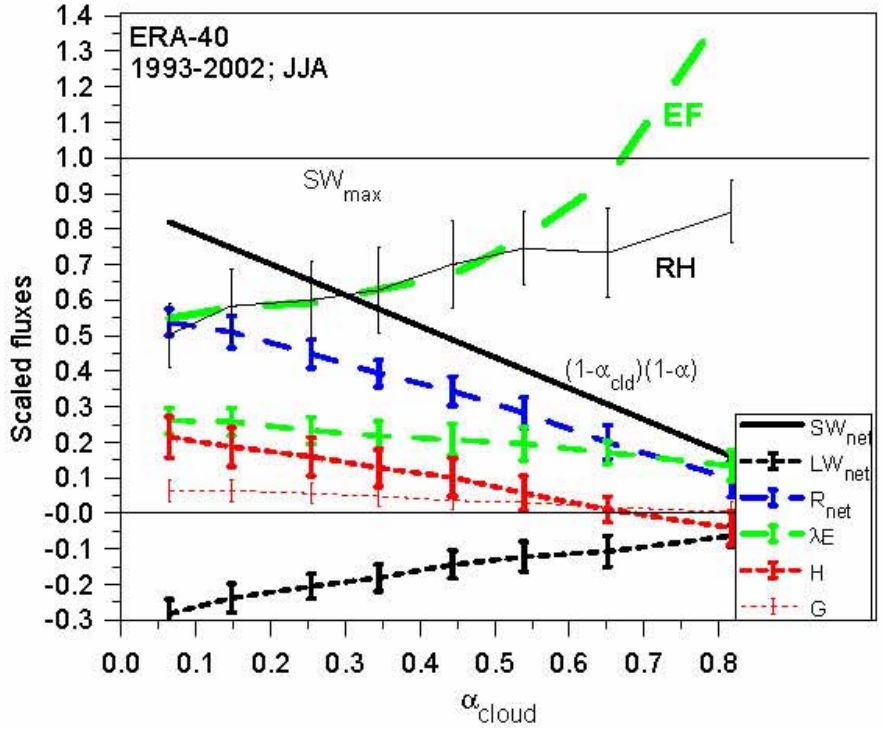


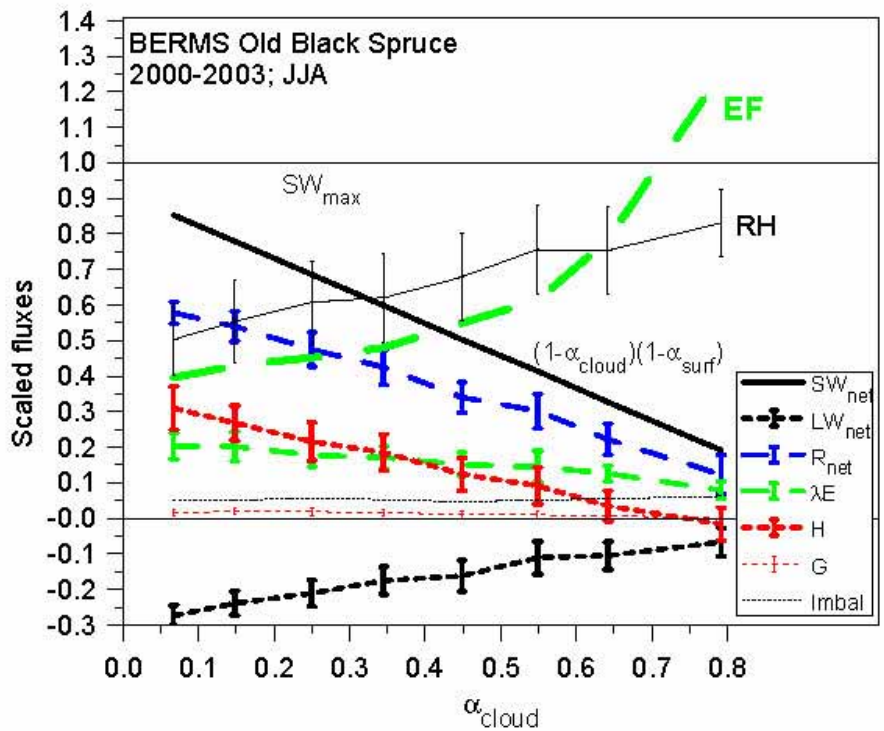
Cloud albedo and LW comparison

- ERA-40 has low α_{cloud} except summer
- ERA-40 has LW_{net} bias in winter?



How do fluxes depend on cloud cover?

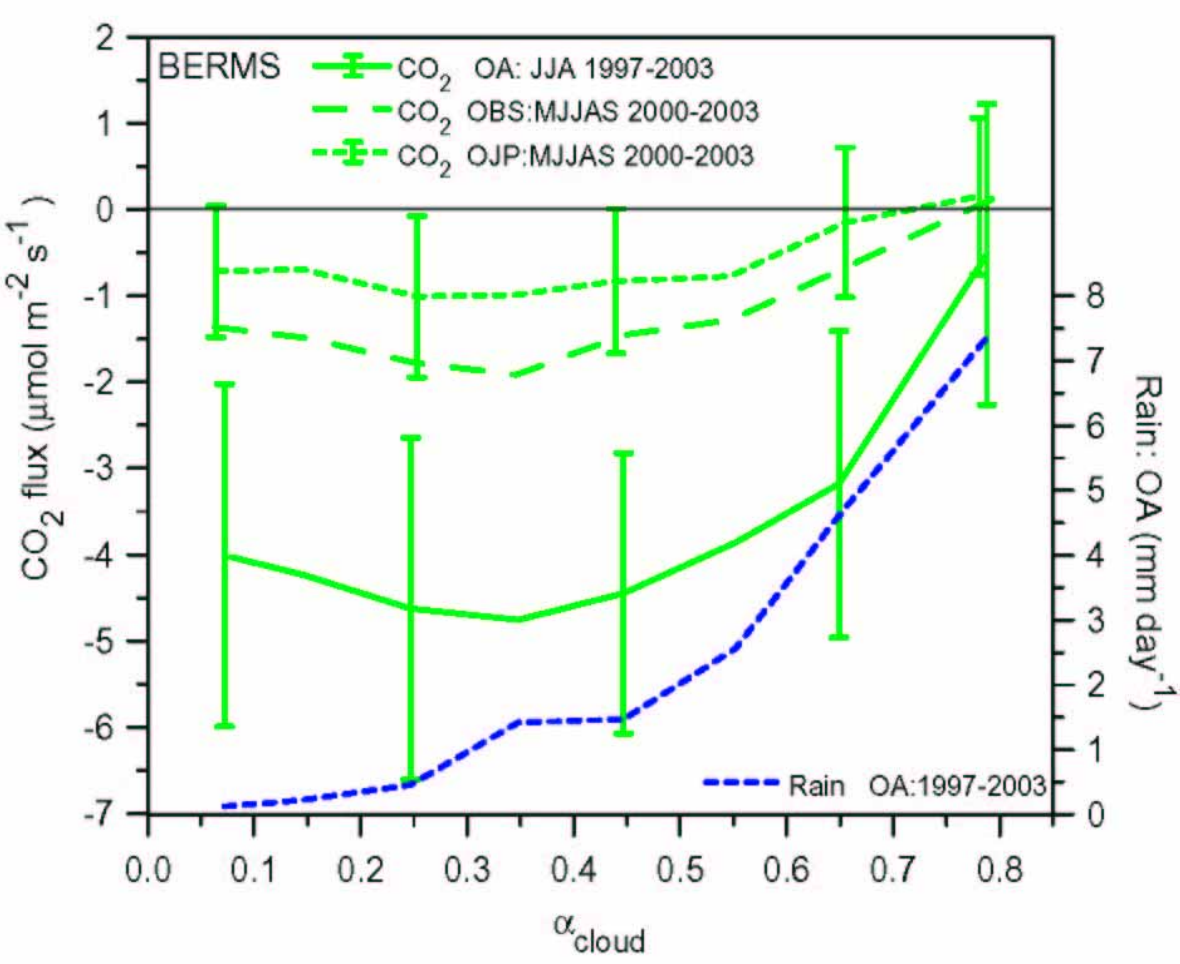




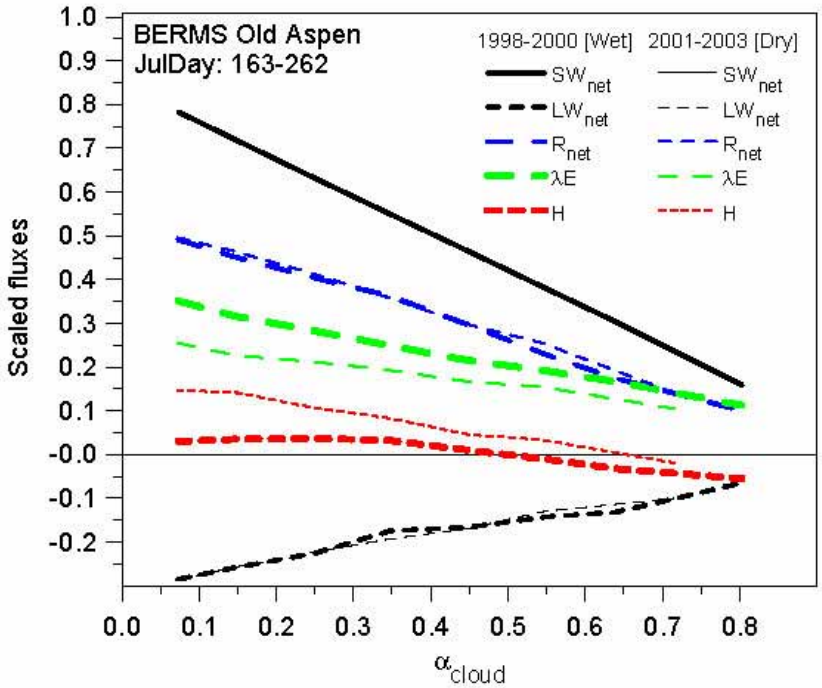
- Bin daily data by α_{cloud}
- Quasi-linear variation
- Evaporation varies less than other fluxes

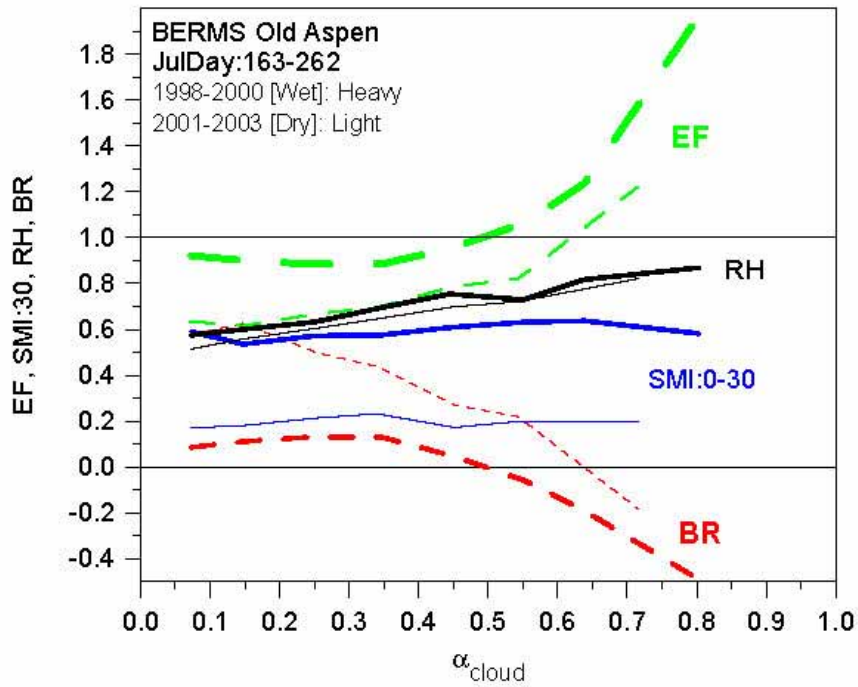
CO_2 fluxes and clouds

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



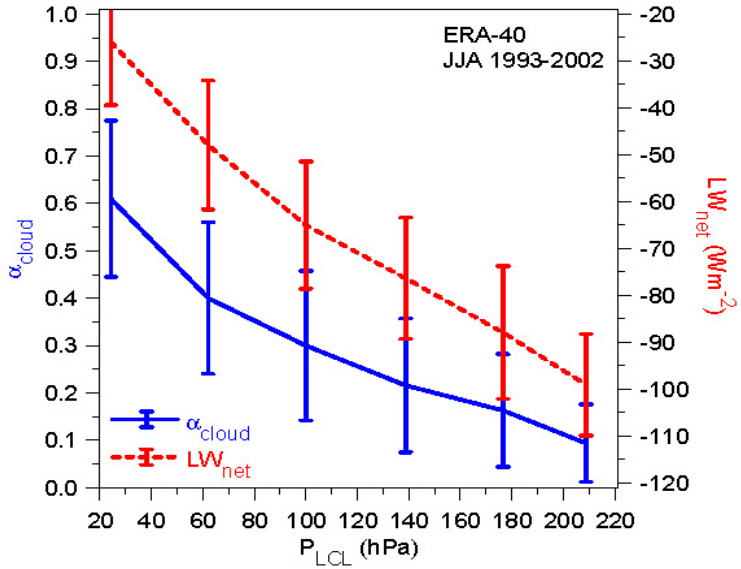
OA Summers 2001-2003 were drier than 1998-2000

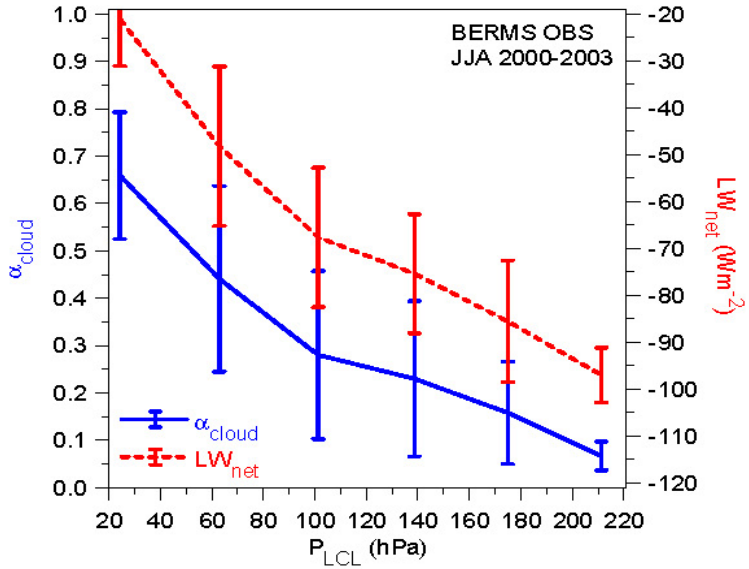


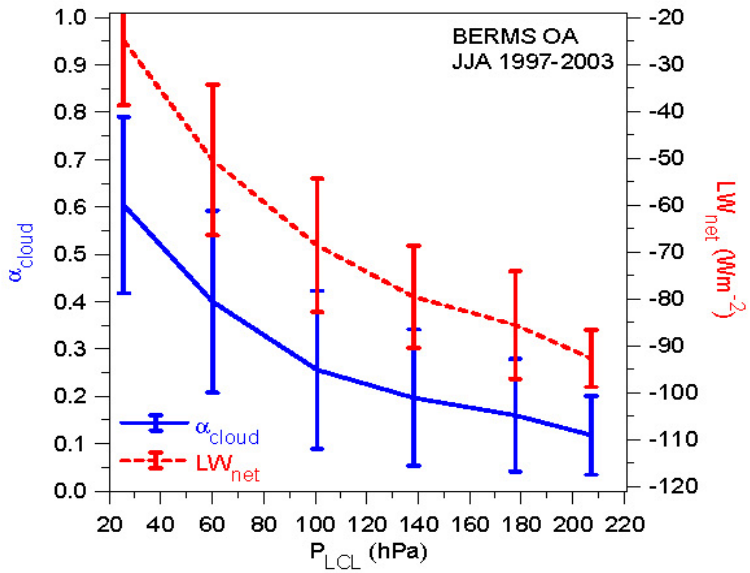


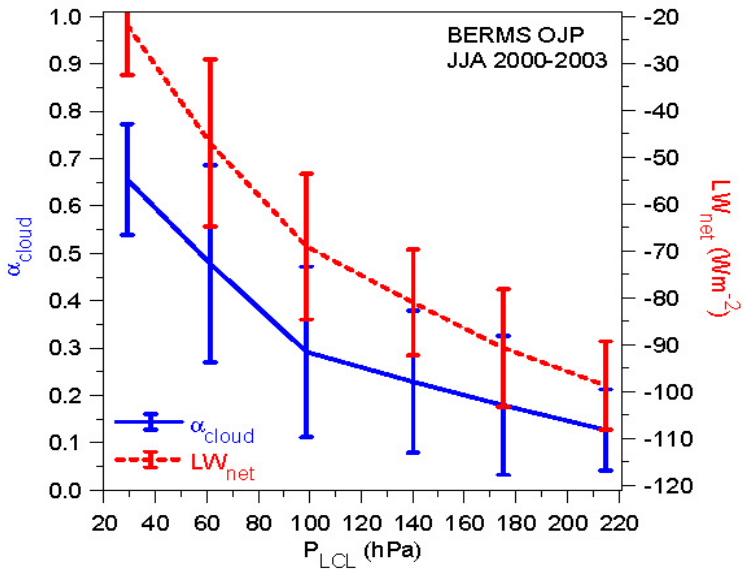
- Radiative fluxes same, but evaporation higher with higher soil moisture

$P_{LCL} \rightarrow \alpha_{cloud}$ and LW_{net}









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

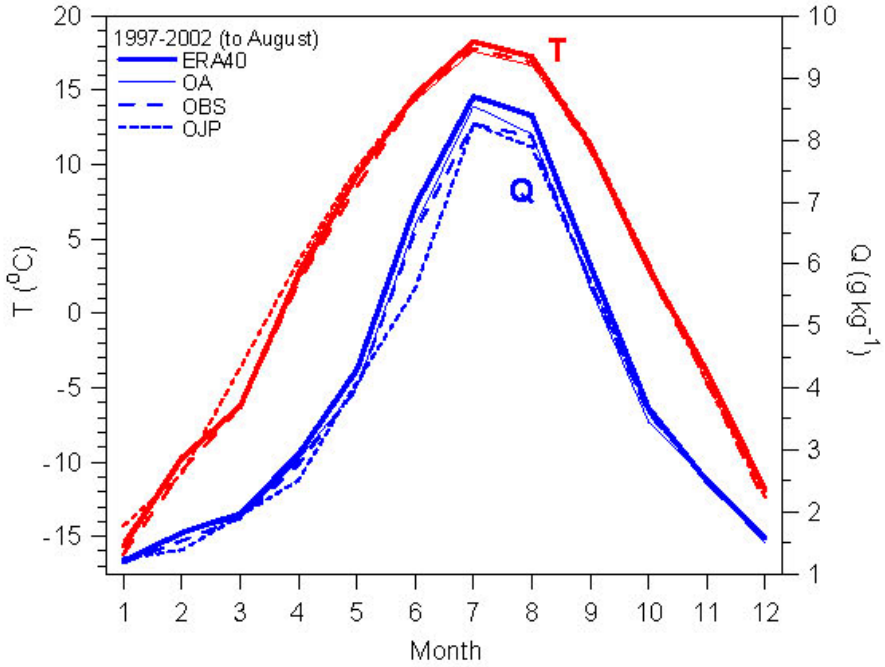
Conclusions - 2

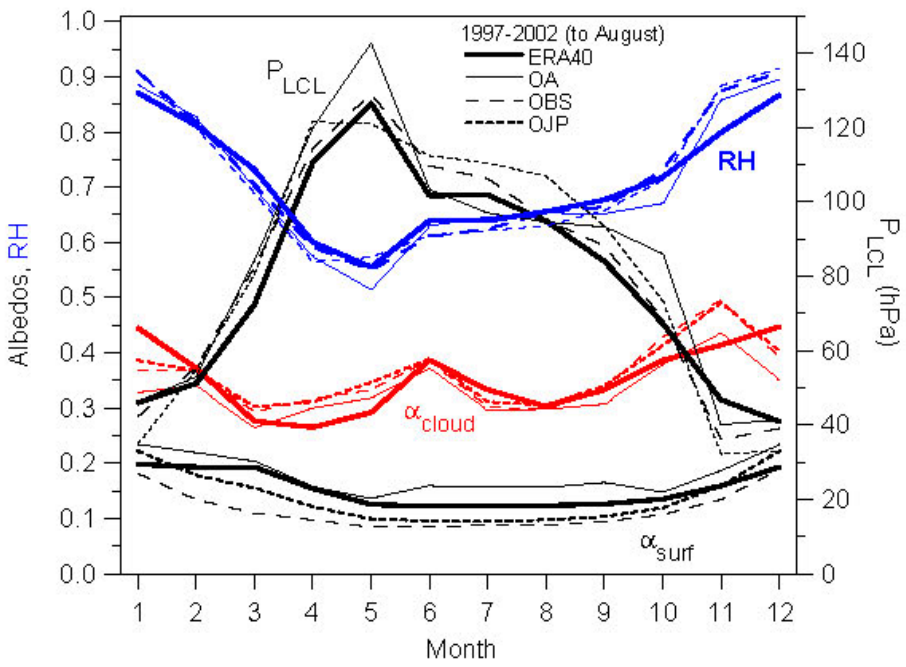
- Now looking for accuracy in key climate processes: will impact seasonal forecasts
- Are observables coupled correctly in a model?
- Key non-local observables:
  - BL quantities: RH, LCL
  - Clouds: reduce SW reaching surface, α_{cloud}

Conclusions - 3

- Cloud albedo is as important as surface albedo [with higher variability]
- Surface fluxes : stratify by α_{cloud}
- Clouds, BL and surface are a coupled system: stratify by P_{LCL}
- Models can help us understand the coupling of physical processes

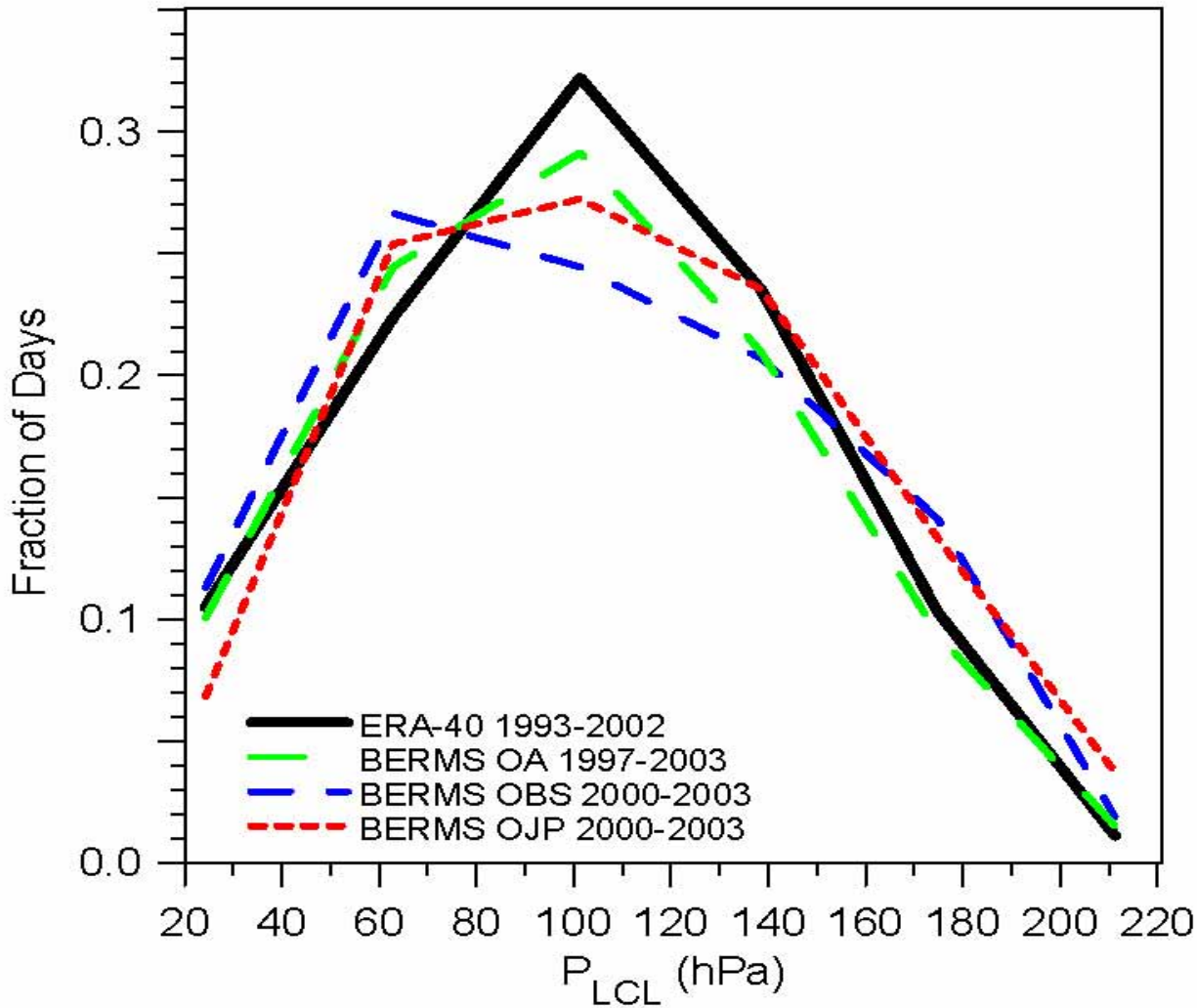
Comparison of T, Q, RH, albedos



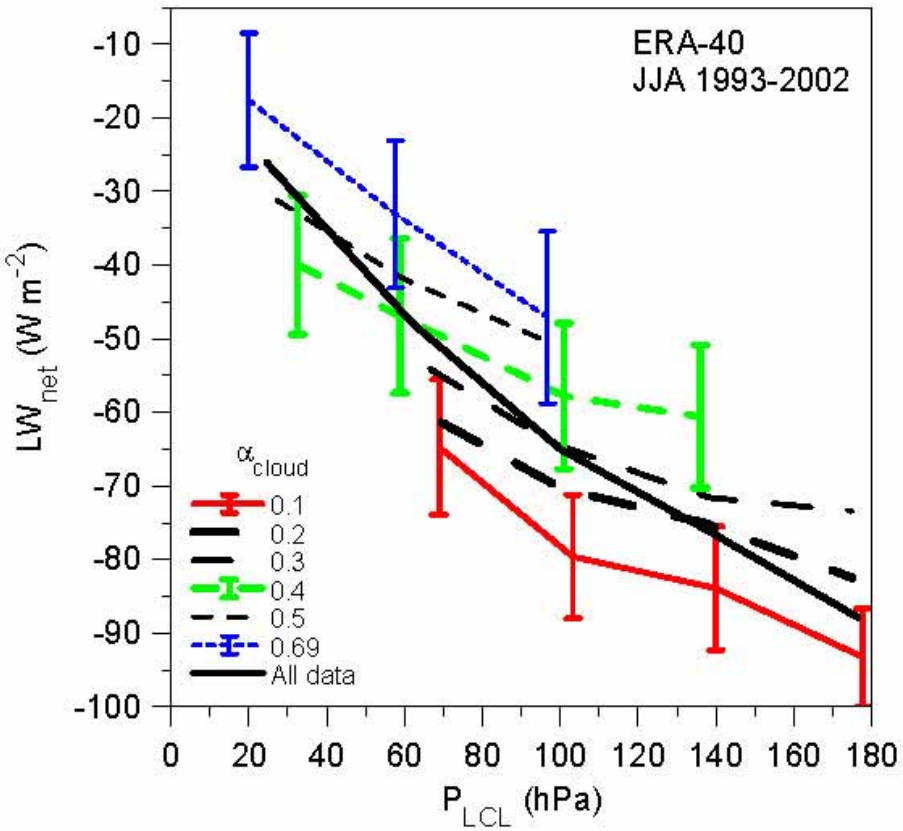


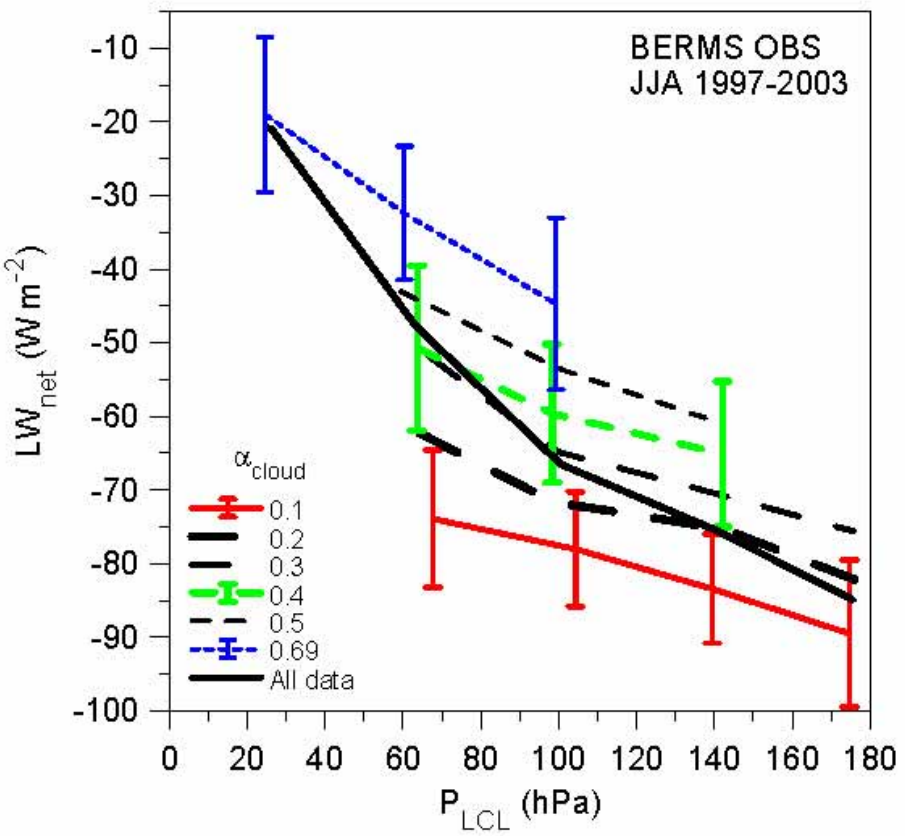
- ERA-40 has small wet bias
- α_{cloud} is BL quantity: similar at 3 sites
- RH, P_{LCL} also 'BL': influenced by local λE

Similar P_{LCL} distributions



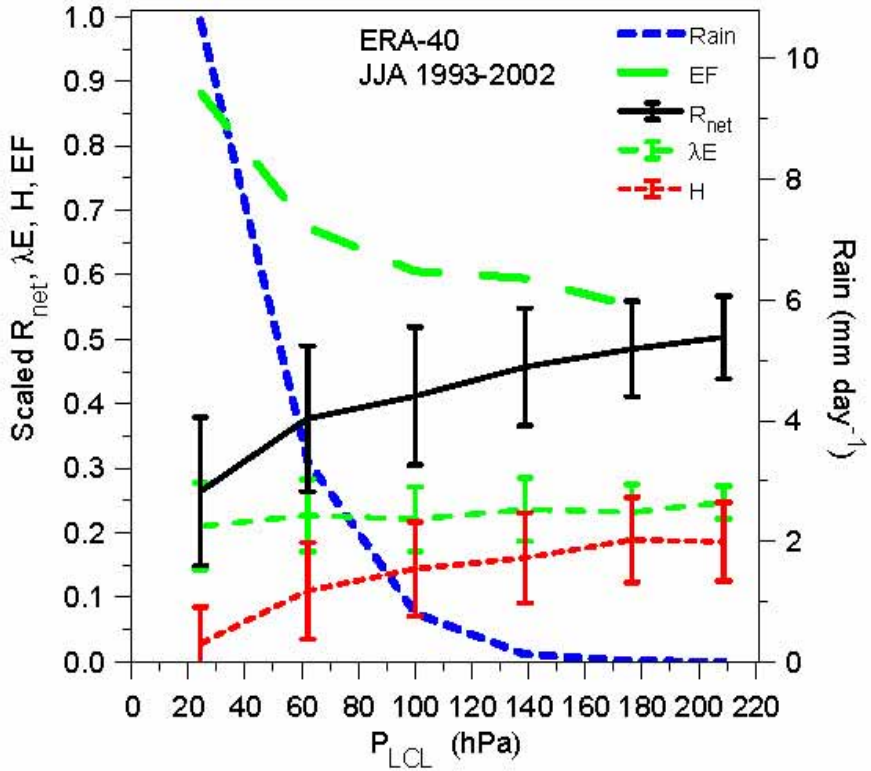
Controls on LW_{net}

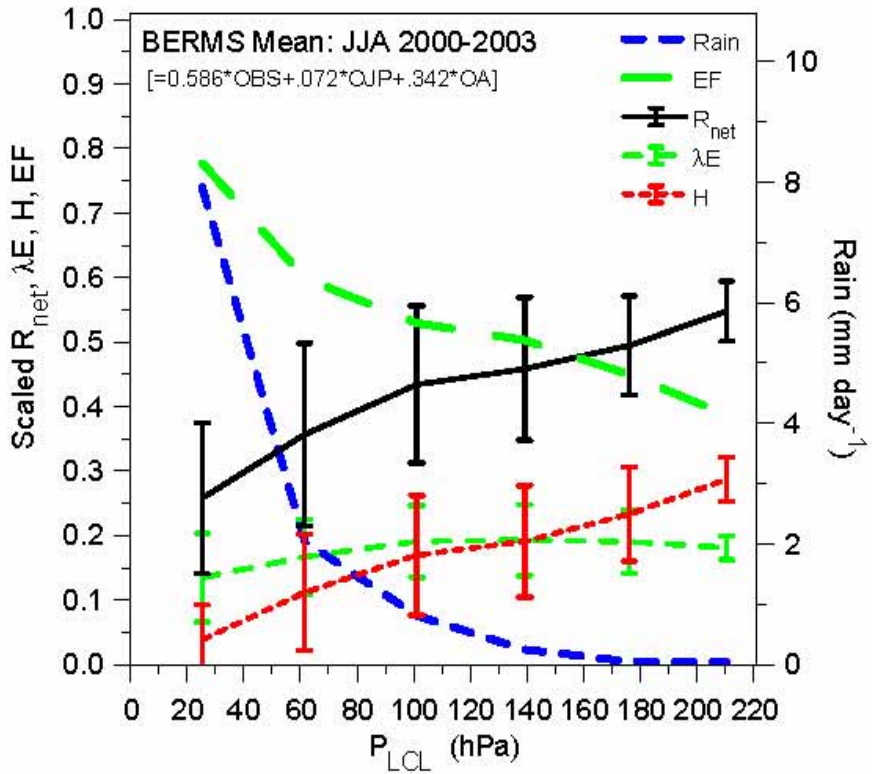




- Same for BERMS and ERA-40
- Depends on P_{LCL} [mean RH, & depth of ML]
- Depends on cloud cover

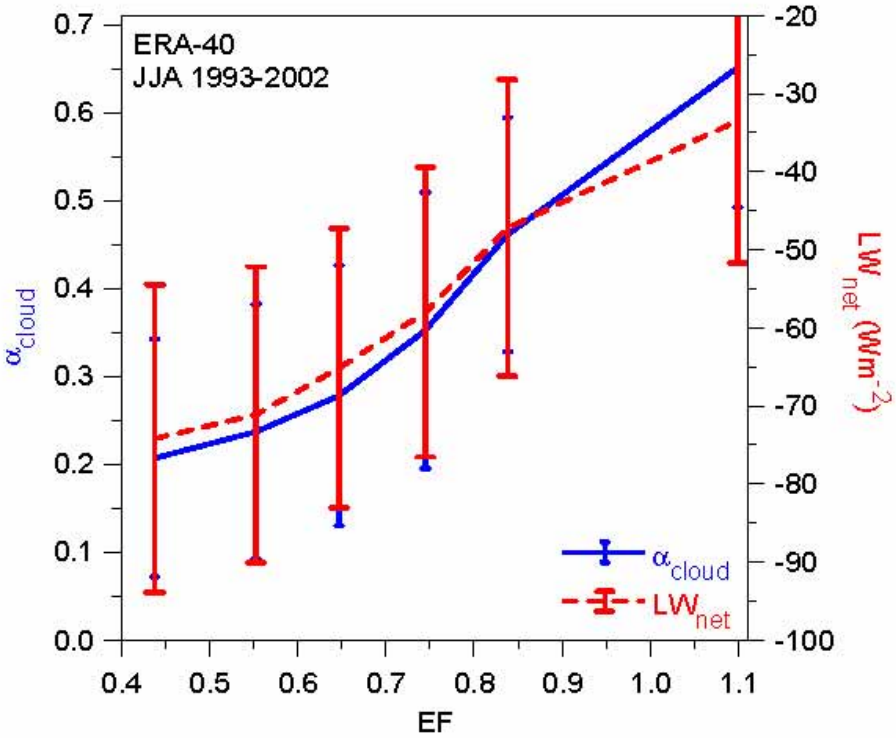
ERA-40 and BERMS average

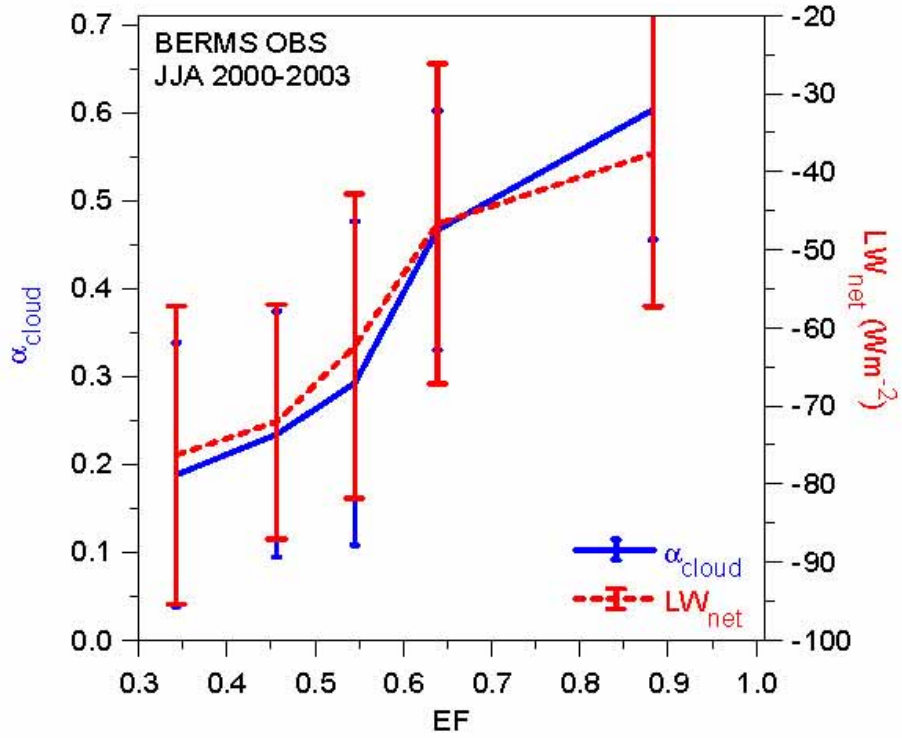




- ERA-40 has higher EF

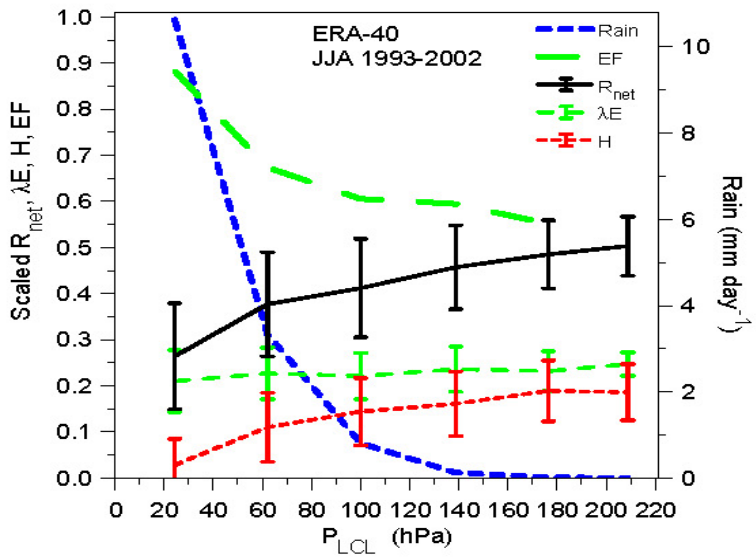
EF to α_{cloud} and LW_{net}

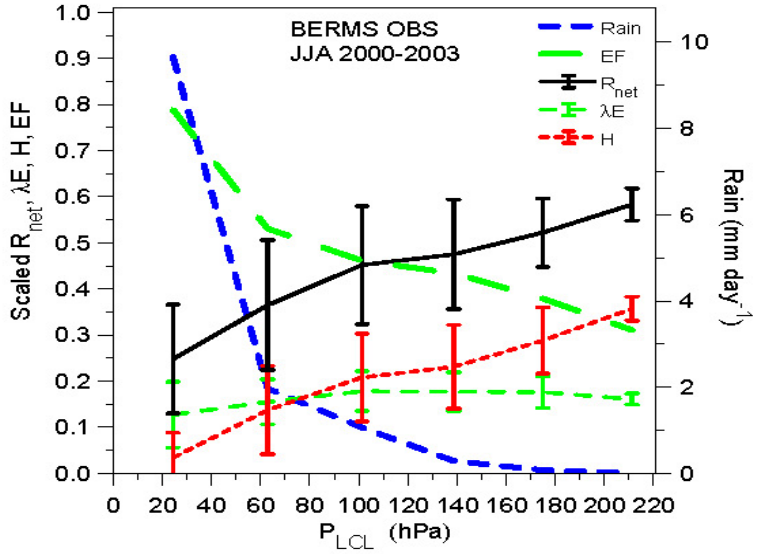


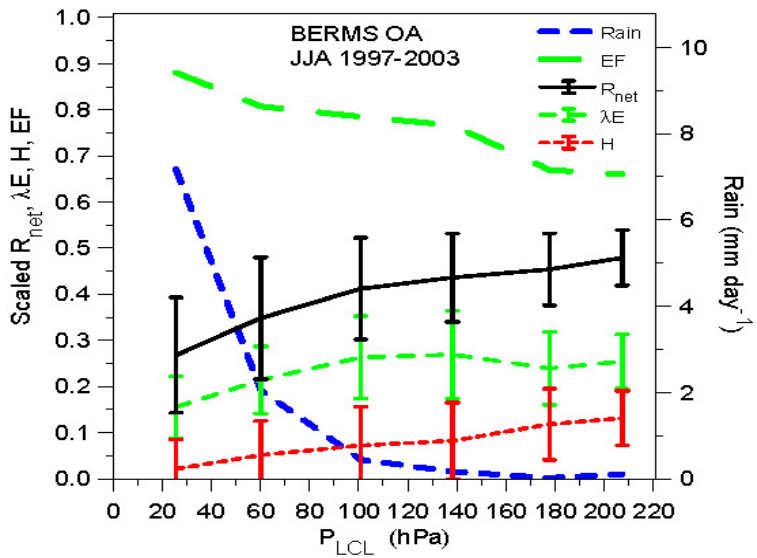


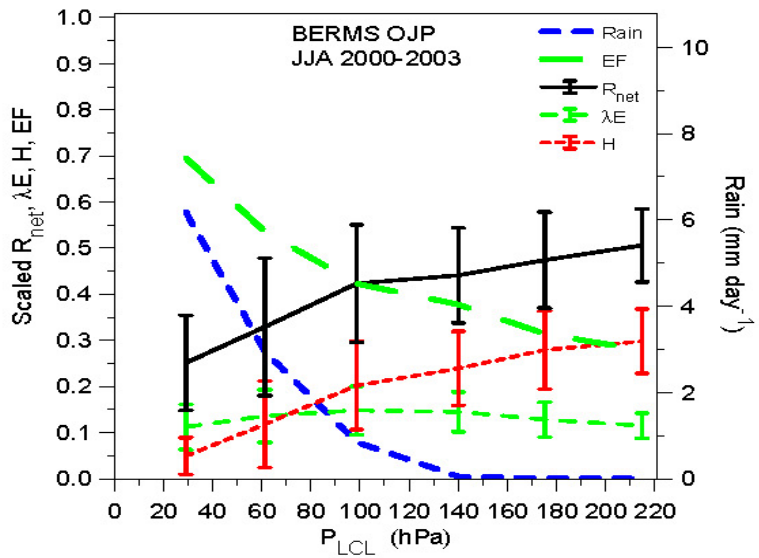
- Similar but EF for ERA-40 > OBS

Energy balance binned by P_{LCL}

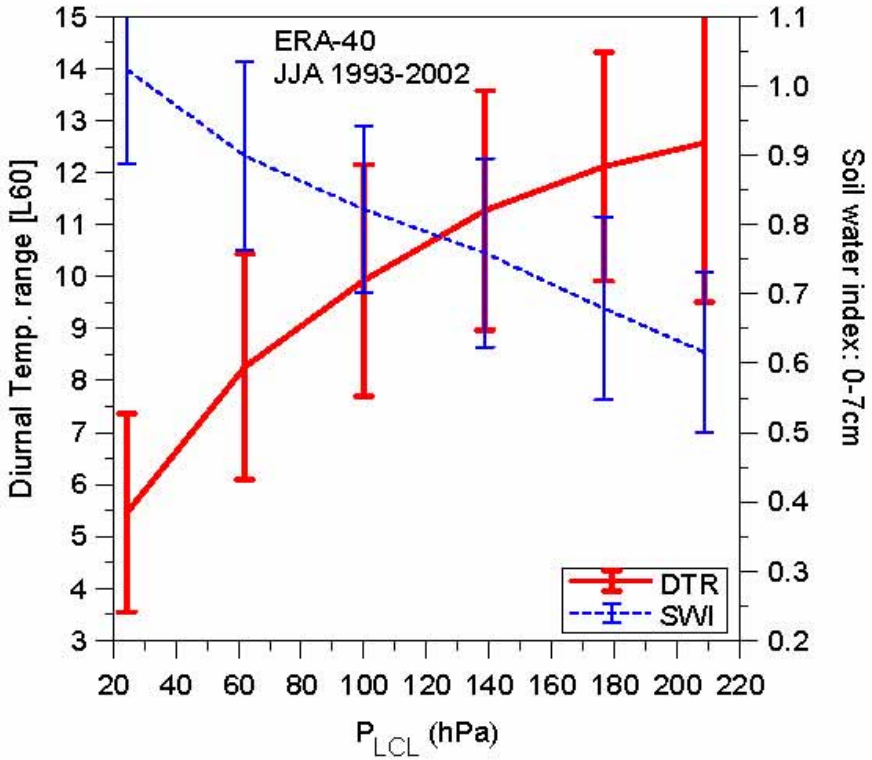


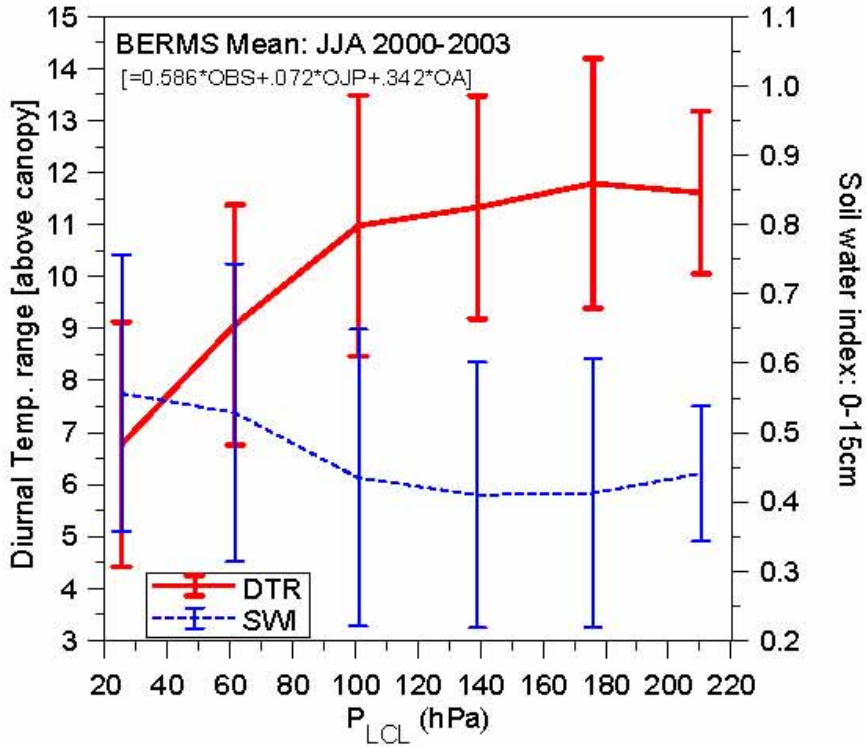






Diurnal Temp. range and soil water





- Similar behavior of DTR
- Evaporation in ERA-40 is soil water dependent; not in BERMS [moss, complex soils]