Coupling of the surface energy balance, clouds and their diabatic forcings

(*Theme is "Fast Processes"*)

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Cloud transports and diabatic forcing are central to the climate system on all scales

- **BL clouds**: surface coupling & vertical motion

  - sensitivity to T, RH, aerosols, subsidence; and over land, diurnal cycle, water availability, CO_2

  - SWCF & LWCF: surface & TOA
- **Deep clouds**: forced by larger scales

  - but tight coupling between precipitation, diabatic heating and vertical motion
- **Deep clouds**: cloud radiative forcing of same order as diabatic heating by WV phase change
- **Cloud sensitivity** to changing aerosols; vertical circulations and RH, increasing temperature and CO_2 - ***for climate change issues***

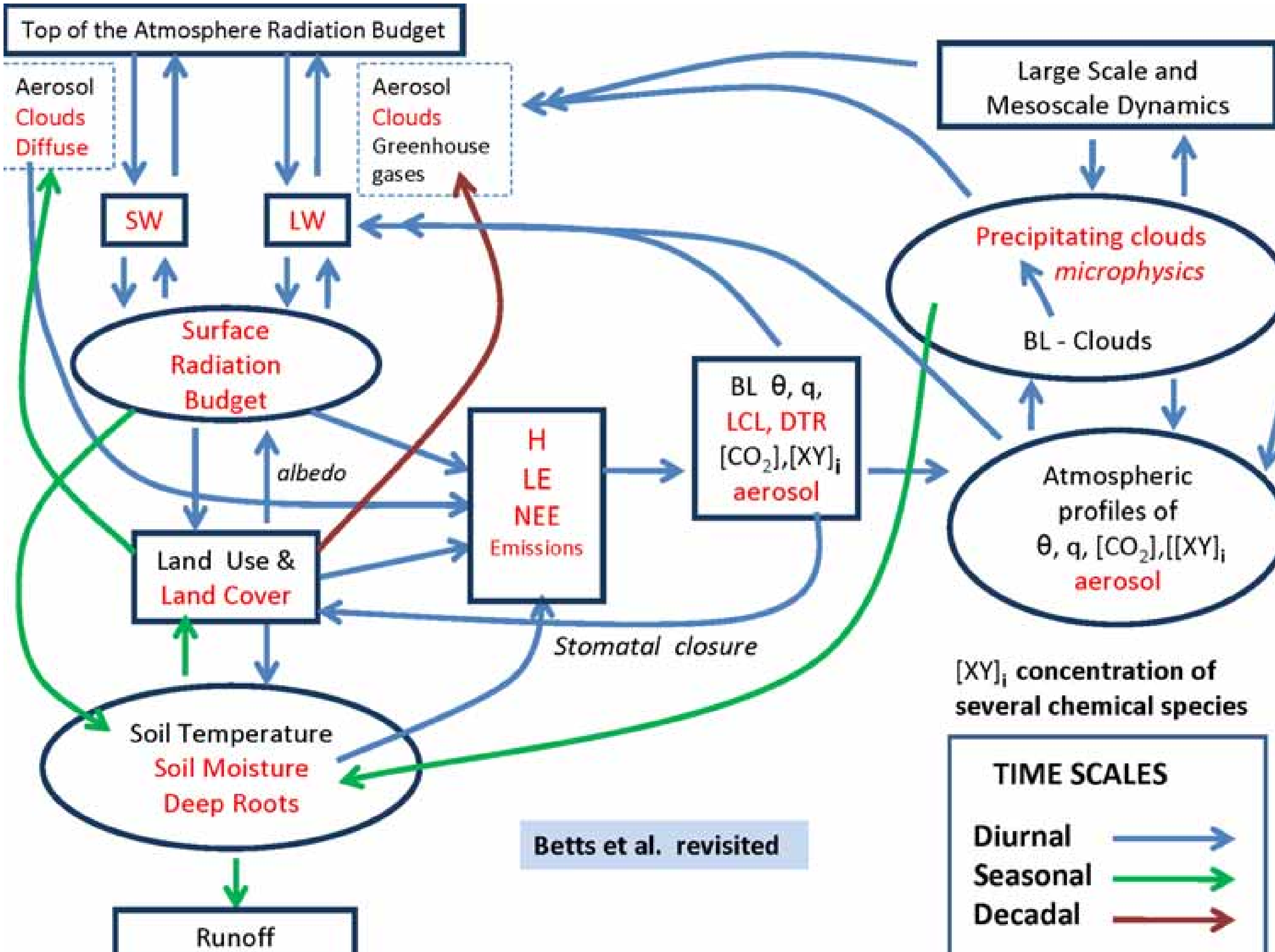
Many Questions!

- **How well do convective models represent the bulk properties of cloud systems?**
- Do they represent the dominant convective modes as well as the SW and LW cloud forcing?
- Can we quantify the coupling of diabatic processes and evaluate them against observations?
- Can we evaluate convective vs stratiform precipitation, updraft and downdraft mass fluxes, and their microphysics against observations?

Conceptual challenges

- Mass transports and precipitation only loosely coupled - dependent on cloud structure and microphysics eg. Precipitation-evaporation couplets can drive circulations with little net precipitation
- Microphysics depends on aerosols – poorly known on global scale
- The diabatic cloud radiative forcing and the latent heating diabatic forcing are of the same order
- Surface forcing is coupled radiatively to clouds & the large-scale circulation evolves quickly in mesoscale convective systems
- **Can we parameterize or must we (partially) resolve cloud-scale?**

Hard to uncouple the many processes!



LBA-Amazônian research: Betts and Silva Dias, JAMES 2010

Mass transports and precipitation flux only loosely coupled

- **The Key Convective Modes**
- **Arakawa and Chen [1987]**.... used canonical correlation analyses on the GATE Phase III data [Esbensen and Ooyama 1983] and an Asian data set [He et al. 1987] to show there were **three principal modes of coupling of (Q_1-Q_R) and Q_2.**

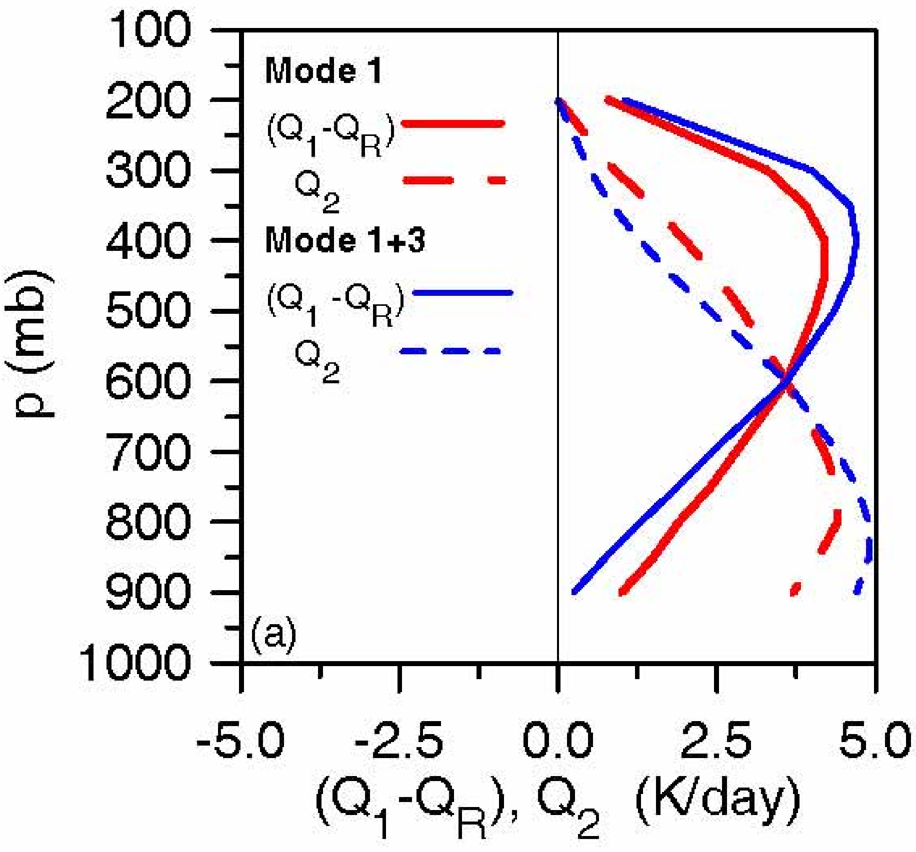
- ***Mode 1*** **is the principal deep convection mode** associated with net precipitation and a **single cell of mean upward vertical motion in the troposphere**, although within that there are moist updrafts and downdrafts.
- ***Mode 2*** is described by Arakawa and Chen as the component representing deviations of "large-scale" condensation and evaporation

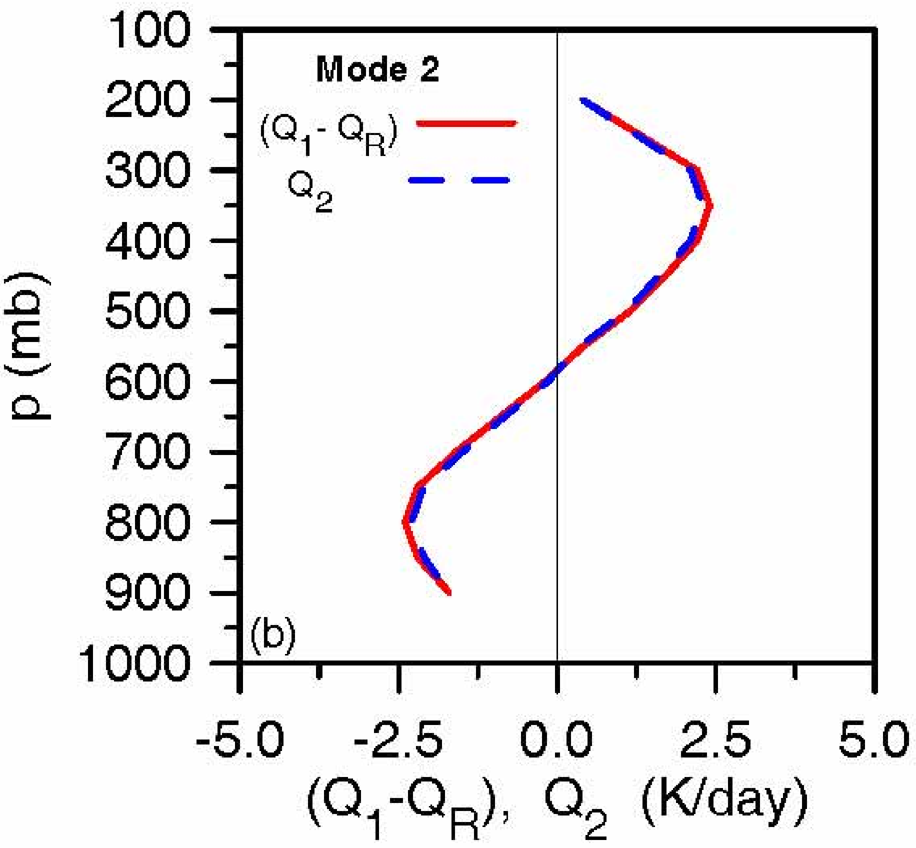
  Heating over cooling couplet driving circulation with no net precipitation

- ***Mode 3***... is a modulation of Mode 1, which *increases* the mid-tropospheric θ_E flux, without impact on net precipitation.

  Upward θ_E flux is *not uniquely* coupled to the precipitation.

Convective Modes 1 to 3

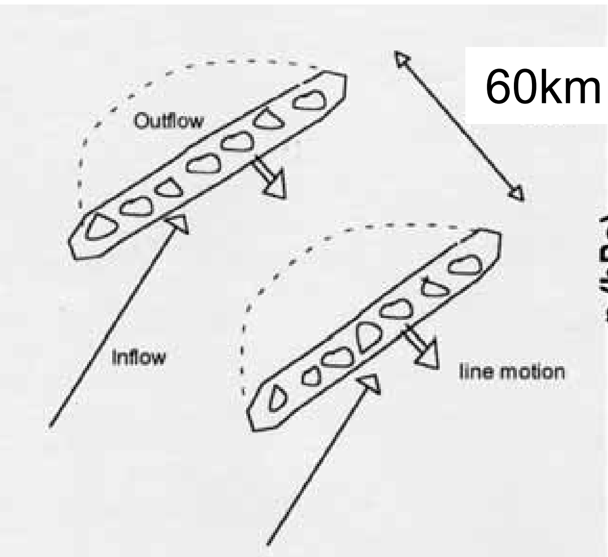


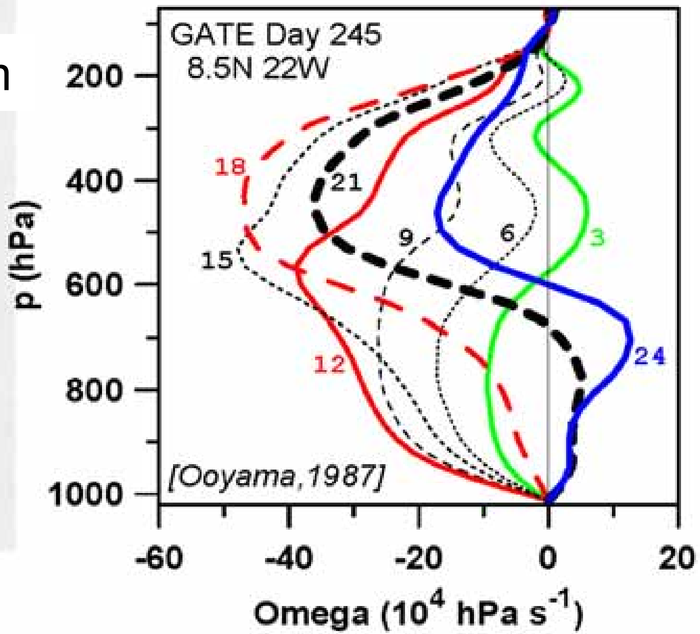


- Same precipitation
- Different θ_E flux

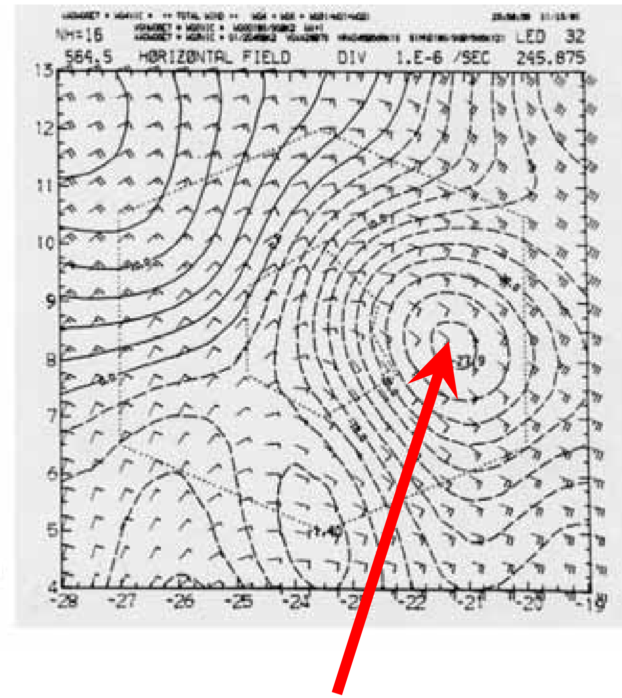
- **'Mesoscale mode'**
- Condensation/evaporation: no precipitation or θ_E flux

Reality - GATE 'cloud cluster' lifecycle on day 245 in 1974





565hPa



Bands oriented along the low level shear, with inflows from SW, developing anvil outflow to the rear

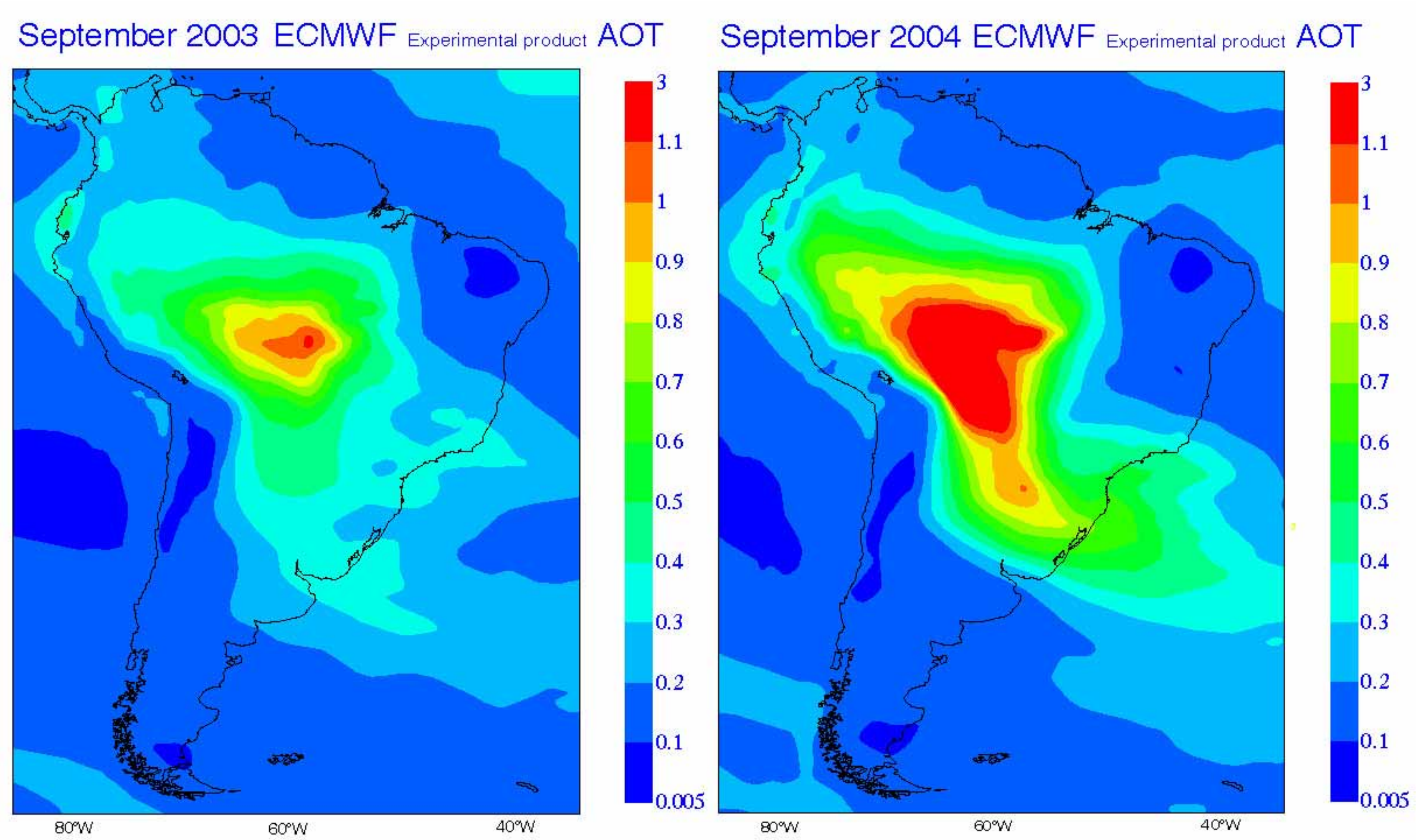
03 low level convergence
12 peak ascent mid-trop.
18 peak at 400mb
21 peak 600mb converg.
24 descent over ascent

21UTC mid-tropospheric convergence peaks at 2.8 10^{-5} in decay phase (> low-level convergence at any time)

Is there a way forward?

- What can we learn from SCMs and CRMs with specified external forcing?
- Do they have the *freedom to develop* these convective modes
- As microphysics/aerosols vary, can we quantify the coupling of updraft/downdraft mass circulations and precipitation, cloud radiative forcing and atmospheric water vapor changes
- **CO_2 budgets $\longrightarrow$ mass transports**

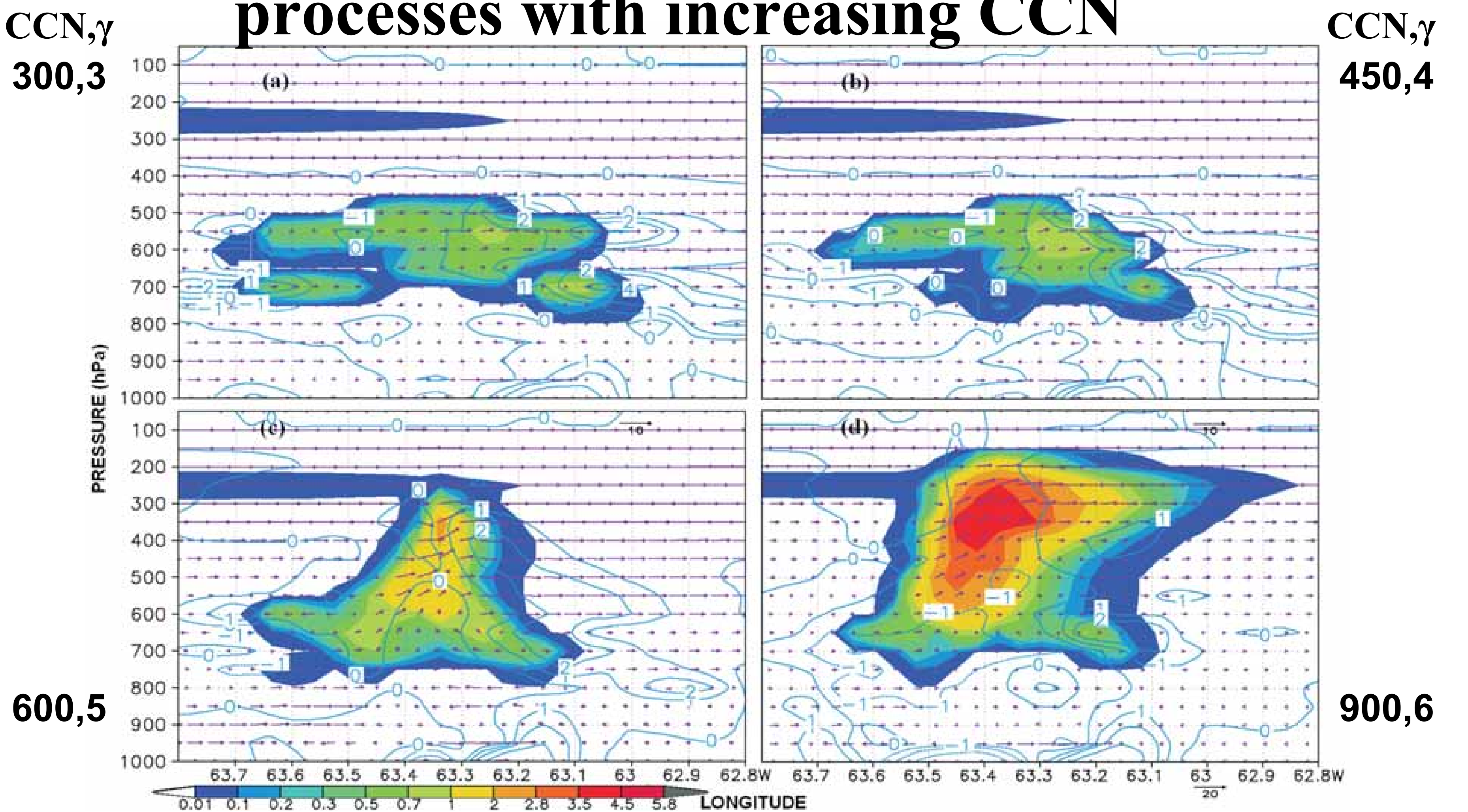
Aerosol issues: South America



- Amazonian September 'fire season' is variable *(Morcrette, 2009)*
- Impacts **microphysics/dynamics**
- Impacts surface **net ecosystem exchange** – diffuse penetrates canopies

Change from warm to cold rain processes with increasing CCN

(Martins et al. JGR 2009)



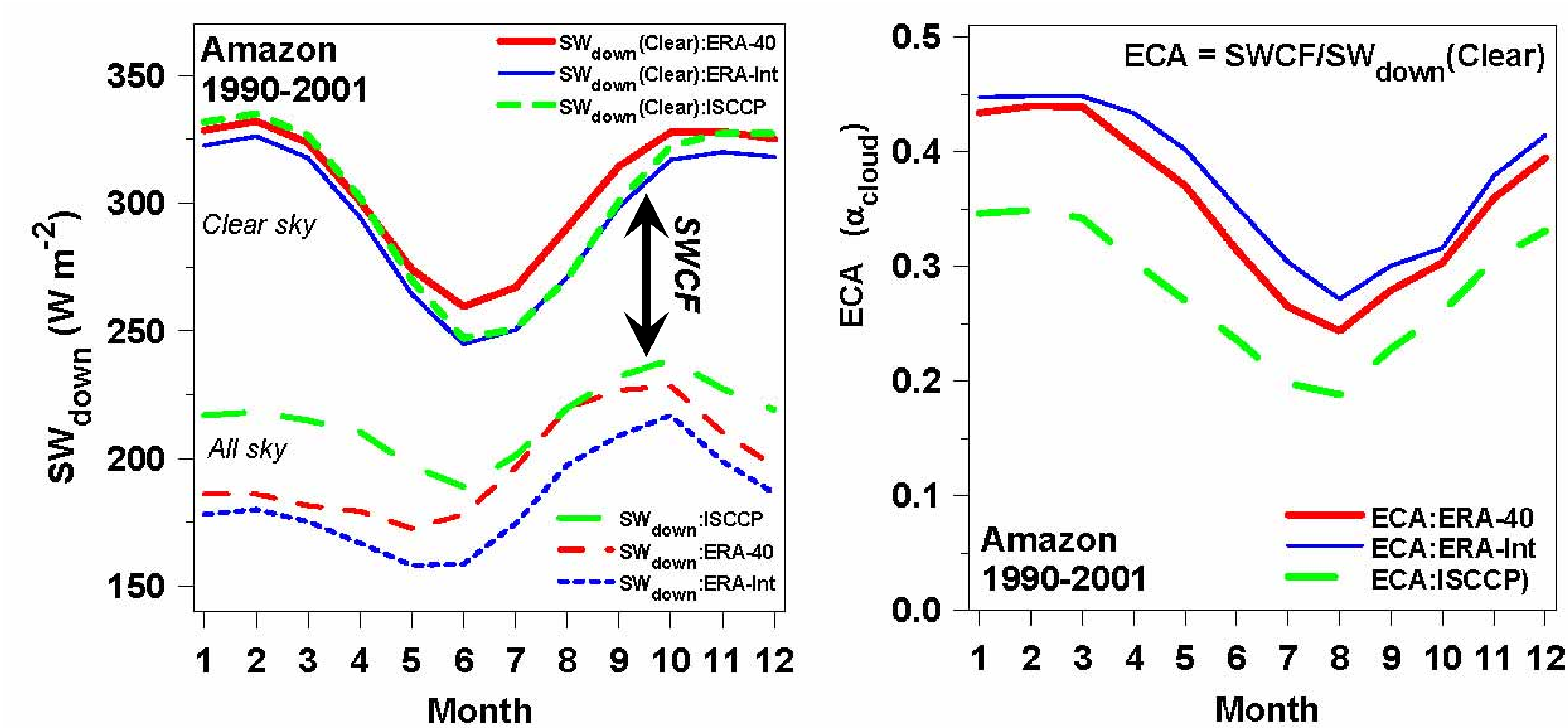
- With increasing CCN concentrations, cloud droplet number, maximum updraft speeds, peak rainfall rates, cloud & ice water concentrations and cloud top heights all increased.

Questions

- Do the drop spectra in our CRMs resemble those observed over the Amazon: from rainy season with ‘warm rain’ to burning season with ‘cold rain’?

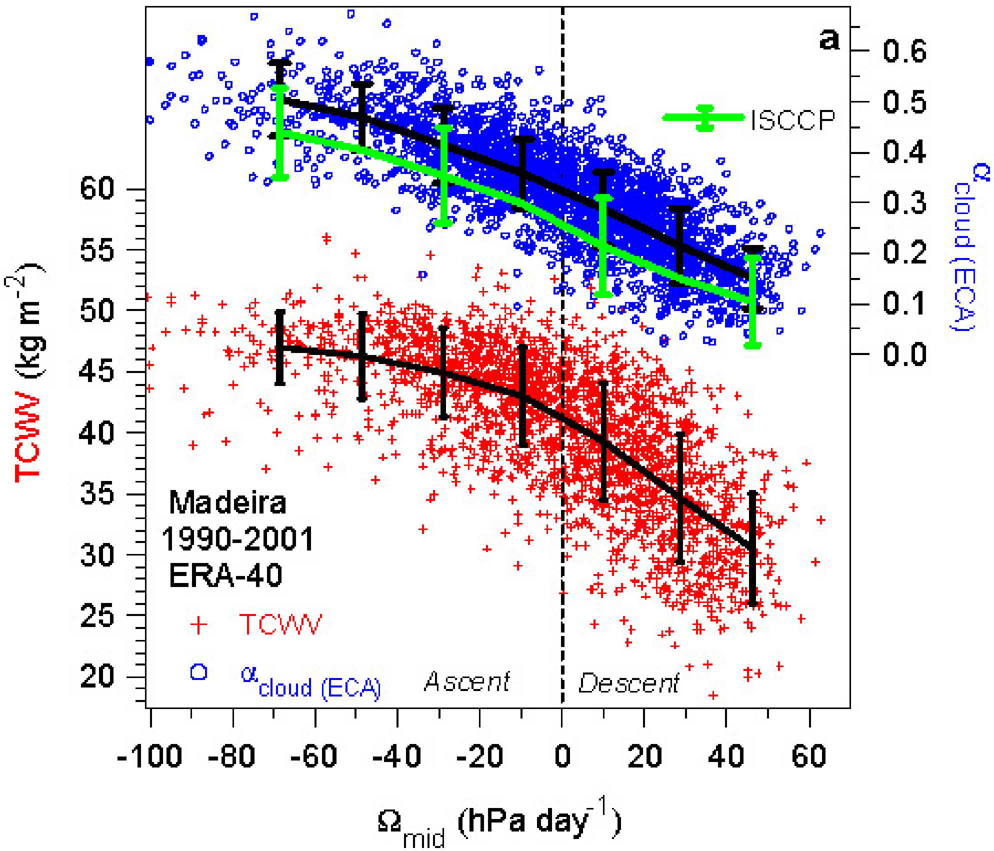
- How do the convective structures compare with those observed in different large-scale flows and aerosol concentrations?

Comparison of SWCF between models and ISCCP

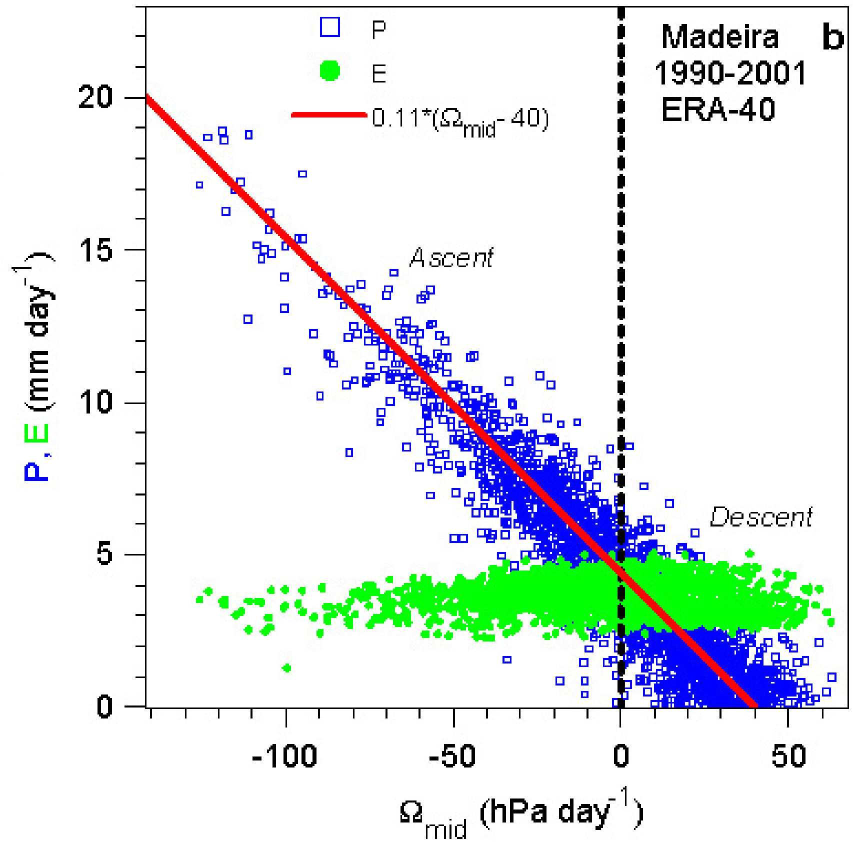


- These positive biases in surface SWCF are large and give cold surface temperature biases

Partition of water budget by daily large-scale vertical motion (Ω)



Amazon



- **Gives clear picture of model partition, which has too much cloud (and too little precipitation)**

Central issue is this partition of water into cloud and precipitation

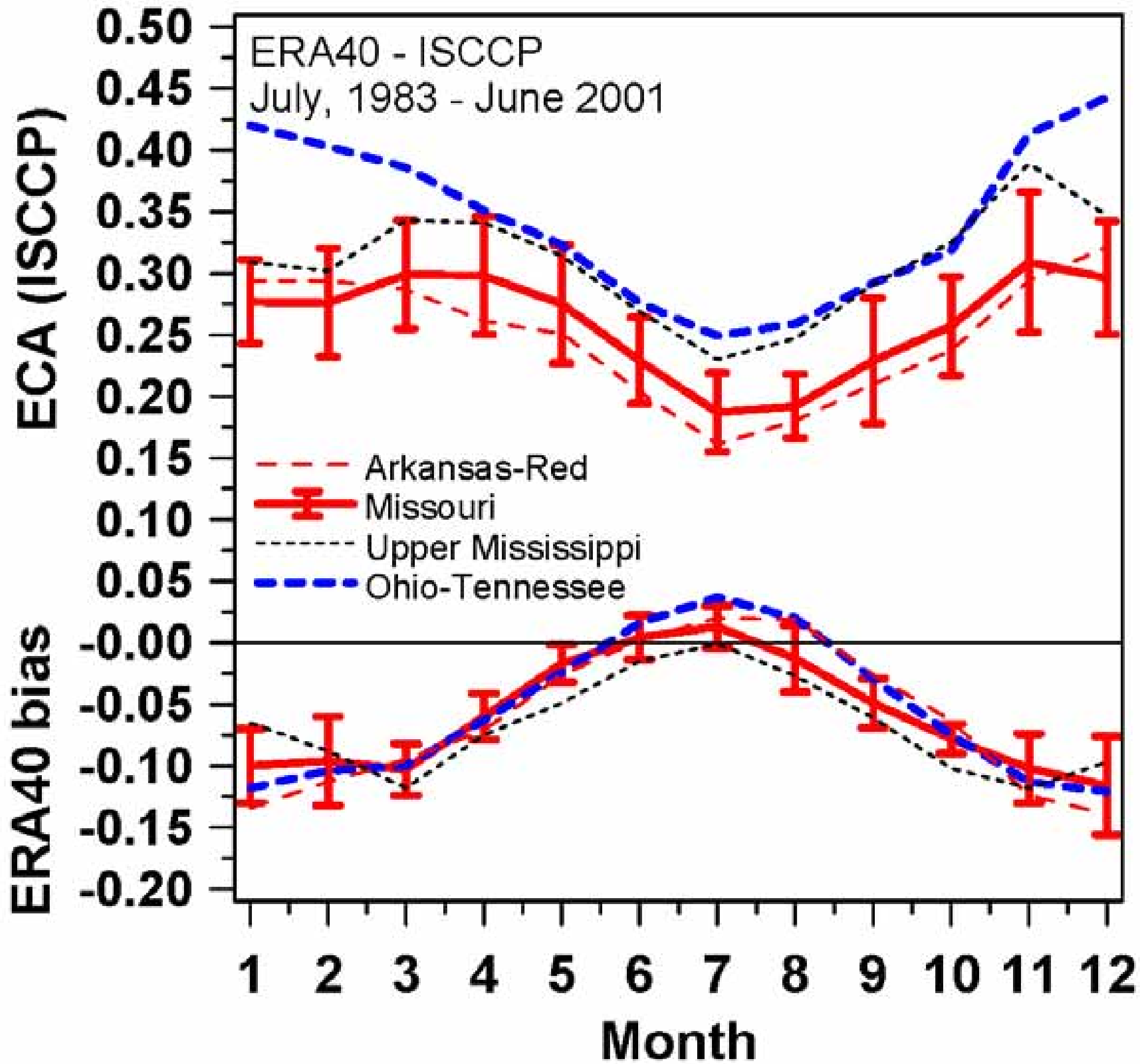
- Cloud radiative forcing is typically smaller but of same order as latent heating
  – and vertical distribution is different

- Critical to both dynamics and climate

- ***ERA-40 Amazon partition bias is too little precipitation and too much surface SWCF***
  [biases of order 30 Wm^{-2} or 1 mm day^{-1}]

Mississippi: ERA40 & ISCCP

Mississippi sub-basins



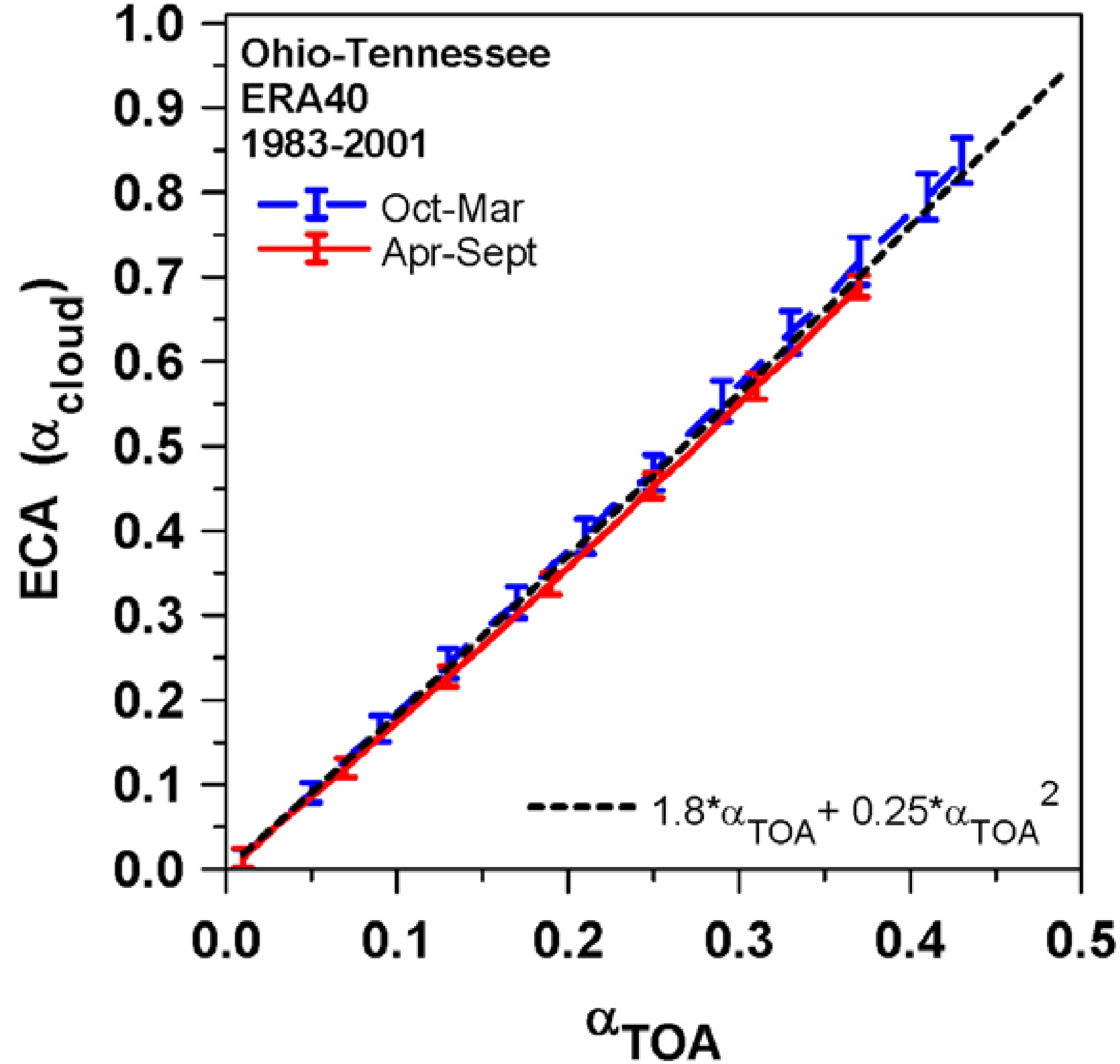
ECA is Effective Cloud Albedo

- **ECA bias in ERA40 is systematic**
- **10% low in winter**

Betts, JGR 2007

Effective cloud albedo (surface) closely related to α_{TOA} in ERA-40

- Less variation in summer than winter

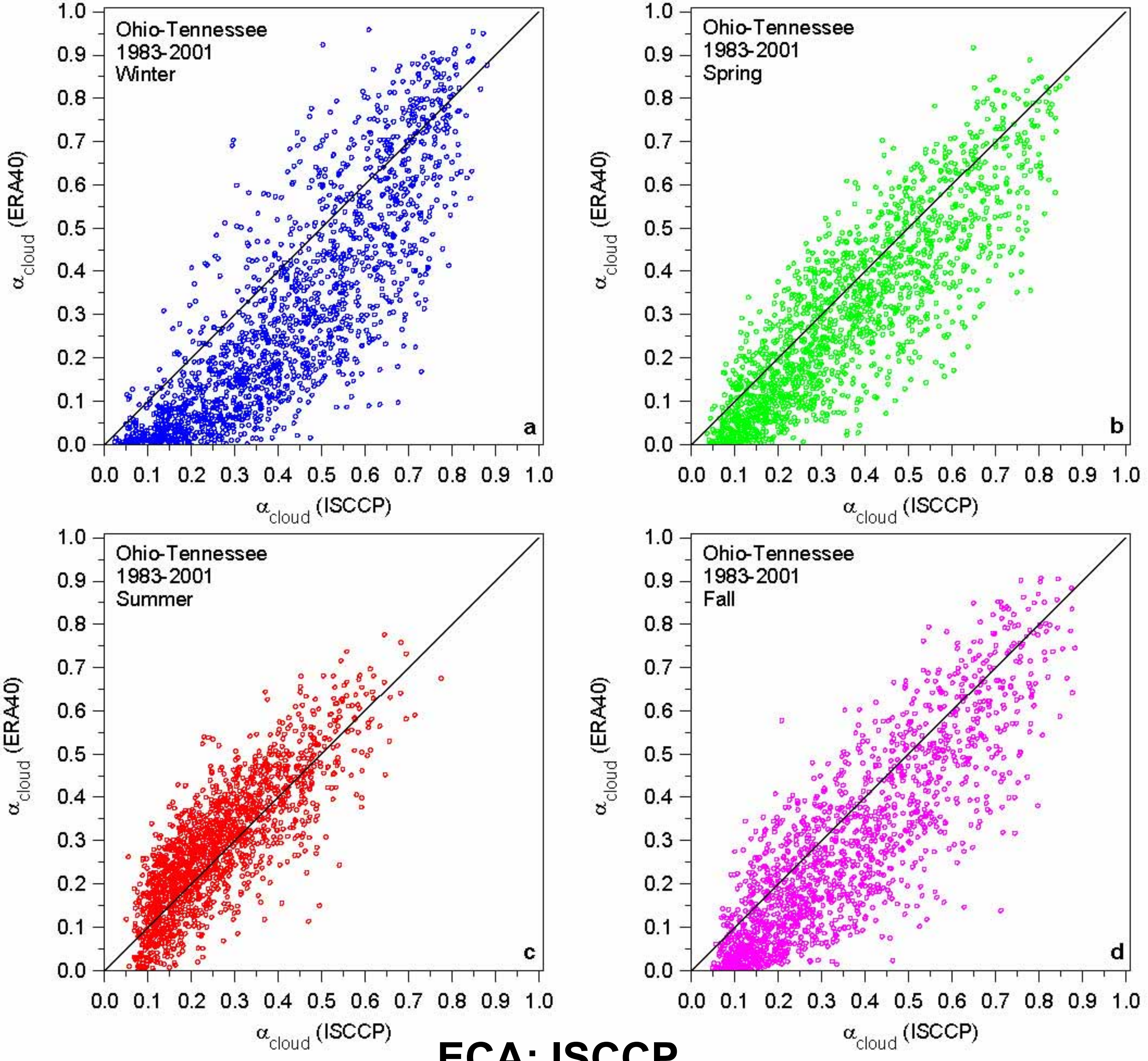


Surface

ECA: ERA40

ERA40 well correlated on daily timescale but seasonal bias changes

ECA: ERA40



ECA: ISCCP

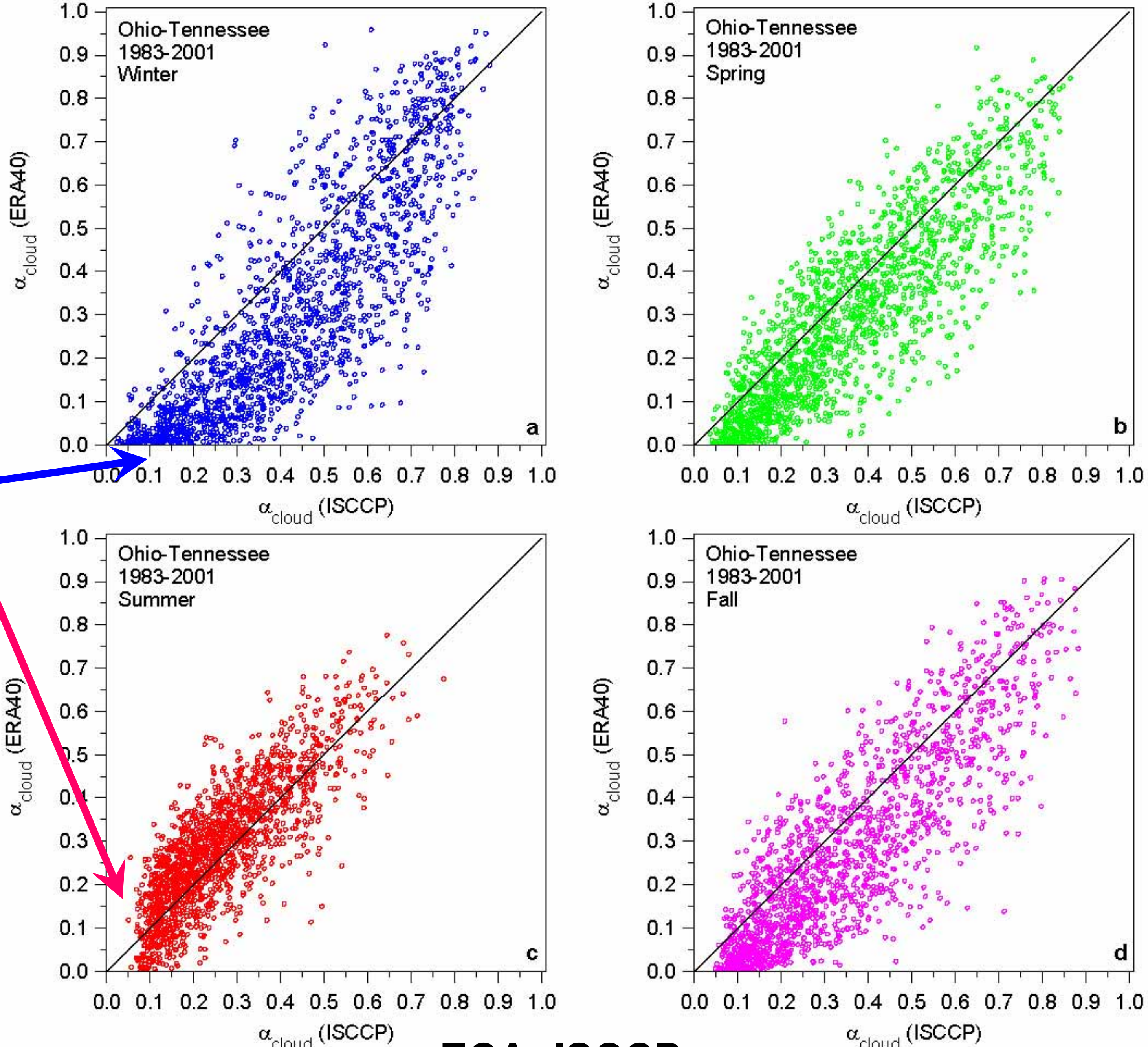
Betts, JGR 2007

Surface

ECA: ERA40

Different distributions

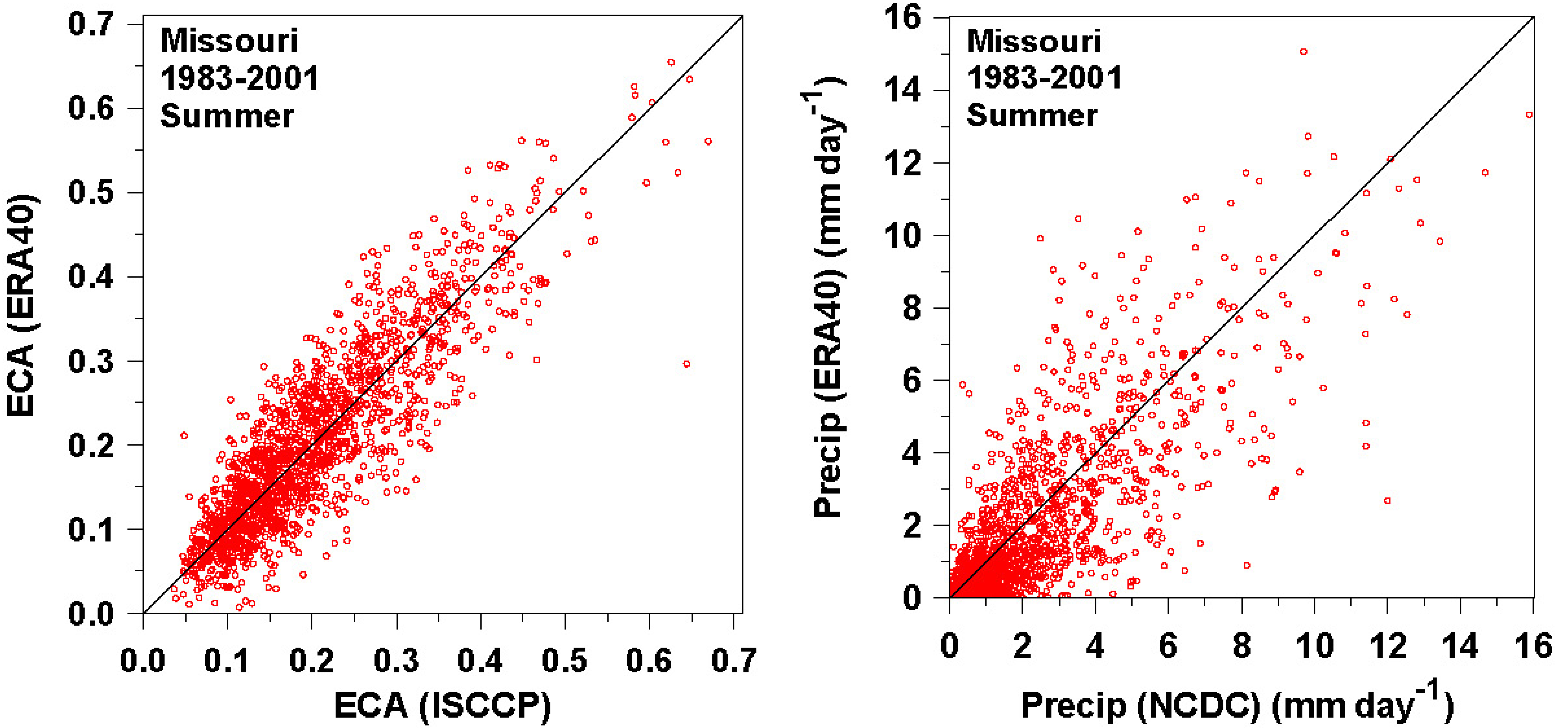
ECA: ERA40



Betts, JGR 2007

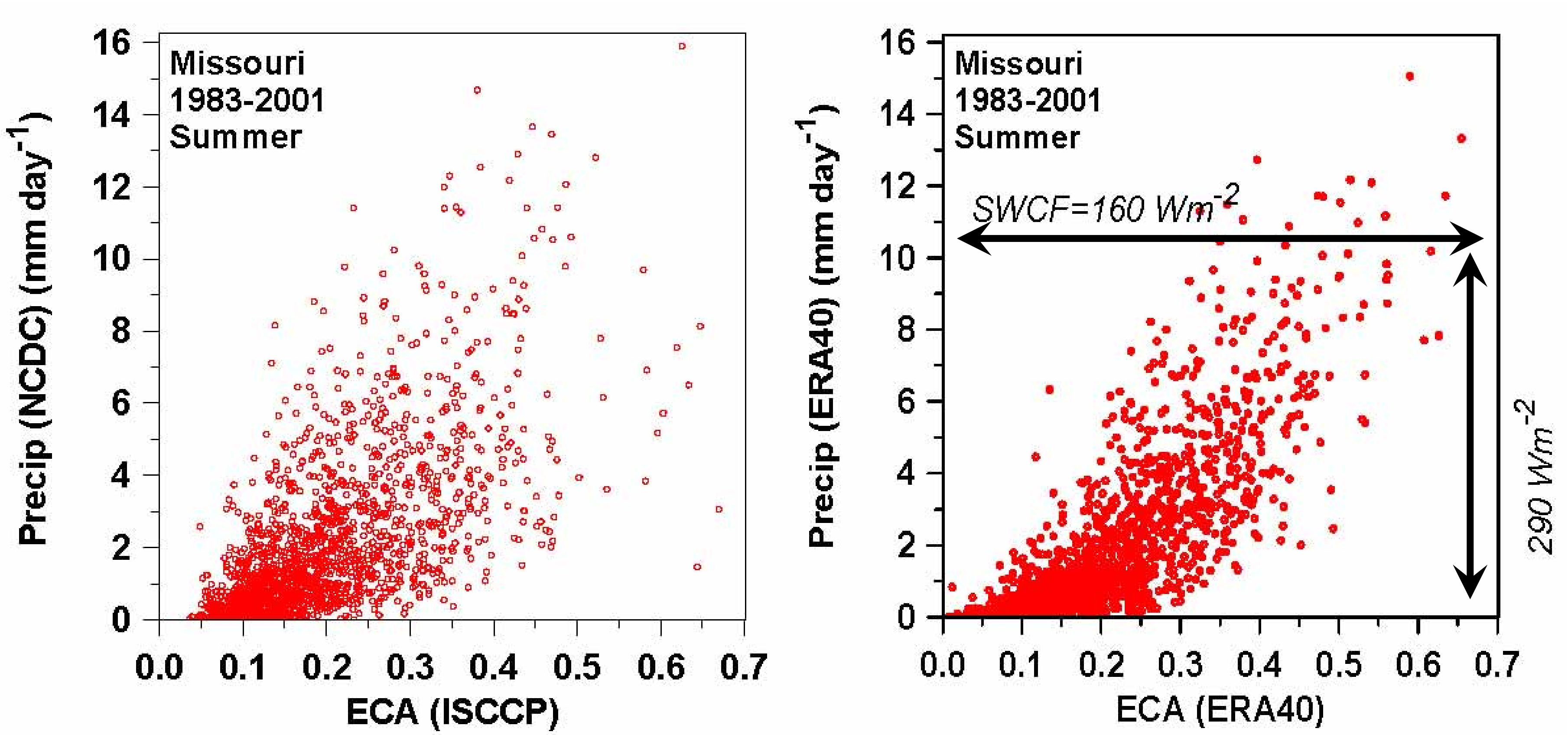
ECA: ISCCP

Missouri Basin: daily means



- Fit better for cloud than Precipitation

Precipitation to SWCF



- Relation of precipitation forcing to SWCF differ between ERA40 and data

Summary

- We don’t have the answers but clouds and the phase changes of water are central to the climate system – **so press on**!
- Need to explore all the tools we have, focusing on **evaluating** the processes that are critical to dynamics and climate **against observations**
- **Keep asking: What useful information can we get from this specific modeling tool?**

References available at http://alanbetts.com

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