CAPT* Analysis of Land-Atmosphere Interactions Manifested in ARM Observations at the U.S. Southern Great Plains Site

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*CAPT: The Cloud-Associated Parameterization Testbed

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Lawrence Livermore National Laboratory

ASR Atmospheric System Research

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Why study land-atmosphere interactions?

The state of the land, *especially in summer*, can influence

- Surface shortwave/longwave fluxes
- Surface latent and sensible heat fluxes
- Boundary-layer moisture and clouds
- Convection
- Precipitation (local “recycling” of soil moisture)

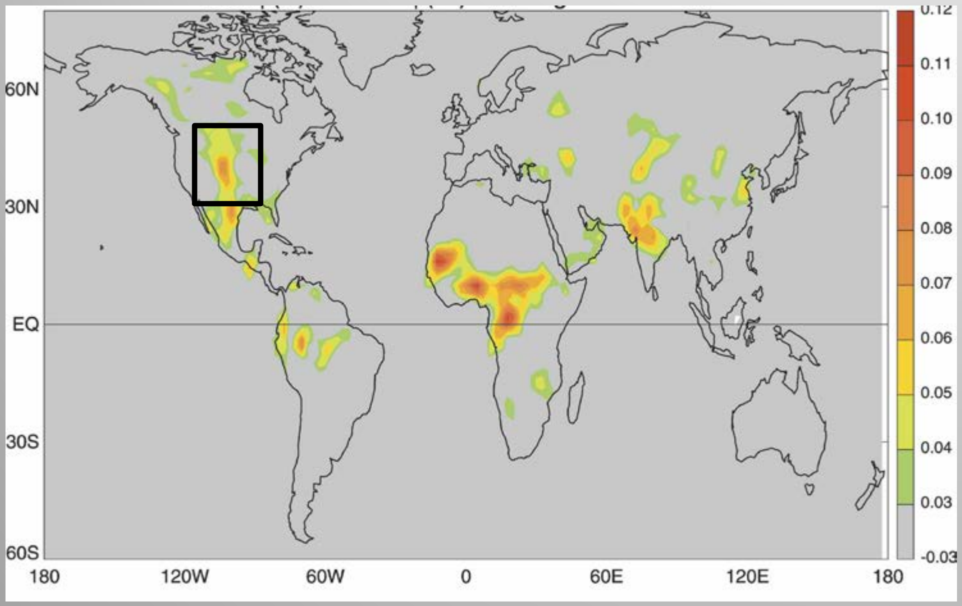
ASR studies of life cycles of different cloud types
should consider land-atmosphere interactions

Background: GLACE modeling experiments

Koster et al. 2006:

- The *ensemble-mean* of 12 GCMs identified several "hot spots" where soil moisture coupled strongly with precipitation and surface air temperature
- One of these hot spots is fortuitously located in the central U.S., where the ARM Southern Great Plains (SGP) site also is situated:

Model Land-Atmosphere "Hot Spots"



How realistic are GCM simulations of land-atmosphere coupling?

ARM observations at the SGP Central Facility (CF)

We can use extensive observations at the SGP Central Facility as a check on model land-atmosphere coupling behaviors:

For 1997-2008 *warm seasons* (May-June-July-August), we utilized:

- ARM "Best Estimate" (ARMBE) hourly measurements (Xie et al. 2010)
  - Low-level cloud cover and base-level heights
  - Surface downward/upward radiative fluxes
  - Surface latent and sensible heat fluxes
  - Surface relative humidity and air temperature
  - Precipitation rate
- Estimated hourly clear-sky surface shortwave fluxes (Long and Shi 2006,2008)
- SWATS hourly soil moisture measurements (Schneider et al. 2003, Bond 2005)

Methodology

We constructed *daily averages* of variables *x* and *y,* and used scatter plots to visualize how these covary (after Betts 2004, 2009).

We also considered normalized variables:

Evaporative Fraction

EF = LH / (LH + SH)

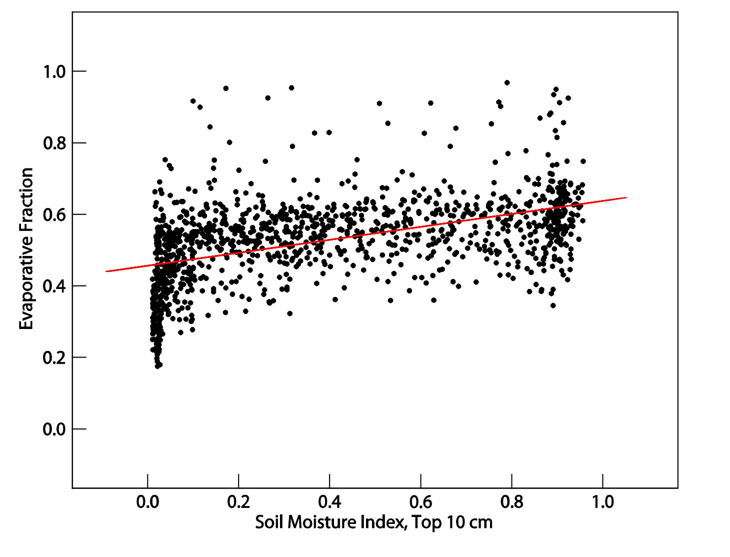
Soil Moisture Index at 10-cm depth

$$\mathbf{SMI = (W - W_{min})/(W_{max} - W_{min})}$$

EF and SMI are especially useful for comparing GCM behaviors with OBS

Scatter plot of *daily averages:*

EF vs SMI



Methodology-2

We inferred the strength of land-atmosphere coupling from:

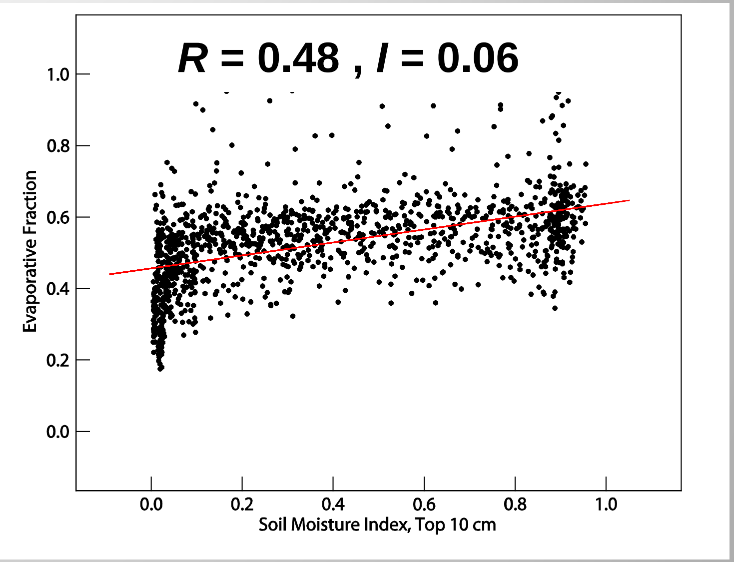
- Correlation $\boldsymbol{R} = \langle x'y' \rangle / \sigma_x \sigma_y$

  R > 0.2 is *statistically significant* at 99% *confidence level*

- Sensitivity Index $\boldsymbol{I} = \sigma_{x} * (\Delta y / \Delta x)$ (Dirmeyer 2011)

  I measures how much the y variable changes for a 1-σ change in the x variable

EF vs SMI

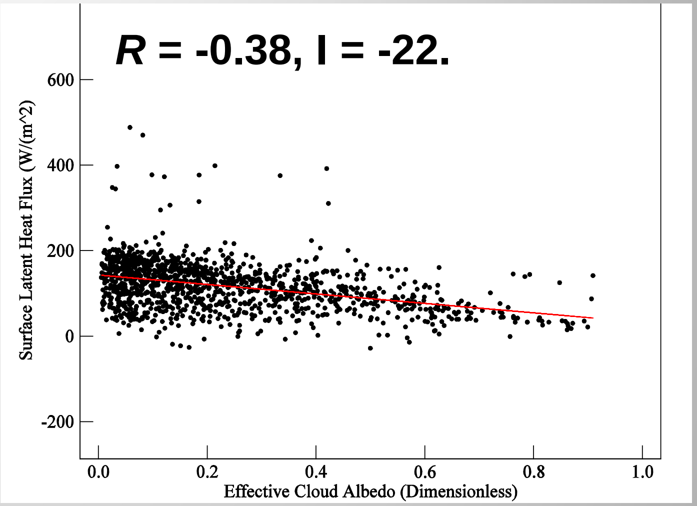


Energetics: atmospheric forcing and land response

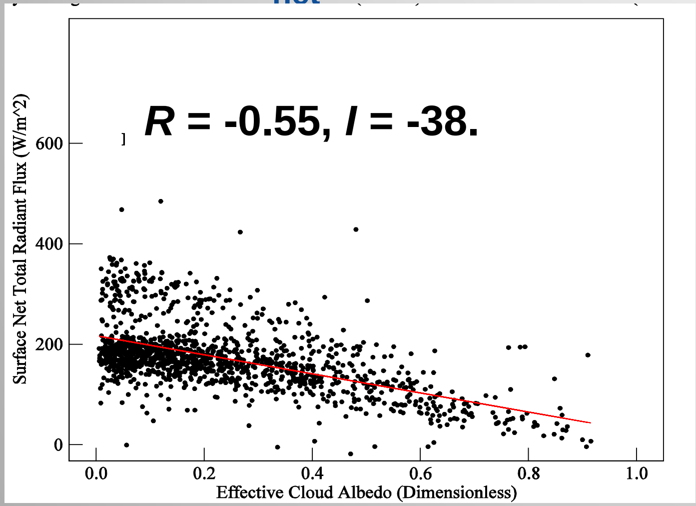
Effective Cloud Albedo

$\alpha = (SW_{clear\text{-}sky} - SW_{obs}) / SW_{clear\text{-}sky}$

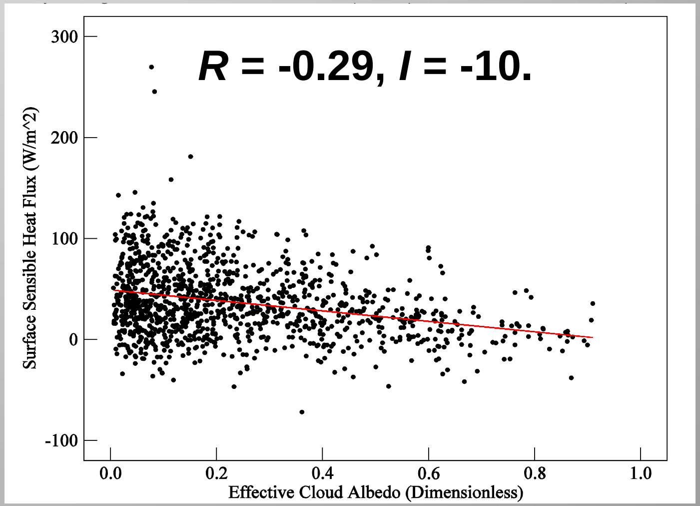
Latent Heat Flux vs α



R_{net} vs α

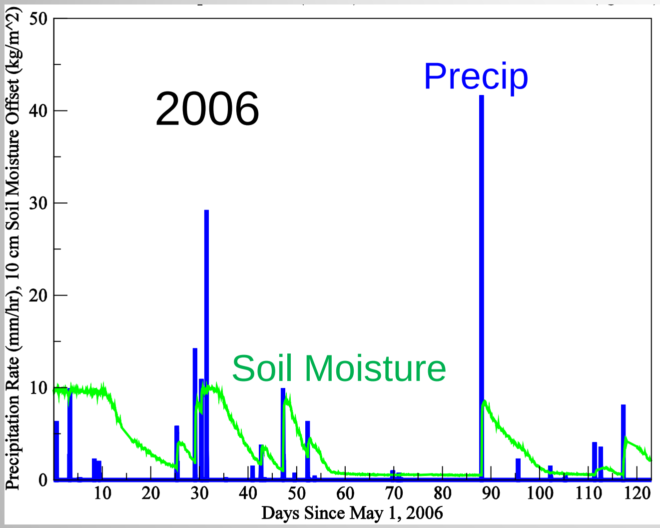


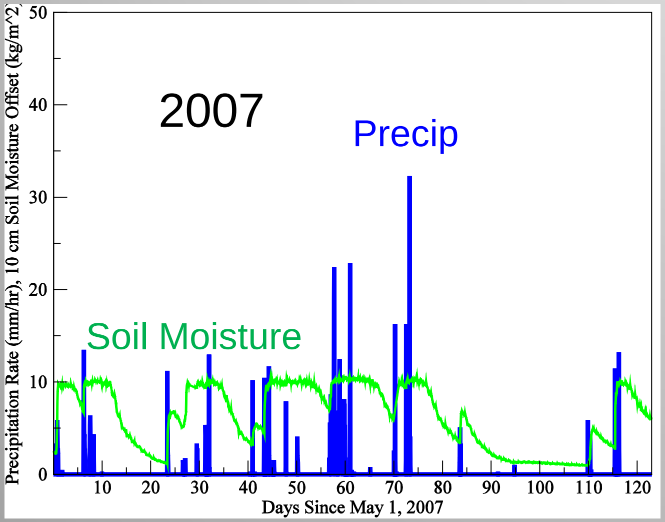
Sensible Heat vs α



- Clouds control much of the variability of the atmospheric radiative forcing of the land, and of the land’s turbulent-flux response.
- Turbulent fluxes vary less coherently with α because they also are influenced by land variables such as soil moisture.

Hydrology: Precipitation forcing and soil-moisture response



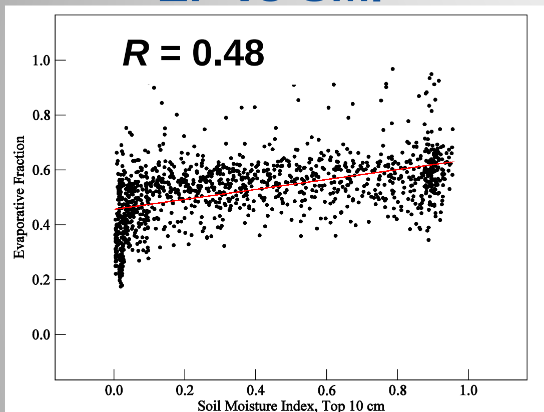


- 10-cm soil moisture abruptly increases after each precipitation event, and then slowly decreases—Soil Moisture ***lags*** Precip
- Most of *summer* SGP precipitation is from convective cells that are ***remotely triggered at night***
- We found that ***daytime*** precipitation is not significantly correlated with soil moisture
- Observed local moisture recycling is probably *not substantial* (Lamb et al. 2013)

→ GCMs do *not* realistically simulate *summer* precipitation at SGP

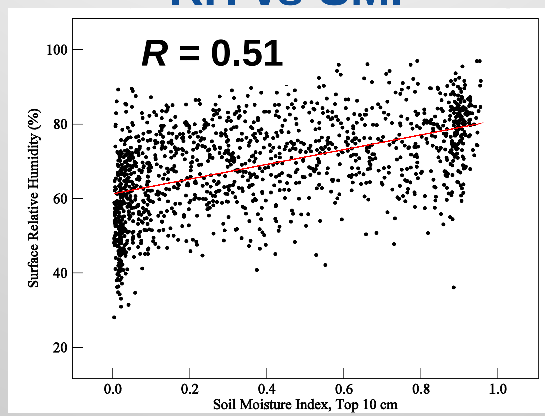
Surface atmospheric variables vs 10-cm soil moisture index (SMI)

EF vs SMI

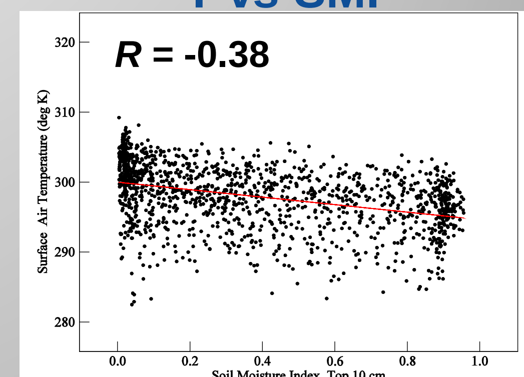


EF and surface **RH** correlate positively, and surface air **T** negatively, with SMI.

RH vs SMI



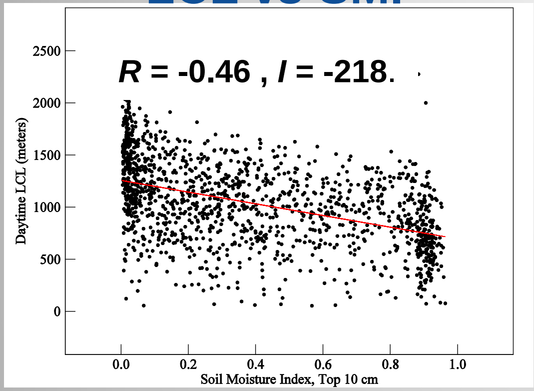
T vs SMI



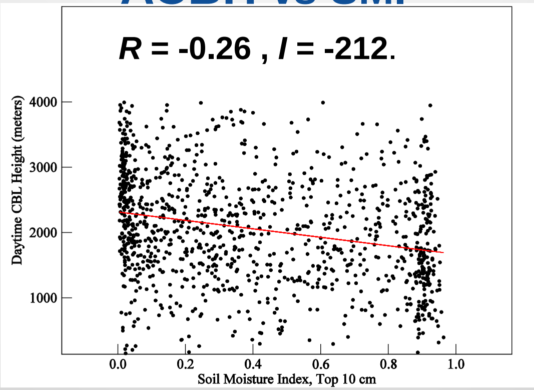
We found that correlations of soil moisture with these surface atmospheric variables all *intensify as the soil increasingly dries out* after each precipitation event.

Correlations of boundary-layer clouds and soil moisture

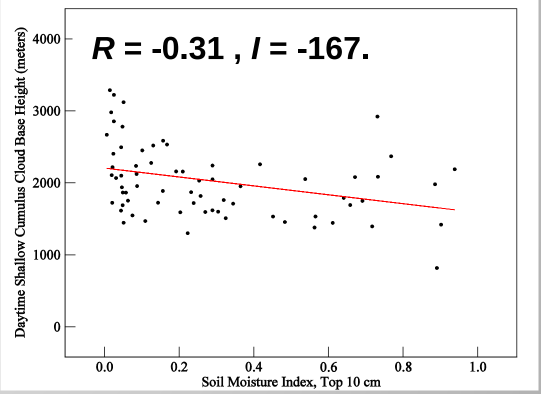
LCL vs SMI



ACBH vs SMI



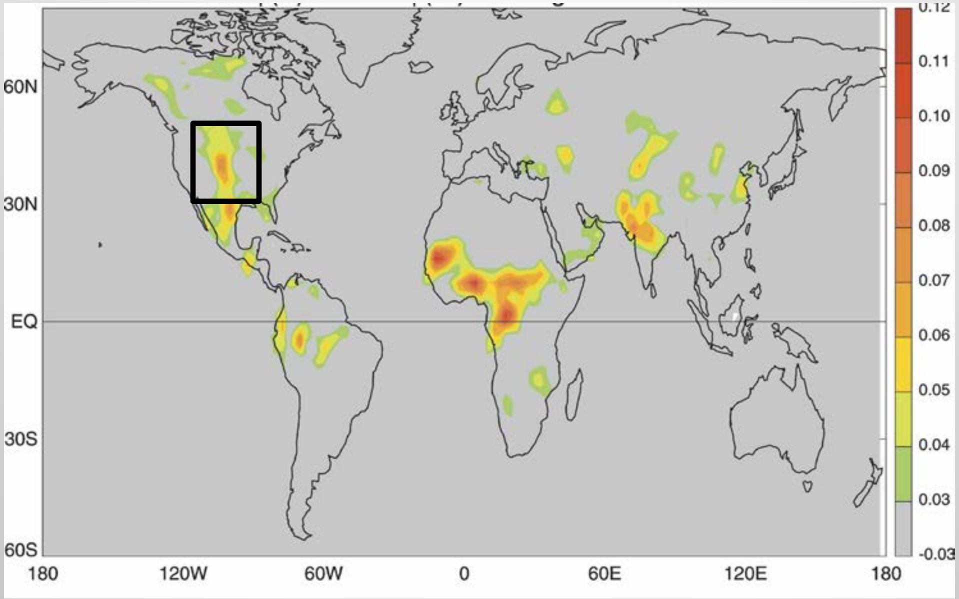
SCBH vs SMI



Acknowlegment: Y. Zhang

- The Lifting Condensation Level (**LCL**) and the *observed all-cloud base heights* (**ACBH**) both couple with soil moisture, but the **LCL** correlates more strongly.
- In both cases, we found that the correlations with soil moisture increase as the soil dries out after each precipitation event.
- The base heights of *daytime shallow cumulus clouds* (**SCBH**) correlate more strongly with **SMI** than does the all-cloud **CBH**.

Model Land-Atmosphere “Hot Spots”



How realistic are GCM simulations of land-atmosphere coupling?

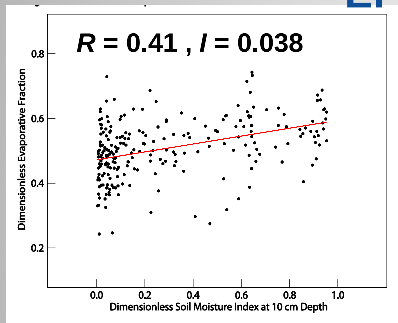
CAM5 model hindcasts in the CAPT diagnostic framework

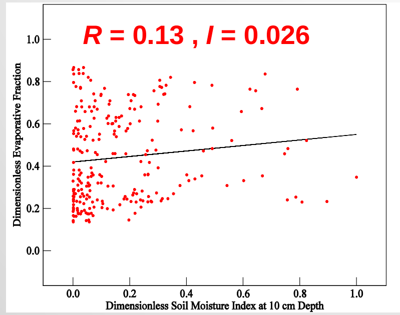
The CAPT Protocol

- Initialize the CAM5 model state from a global reanalysis for each day of a period of interest (e.g. 2008/2009 warm seasons)
- Run CAM5 in NWP mode, generating continuous global hindcasts
- Downscale these hindcasts to the SGP region, and compare CAM5 covariations of land/atmospheric variables with those in the OBS

Soil Moisture Relationships: **OBS** vs CAM5 in 2008/2009 warm seasons

EF vs SMI

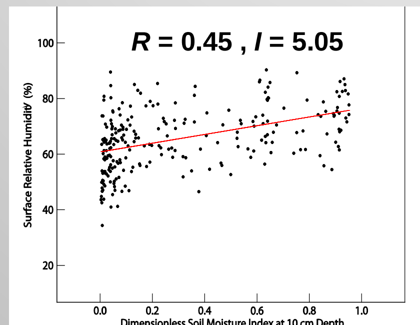


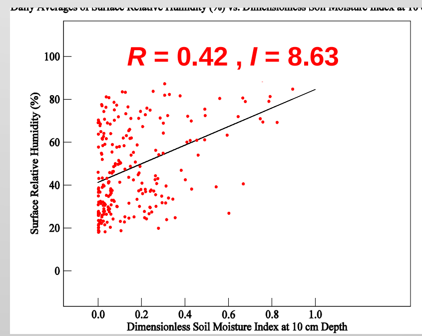


CAM5 correlations *R* or sensitivities *I* differ substantially from the **OBS:**

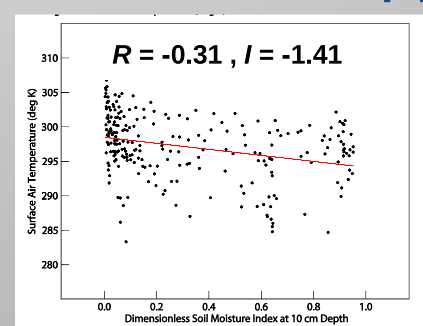
Model ***R*** values tend to be lower, and ***I*** values to be higher

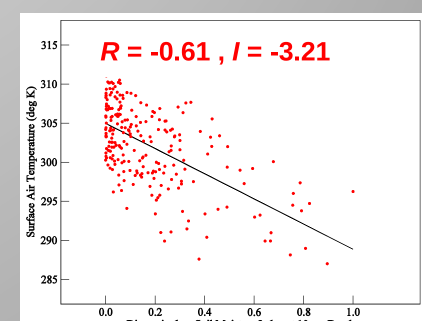
RH vs SMI





T vs SMI





Our goal is to attribute **CAM5** errors to model parameterization deficiencies.

Summary

- Atmospheric forcings (R_{net} and Precipitation) of the land predominate over land feedbacks on the atmosphere.
- Precipitation from recycling of local soil moisture is probably *not* substantial.
- However, soil moisture couples more strongly with the atmosphere (both surface variables and ABL clouds) as the soil becomes increasingly drier after each precipitation event.
- CAM5 land-atmosphere correlations in the CAPT framework show substantial deviations from OBS.
- We will try to attribute these apparent CAM5 errors to specific deficiencies in parameterizations of the CAM5 atmospheric or land models.

Thanks!

NCAR CAM5 hindcasts in the CAPT framework

CAPT Protocol

- Initialize the CAM5 model's atmospheric state variables *each day* from a global reanalysis for the period of interest
- Spin up the land model using reanalysis precipitation starting ~ 6 months prior to the period
- Run CAM5 in NWP mode, generating continuous global hindcasts during the period
- Downscale CAM5 hindcasts to the SGP region by interpolating nearest-neighbor grid cell values
- Compare model covariations of land and atmospheric variables with those identified in the SGP observations
- Where possible, attribute model errors to parameterization-scheme deficiencies