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

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***CAPT: Cloud Associated Testbed Project**

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Background

Our study (Phillips and Klein, 2014: Land-atmosphere coupling manifested in warm-season observations on the U.S. southern great plains, *JGR* , in press) investigates selected features of land-atmosphere coupling observed at the ARM SGP Central Facility (CF) site near Lamont, Oklahoma during the May-August warm seasons of multiple years. Following the perspective of boundary-layer meteorologist Alan Betts (e.g. Betts, 2009 *JAMES*), the atmosphere couples with the land via radiation and precipitation fluxes that are modulated by clouds, and the land couples with the atmosphere via surface radiant and turbulent fluxes that are modulated by soil moisture.

Land-atmosphere coupling is manifested in the covariations of atmospheric and surface fluxes or state variables, as expressed for example in scatter plots. To investigate details of such land-atmosphere interactions at the SGP site, we exploited the ARM Best Estimate (ARMBE) and supplementary field observations that were available at hourly sampling rates for the 12 years from 1997 through 2008.

Climate models--when operating realistically--should exhibit similar covariance relationships in their land-atmosphere interactions. To determine whether this is the case, we are starting to analyze hindcasts of the summers of 2008-2009 made with version 5 of the Community Atmospheric Model (CAM5) that was initialized realistically following standard **CAPT*** procedures. The CAM5 hindcasts then were downscaled to the SGP site, allowing a close comparison with ARM 2008-2009 summer observations. Failure to simulate the observed land-atmosphere covariance relationships implies a need to make appropriate initialization and/or parameterization changes in the CAM5 land and/or atmospheric components.

Methodology

In elaborating his perspective on land-atmosphere coupling, Betts makes use of several derived dimensionless quantities:

- **Effective Cloud Albedo**

  α **= 1 - Sfc Downward SW / Sfc Downward *clear-sky* SW**

- **Surface Evaporative Fraction**

  EF = LH/ (LH + SH)

  where **LH** = Surface Latent Heat Flux
  SH = Surface Sensible Heat Flux

- **Soil Moisture Index**

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

  where **W** is the soil moisture at 10 centimeter depth

  W_{min} is the minimum multi-year soil moisture

  W_{max} is the maximum multi-year soil moisture

Metrics to quantify the covariations of land and atmospheric variables **x** and **y** include:

Correlation Coefficient $R = x' \cdot y' / (\sigma_x \cdot \sigma_y)$

where the numerator is the product of multi-year deviations **x'** and **y'** from the long-term means of **x** and **y**, and the denominator is the product of the corresponding standard deviations. For daily-average samples of **x** and **y** over 12 warm seasons, a correlation **R** > ~0.2 is statistically significant at the 99% confidence level, assuming every 5th sample is statistically independent.

Because **R** may be sensitive to mismatches in the ranges of variables **x** and **y**, a "sensitivity index" **I** (Dirmeyer, 2011 *GRL*) is also calculated:

Sensitivity Index $I = \sigma_x \cdot \beta$

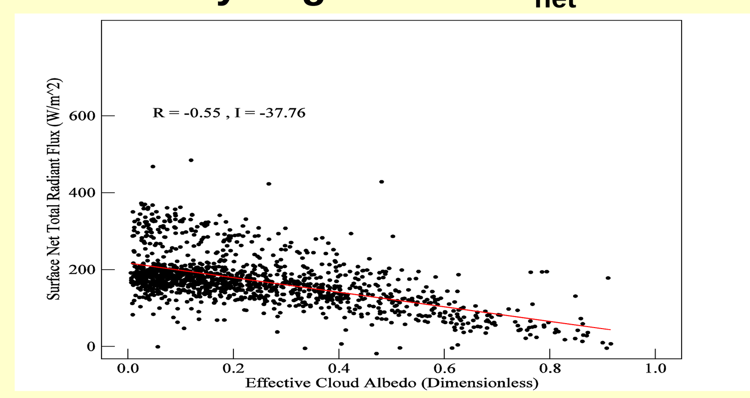
where σ_x is the **x** variable's standard deviation, and β is the slope of the linear regression of **y** versus **x**. (Note that **R** is a dimensionless metric, while **I** takes on the same units as **y**.). **I** thus measures how much a change in variable **y** occurs for a standard-deviation change in variable **x**.

1997-2008 Observational Examples

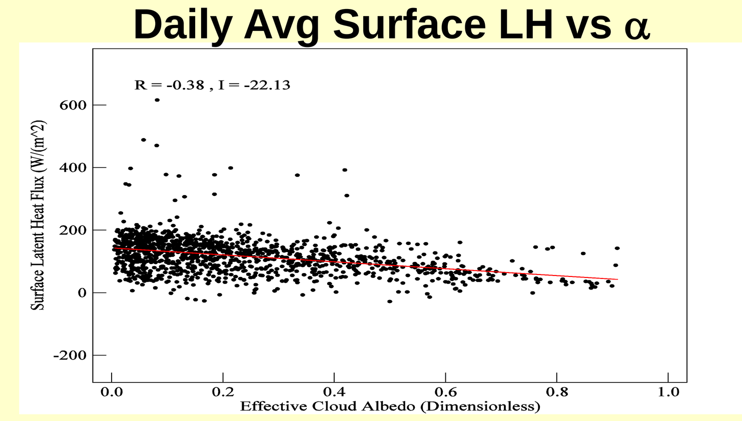
For May through August of 12 years of observations at the SGP Central Facility site, scatter plots illustrate the covariation of paired *daily averaged* land-surface or lower atmospheric variables. Values of the correlation coefficient **R** and sensitivity index **I** also are shown for each variable pairing.

Surface Energetics

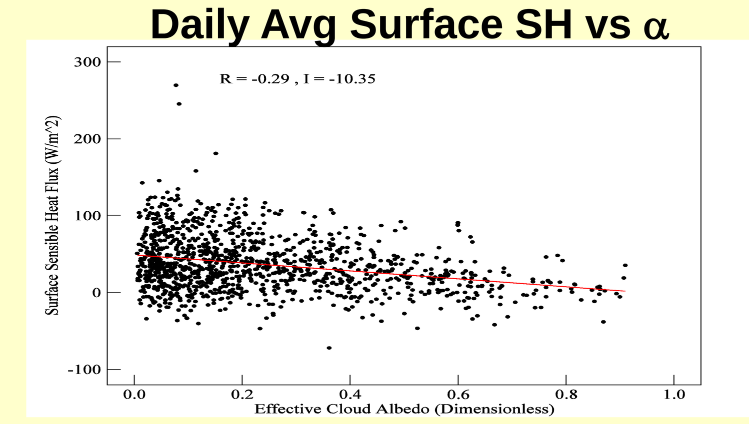
Daily Avg Surface R_{net} vs α



Daily Avg Surface LH vs α

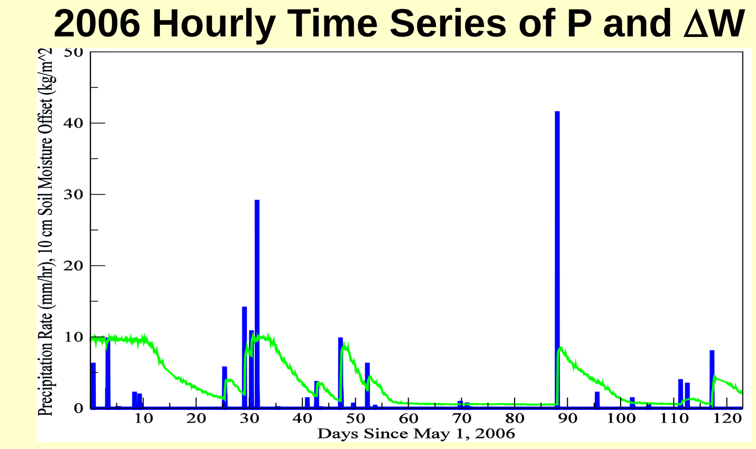


Daily Avg Surface SH vs α



Surface Precipn and Soil Moisture

2006 Hourly Time Series of P and ΔW

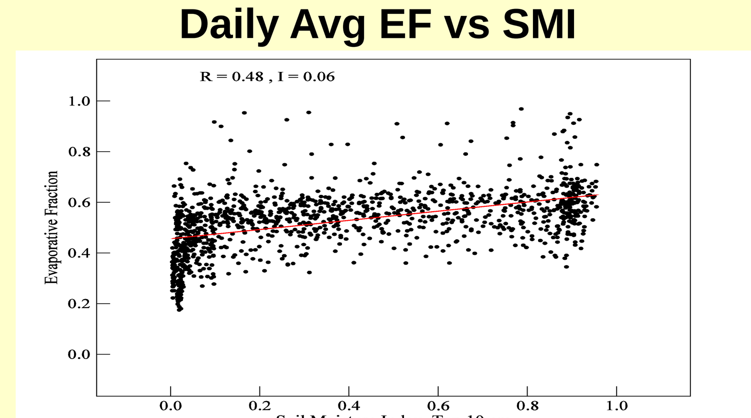


The surface total net radiation $R_{net} = SW_{net} - LW_{net}$ decreases with effective cloud albedo α. In addition, the surface net radiation R_{net} is roughly balanced (neglecting the ground heat storage) by the sum of the latent and sensible heat fluxes **LH + SH**. Like R_{net}, **LH** and **SH** both vary inversely, but less coherently, with α (middle plots above), implying that **LH** and **SH** are also influenced by land variables such as soil moisture, which is closely tied to precipitation.

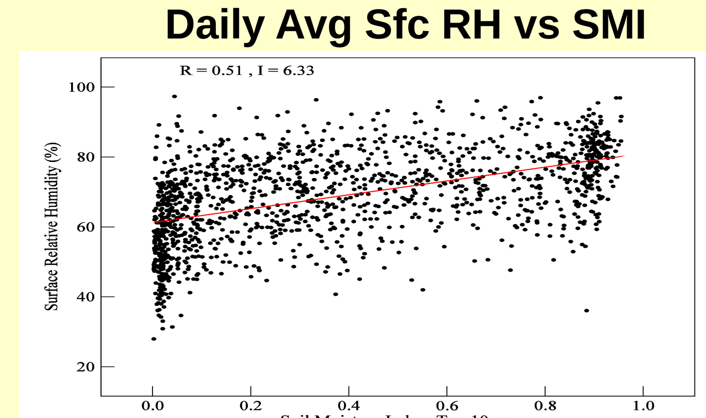
In the rightmost plot above, a time series of the hourly precipitation rate **P** during the relatively dry 2006 warm season (units of mm hr^{-1}—shown in blue) and of the soil moisture offset Δ**W** (defined as the soil moisture **W** - 25 kg m^{-2} at 10 centimeter depth—shown in green) illustrates the sudden increase of 10-cm soil moisture amount that closely follows upon each precipitation event, and then gradually decreases until the next **P** event. Most of the precipitation at SGP originates from nocturnal convective cells that are remotely triggered in the lee of the Rockies, and then propagate over the site. The "recycling" of precipitation from local soil moisture/surface evaporation thus is probably not very substantial, as implied by the statistically insignificant correlation (**R** ~ 0.08, figure not shown) of the 10-cm soil moisture index **SMI** with daytime-averaged precipitation.

Surface Evaporative Fraction, Relative Humidity, Air Temperature, and Lifting Condensation Level versus Soil Moisture Index

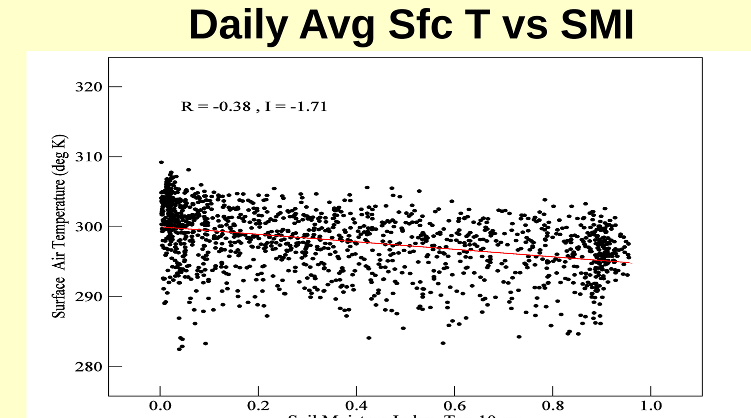
Daily Avg EF vs SMI



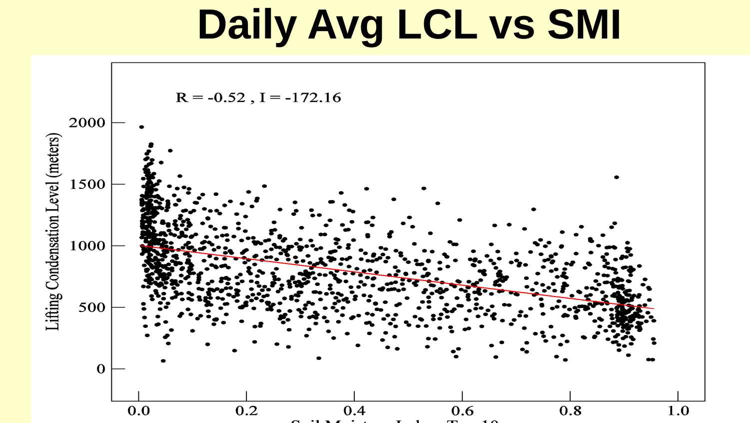
Daily Avg Sfc RH vs SMI



Daily Avg Sfc T vs SMI

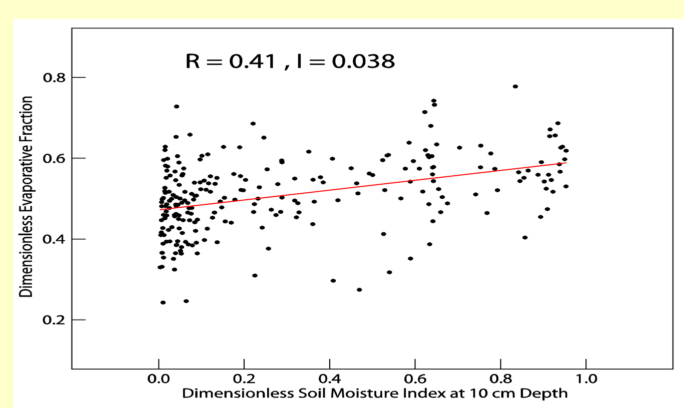


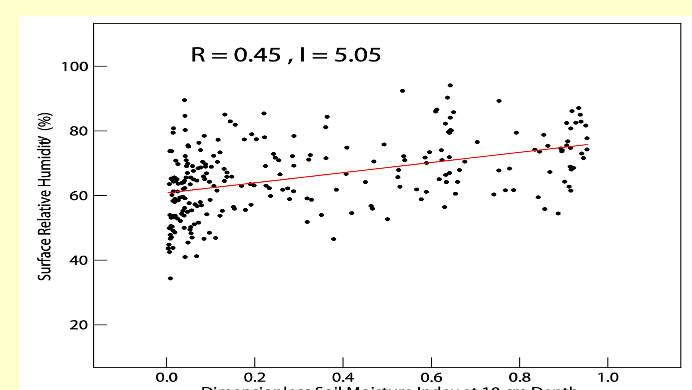
Daily Avg LCL vs SMI

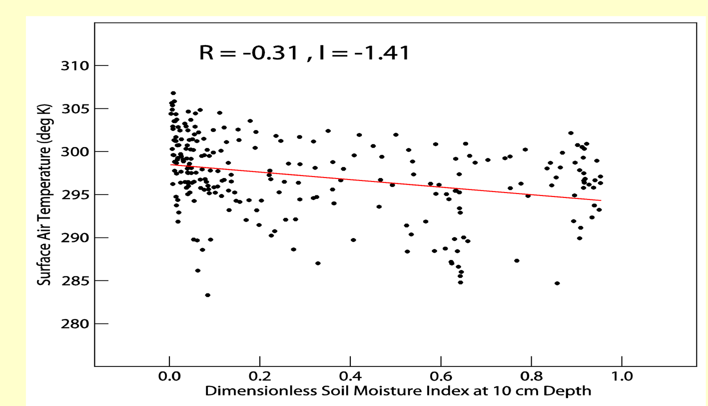


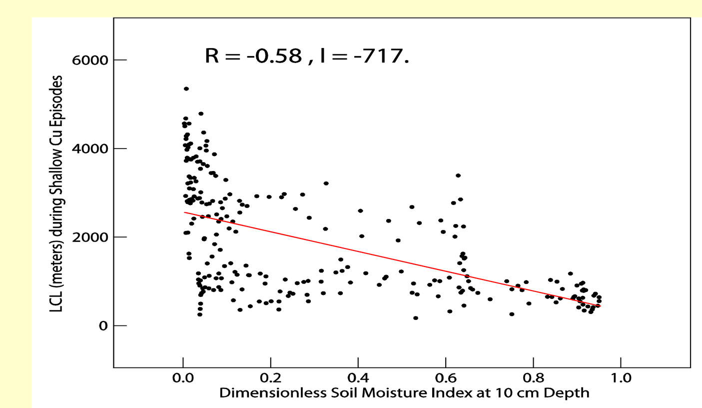
The observed surface evaporative fraction **EF** correlates positively with the 10-cm **SMI** , and the amount of surface evaporation thus is limited mainly by soil moisture amount rather than by net radiation R_{net} (i.e. moisture-stressed conditions tend to prevail at this SGP site). The surface relative humidity **RH** also correlates positively with **SMI,** while the two-meter surface air temperature **T** correlates negatively (**T** increases as the soil dries out). Because the lifting condensation level (**LCL**) becomes lower as surface **T** decreases and surface **RH** increases, the **LCL** varies inversely with **SMI**.

OBS versus CAM5: Preliminary Analysis of Land-Atmosphere Feedbacks in Overlapping Years 2008 & 2009:

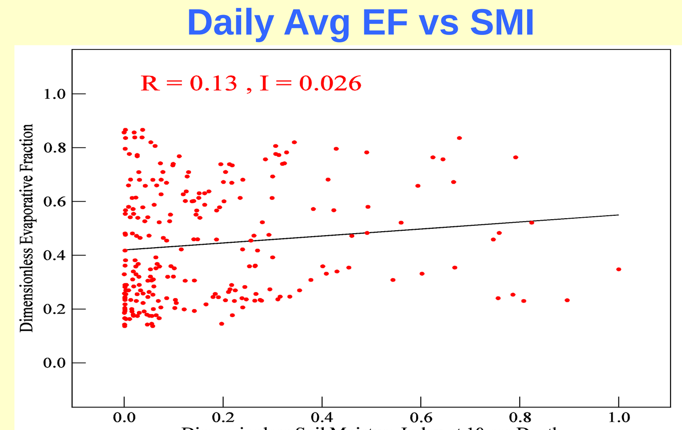




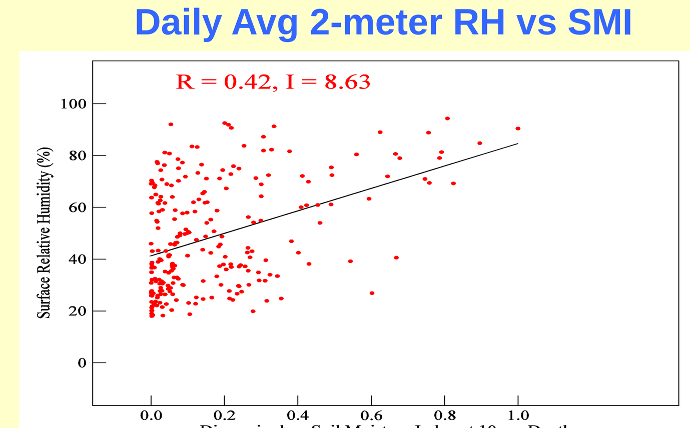




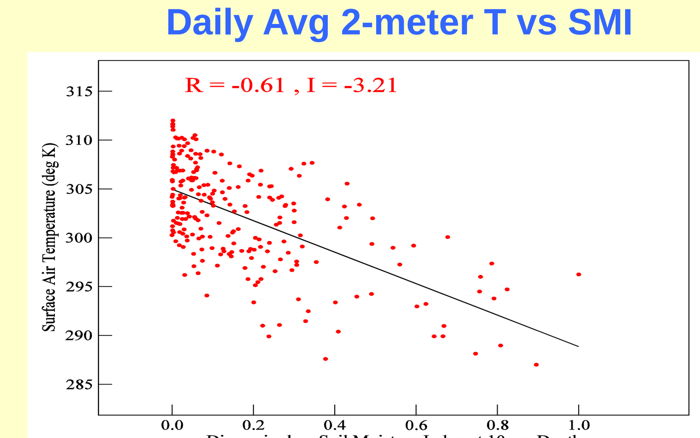
Daily Avg EF vs SMI



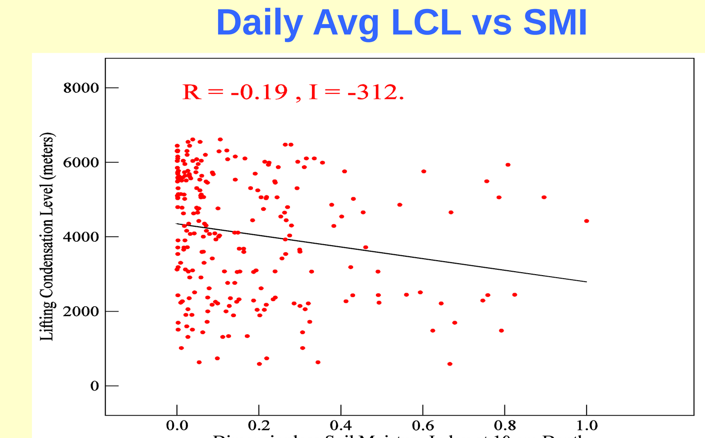
Daily Avg 2-meter RH vs SMI



Daily Avg 2-meter T vs SMI



Daily Avg LCL vs SMI



Comparing covariations of **CAM5** atmospheric surface or boundary-layer variables versus soil moisture index **SMI** with the corresponding observed covariations (**OBS**) indicates that **CAM5** variables mostly correlate less coherently (lower **R** coefficients**)**, but some display more "sensitivity" (higher **I** values) to changes in soil moisture. However, **CAM5** soil moisture also tends to frequent relatively drier states than observed, implying that the model's summer precipitation is too scant, or that model surface evaporation and/or drainage of soil water is too large. Identification of the cause(s) of apparent model deficiencies is In progress.

***The CAPT (Cloud-Associated Parameterization Testbed) Project operates under the auspices of the U.S. Department of Energy's Atmospheric System Research (ASR) Program, and conducts its work at Lawrence Livermore National Laboratory under general contract DE-AC52-07NA27344.**

LLNL-POST-650778