Coupling of clouds, precipitation and land-surface processes in the climate over land

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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 south-we stern Amazon in ERA-40. *J. Geophys. Res., 110*, D14108, doi:10.1029/2004JD005702.
- Betts, A.K., J.H. Ball, A.G. Barr, T.A. Black, J.H. McCaughey and P. Viterbo, 2006: Assessing land-surface-atmosphere coupling in the ERA-40 reanalysis with boreal forest data. *Agric. Forest Meteorology*, doi:10.1016/j.agrformet.2006.08.009.
- Betts, A. K., 2007: Coupling of water vapor convergence, clouds, precipitation and land-surface processes. JGR [submitted].

Linking Weather and Climate…

- Interactions of water are central to weather and climate *[phase changes and radiation interactions]*
- Global models are powerful tools for modeling interacting processes, but do they have the right “climate”?
- Evaluation against data is critical, but what matters?

Clouds are the crucial link in surface-atmosphere coupling

- Ocean timescales longer than over land

- Over land, cloud fields are a tightly coupled component; with daily impact on surface energy budget and evaporation
- *Partly linked to large-scale convergence*
- *Partly linked locally to 'soilwater' which impacts evaporation, and LCL*

Historical perspective

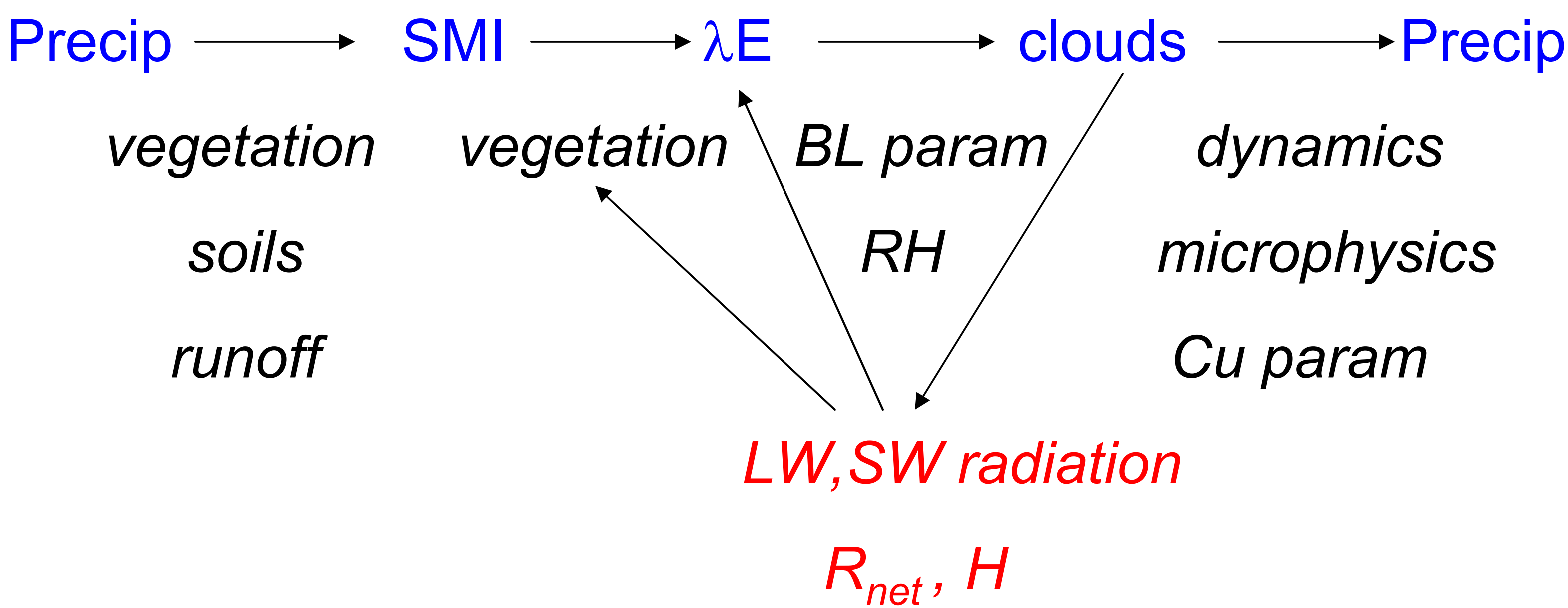
- For 20 years, ‘cloud radiative forcing’ has been a ‘challenge’; a ‘major source of uncertainty in climate modeling’
- Why? Seems odd because they are so easily observed!
- A quantitative framework, which links them to both surface and large-scale processes has been missing.

Why do surface coupled processes matter?

- Oceans: timescale of surface response longer, but clouds play major role
- Land: Cloud variability dominates surface energy balance on diurnal and daily timescales

- How does the coupled system work?
- How can we quantify the cloud fields?
- Use models to map links…

Consider the chain of processes involving water



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

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

Data organized by

- α_{cloud} *:* ‘cloud albedo’ viewed from surface – *measure of surface SW cloud forcing*

- *SMI :* soil moisture index

  [0<SMI<1 as PWP<SM<FC]

- P_{LCL}*:* Lifting condensation level [in hPa]

- *VIMC*: Vertically integrated moisture convergence

Land-surface climate view

- Model "climate" is a 24-hr mean problem [with a superimposed diurnal cycle]
- Seasonal cycle is sequence of daily mean states + "*synoptic noise*"
- Spatial scale ≈ 900 km [at 10 m/s]
- Errors on these time- and space-scales cause drifts in model climate

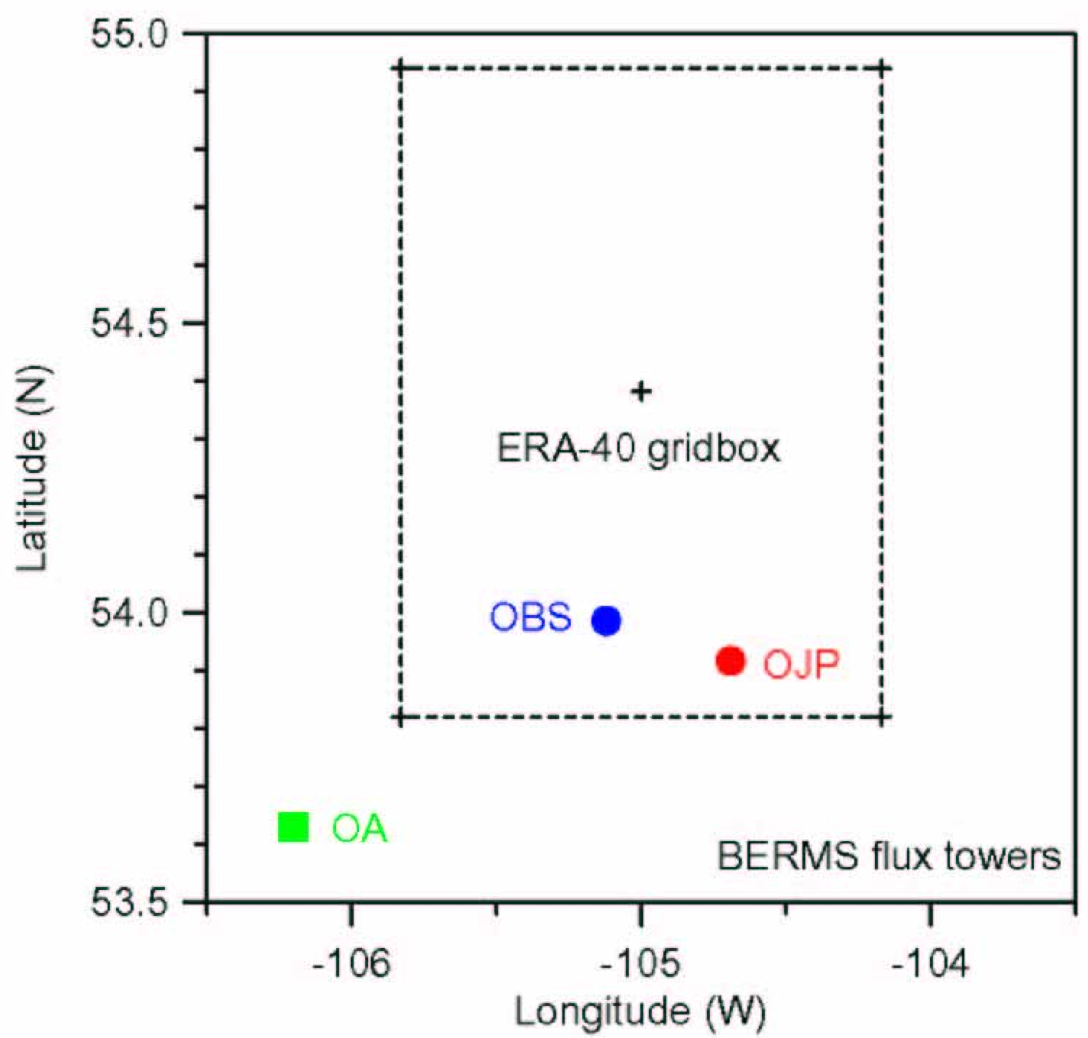
How well are physical processes represented?

- Basin-scale assessment of ERA40 biases
  [Betts et al. 2003a, 2003b, 2005; Betts 2007]

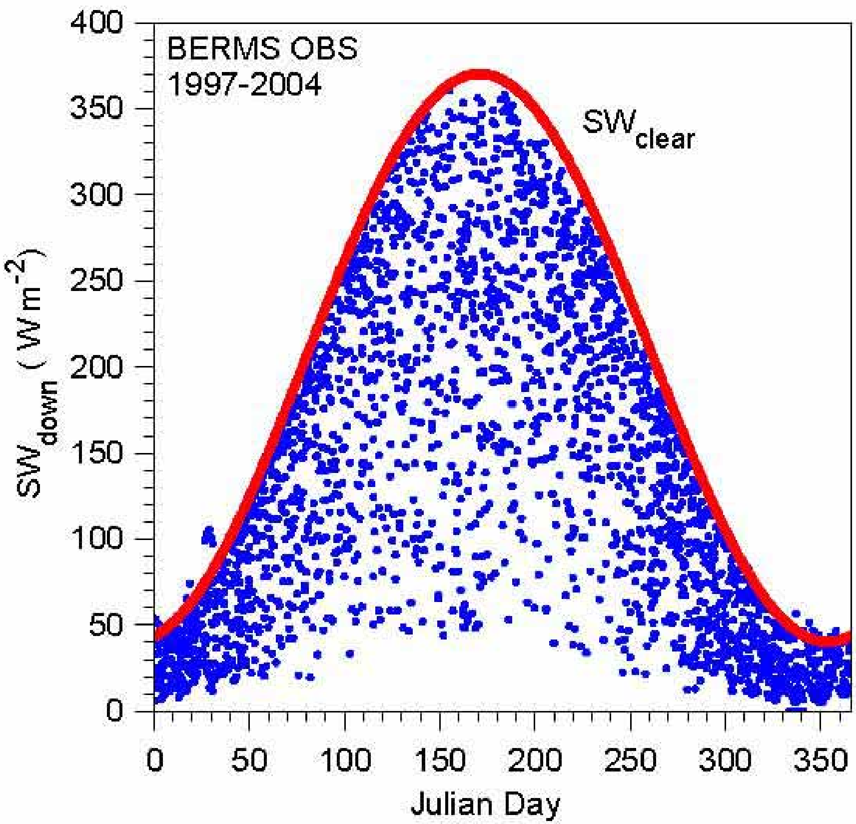
- FLUXNET data can assess both biases and the coupling of physical processes *on the point scale* *[Betts et al. 2006]*

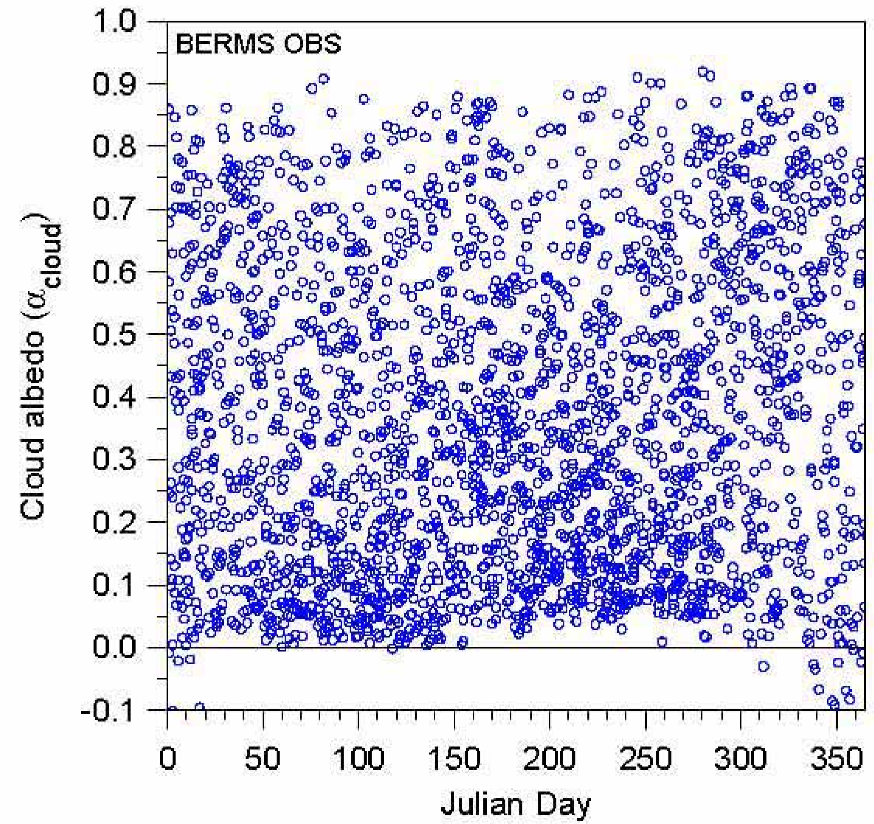
Compare ERA-40 with BERMS

- 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



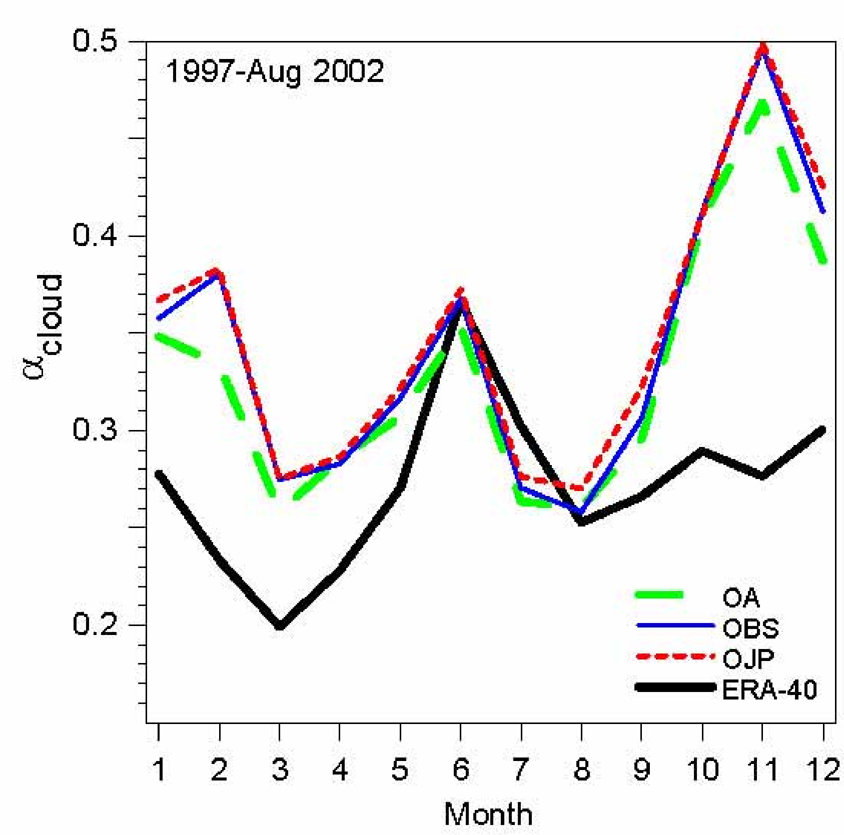
BERMS: Old Black Spruce

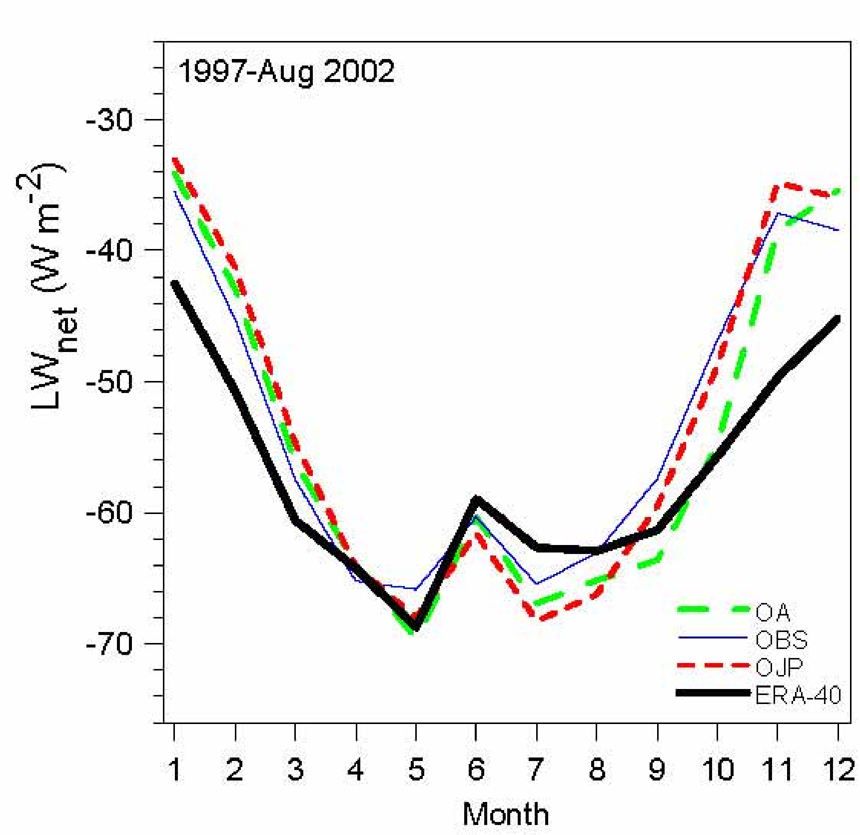




- Cloud 'albedo': $\alpha_{cloud} = 1 - SW_{down}/SW_{clear}$

Cloud albedo and LW comparison

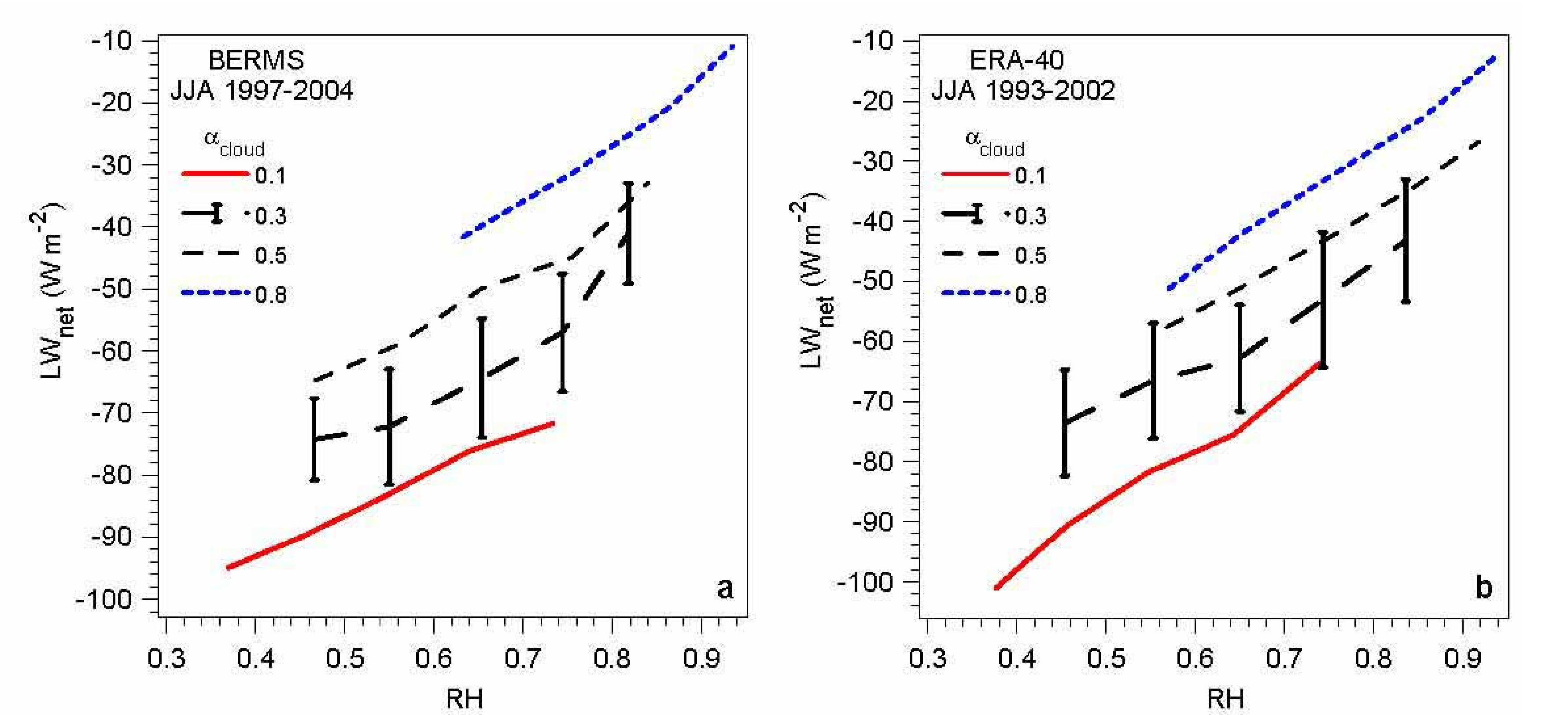




ERA-40: low α_{cloud} [except summer]

LW_{net} bias [winter]

LW_{net} on RH and α_{cloud}

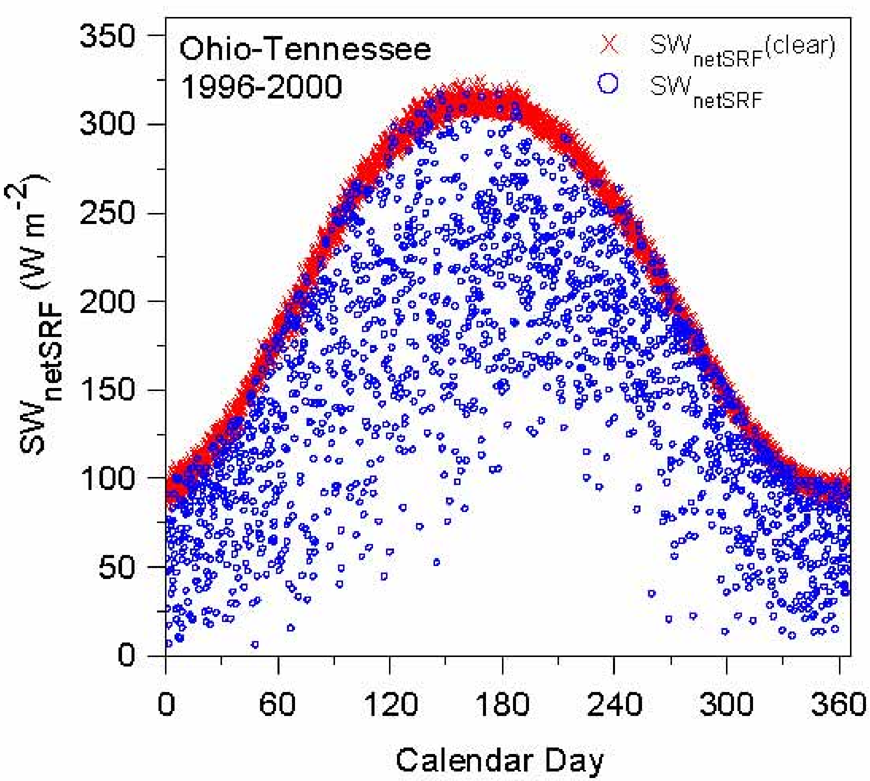


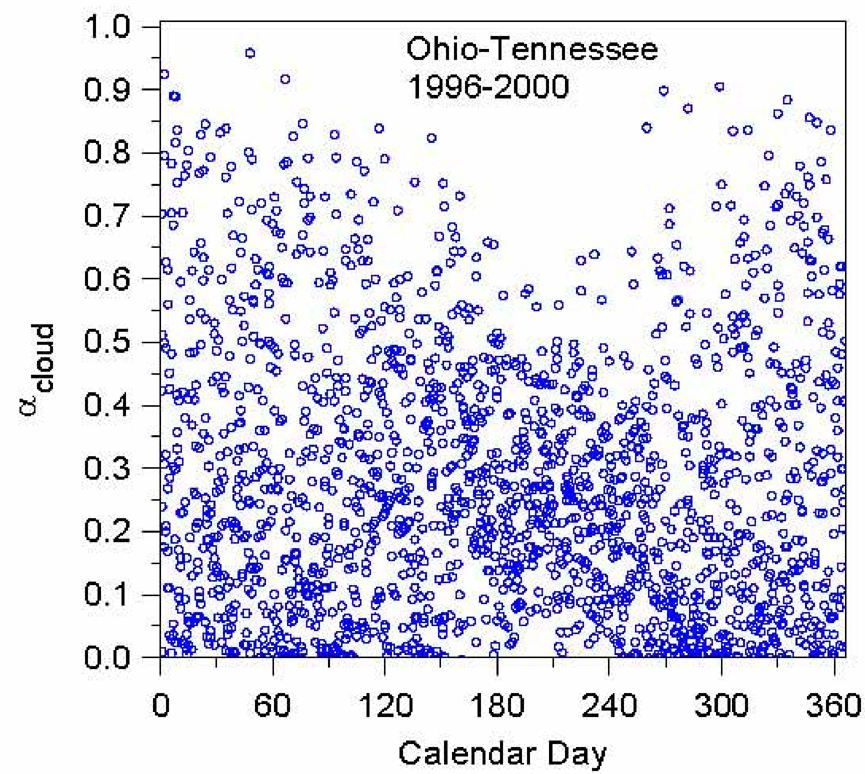
- Outgoing LW_{net} falls as RH and cloud cover increase
- Higher RH means lower LCL & depth of ML
- *LW coupling same for BERMS and ERA-40*

Mississippi: explore & evaluate

- α_{cloud} : ISCCP as ‘truth’ [using ERA40 clear-sky]
- Precipitation : NCDC as ‘truth’

ERA-40 Ohio-Tenn. river basin

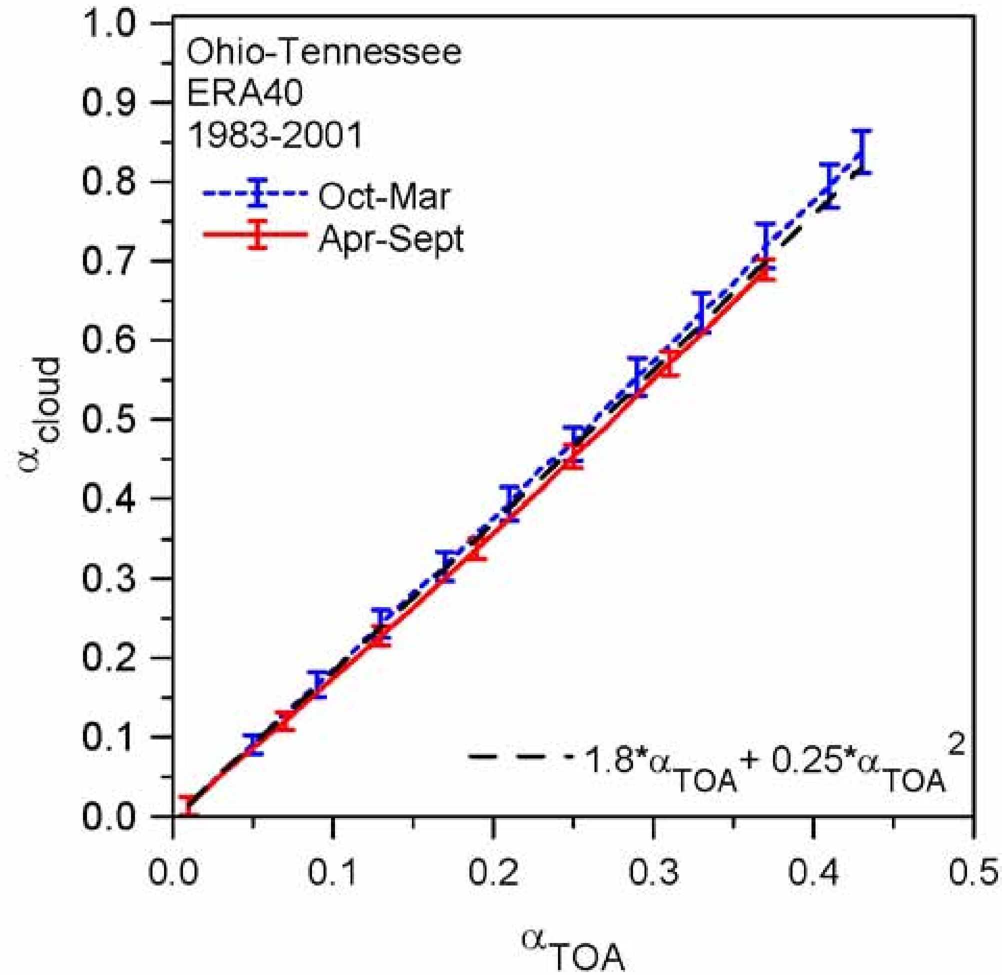




- Cloud 'albedo': $\alpha_{cloud} = 1 - SW_{netSRF}/SW_{netSRF}$ (clear)
- $SW_{netSRF} = (1 - \alpha_{cloud})(1 - \alpha_{SRF})\ SW_{dnSRF}$(clear)

TOA and surface cloud albedos

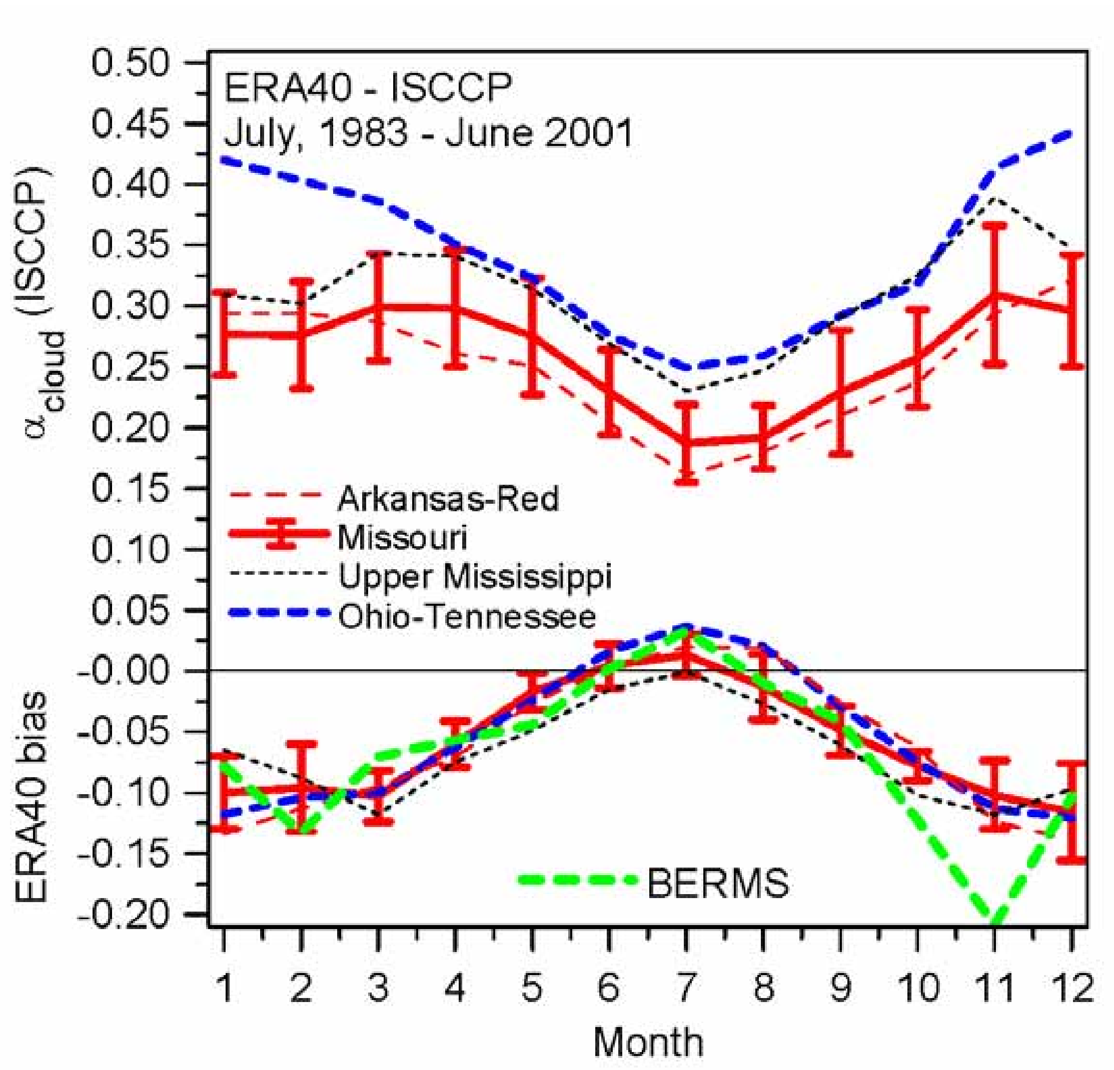
- tightly related



- $\alpha_{cloud} = -SWCF_{SRF}/SW_{netSRF}(clear)$
- $\alpha_{TOA} = -SWCF_{TOA}/SW_{dnTOA}(clear)$

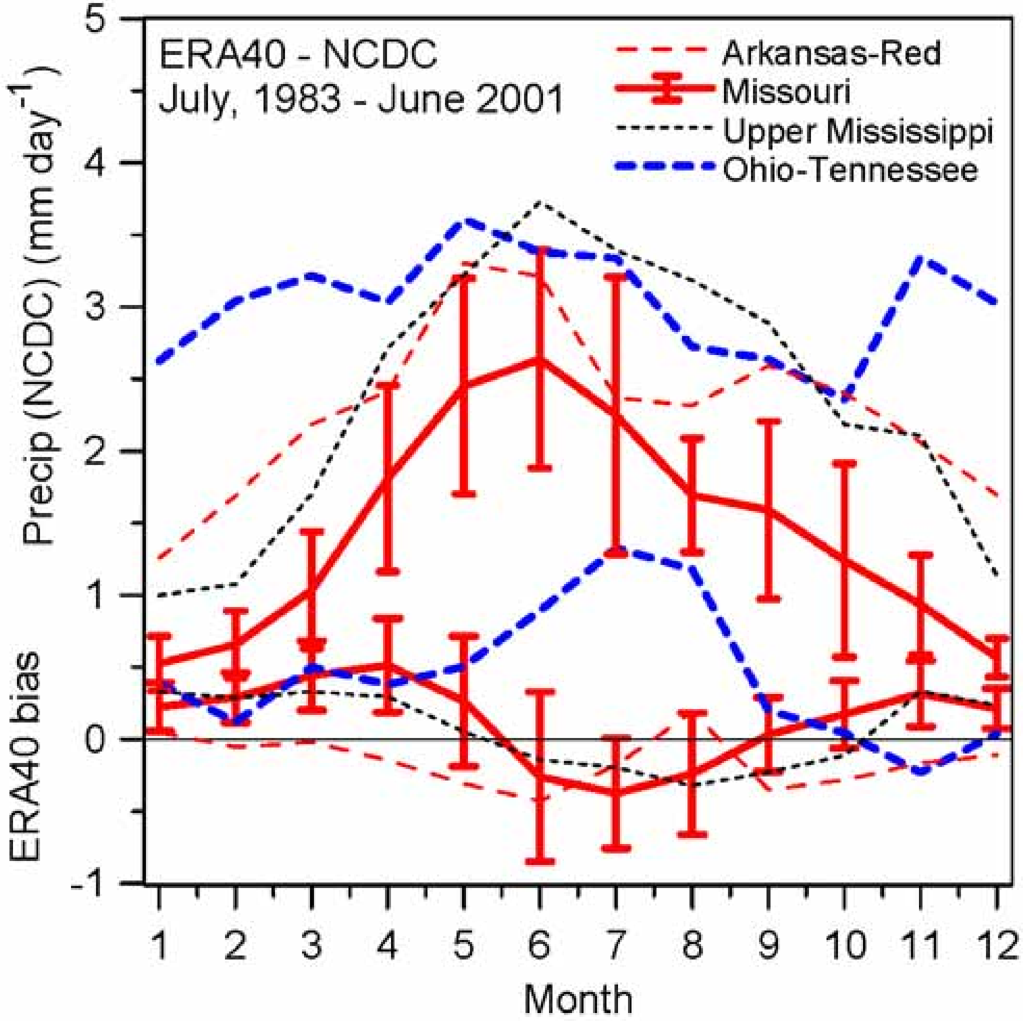
Seasonal cloud bias

- Systematic bias for all basins
- Largest negative in winter: -10%
- **Bias from ISCCP and BERMS agree!**



Seasonal precipitation bias

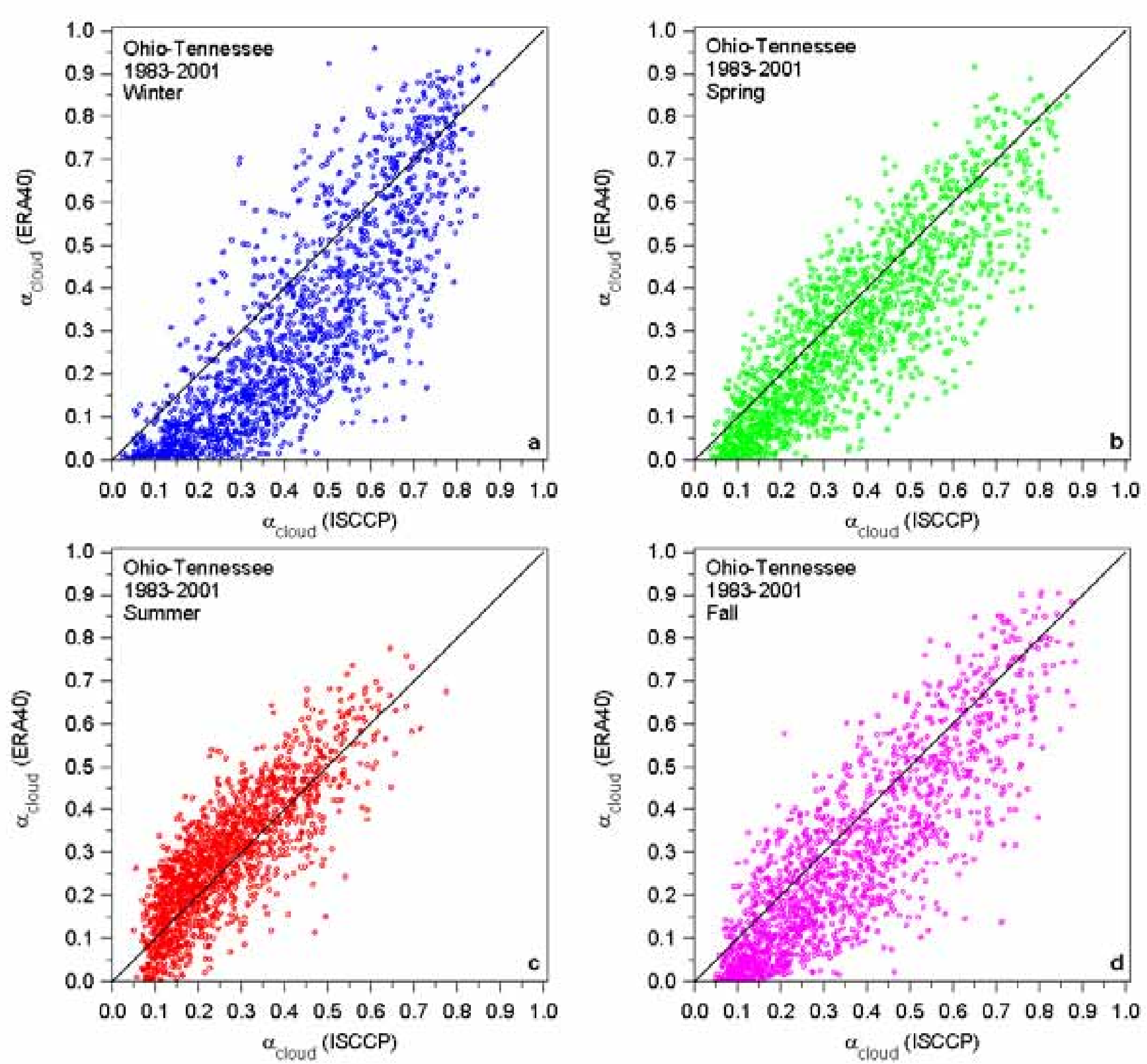
- ERA40 bias differs across basins
- Positive in winter:
- **Large-scale precip. efficiency too high?**



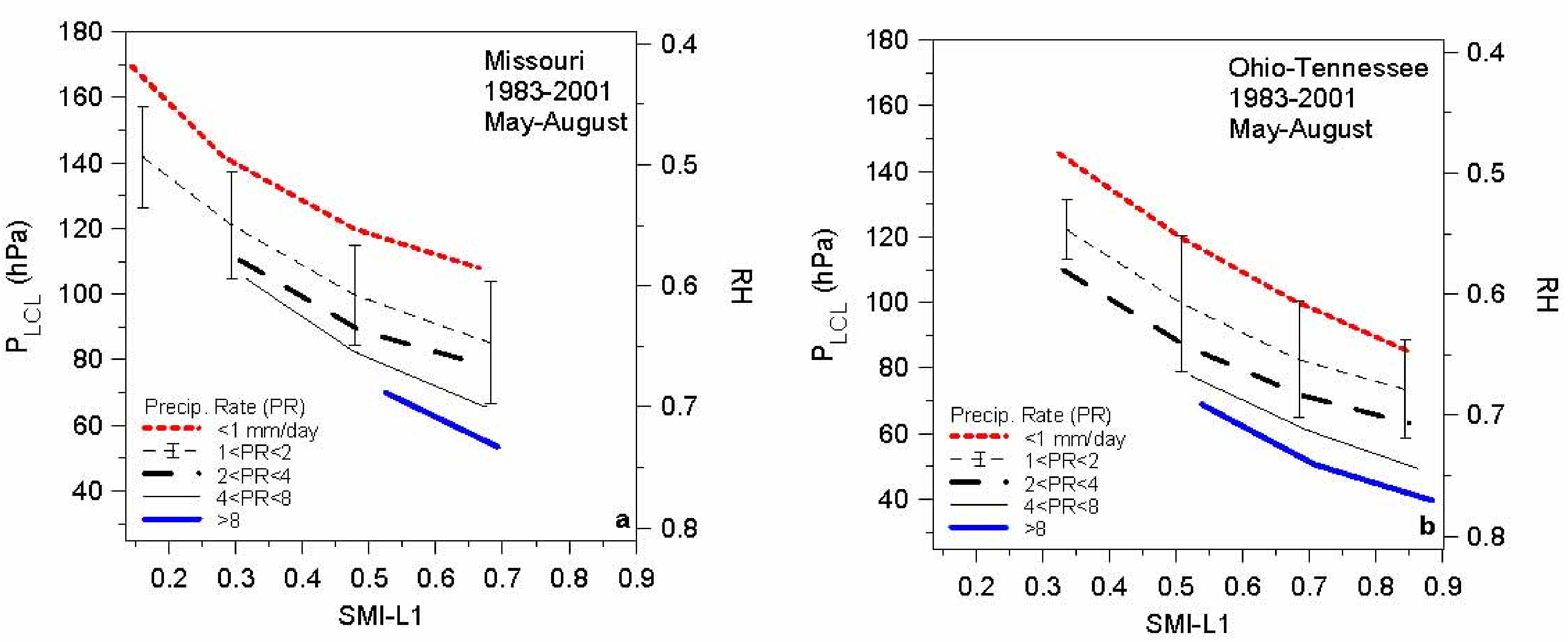
Daily α_{cloud} by season

- Winter low bias largest

- Scatter small



Coupling of soil moisture, LCL and precipitation

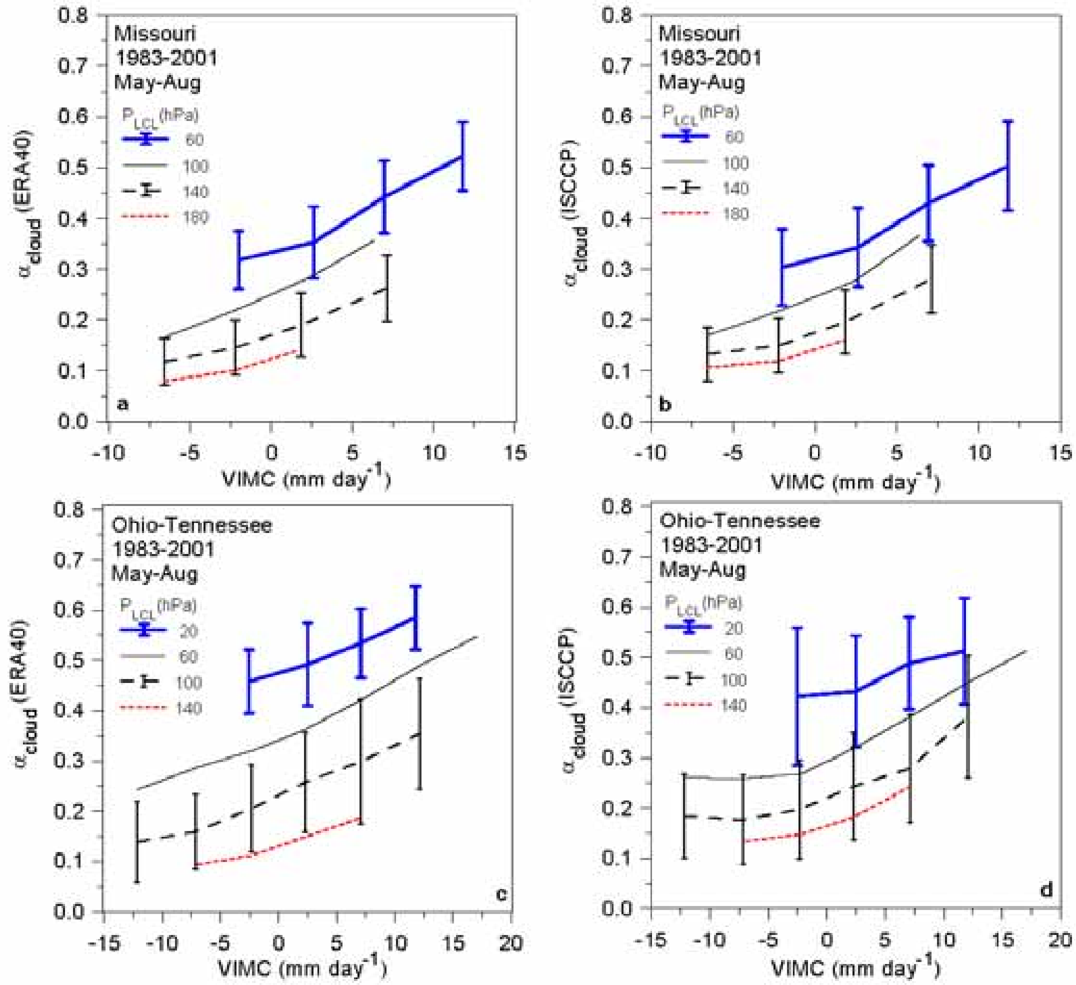


- LCL descends with increasing SMI-L1 and precip.
- Highly coupled
  - precipitation increases SMI-L1
  - wetter SMI increases evaporation from surface
  - falling precip. evaporates, lowering LCL

How does α_{cloud} depend on VIMC and P_{LCL}?

Missouri

Ohio-Tenn



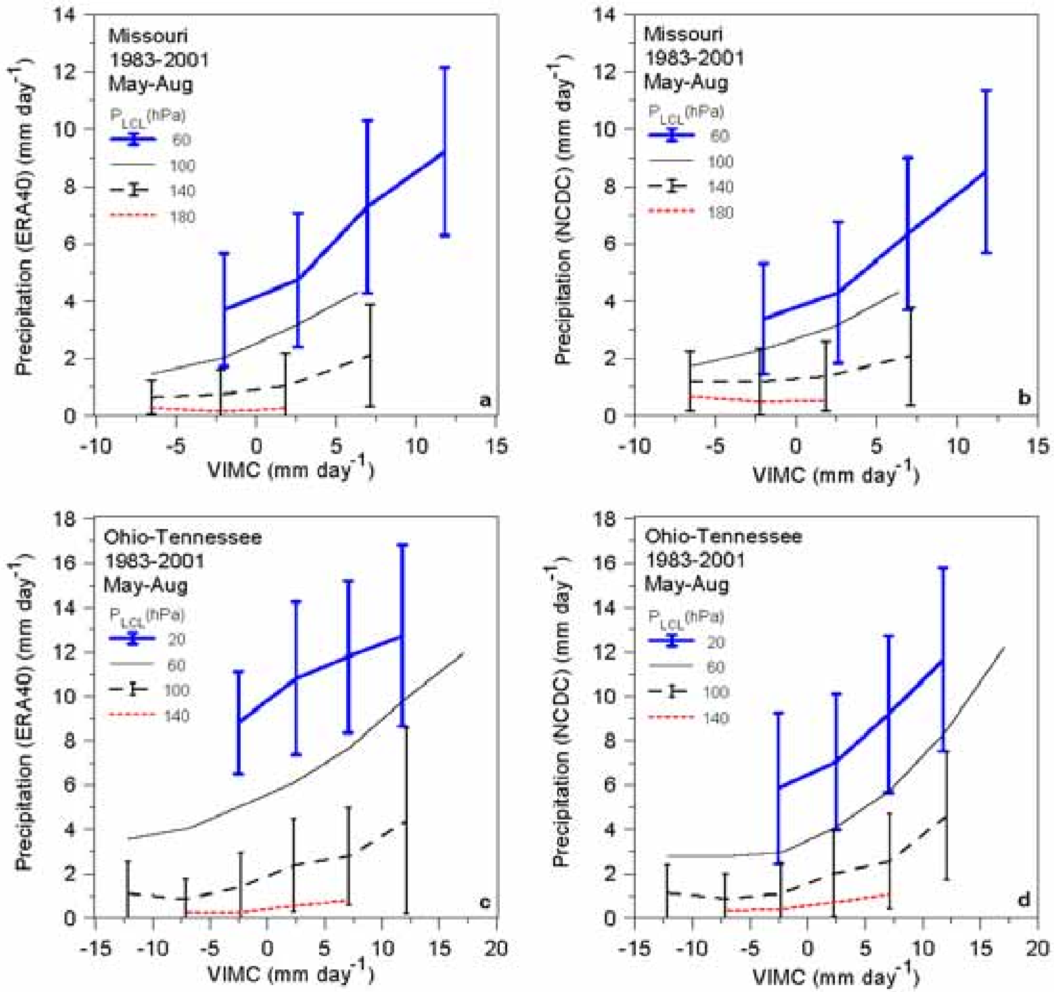
ERA40

ISCCP

How does Precip. depend on VIMC and P_{LCL}?

Missouri

Ohio-Tenn

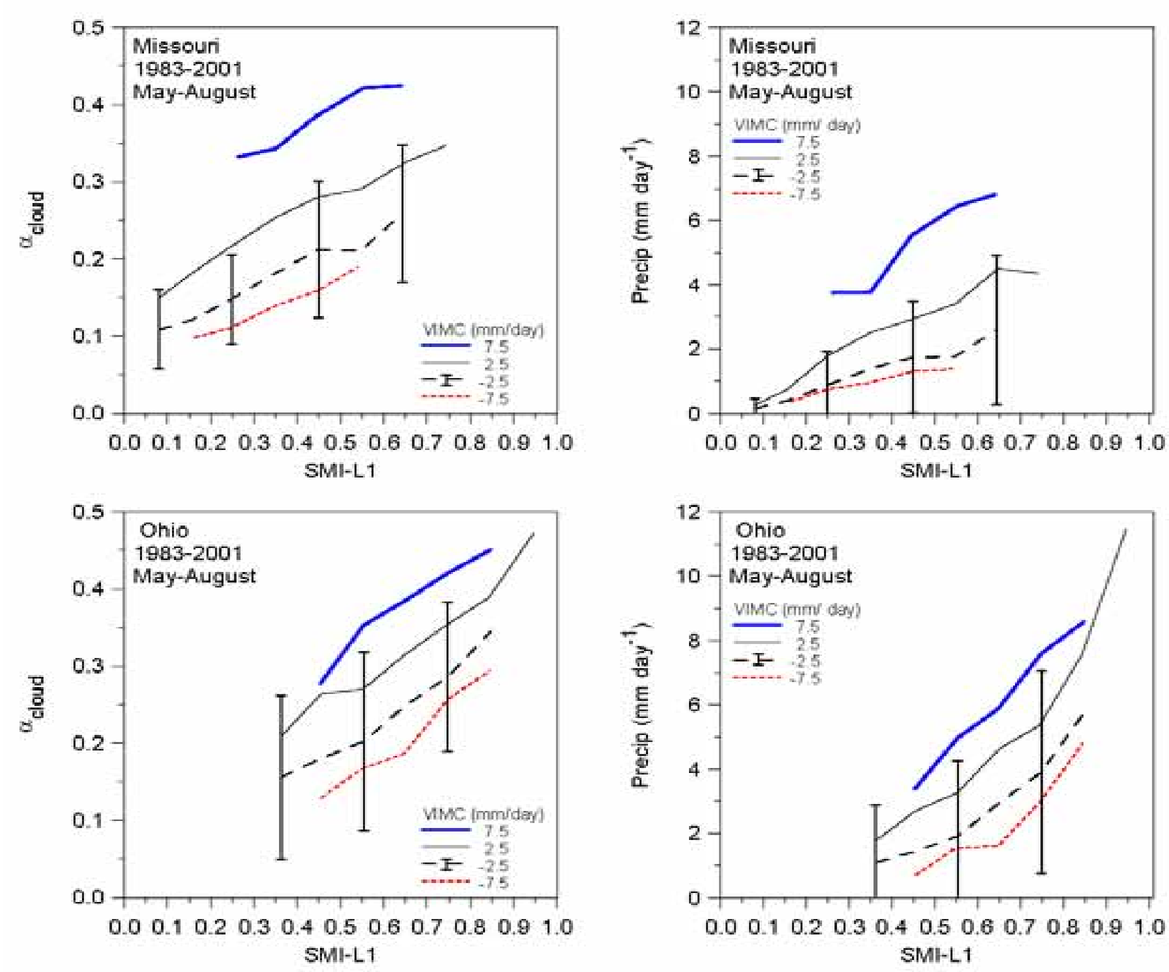


ERA40 NCDC

α_{cloud}, Precip. increase with SMI and VIMC

Missouri

Ohio-Tenn



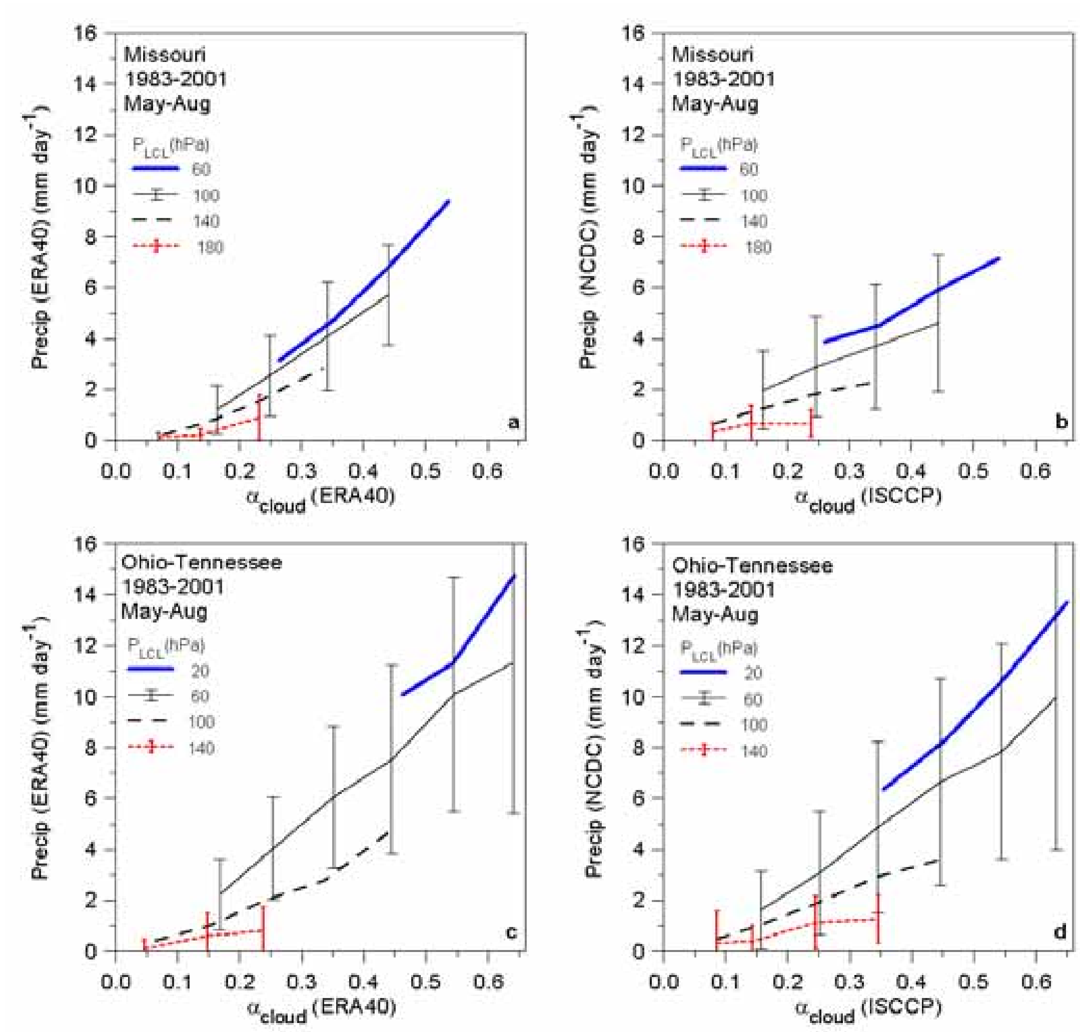
α_{cloud} Precipitation

Organize data by ‘surface cloud albedo’

How does Precip. depend on α_{cloud} and P_{LCL}?

Missouri

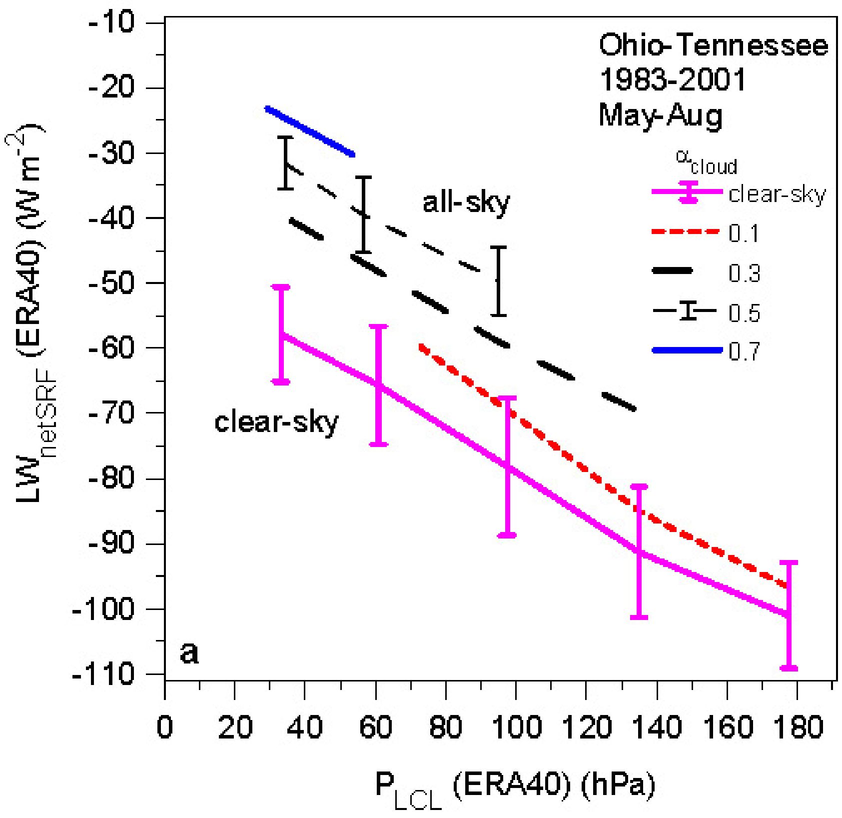
Ohio-Tenn

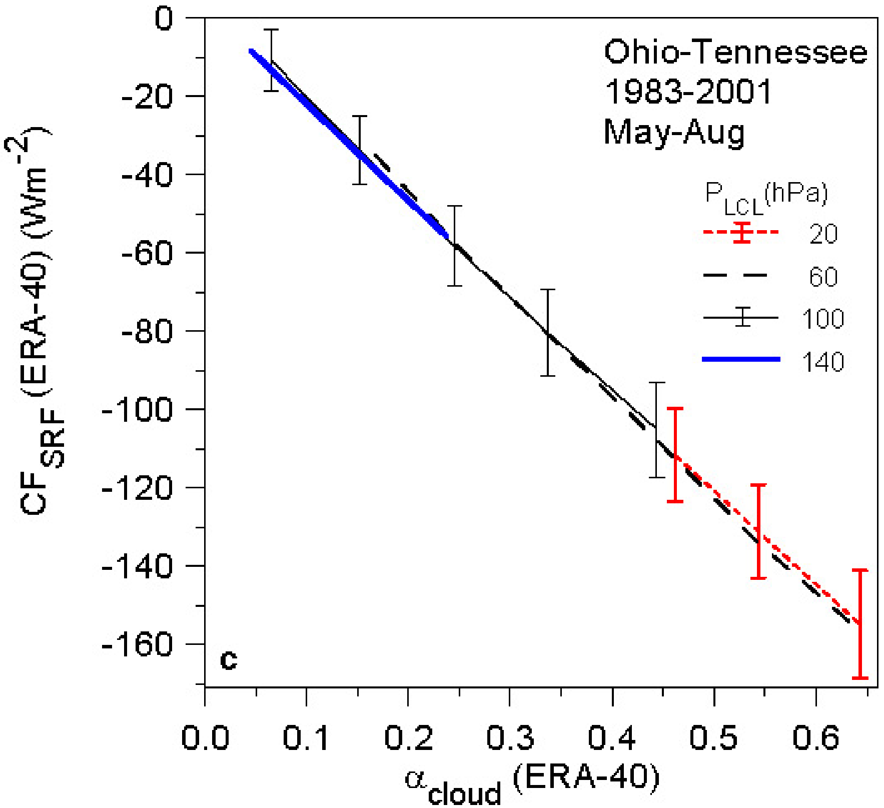


ERA40

ISCCP & NCDC

Surface cloud forcing has linear relation to α_{cloud}



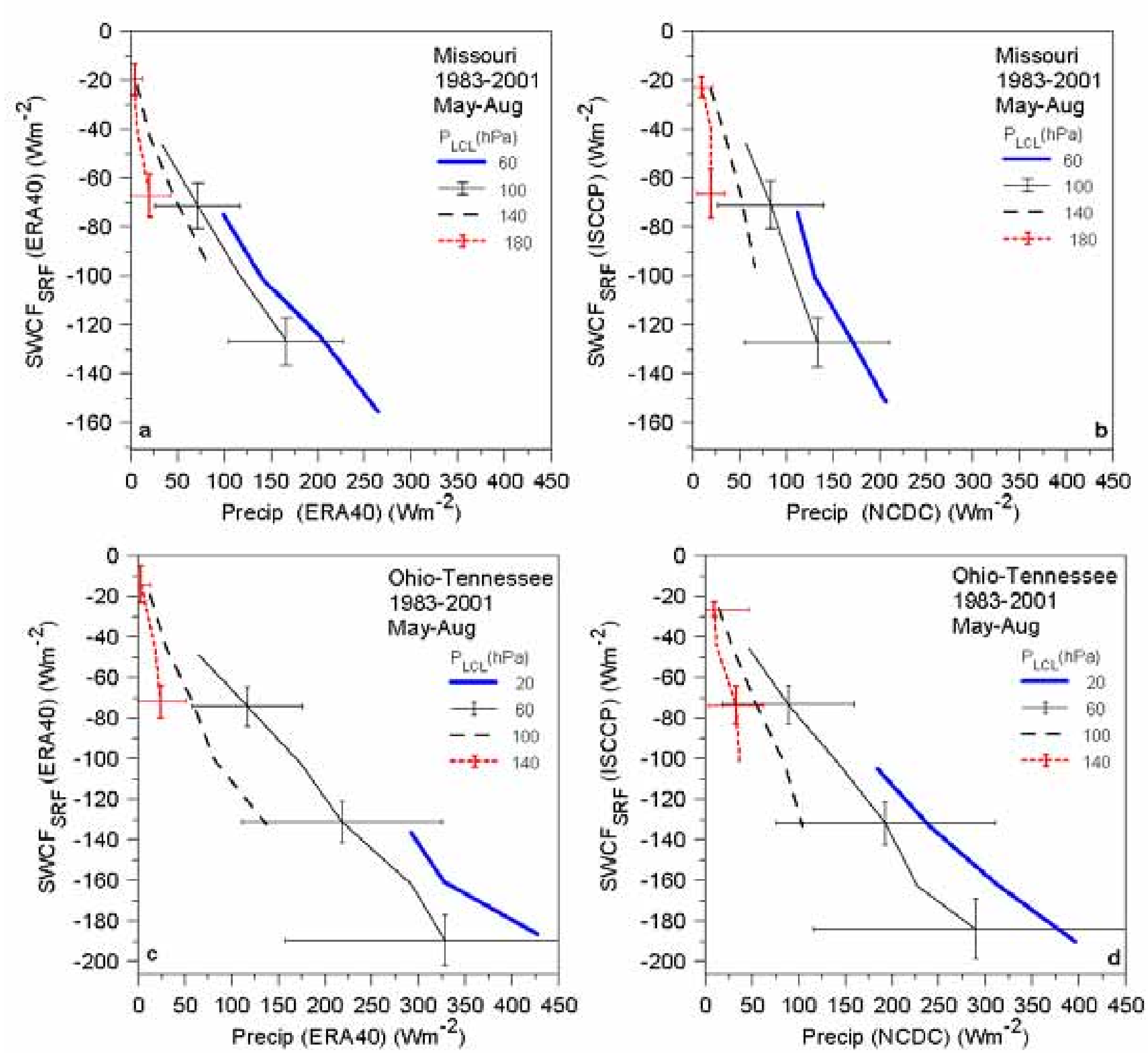


- Clear-sky LW_{net} depends on P_{LCL}
- Cloud forcing does not

Compare SWCF/Precip

Missouri

Ohio-Tenn



ERA40

ISCCP & NCDC

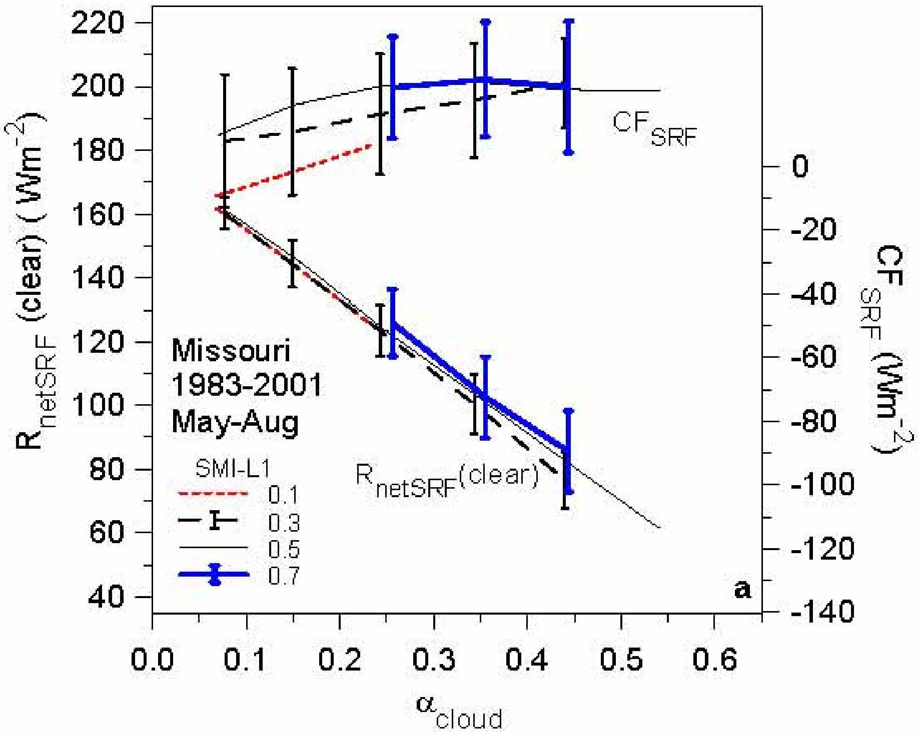
$SWCF_{SRF}$/Precip is less for ERA40 than observations

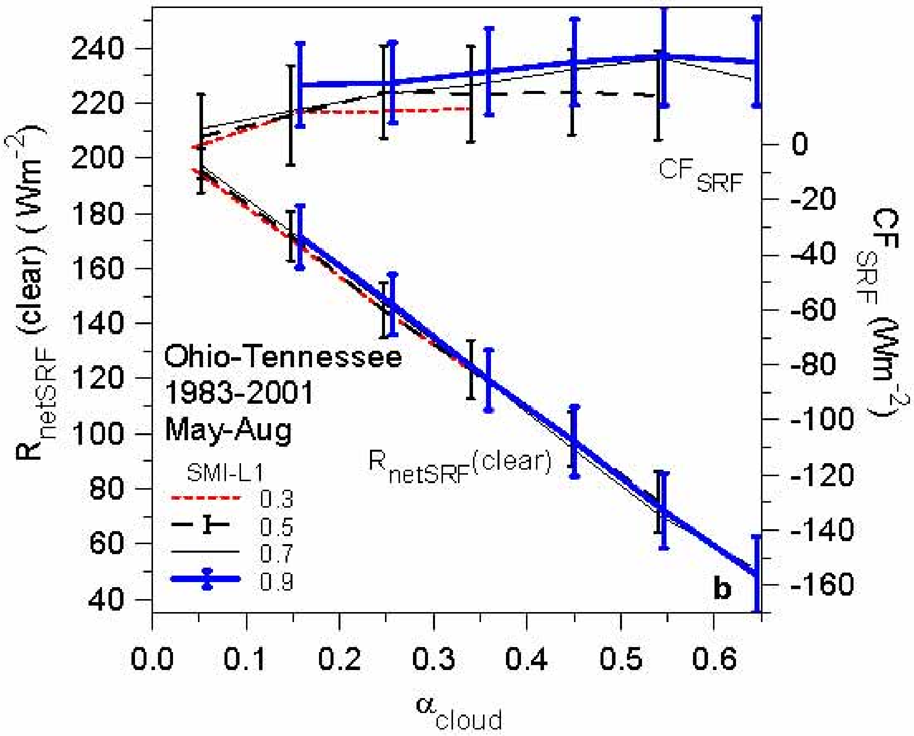
ERA-40/Satellite perspective on surface energy balance

SEB energy balance a ‘soluble problem’ ?

1) Surface cloud forcing/α_{cloud} [visible]
2) EF from surface layer SMI [microwave], T
3) Vegetation a slower component [NDVI]

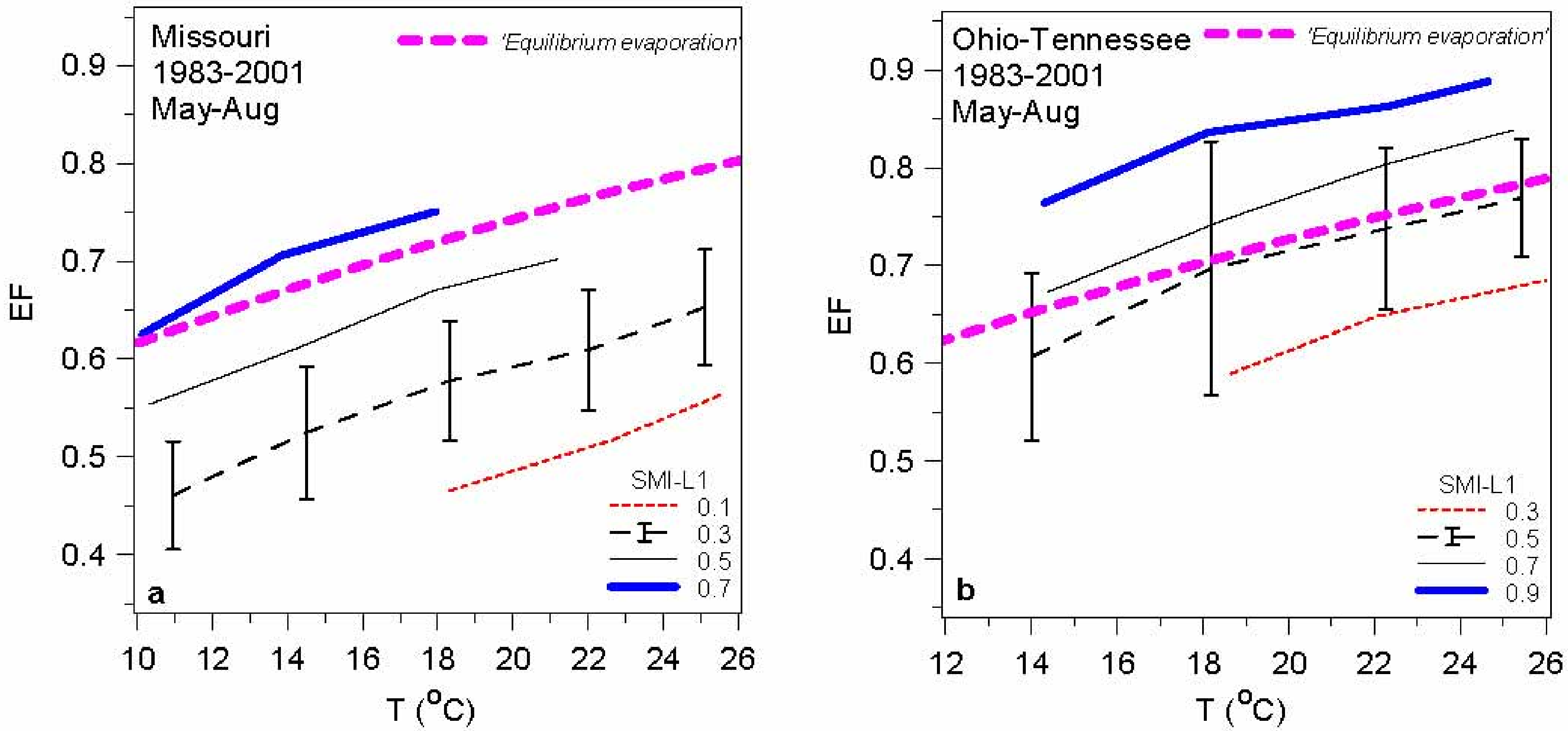
Net radiation variability depends mostly on α_{cloud}





- R_{netSRF}(clear) varies weakly
- CF_{SRF} linear with $\boldsymbol{\alpha}_{\mathbf{cloud}}$

EF depends on T and SMI-L1



- EF increases with SMI
- Slope with T ≈ 'equilibrium evaporation'

Conclusions

- ERA-40 has low bias in effective surface cloud albedo, except in summer
- Moisture convergence, SMI and LCL linked to clouds and precipitation.
- **Organize data by α_{cloud}**
- $SWCF_{SRF}$/Precip is less for ERA40 than observations
- Split SEB into ….
- α_{cloud} dependence of $CF_{SRF} \longrightarrow R_{net}$
- Evaporative fraction linked to T, SMI-L1

Model 'climate' evaluation

- Are observables coupled correctly in a model on the daily timescale?
- What are observables:
  - BL quantities: RH, LCL linked to SMI, precip
  - Clouds [α_{cloud}] determine surface and TOA SW and LW cloud forcing
  - Moisture convergence and precipitation

Background references

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