Using ARM Observations to Evaluate Land-Atmosphere Coupling in CAM5.1/CLM4 Hindcasts on the U.S. Southern Great Plains

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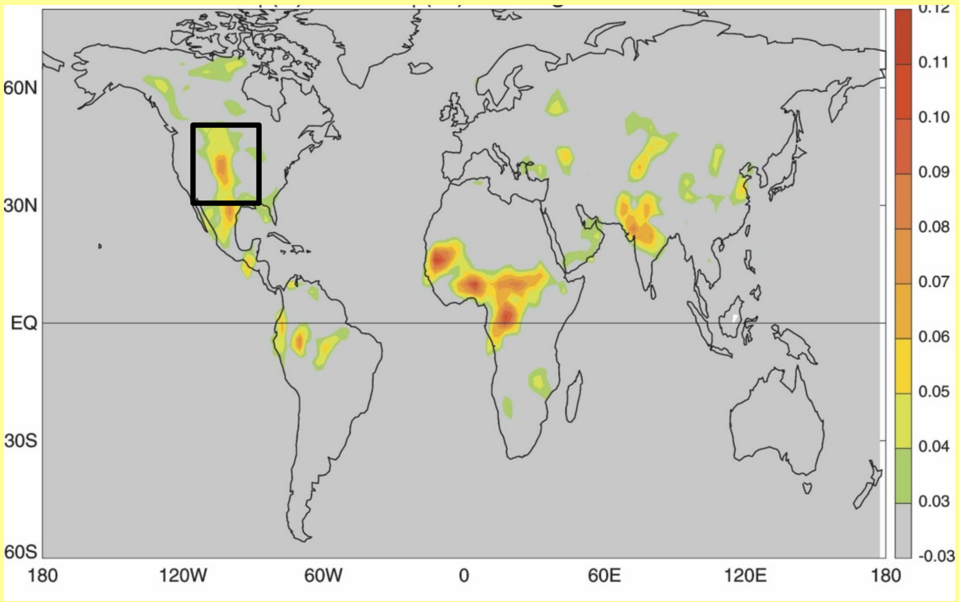
Why evaluate Model land-atmosphere coupling strength?

- The degree to which the land couples with the atmosphere is important for obtaining accurate continental weather predictions and climate simulations

GCM Land-Atmosphere "Hot Spots"



By "model consensus", the U.S. Southern Great Plains (SGP) is a "hot spot" for especially strong land-atmosphere coupling—Koster et al. (2004)

Phillips and Klein (2014 *JGR*): Statistically significant observed SGP coupling strength, but weaker than the GCMs indicate.

How realistic are GCM simulations of land-atmosphere coupling strength at SGP (do the GCMs overdo it)?

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CAM5.1/CLM4 model hindcasts

In a *continuous series* of Model 3-day hindcasts, SSTs and sea ice extents were *prescribed from observations* (as in a free-running AMIP experiment), but with these added constraints:

Initialization for hindcasts (see Ma et al., 2015 *JAMES*):

- The CLM4 land model was forced (offline) by *observed* precipitation, net radiation, and surface winds, ensuring more realistic predictions of soil moisture and surface fluxes
- The CAM5.1 atmospheric model wind fields were nudged toward the ERA Interim reanalysis, leading to a more realistic atmospheric state and a better representation of observed clouds and aerosols

➢ In these hindcasts, the atmospheric and land states remain closer to "reality" than in a *free-running* AMIP experiment, thus exposing *systematic errors* that otherwise might be obscured by the *model drift*

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Evaluation Method

Use DOE Atmospheric Radiation Measurement (ARM) field data at the Southern Great Plains Central Facility (SGP-CF) near Lamont, Oklahoma:

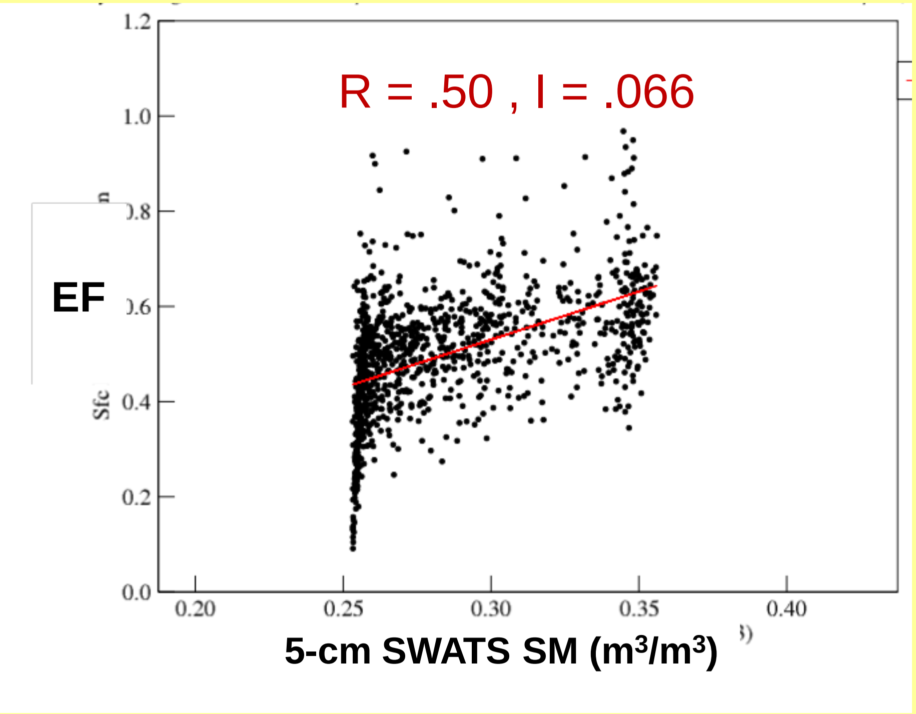
- To estimate observed coupling strength between land variables (e.g. Soil Moisture or Leaf Area Index) and surface atmospheric variables (e.g. EF, RH, T—the *"terrestrial leg"* of the coupling) on *daily* time scales during May-August of 2003-11

- To evaluate the ability of the Model to predict observed coupling strengths near the SGP-CF site *for the same time period*

> Then, try to infer apparent deficiencies in the relevant Model parameterizations or surface characteristics (e.g. Leaf Area Index) that might be responsible for the perceived systematic errors in the Model couplings at SGP-CF

Metrics of land-atmosphere coupling strength

- Assume that coupling strength is proportional to the *co-variability* of the designated *land* and *atmospheric* variables
- Construct *daily averages* of these variables, and *plot their scatter*
- Example: Evaporative Fraction (EF) vs 5-cm 'SWATS' Soil Moisture



Evaporative Fraction

EF = LH / (LH + SH)

<u>Metrics of Coupling Strength</u>

Correlation Coefficient

R = $< x' y' > / (\sigma_x \sigma_y)$

"Sensitivity Index" (Dirmeyer 2011)

I = $\boldsymbol{\beta \sigma_x}$ **,** where β is the slope of the regression-line.

I takes on the units of variable **y**

Caveats

- The ARM OBS are available over a relatively short time period (2003-2011), and there are many missing data samples. Instrument errors also impact these measurements.

- We therefore can't expect to estimate observed coupling statistics very accurately (Findell et al., 2015 *JHM*)

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3 Observations of *shallow-depth* soil moisture at SGP-CF

We use 3 independent measurements of shallow-depth soil moisture at SGP-CF in order to *roughly* estimate the inherent uncertainties in observed coupling strength:

- ‘SWATS’ SM: ~ 1100 daily samples at 5-cm (and at several lower depths)
- ‘CO2FLX’ SM: ~ 900 daily samples at 5-cm depth (and at one lower depth)
- ‘EBBR’ SM: ~ 800 daily samples at 2.5-cm depth *only*

> SWATS has a nearly complete temporal record (few missing samples), but does not reliably record very dry and wet SM values, in contrast to the CO2FLX and EBBR data sets.

Coupling of shallow-depth SM with surface evaporative fraction EF at SGP-CF

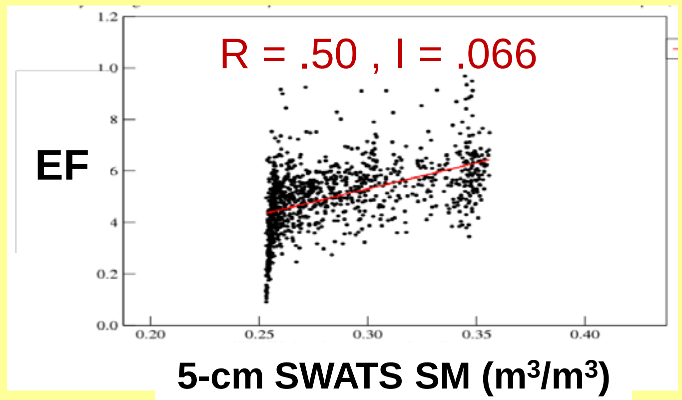
Estimates of coupling strength using SWATS, CO2FLX, and EBBR SM data sets versus EF from ARM observations of latent and sensible surface fluxes LH and SH:

Ranges

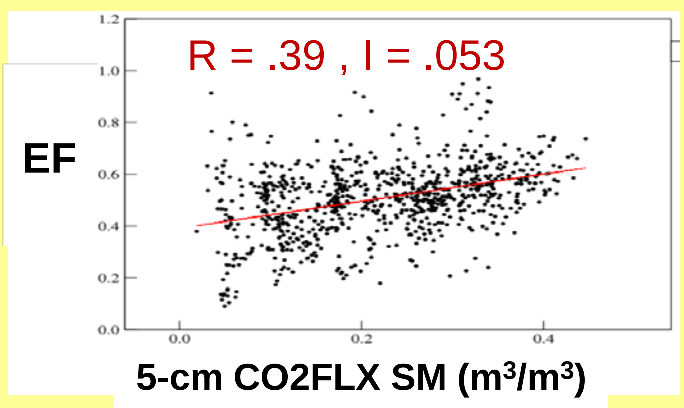
R = .34 to .50

I = .039 to .066

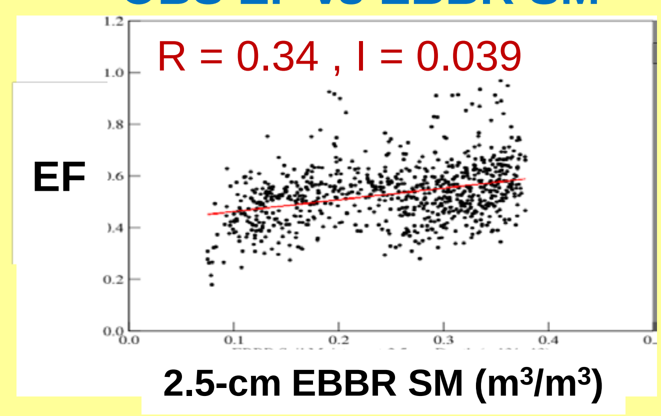
OBS EF vs SWATS SM



OBS EF vs CO2FLX SM

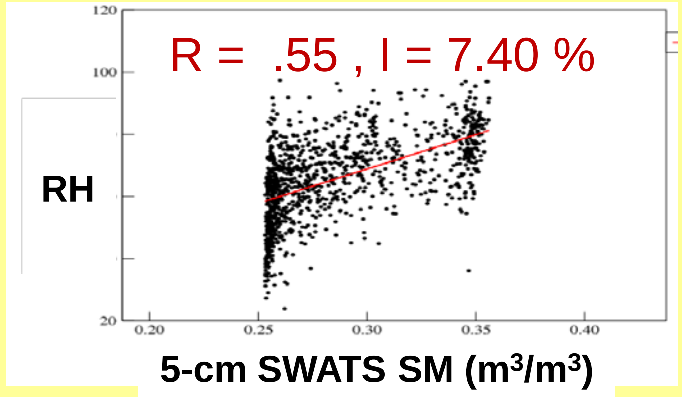


OBS EF vs EBBR SM



Coupling of shallow-depth SM with ARM-observed surface relative humidity RH at SGP-CF

OBS RH vs SWATS SM

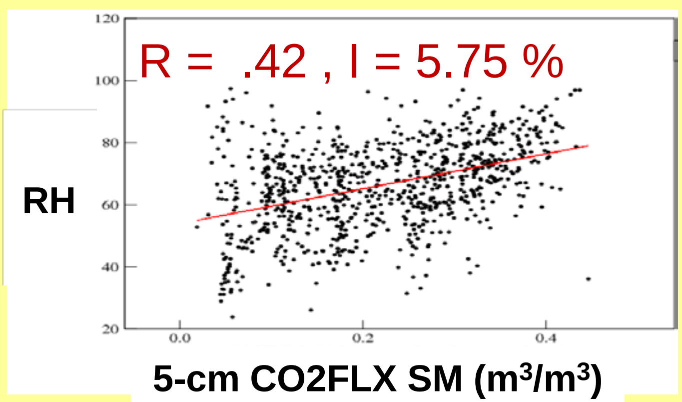


<u>Ranges</u>

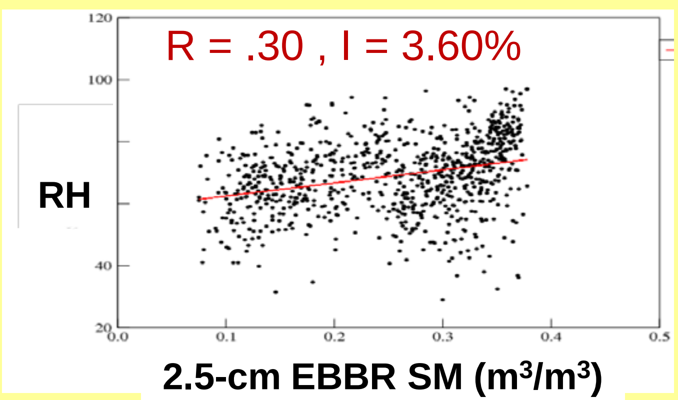
R = .30 to .55

I = 3.60 to 7.40 %

OBS RH vs CO2FLX SM



OBS RH vs EBBR SM



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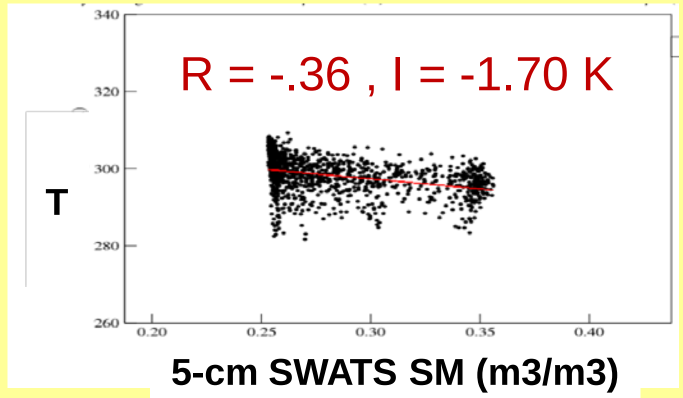
Coupling of shallow-depth SM with ARM-observed surface air temperature T at SGP-CF

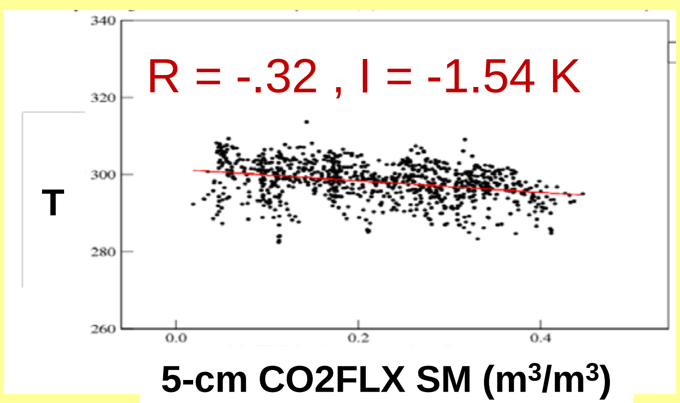
OBS T vs SWATS SM



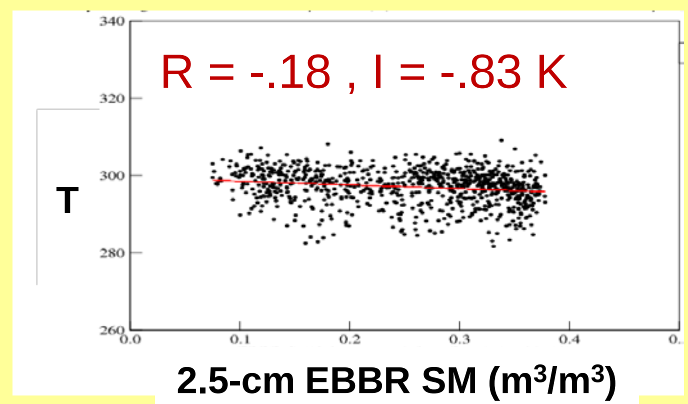
Ranges

R = -.18 to -.36
I = -.83 to -1.70 K

OBS T vs CO2FLX SM



OBS T vs EBBR SM



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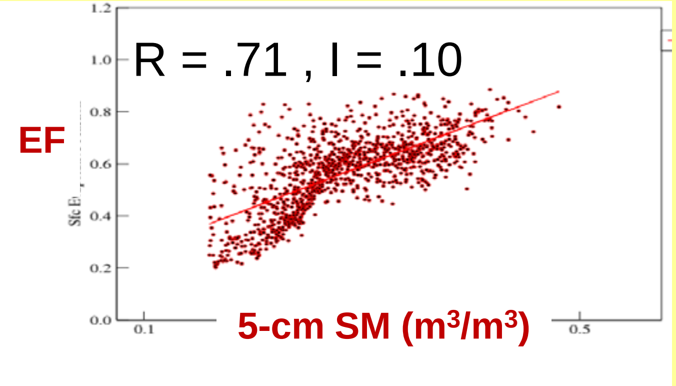
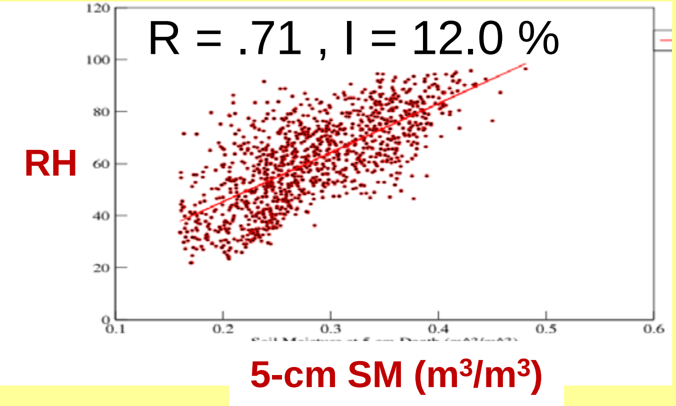
Coupling of Model 5-cm SM with surface EF, RH, and T near SGP-CF

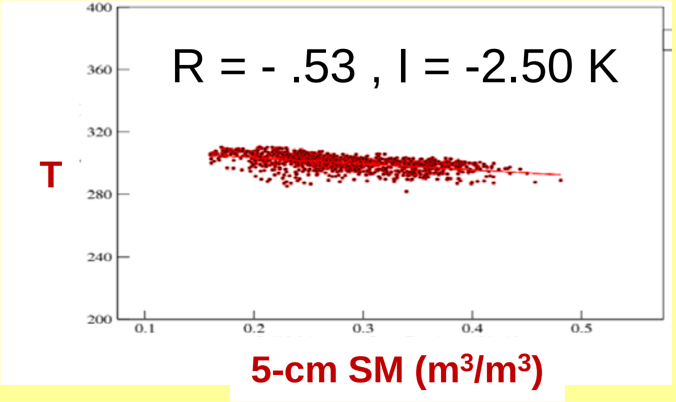
Model EF vs SM



Model RH vs SM



Model T vs SM



Coupling strengths of shallow-depth SM with EF, RH, and T: Model vs OBS

OBS Coupling Ranges	
EF	R = .30 to .50
	I = .04 to .07
RH	R = .30 to .55
	I = 3.60 to 7.40 %
T	R = -0.18 to -0.36
	I = -.83 to -1.7 K

Model Couplings	
EF	**R = .71**
	I = .10
RH	**R = .71**
	I = 12.0 %
T	**R = -.53**
	I = -2.50 K

Red denotes Model couplings stronger than observed

→Coupling of Model EF, RH, and T with SM are *all stronger than OBS*.

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Another Caveat

- Our observations also are only at a *single point*—the SGP Central Facility. We can analyze Model outputs at a grid point very near SGP-CF, but these actually *represent a gridbox (~1x1-degree) average—scale mismatch may be an issue.*

> The presented results thus should be regarded as *preliminary*

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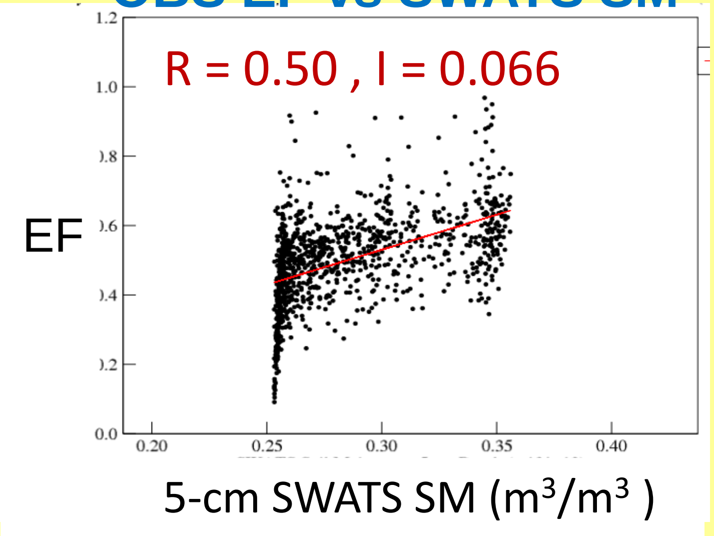
EF coupling with Leaf Area Index (LAI)

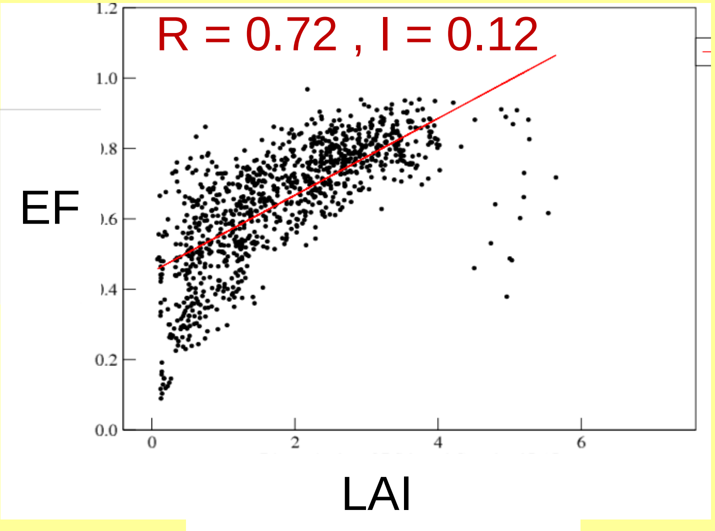
Observed coupling of LAI with EF

- The coupling of EF with observed estimates of *daylight-average* LAI is stronger than its coupling with soil moisture at SGP-CF (Williams and Torn, 2015 *GRL*):

OBS EF vs SWATS SM



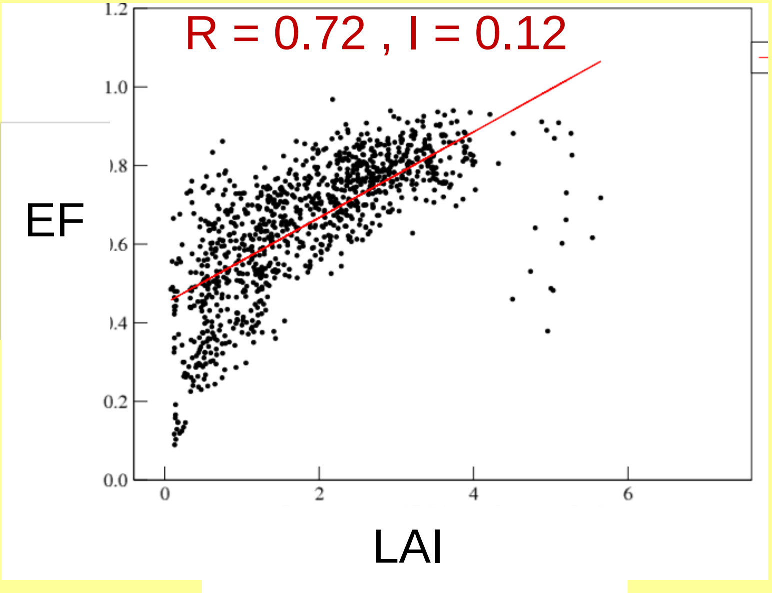
OBS EF vs LAI



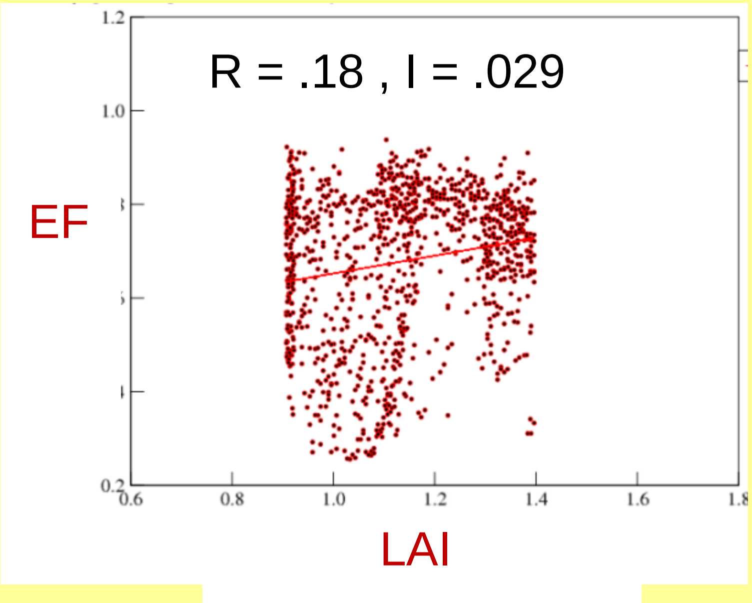
Coupling of Model LAI with EF, RH, and T

Model LAI couples much too weakly with EF:

OBS EF vs LAI

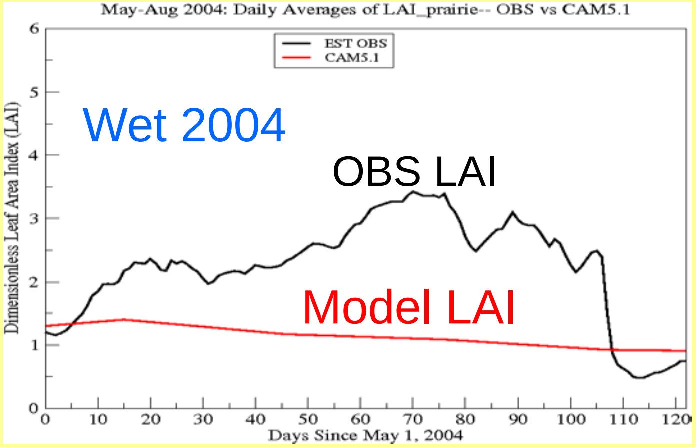


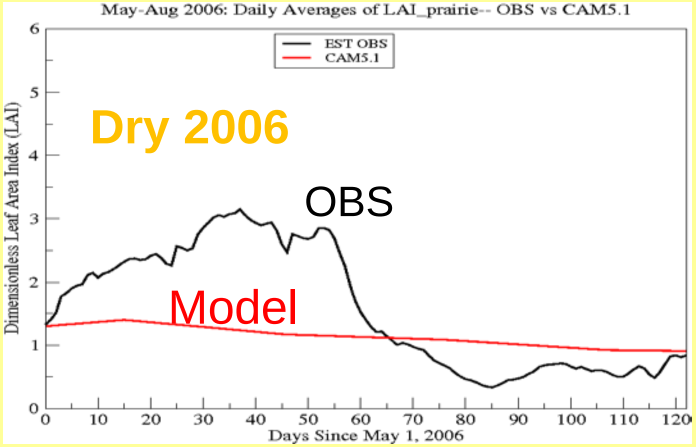
Model EF vs LAI

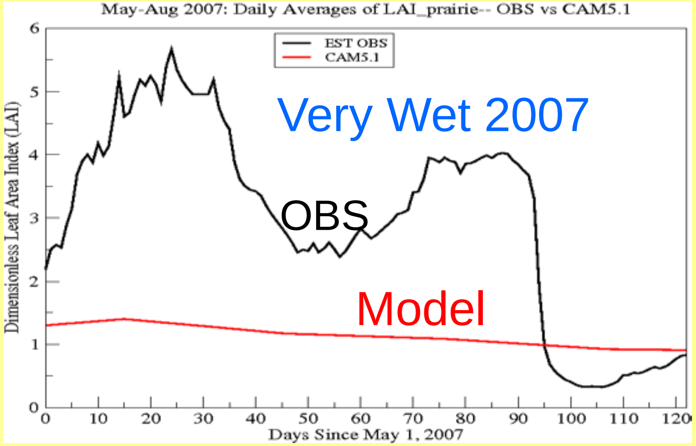


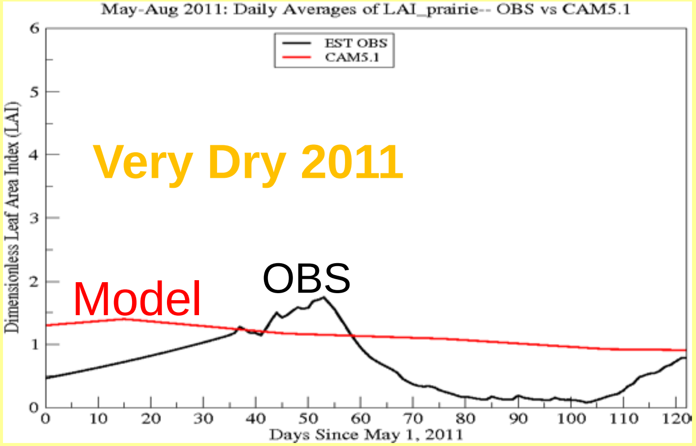
CLM4 prescribed LAI versus OBS-estimated: Selected summers at SGP CF

The weak coupling strength appears to be related to low inter-annual and intra-seasonal variability of the Model's *prescribed* LAI (**again, *however, scaling mis-match may be an issue here***):



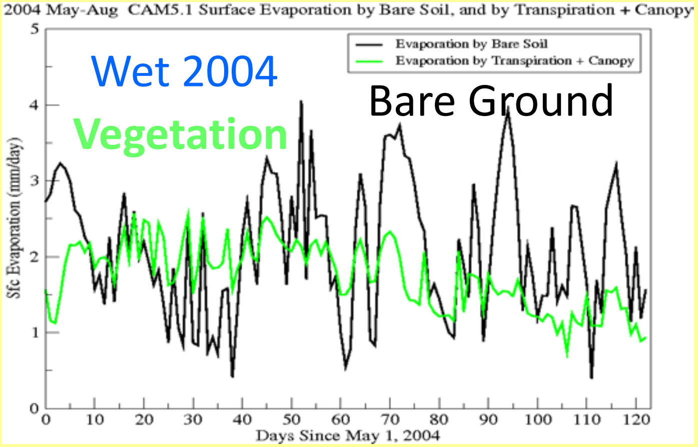


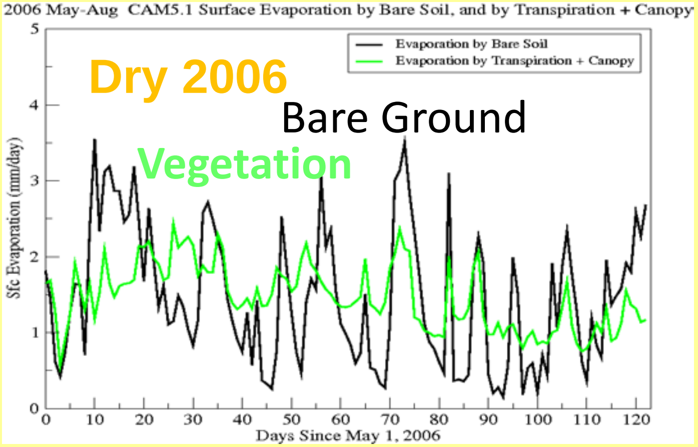


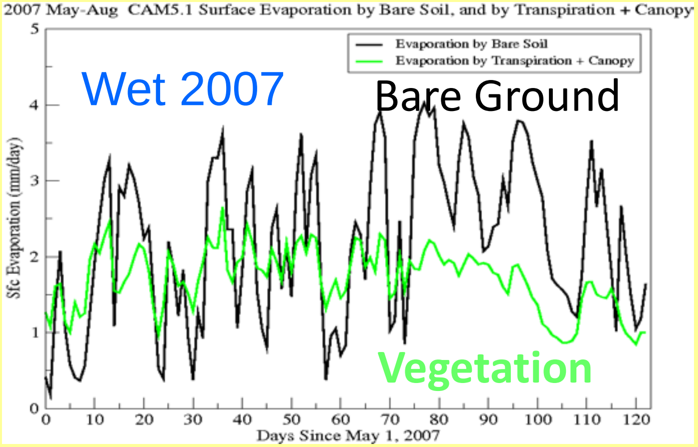


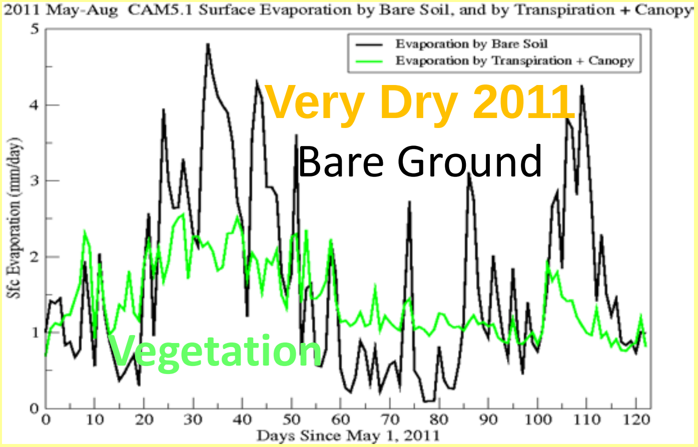
CAM5.1/CLM4 partitioning of surface evaporation into bare-ground versus vegetation components at SGP-CF

In the Model, the **bare-ground flux of moisture** contributes more to the overall variability of surface evaporation than does the flux from the vegetation :









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Summary of Preliminary Results

In the CAM5.1/CLM4 hindcasts at the SGP-CF site:

- The Model's couplings of shallow-depth soil moisture with EF, RH, and T are *substantially stronger than the OBS estimates.*

- However, the corresponding coupling of Model LAI with EF is *much weaker than the OBS-estimated coupling*, apparently a result of insufficient inter-annual and intra-seasonal variability in the prescribed Model LAI.

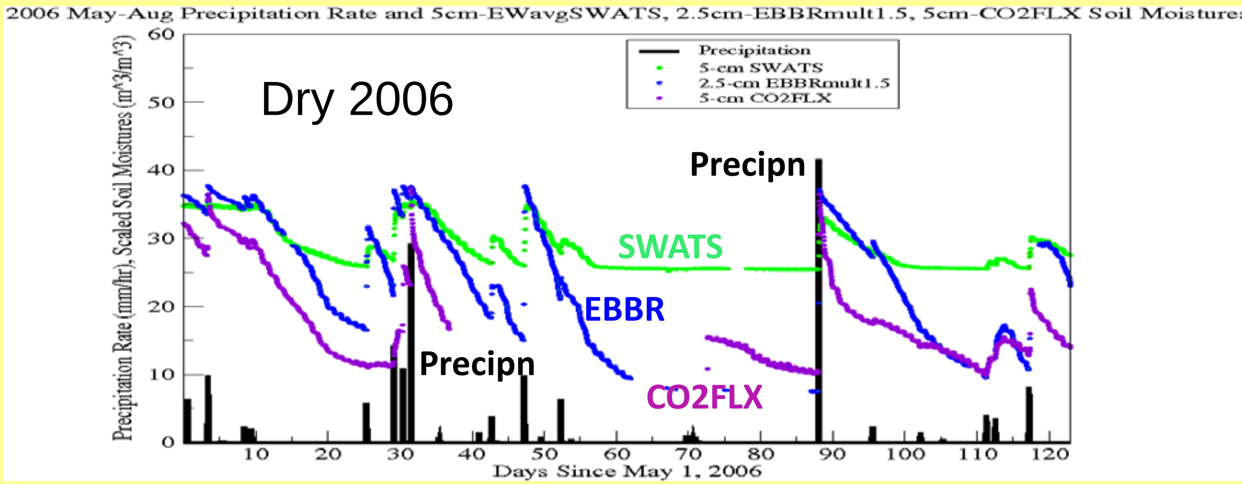
- These results also imply that too much of the Model's variability in surface evaporation is from bare-ground evaporation, and not enough from vegetation (transpiration + canopy evaporation).

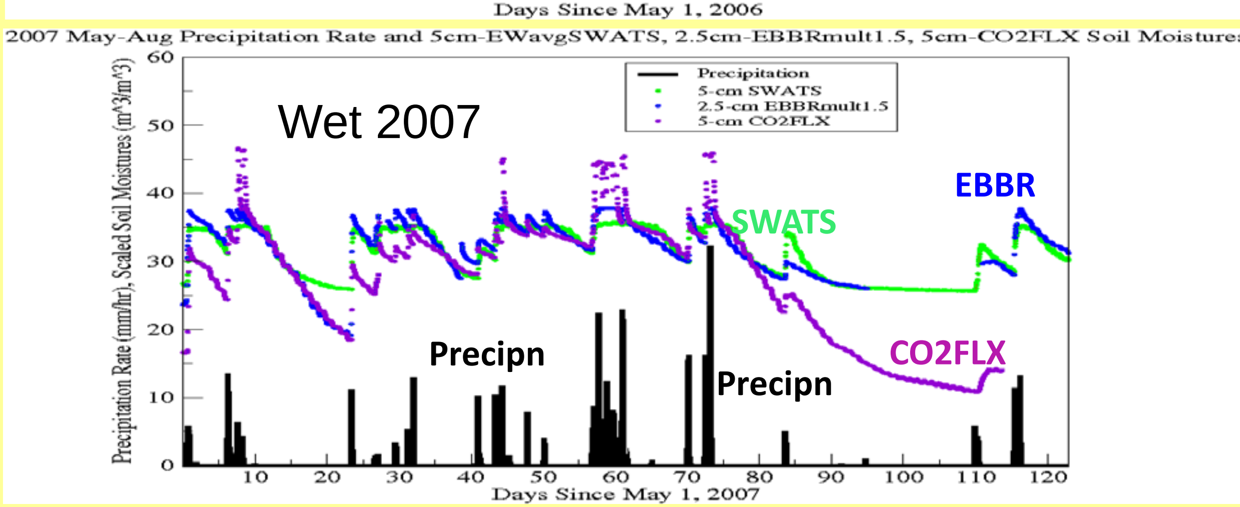
> We will need to revisit these results as more quality-controlled data become available from the *entire SGP region (*e.g. from the upcoming ARM Cross-Scale Land-Atmosphere Experiment).

End

3 independent measurements of shallow (2.5-5.0 cm depth) soil moisture (scaled 100 x m^3/m^3at SGP CF)

Time series of ‘SWATS’, ‘EBBR’, and ‘CO2FLX’ in dry year 2006 versus wet 2007:





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Available soil moisture data sets at SGP CF

- At the SGP Central Facility, 3 observational soil moisture data sets are available for comparison *at shallow depths* in the years 2003-2011:

  > Soil Water and Temperature System (SWATS) soil moisture at 5-cm depth
  inferred from soil-water potential, estimated from sensor DT/Dt heating pulse

  > Carbon Flux (CO2FLX) soil moisture at 5-cm depth
  inferred from dielectric constant of soil, estimated by sensor probes

  > Energy Balance Bowen Ratio (EBBR) soil moisture at 2.5-cm depth
  inferred from electrical ‘resistance-type’ sensor probes

  >

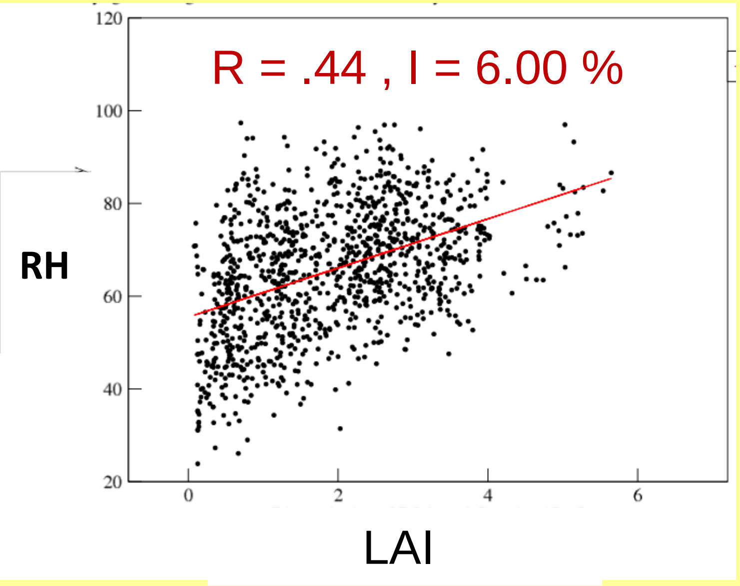
Leaf area index--LAI

- LAI is a non-dimensional measure of vegetation area relative to bare ground. It can be estimated from *visible* versus *near-IR* surface radiances observed at SGP-CF (see Williams and Torn, 2015 *GRL*).
- In the Model, LAI affects *that part of surface evaporation associated with vegetation* (in addition to the surface albedo and emissivity)
- In the CLM4, the annual cycle of LAI is *climatologically prescribed* from 0.50-degree MODIS data (Peterson and Chase, 2007 *JGR*).

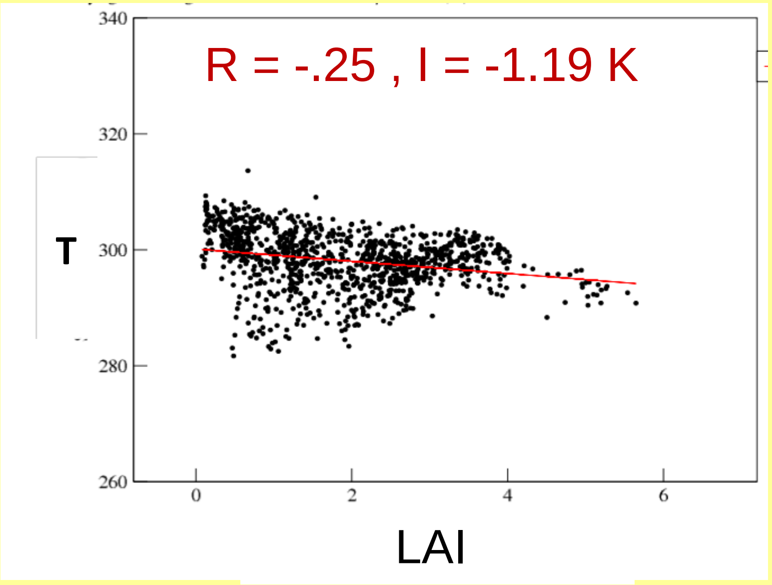
Observed coupling of *daylight averages* of LAI with surface RH and T at SGP-CF

However, the couplings of surface RH & T with LAI are *comparable in strength* to their couplings with shallow-depth SM:

OBS RH vs LAI



OBS T vs LAI



<u>OBS Range of RH Coupling with SM</u>

R = .30 to .55 , I = 3.60 to 7.40.

<u>OBS Range of T Coupling with SM</u>

R = -.18 to -.36 , I = -.83 to -1.70

Coupling of Model LAI with EF, RH, and T

Model LAI couples much too weakly with EF and RH, but too strongly with T :

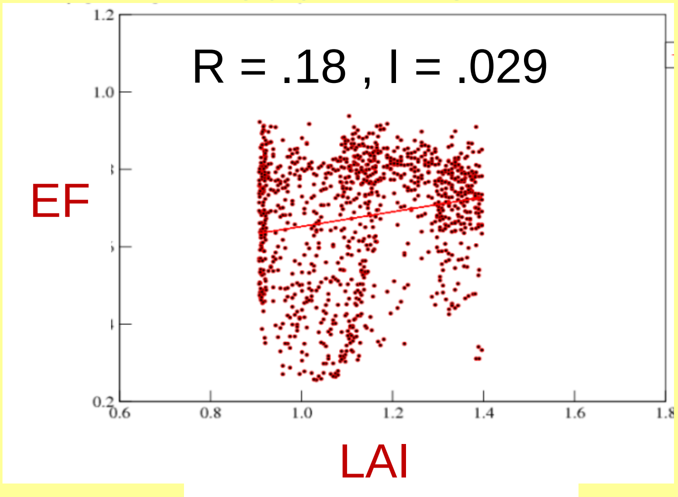
OBS-estimated Couplings

EF: R = .72 , I = .12

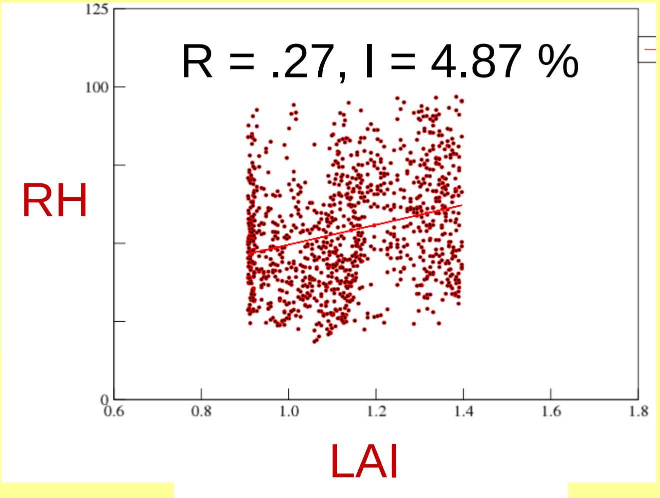
RH: R = .44 , I = 6.00 %

T: R = -.25, I = -1.19 K

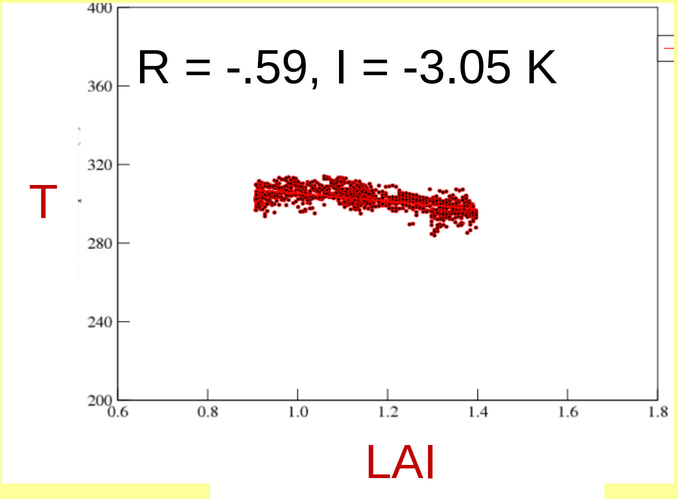
Model EF vs LAI



Model RH vs LAI

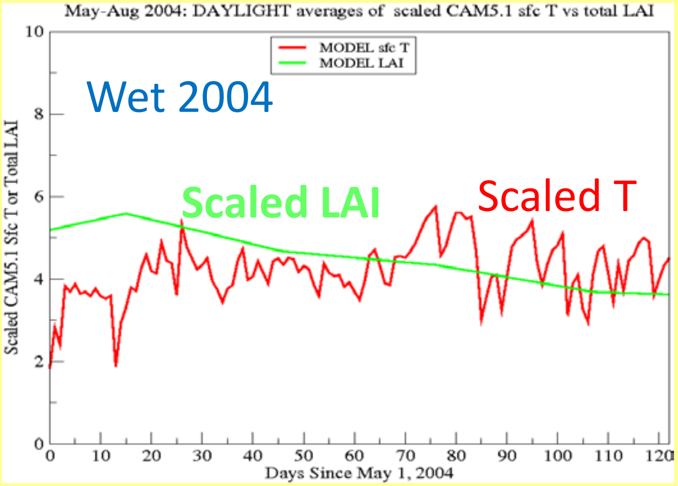


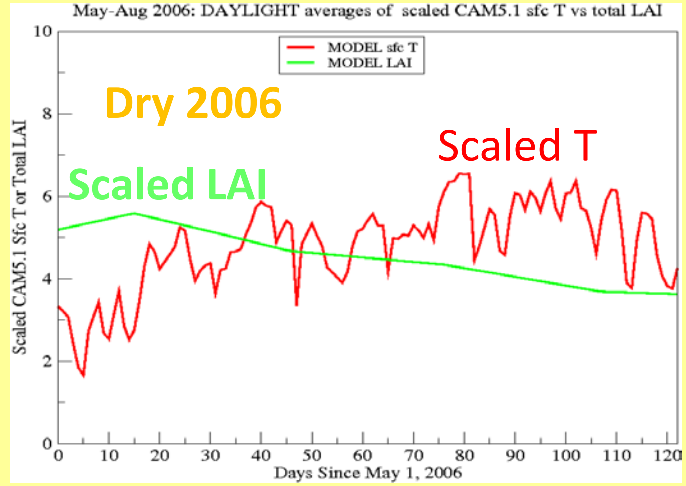
Model T vs LAI

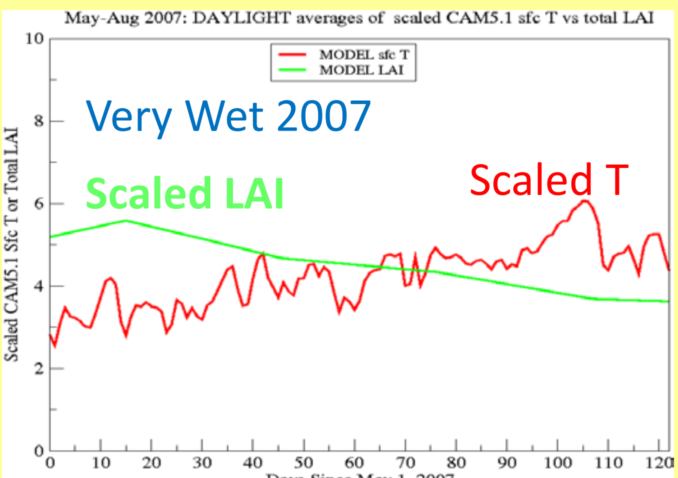


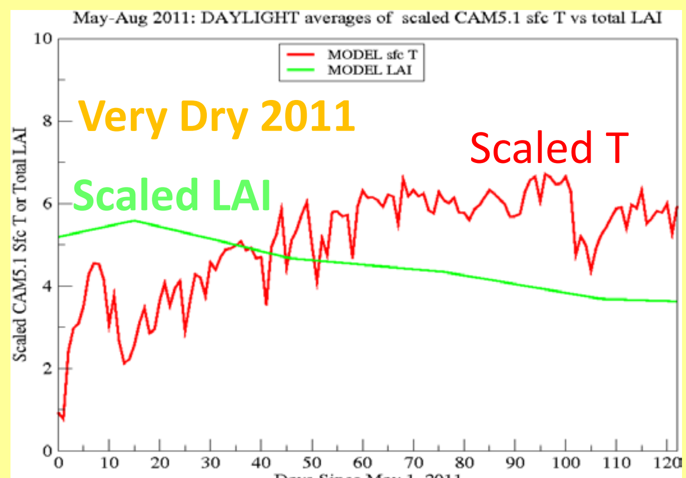
Model LAI vs T in Selected Summers

The too-strong coupling of Model LAI with T appears to be an artifact of the prescribed LAI which peaks early in summer when surface T is relatively low:









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