The Cusp of Progress in Climate Prediction from Land-Atmosphere Interactions

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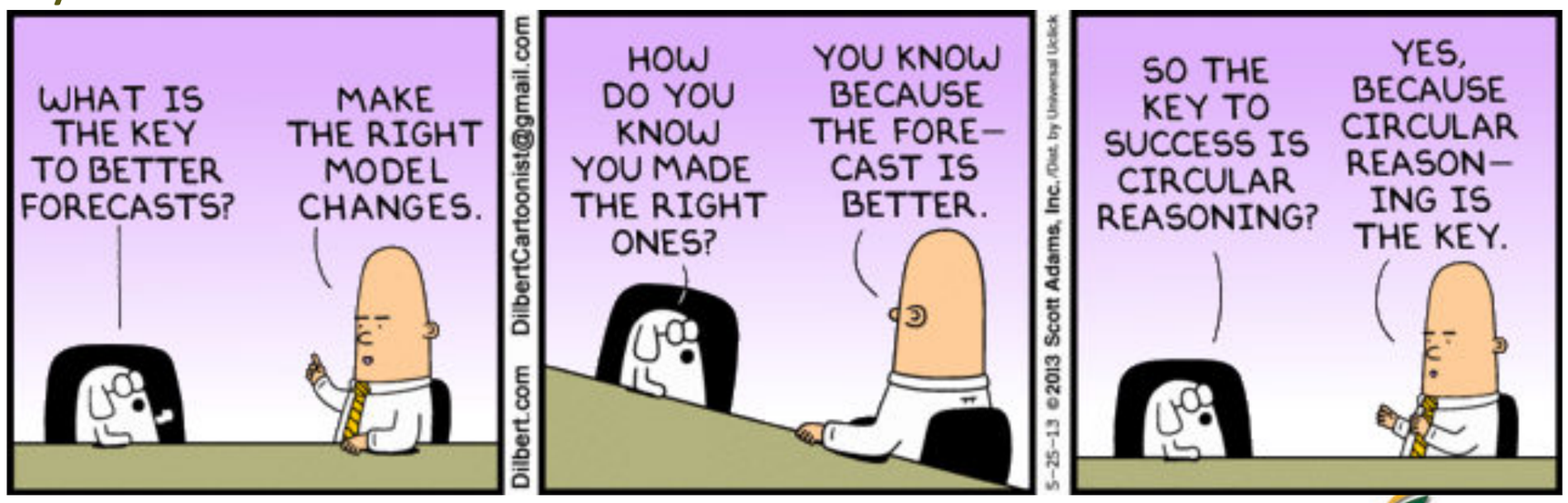
Fairfax, Virginia, USA



Predictability and Prediction

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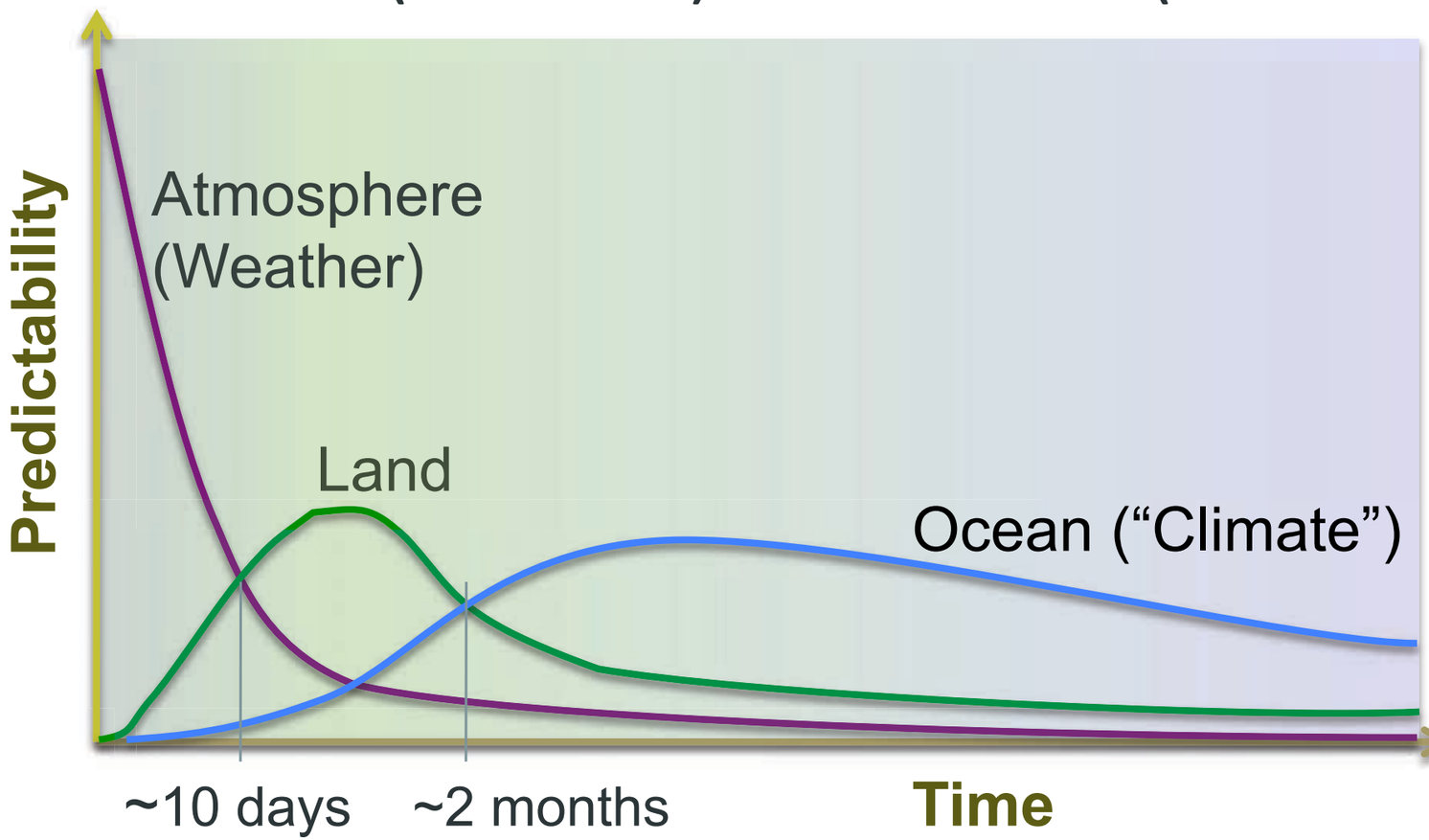

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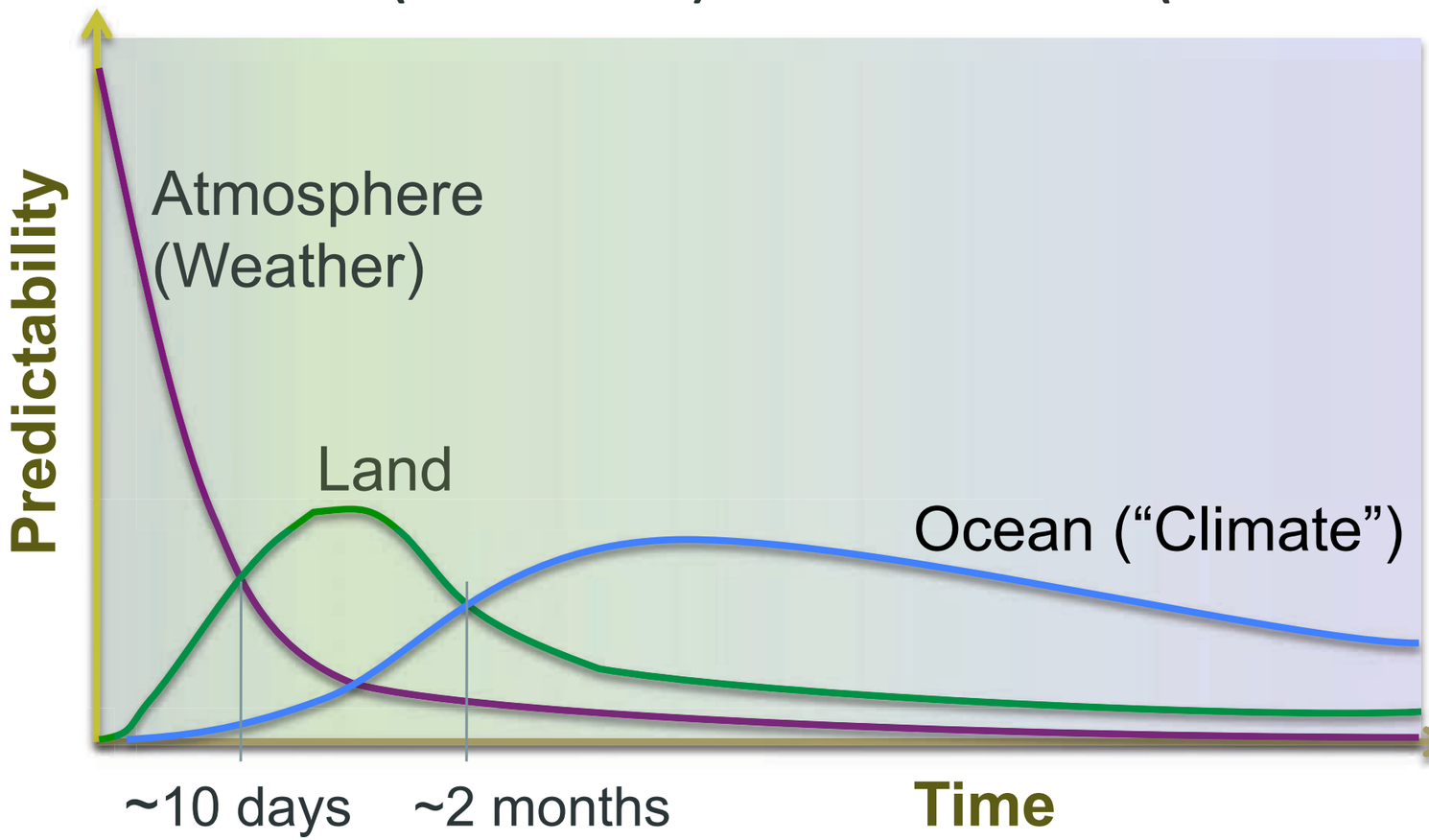

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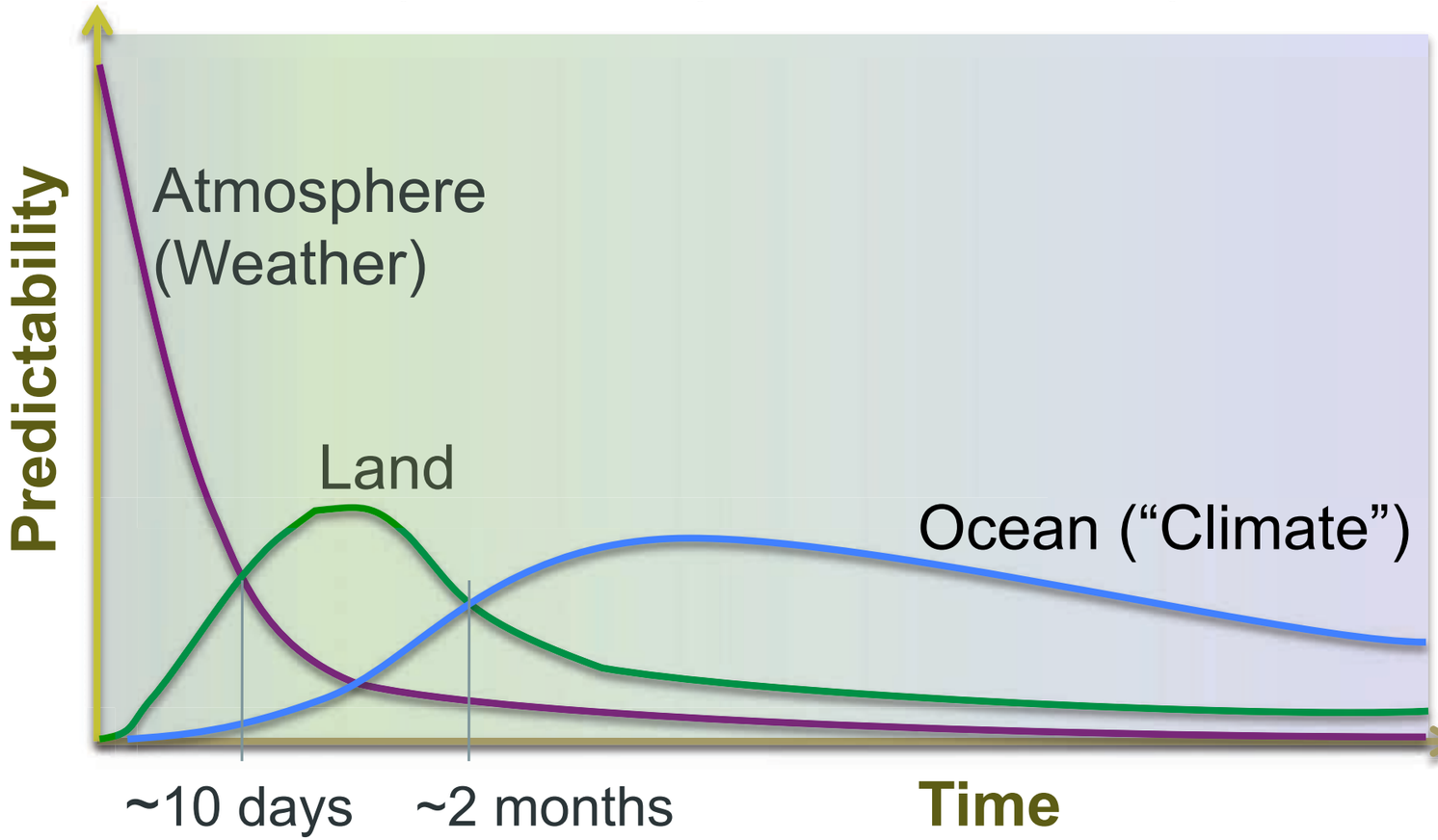

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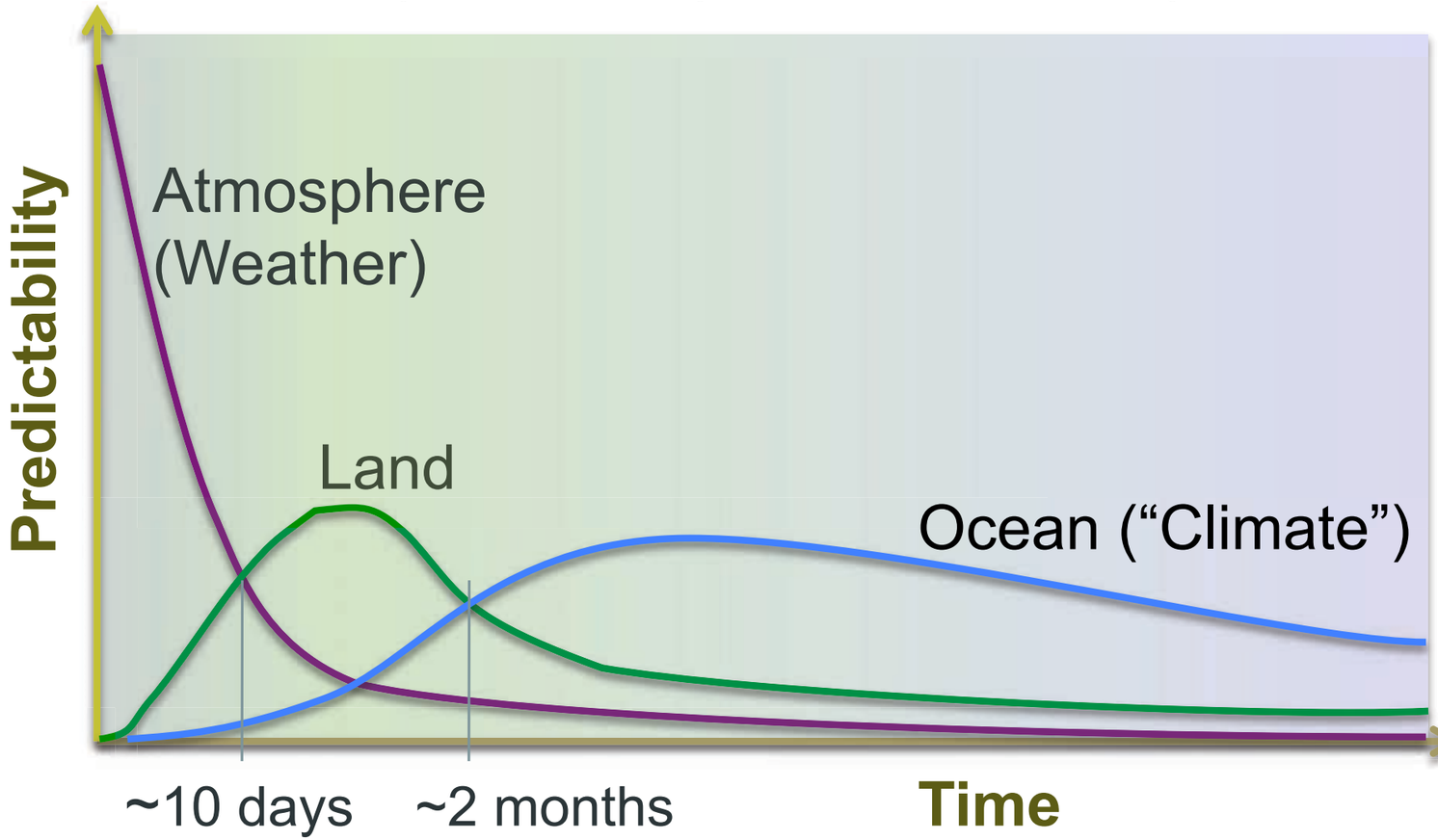

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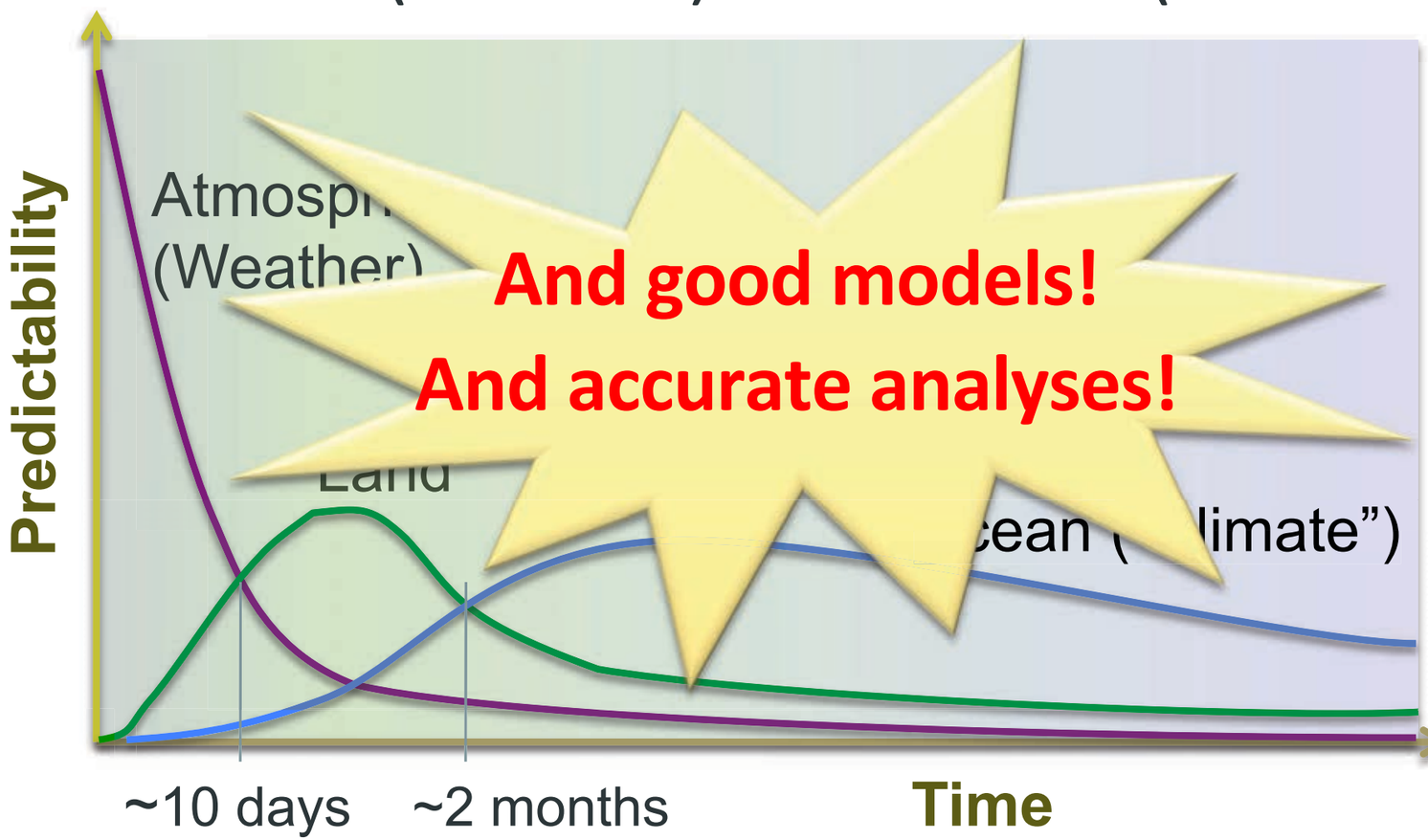

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Hotspots of Land-Atmosphere Coupling

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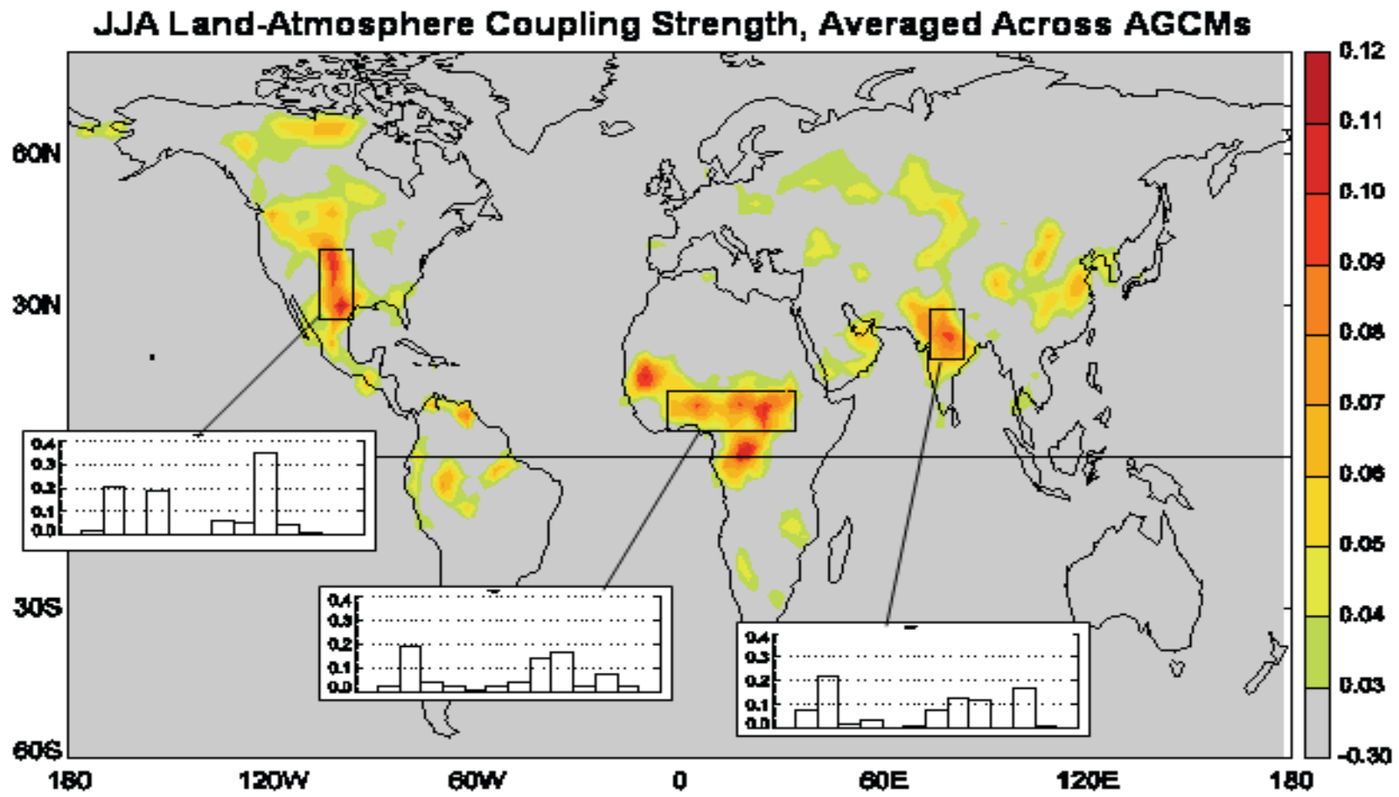

"Famous" figure from *Science* paper which became used (and over-used) to justify the role of the land surface in climate.

This includes *sensitivity* and *variability* but not *memory*!

Koster et al. (2004; *Science*)

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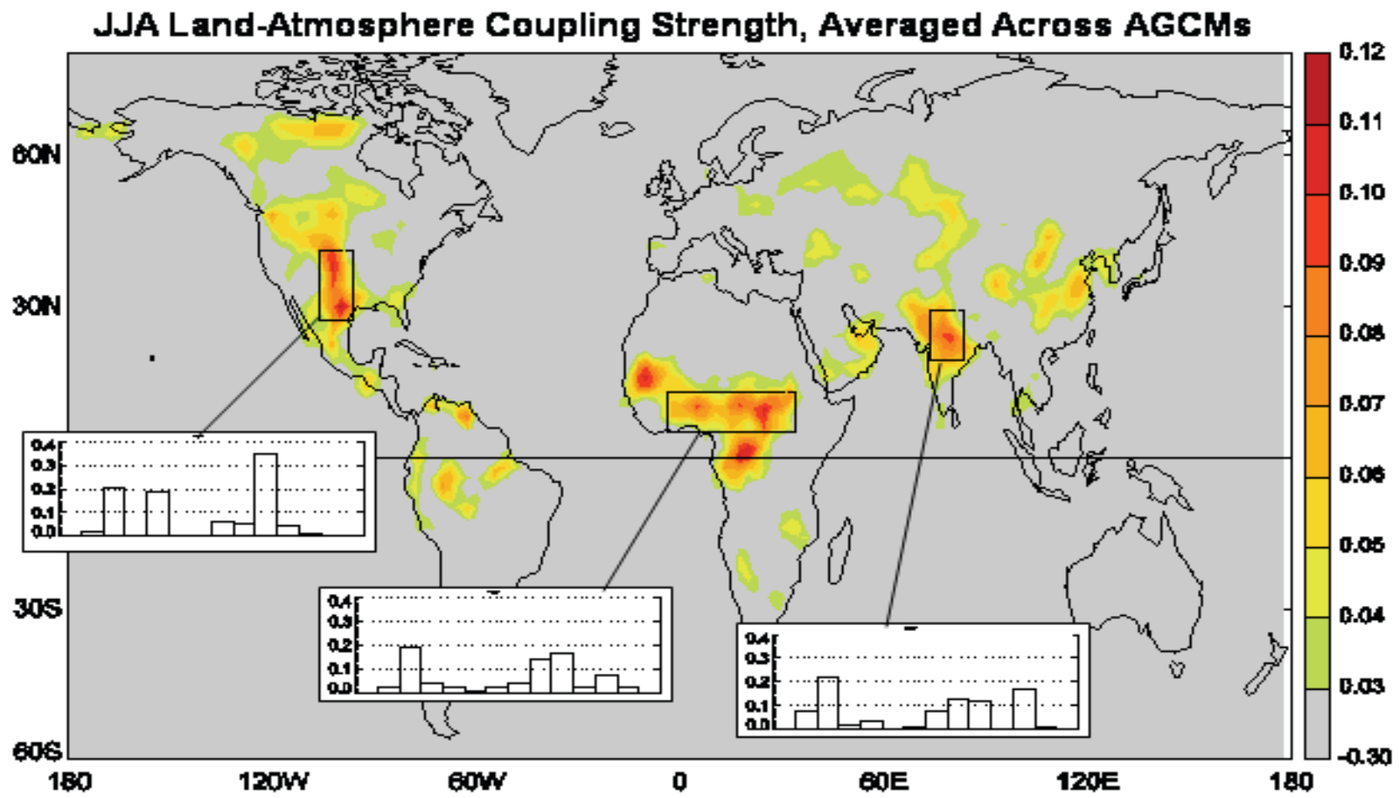
- These largely correspond to major agricultural areas!
- Thus, places of intense land management are also where atmosphere is most sensitive to the land state!



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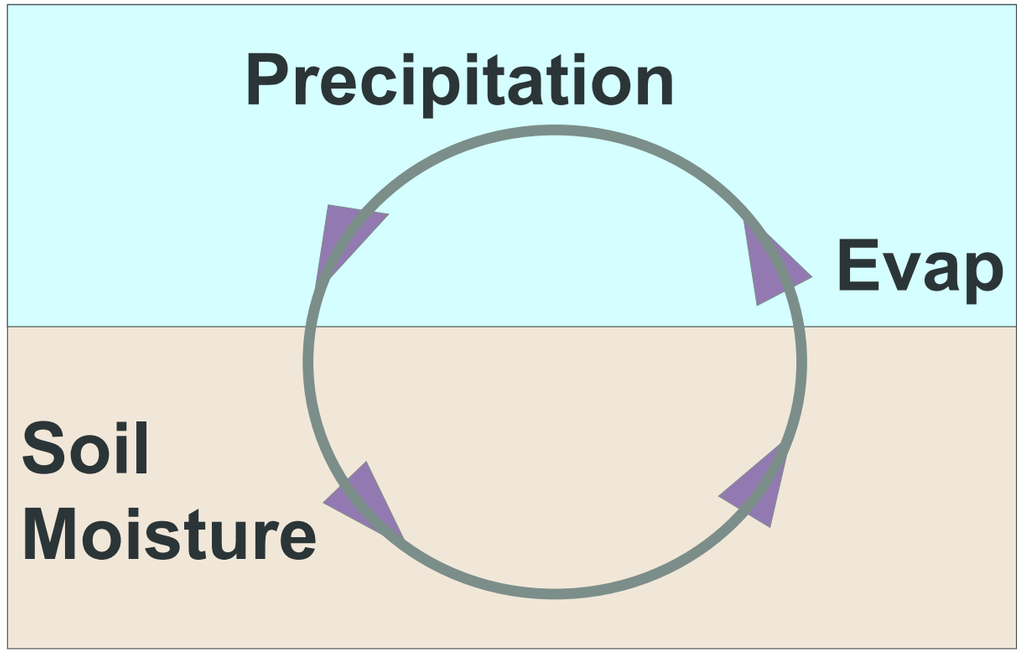

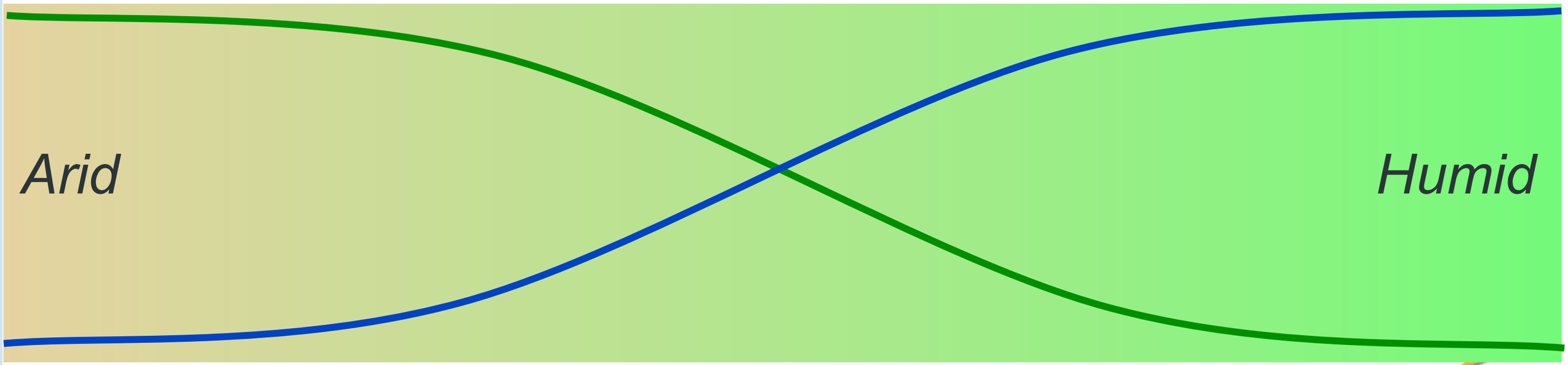

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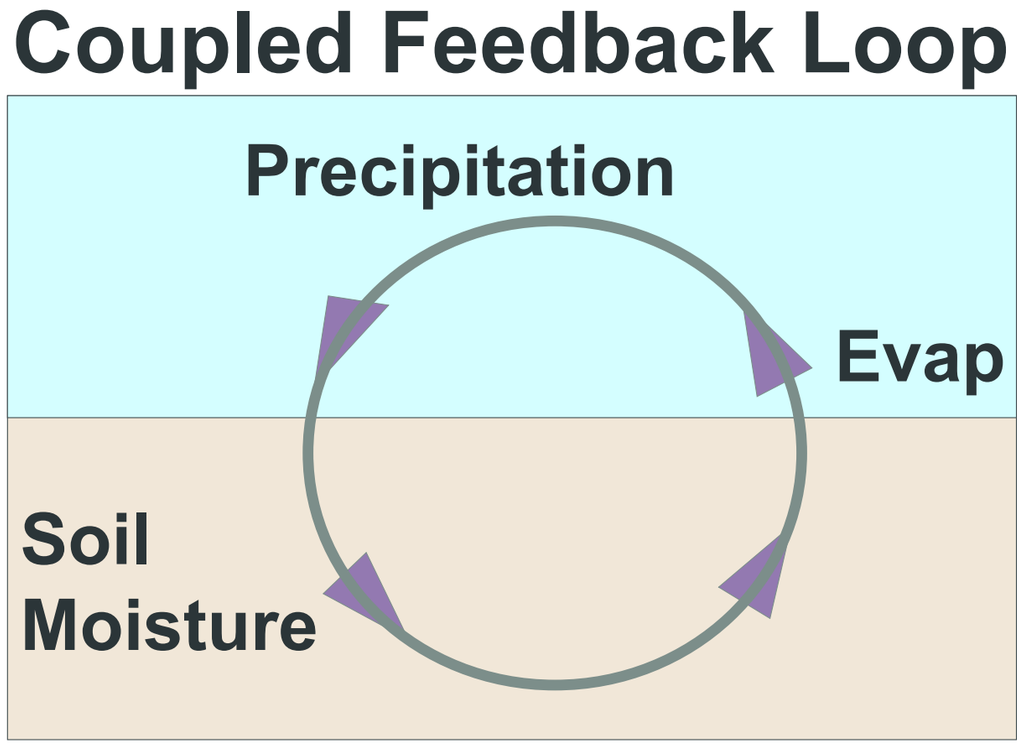
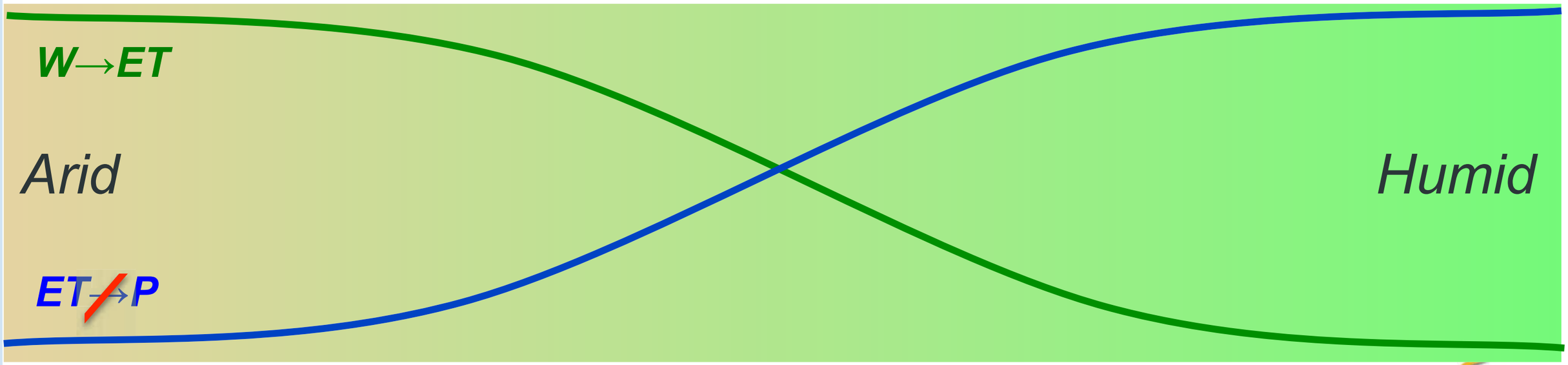
ET (mostly surface evaporation) is very sensitive to soil wetness variations, but the dry atmosphere is unresponsive to small inputs of water vapor.





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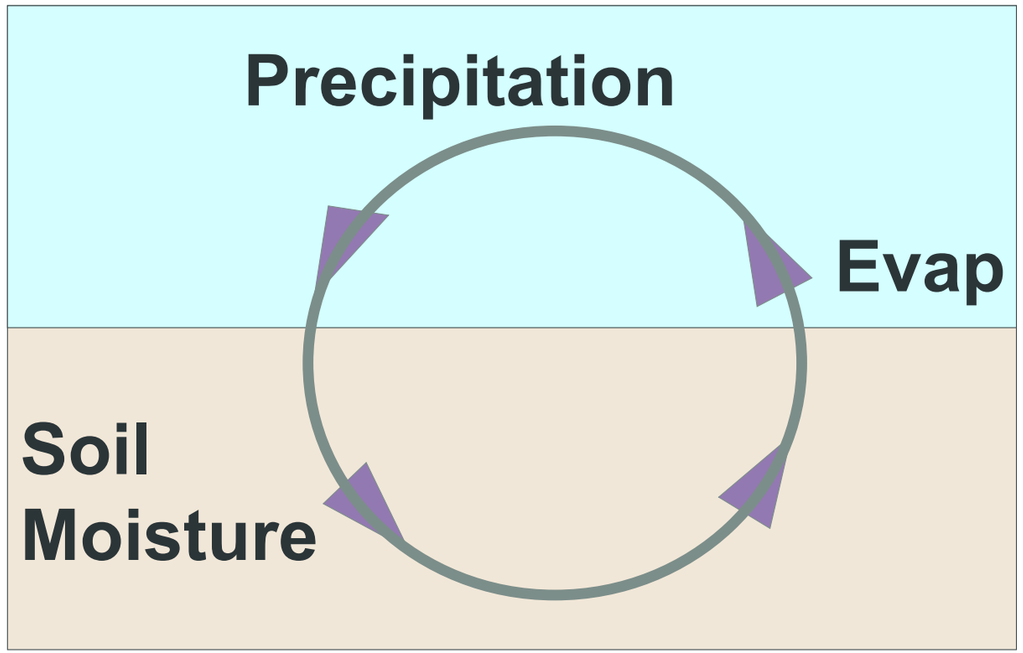

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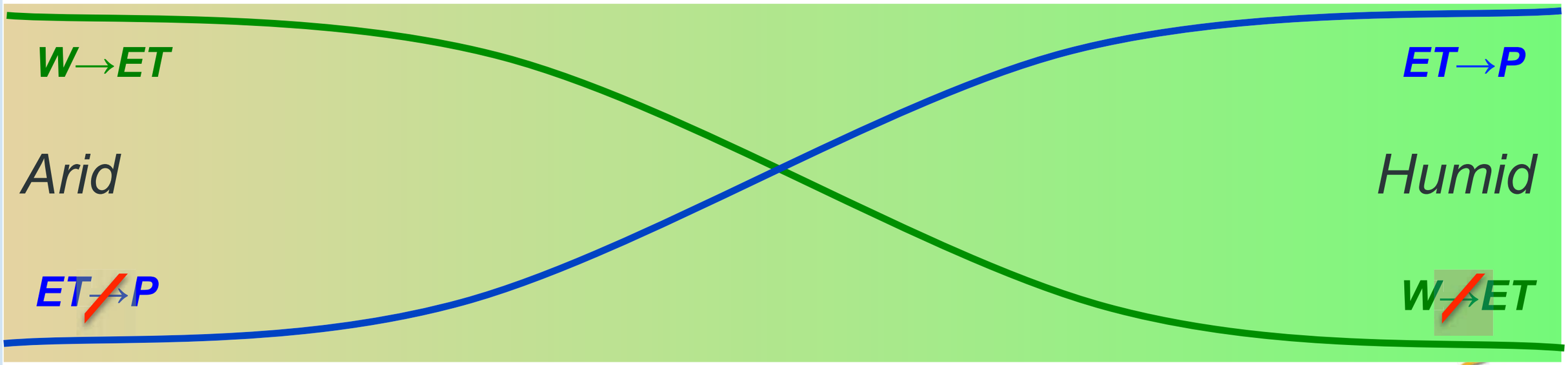
Small variations in evapo-ration affect the conditionally unstable atmosphere (easy to trigger clouds), but deep-rooted vegetation (transpiration) is not responsive to typical soil wetness variations.



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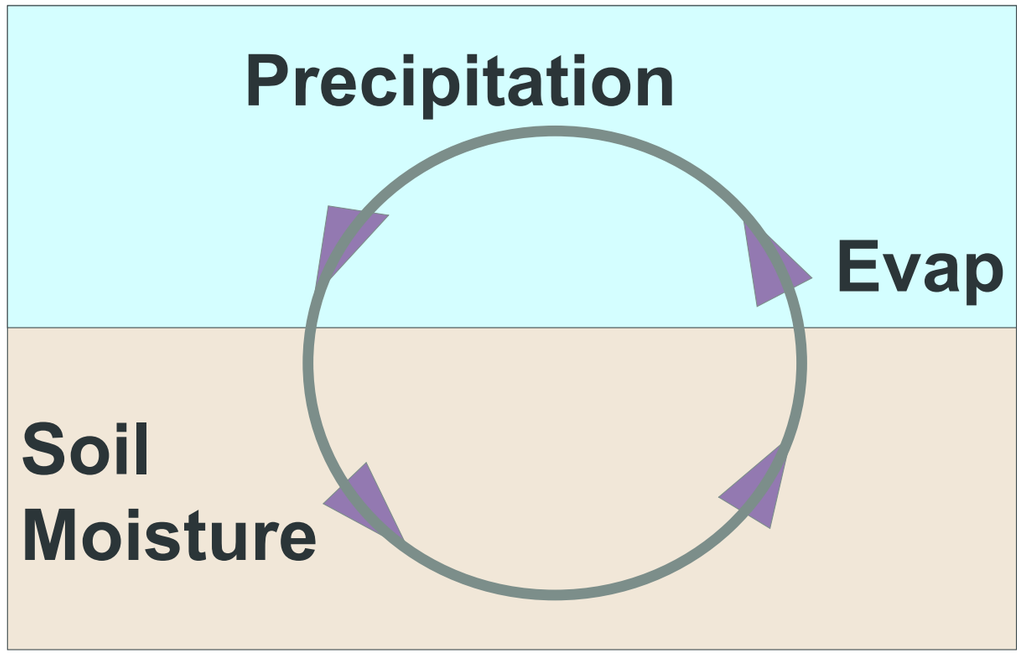

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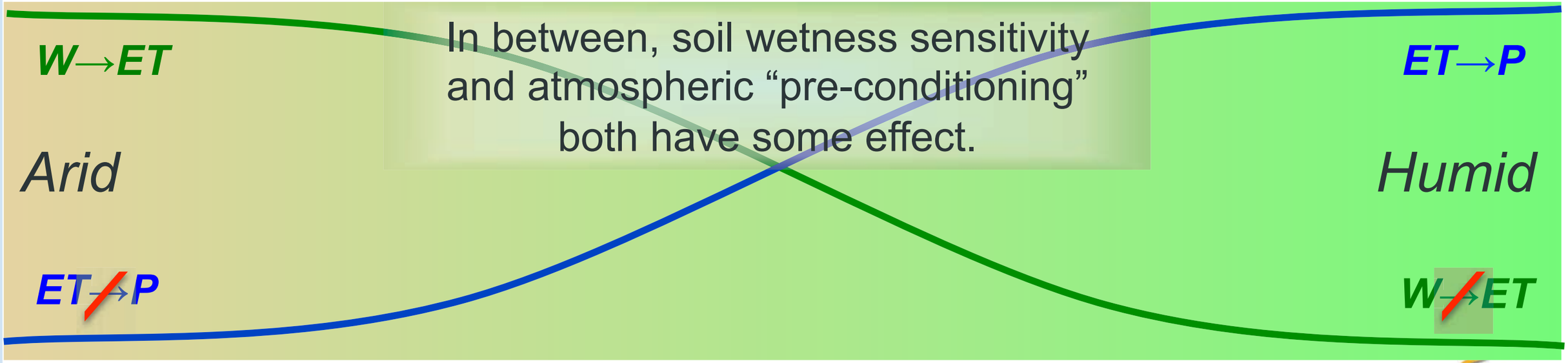

In between, soil wetness sensitivity and atmospheric "pre-conditioning" both have some effect.

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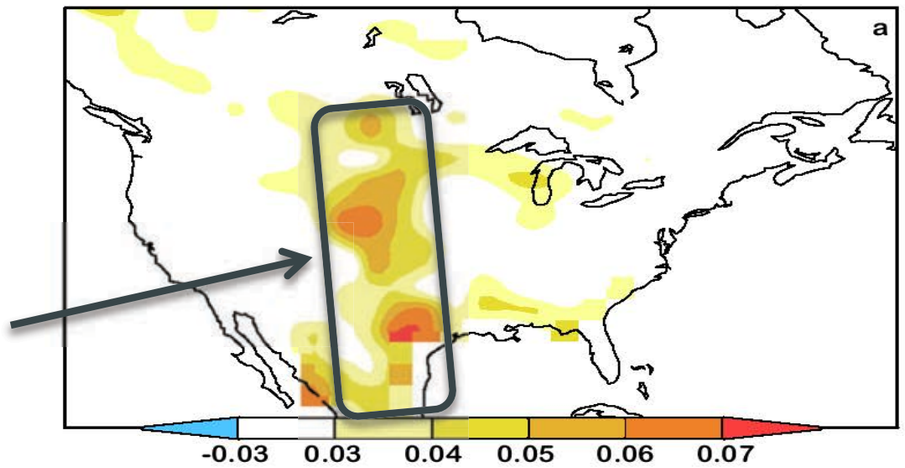

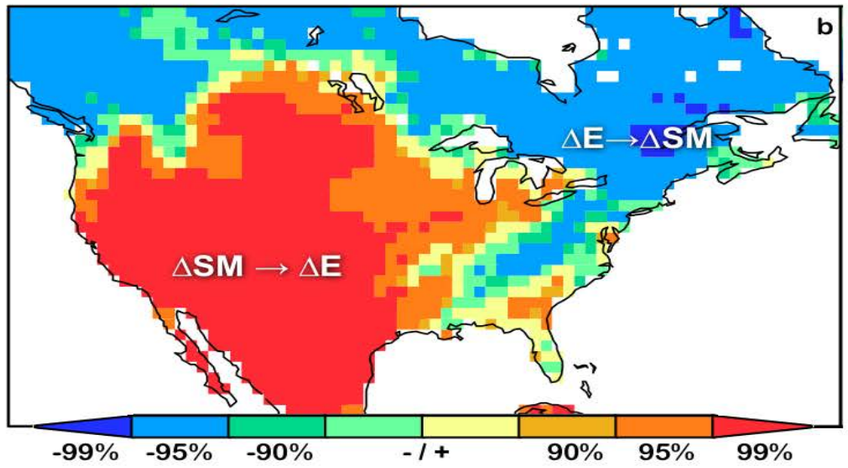

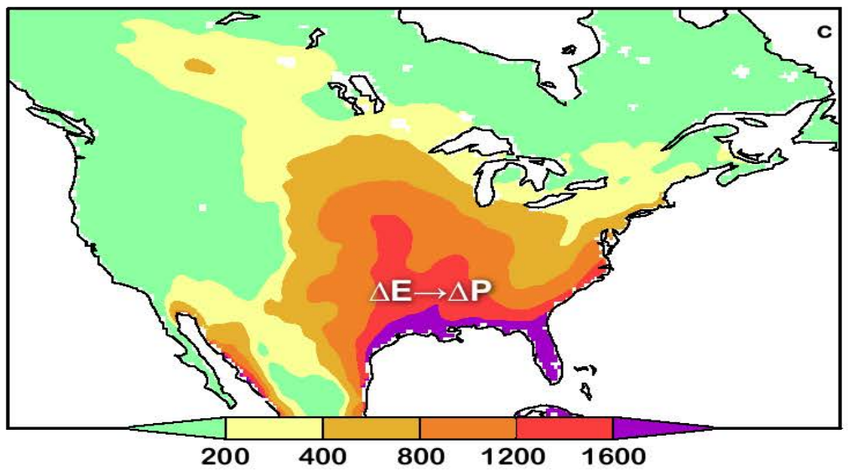

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Feedback path: Terrestrial leg Atmospheric leg

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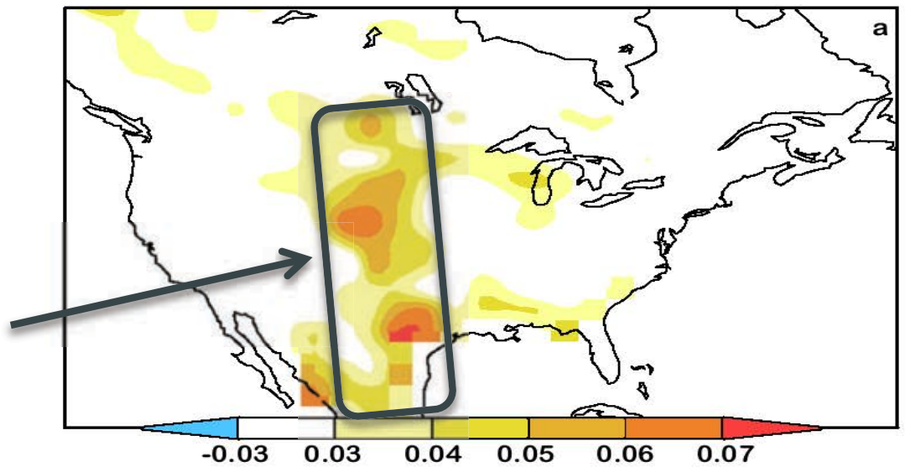

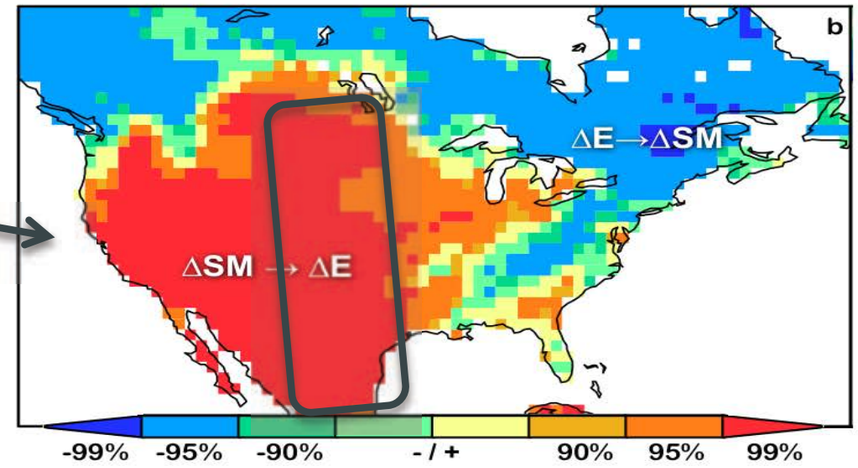

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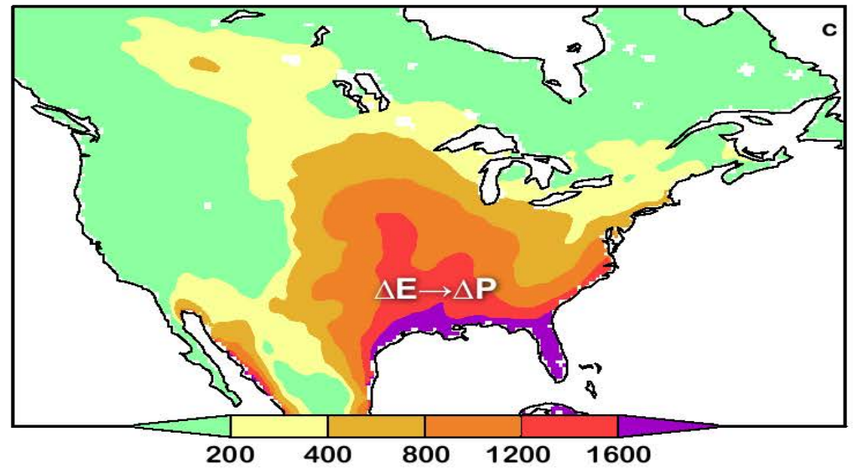

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- High CAPE [from the North American Regional Reanalysis, J/kg]

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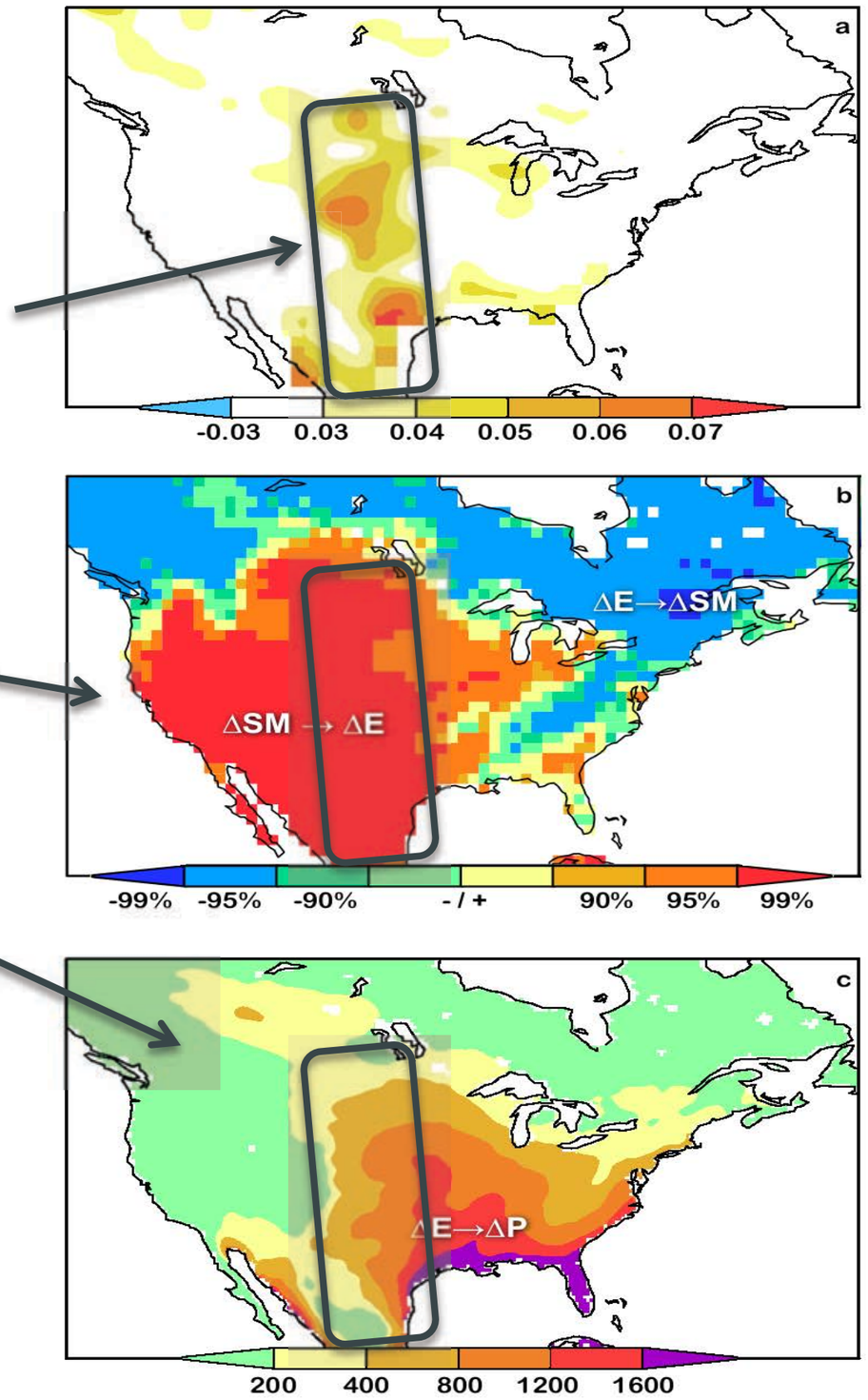

GLACE-2: A 12-Model Prediction Experiment

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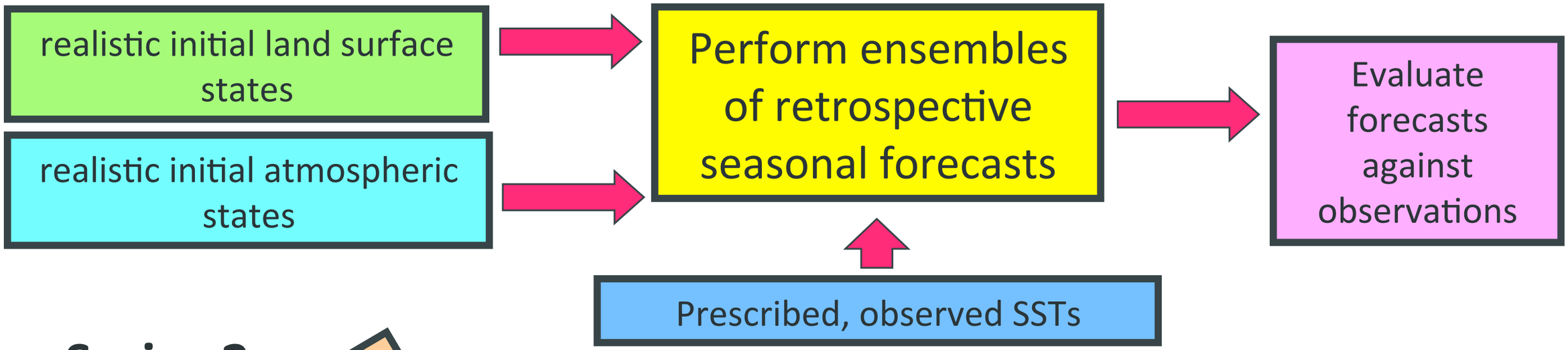

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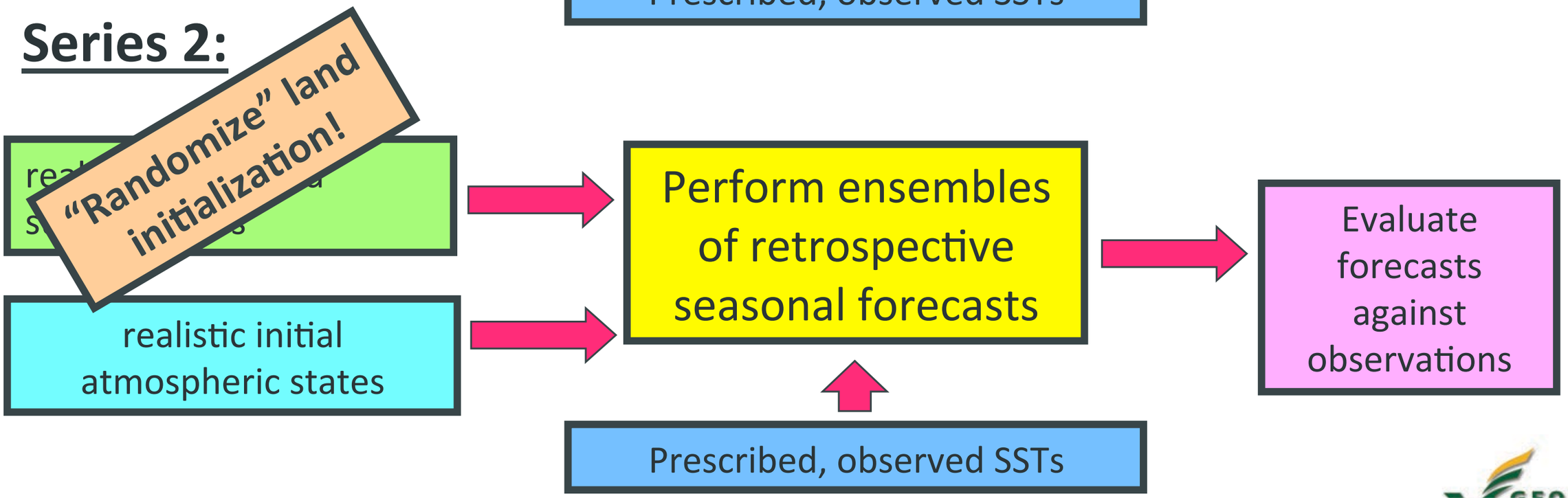

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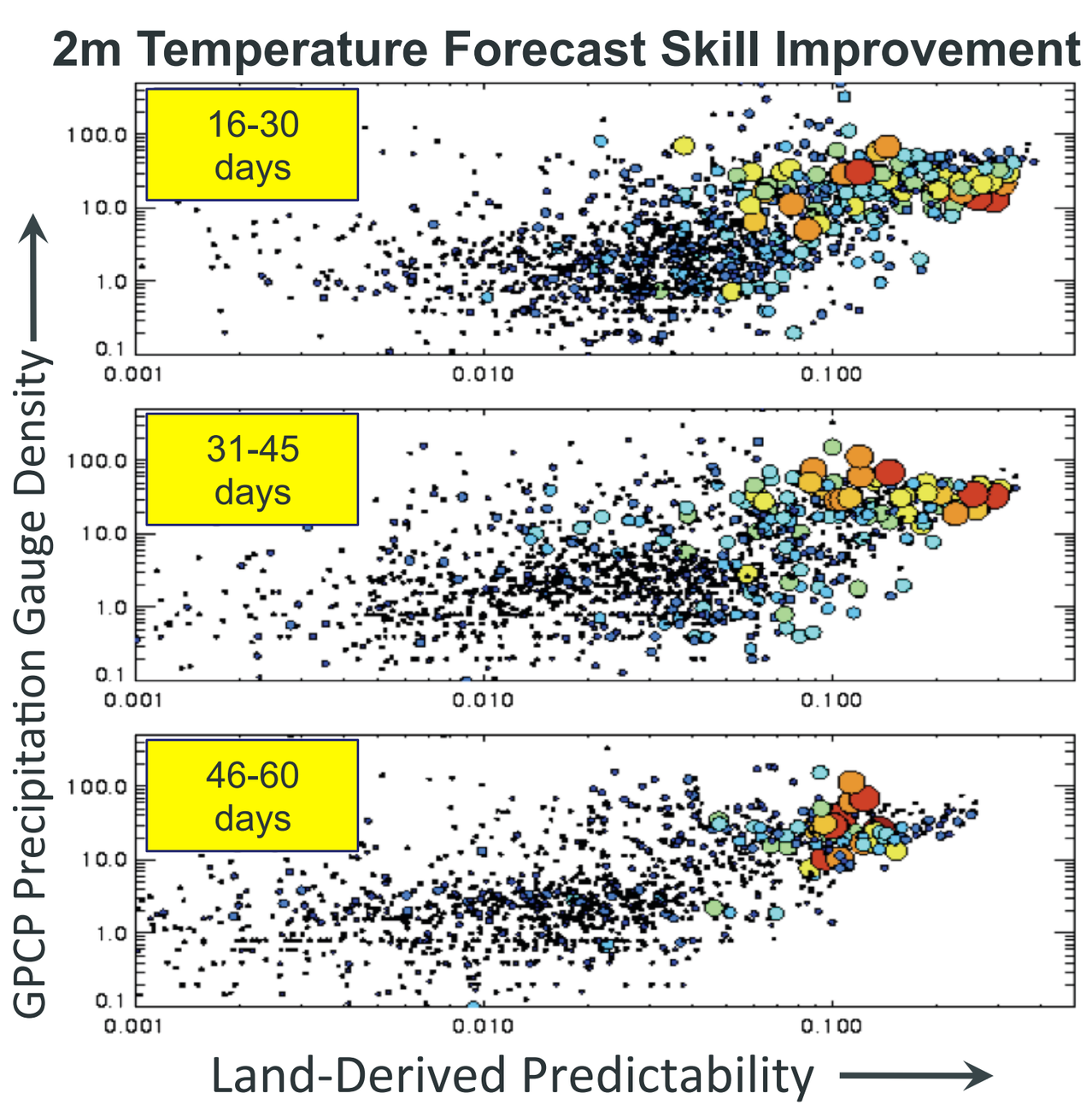

Koster et al. (2011: *JHM*)

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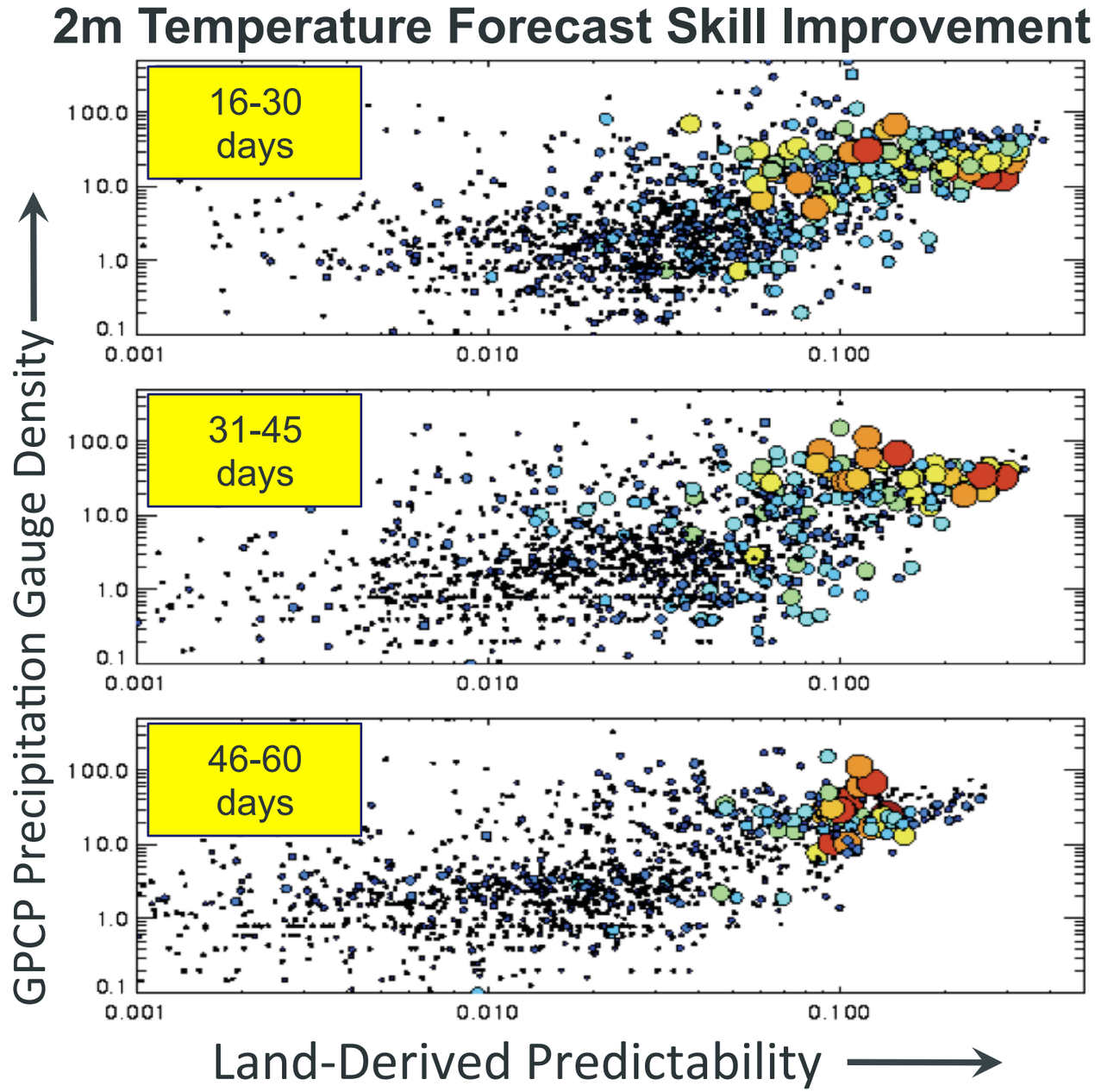

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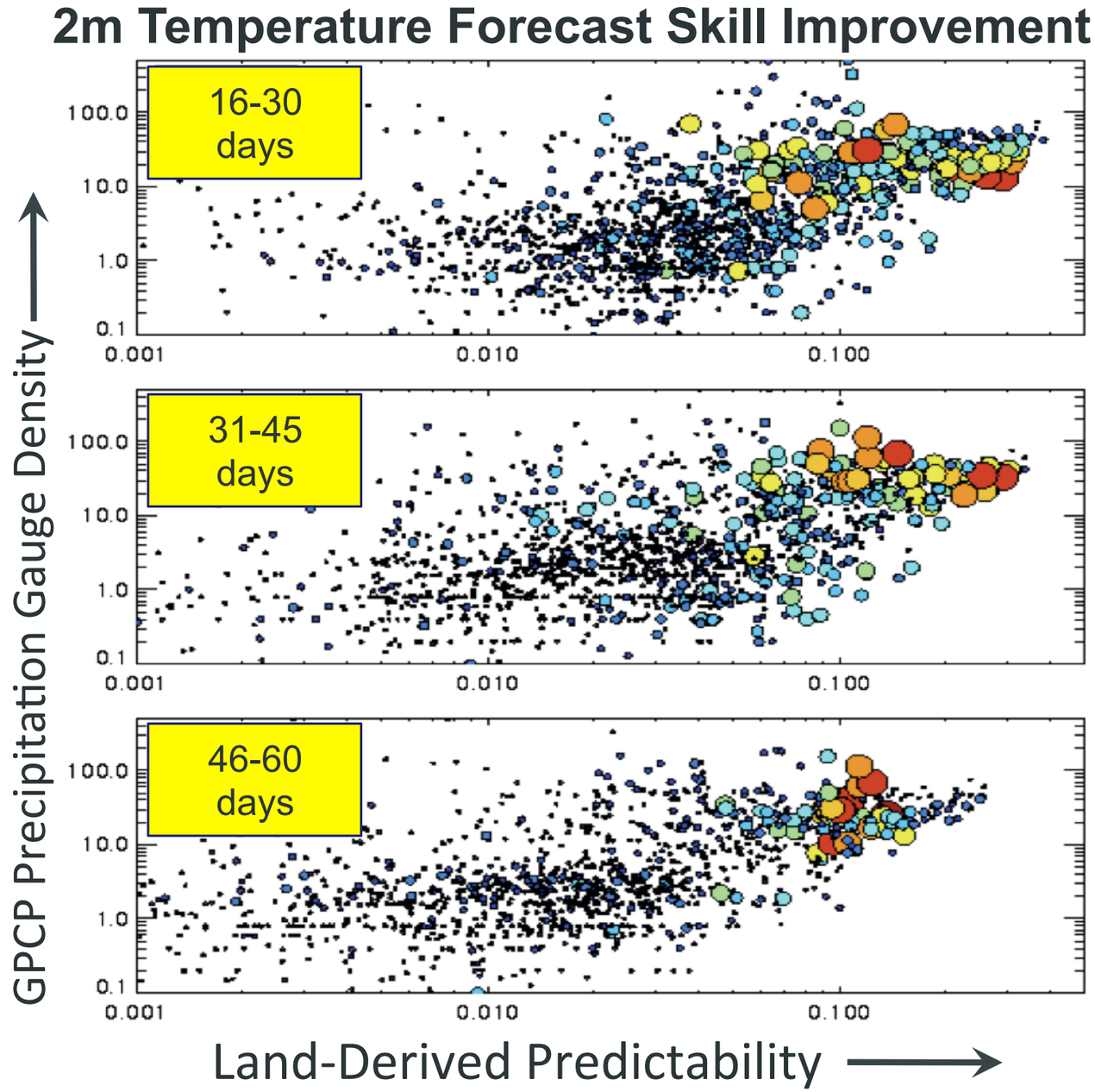
  - So-called "land data assimilation" *still not assimilating any data* – working on it…



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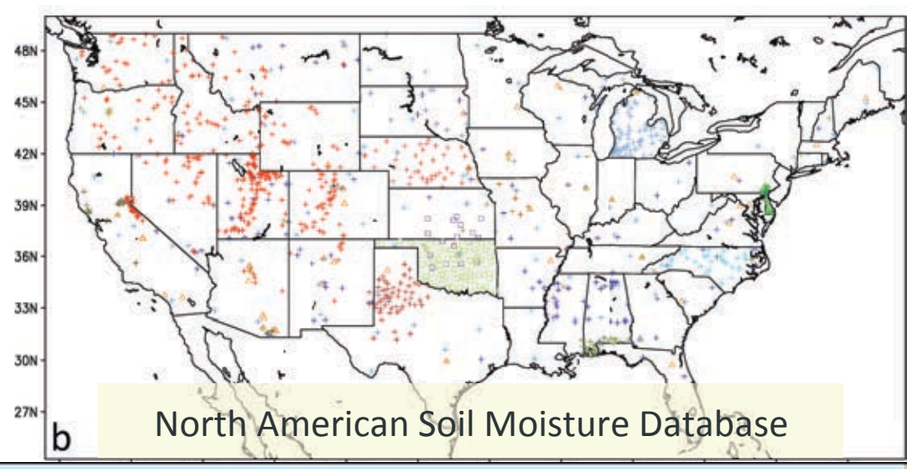

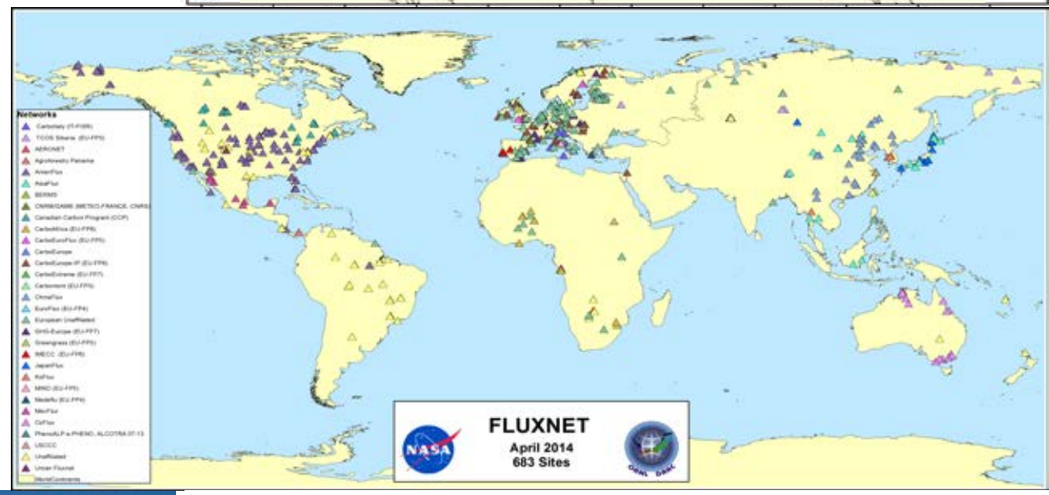

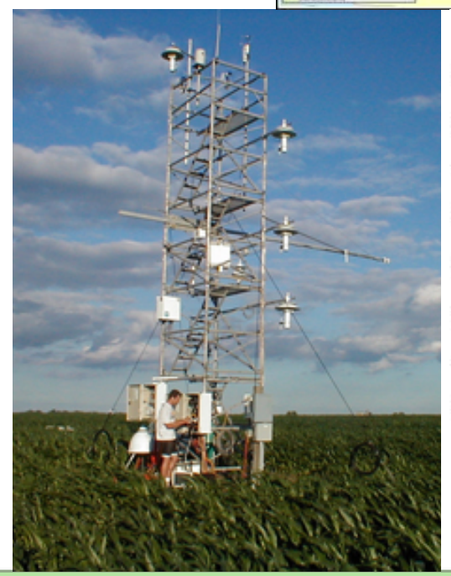

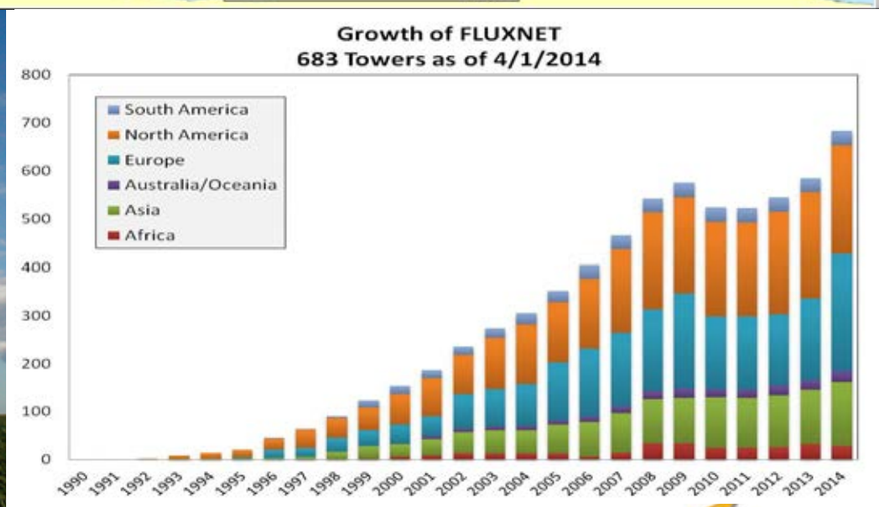

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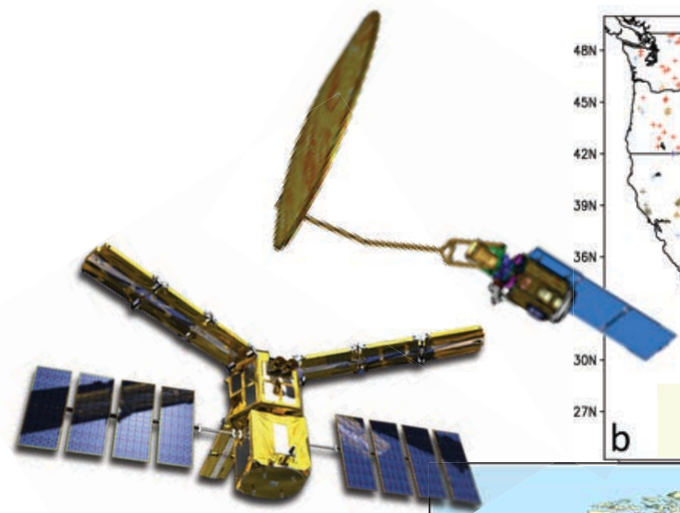
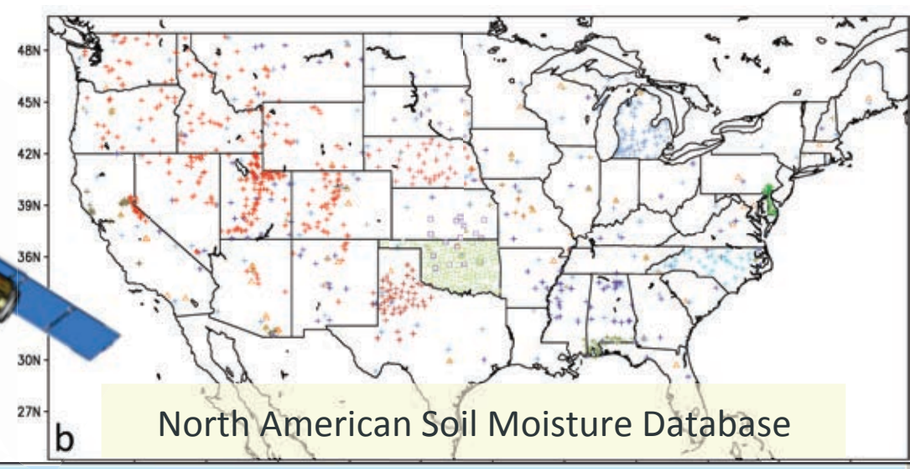
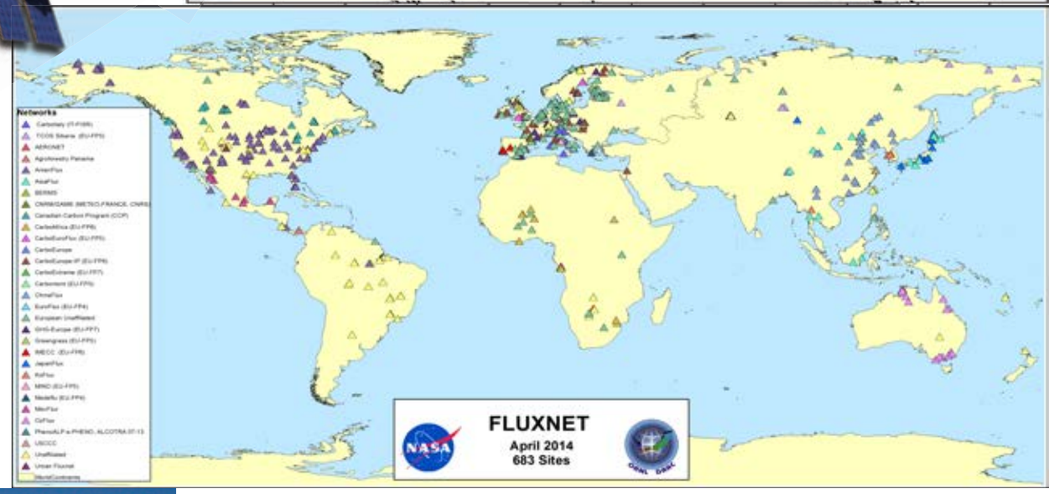
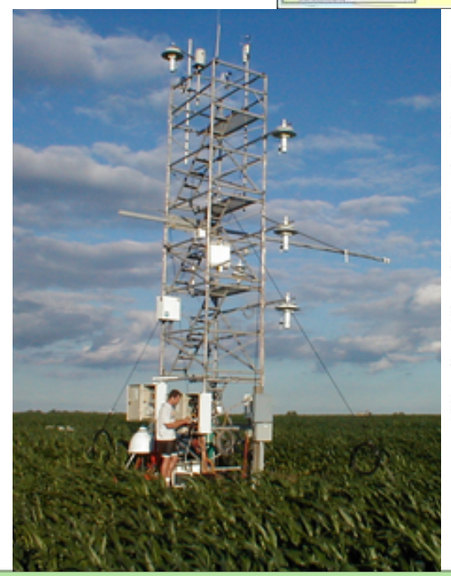
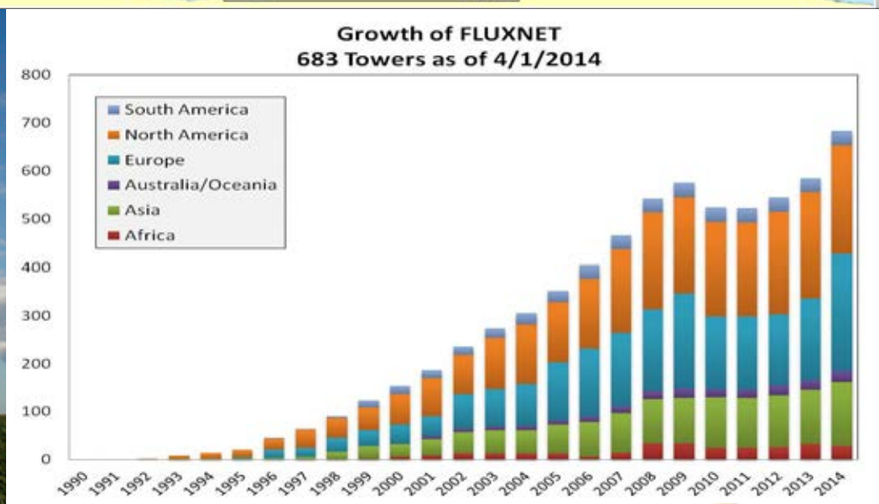




North American Soil Moisture Database







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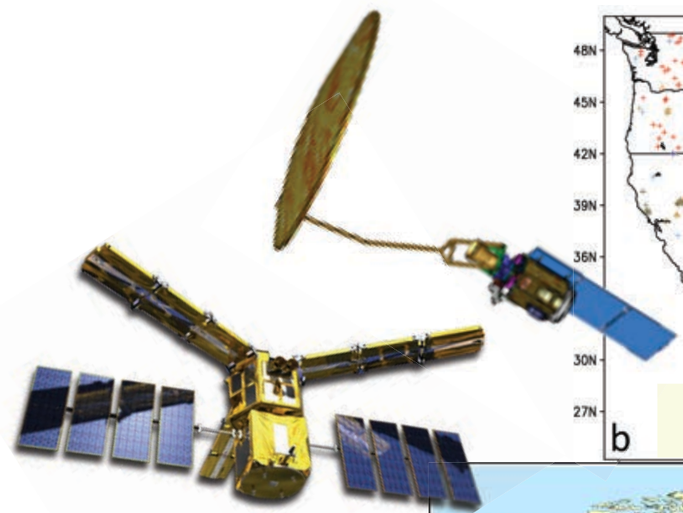
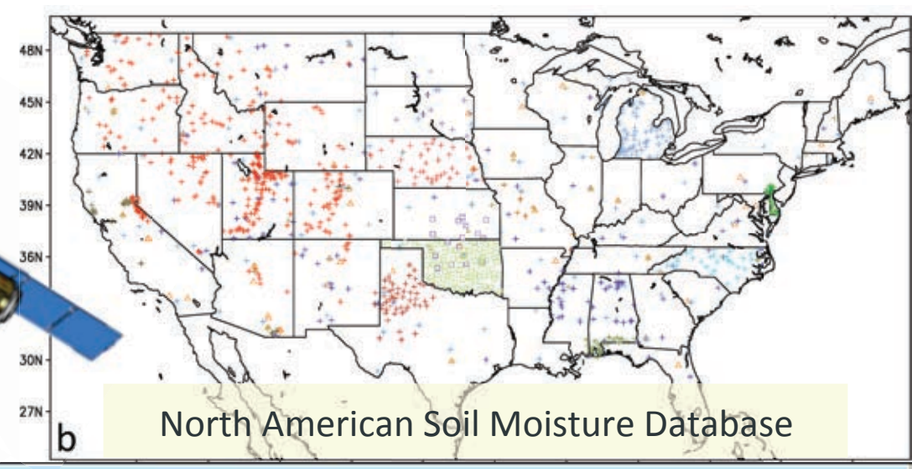
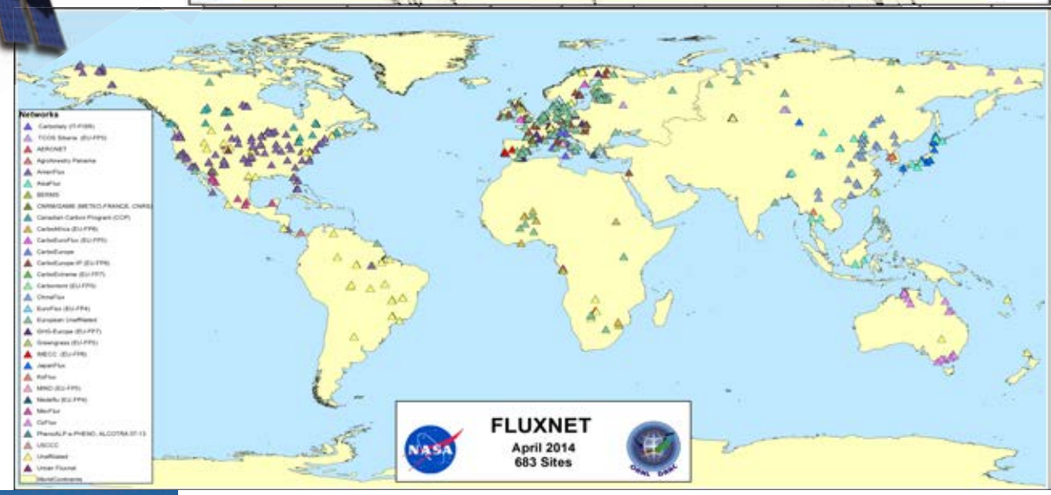
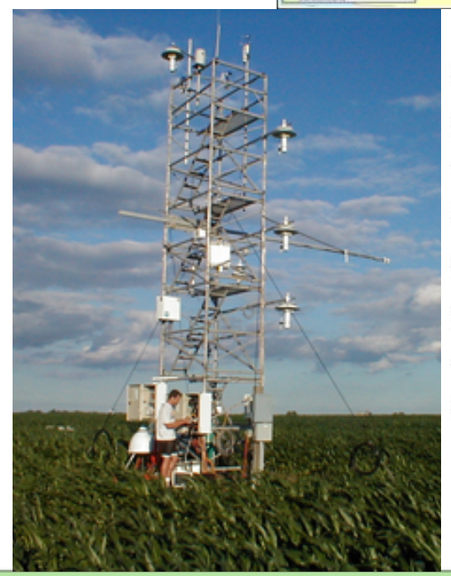
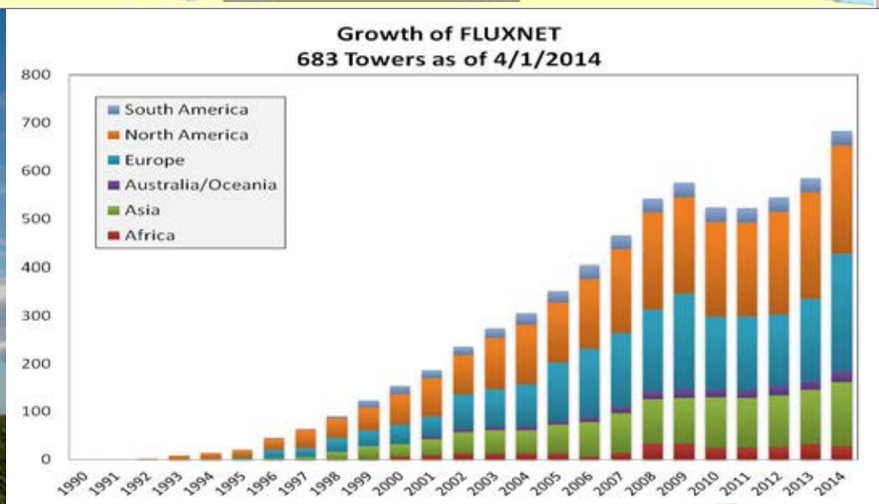
- Long time series, co-location, QC are essential – we need land & PBL measurements together!!











Remote Sensing

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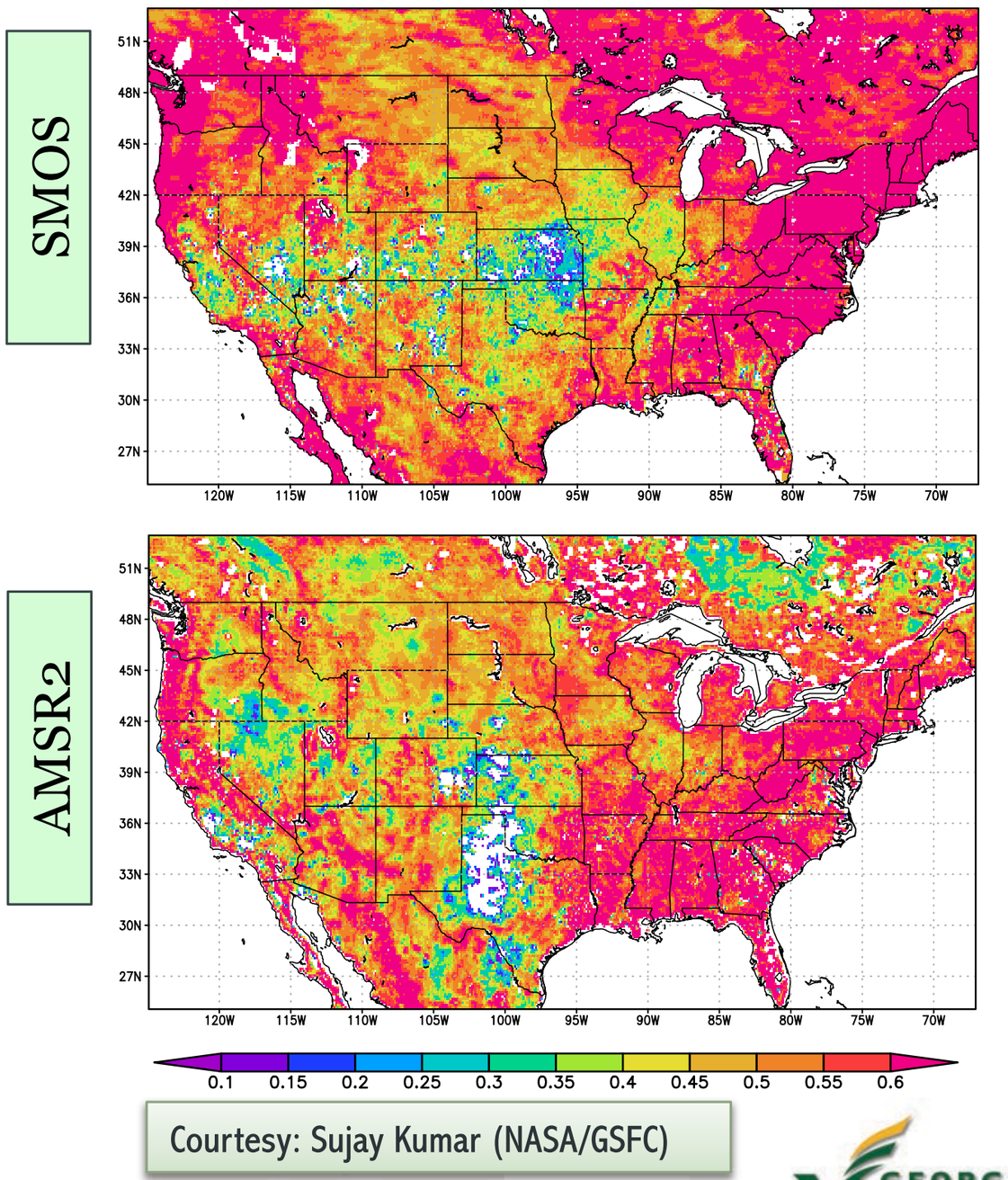

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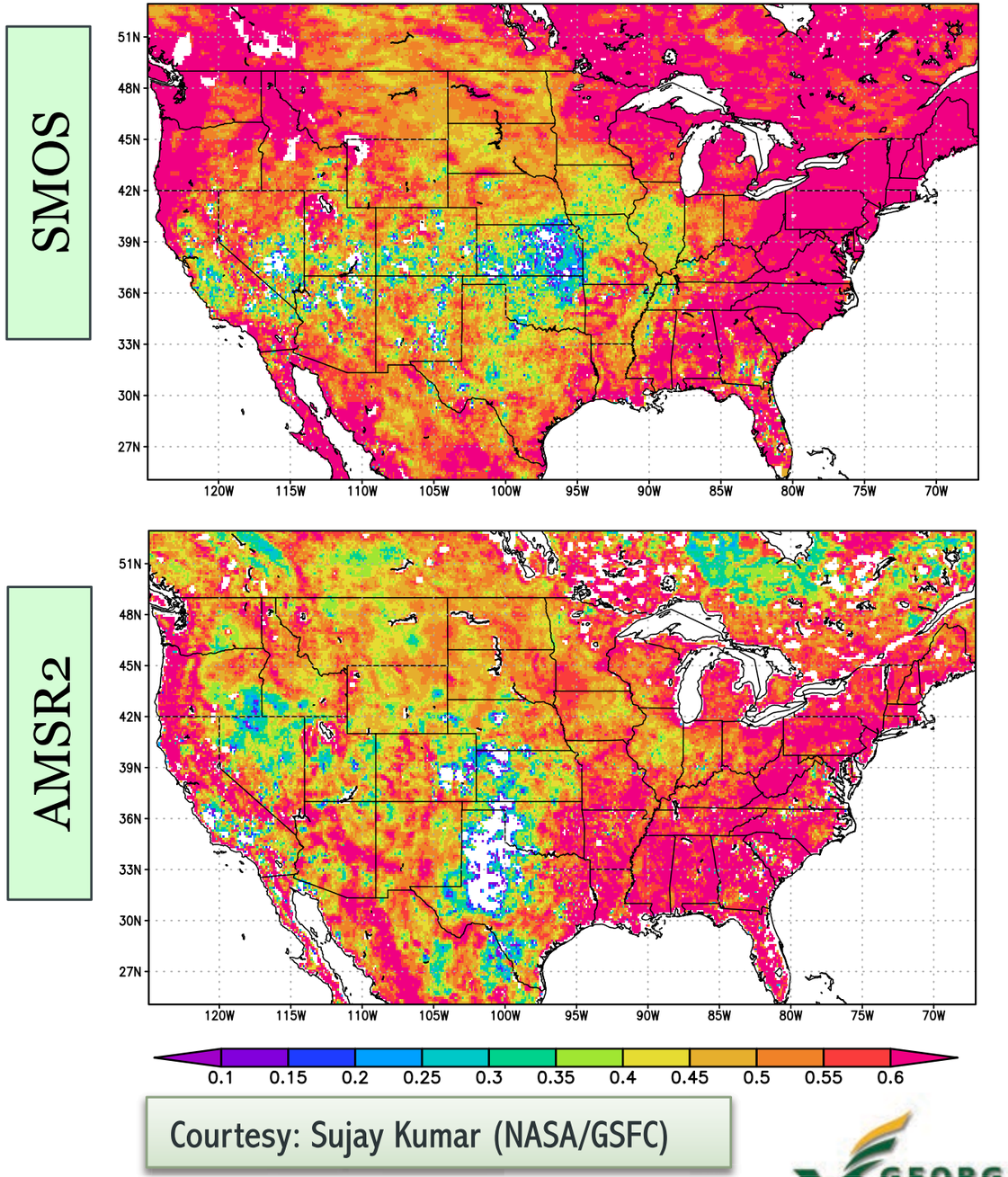

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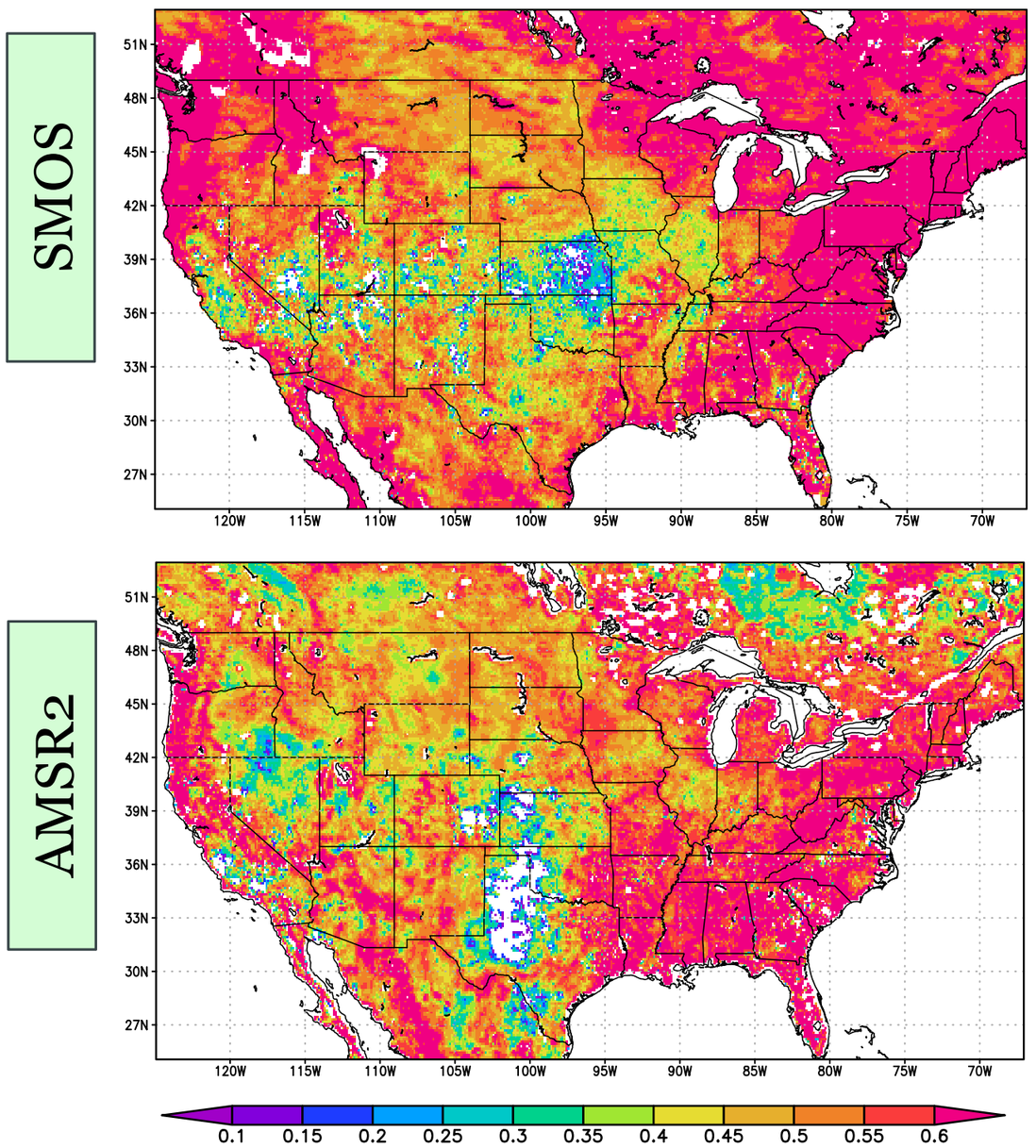
- We find accuracy "hot spots" that seem to correspond to ground-truth cal-val sites! Suggests we need much more "ground truthing" of satellite data than has been done so far.

Ratio of Random to Real StdDev



Courtesy: Sujay Kumar (NASA/GSFC)

Remote Sensing

- Satellites hold much promise for monitoring soil moisture globally.
- We can estimate random measure-ment error of red-spectrum data like soil moisture from the statistical behavior of lagged autocorrelations.
- We find accuracy "hot spots" that seem to correspond to ground-truth cal-val sites! Suggests we need much more "ground truthing" of satellite data than has been done so far.
- Preliminary results – more to do….

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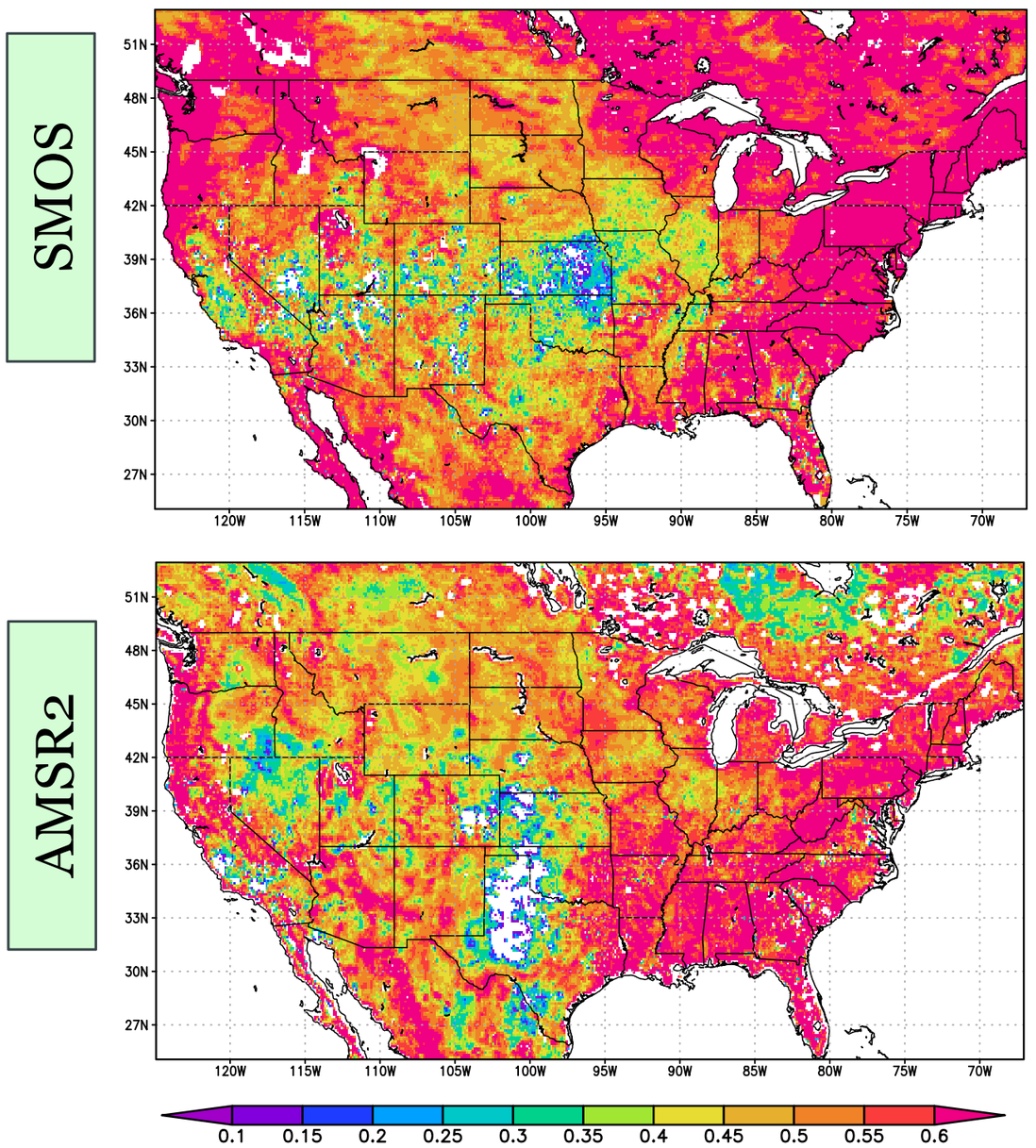

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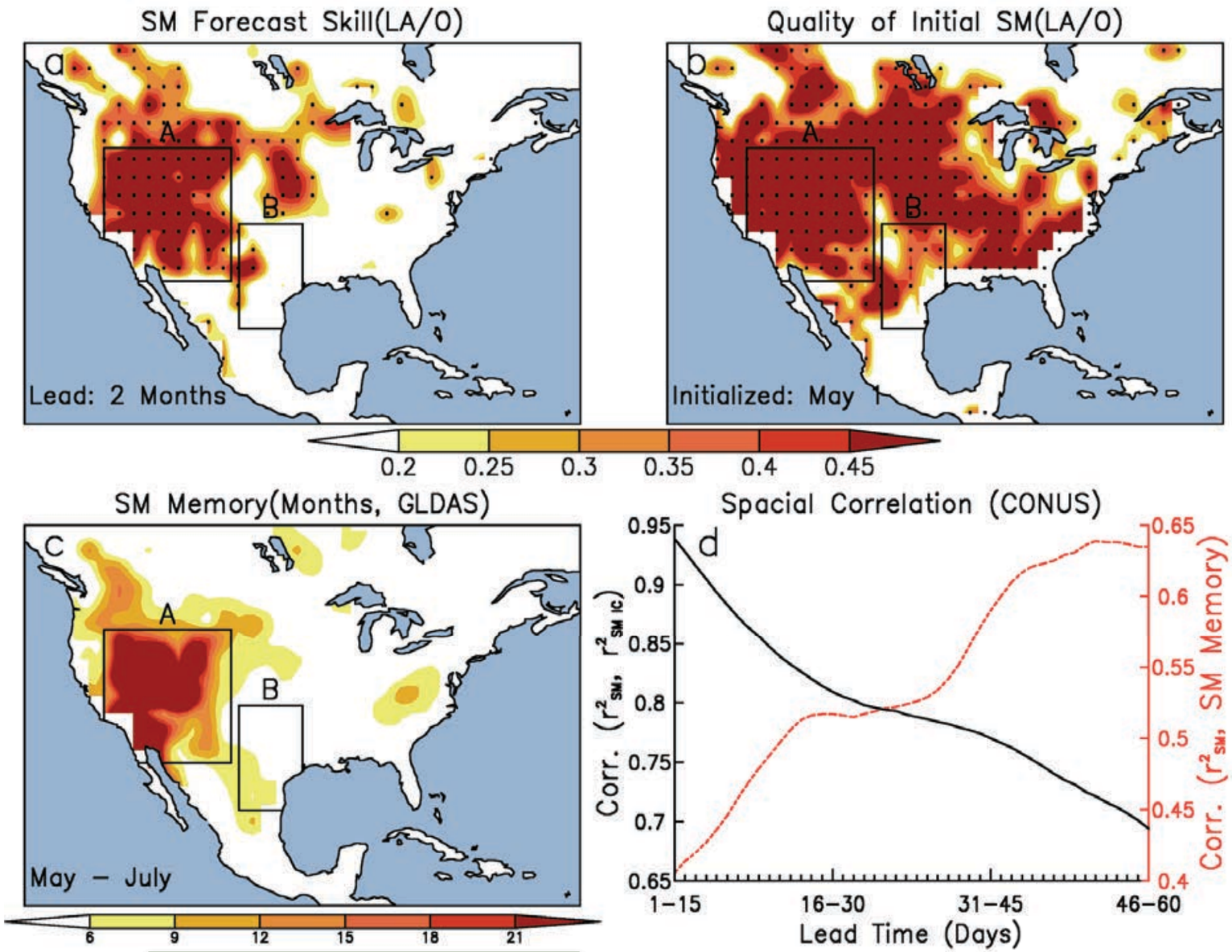
US Hotspot Weak on Memory?

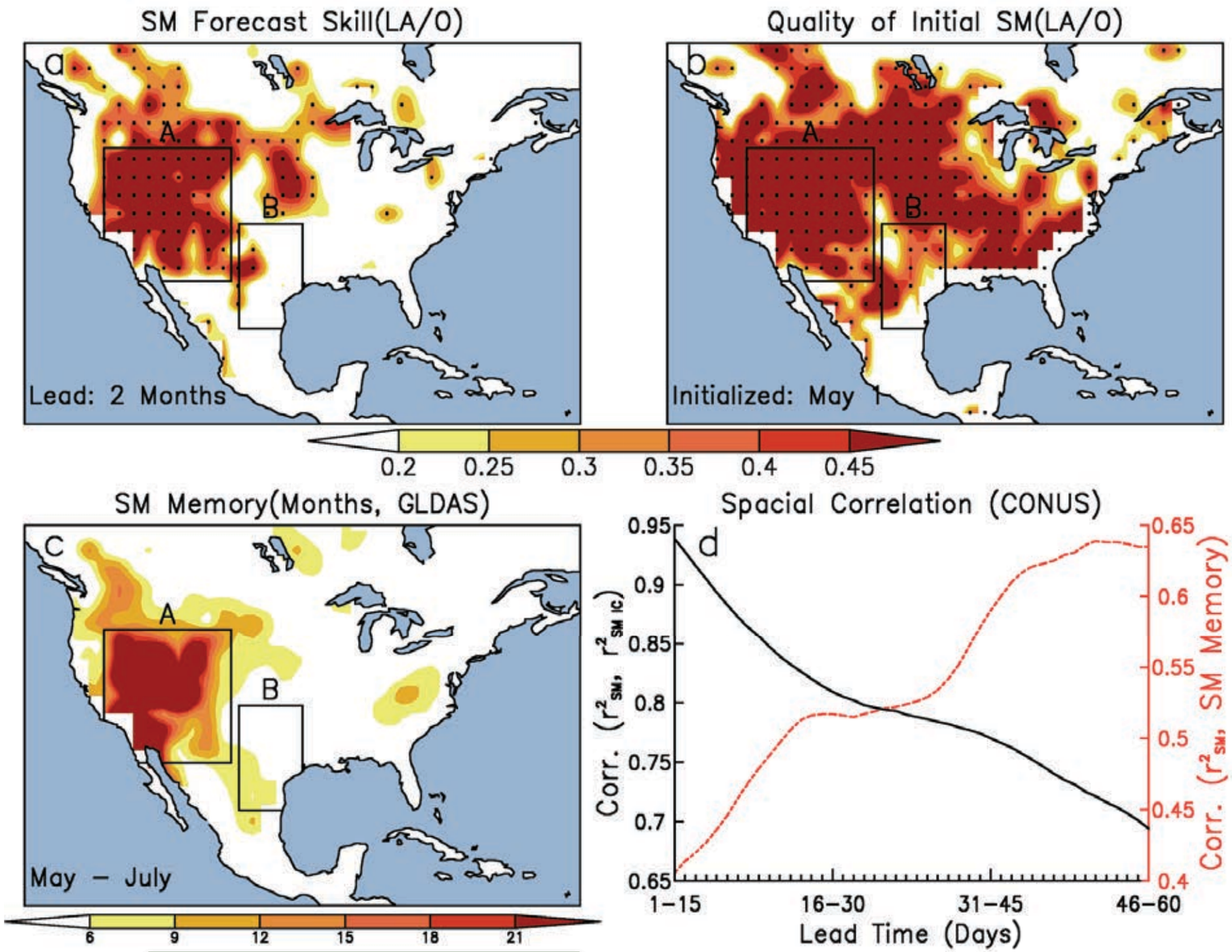
- GLACE-2 found increased forecast skill from soil moisture initialization in subseasonal forecasts, but not centered over the “hotspot”.



Guo, & Dirmeyer, (2015; *GRL*)

US Hotspot Weak on Memory?

- GLACE-2 found increased forecast skill from soil moisture initialization in subseasonal forecasts, but not centered over the "hotspot".
- Reason may be a lack of persistence of anomalies there, compared to regions further west.



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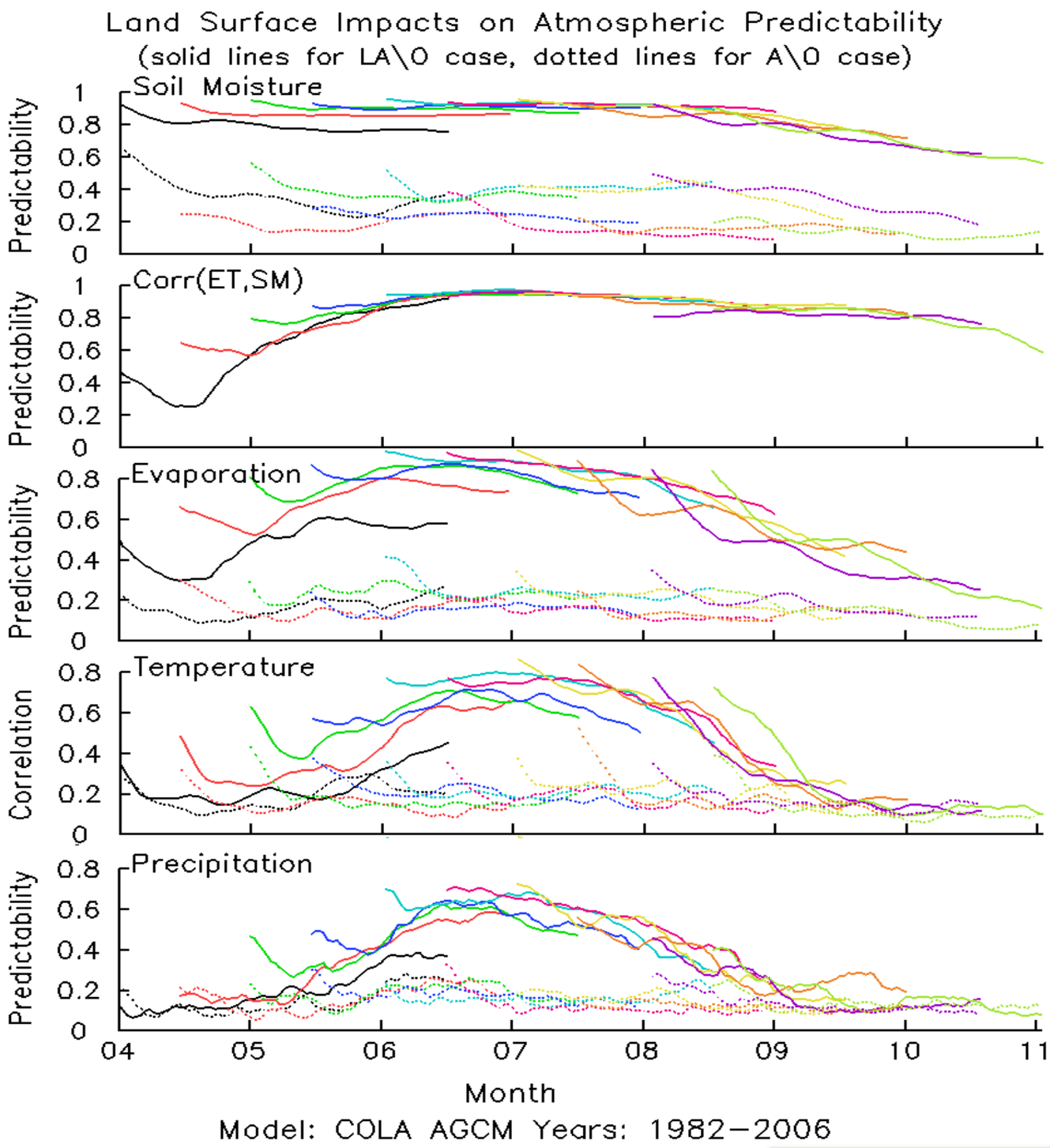
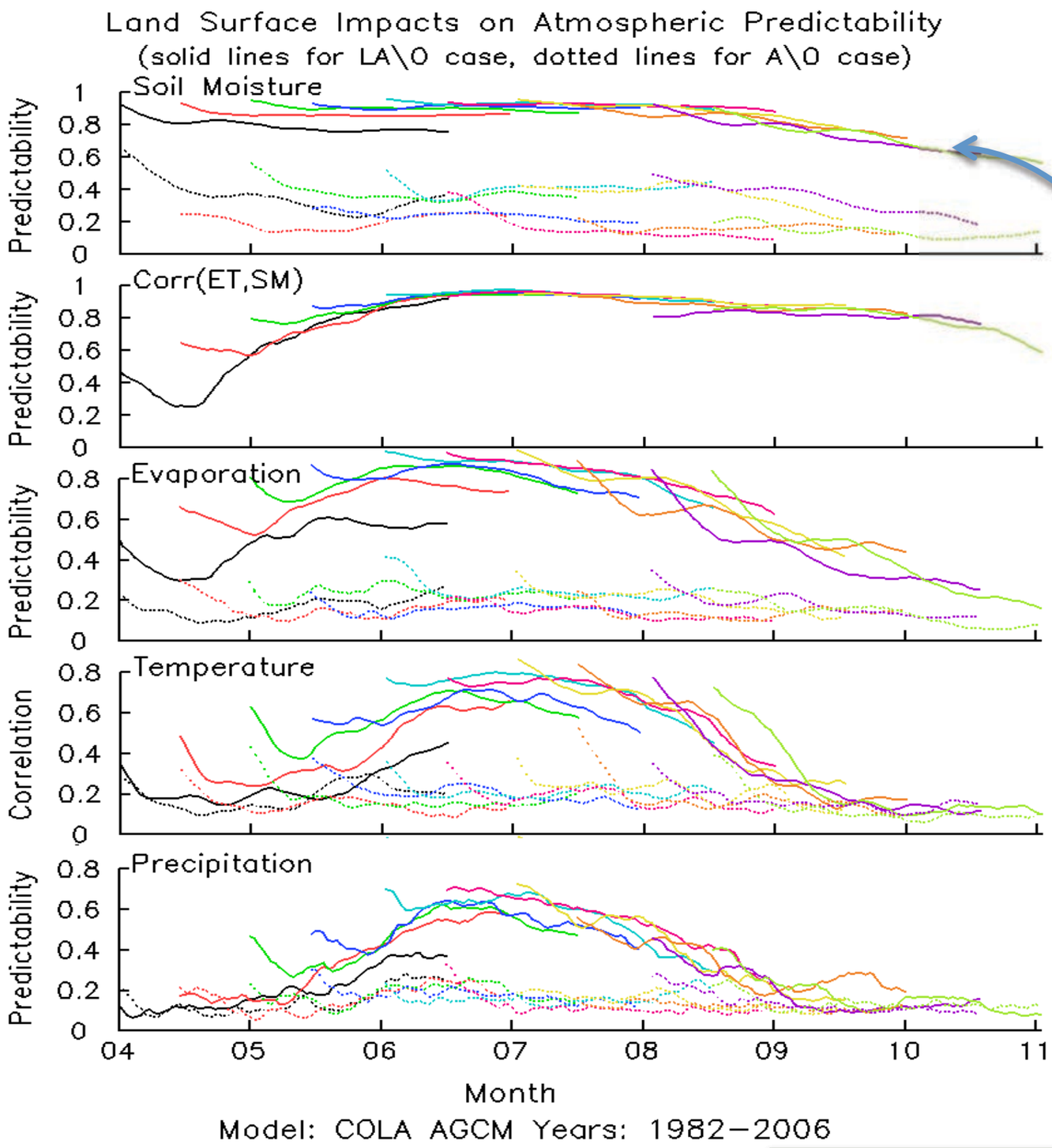


GLACE-2 Predictability Rebound

- Box over US Great Plains.

Guo et al. (2013: *J. Hydromet*)



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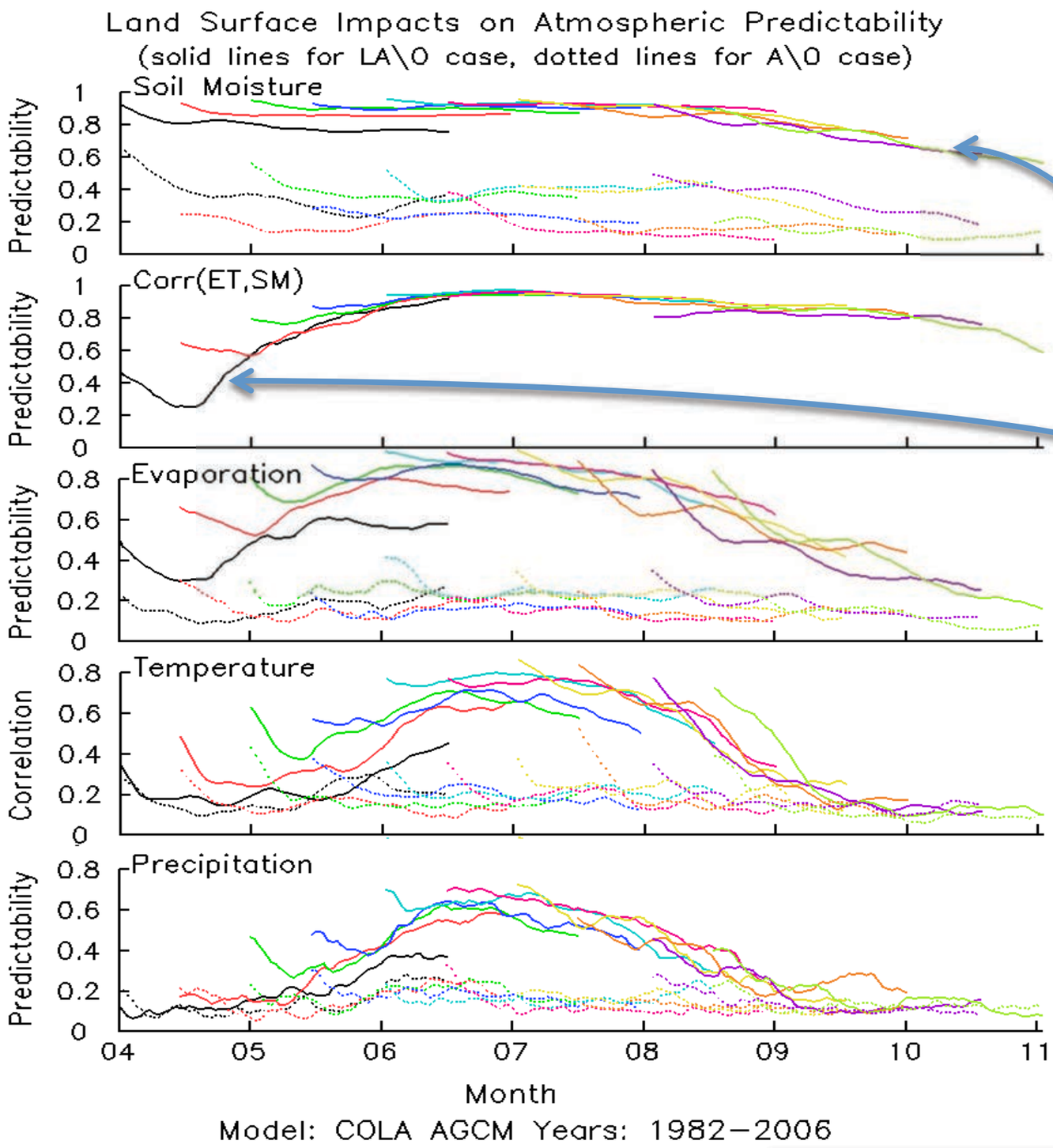

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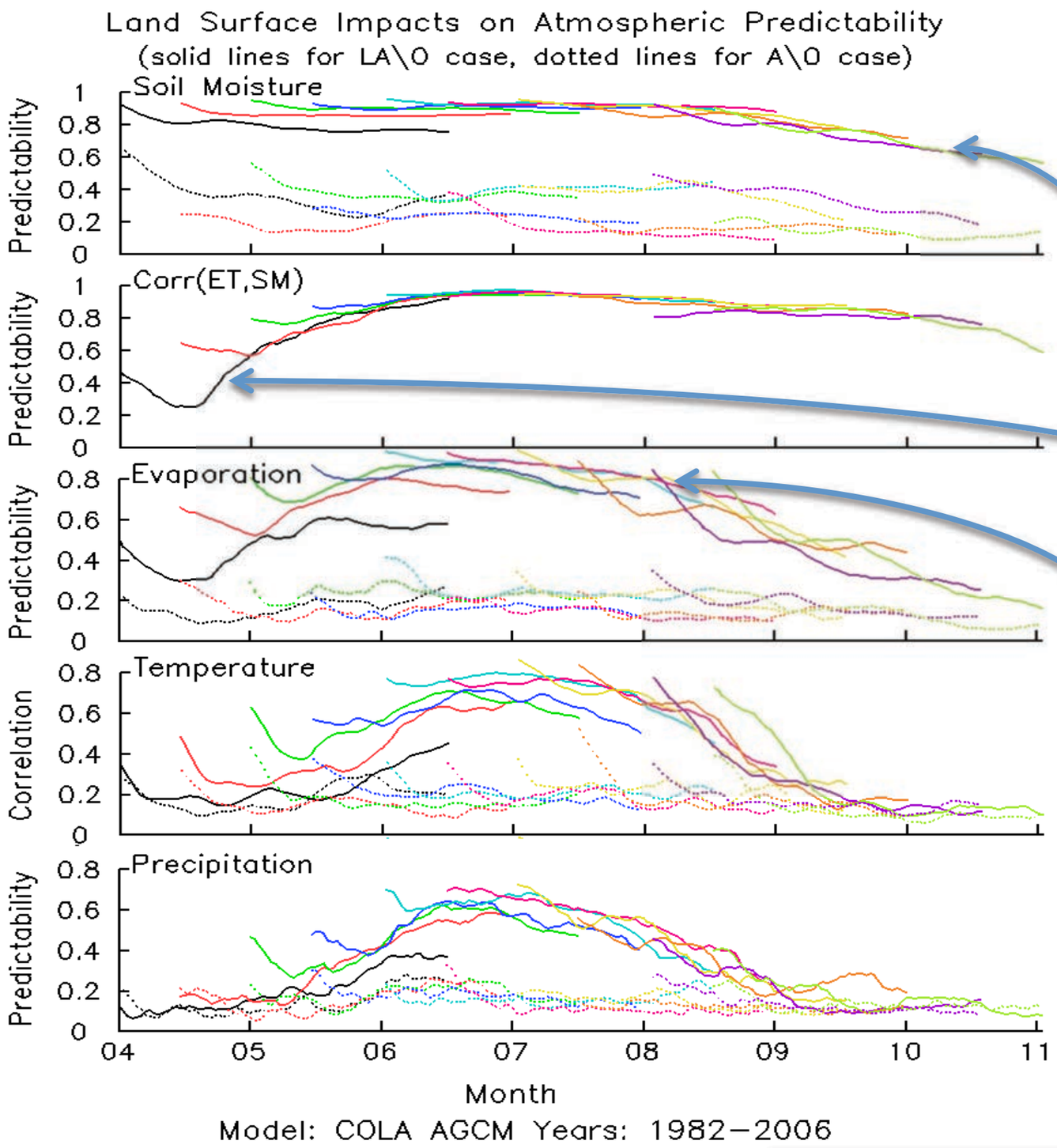

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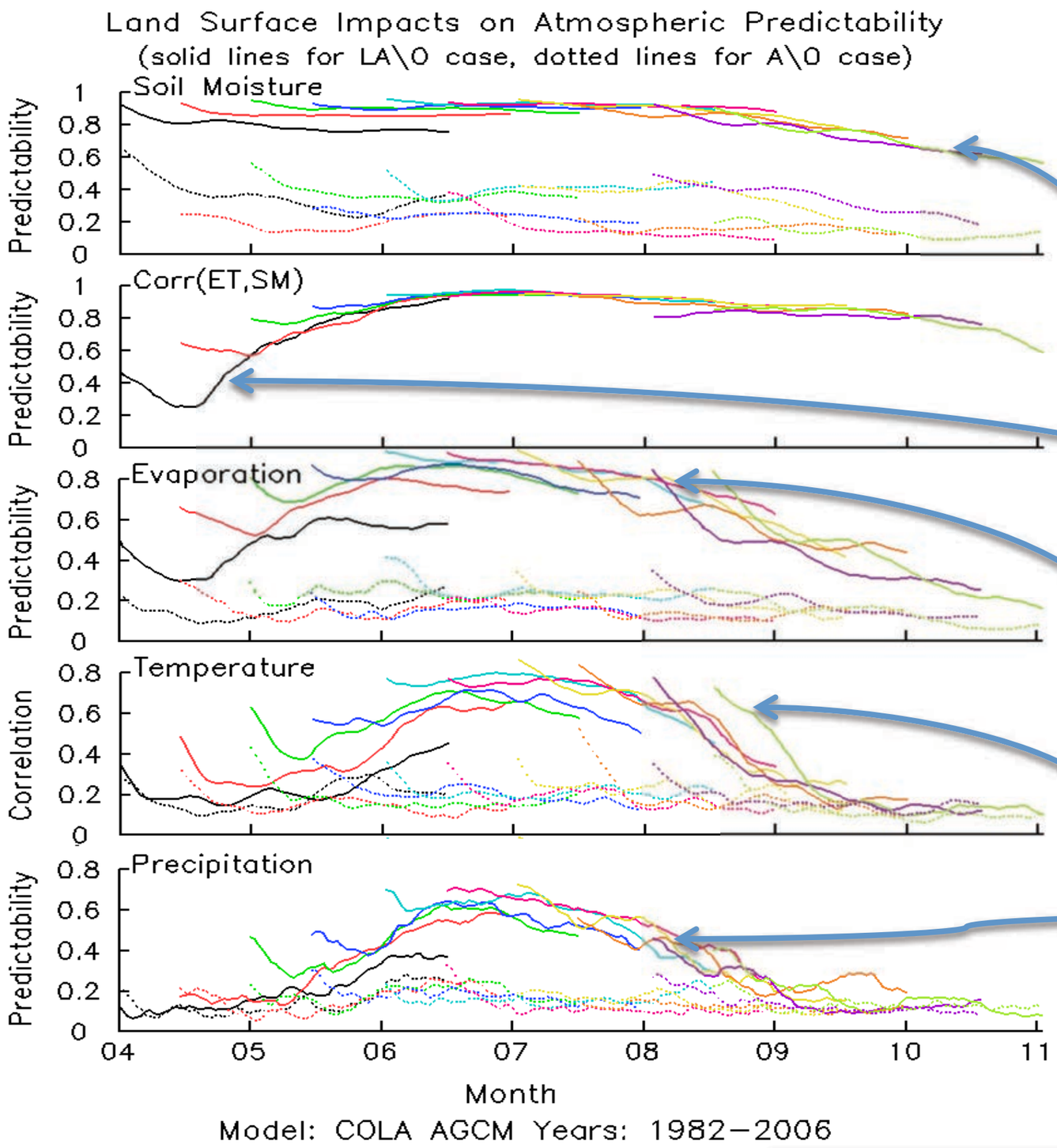


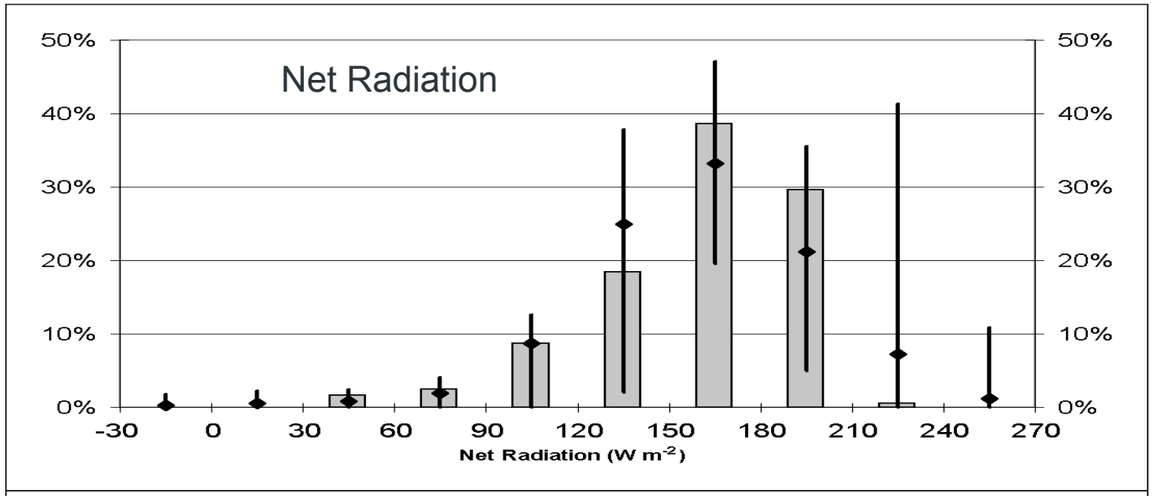
GLACE-2 Predictability Rebound

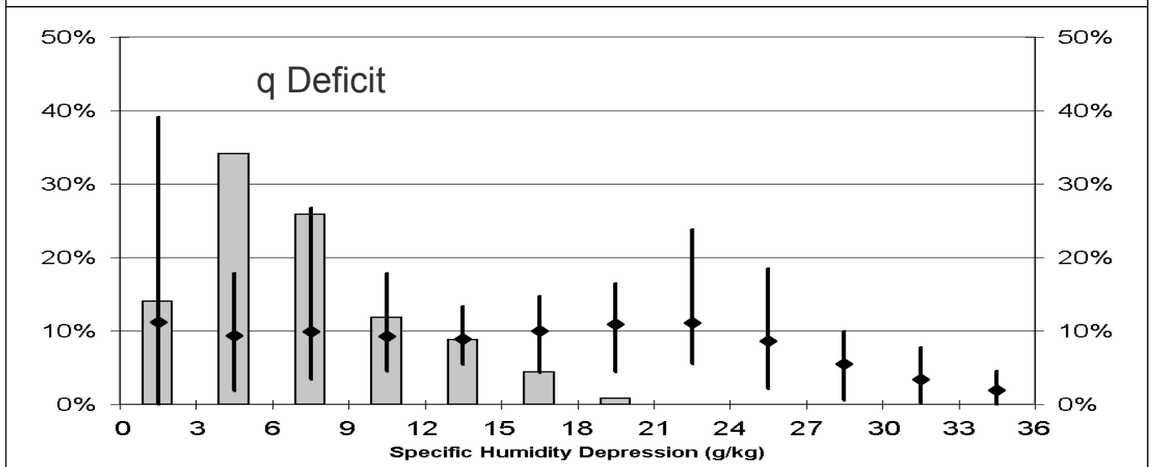
- Box over US Great Plains.
- Soil moisture memory is high during spring and summer.
- In early spring soil moisture does not control ET.
- Late spring and summer, all pieces are in place.
- The impact of soil moisture on temperature and precip maximizes, predictability "rebounds"

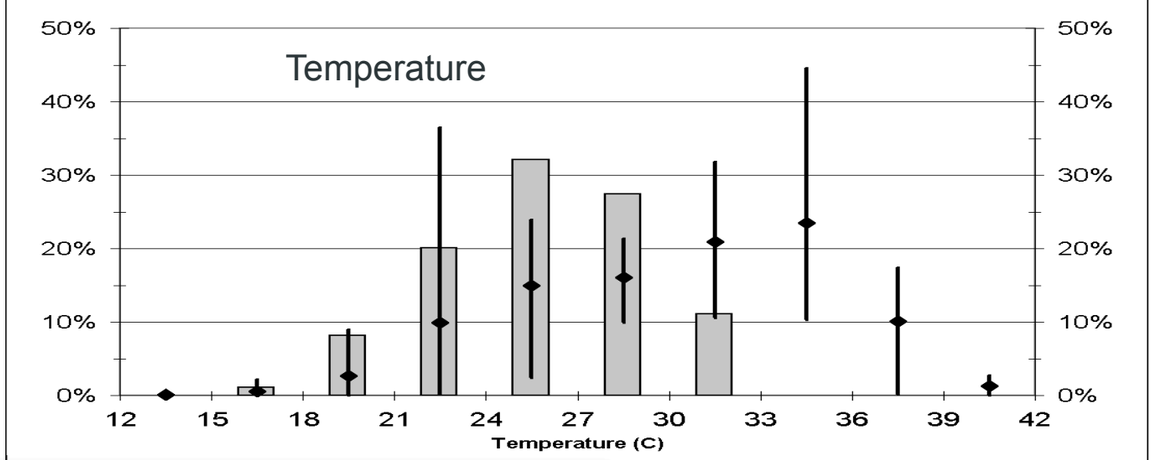
Guo et al. (2013: *J. Hydromet*)

Coupled Errors

- GLACE models suffered from a tendency to simulate excessively warm temperatures and unrealistically low daytime relative humidity over the Southern Great Plains.
- Figure: categorical frequency of occurrence of indicated variables over the ARM region for observations (bars), and the mean of 12 GCMs (markers). Vertical lines span the range of models for each bin.







Dirmeyer et al. (2006: *J. Hydromet*)

Coupled Errors

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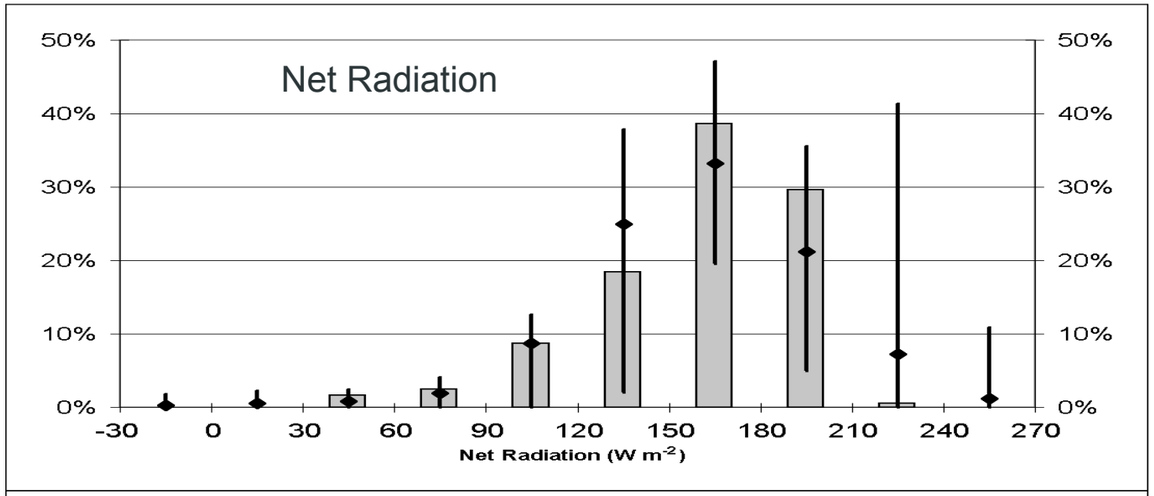
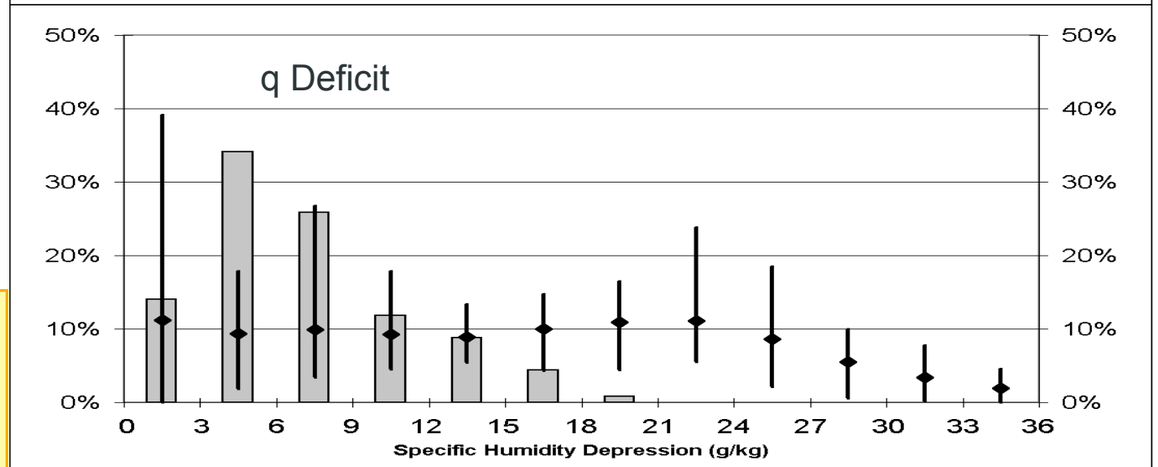
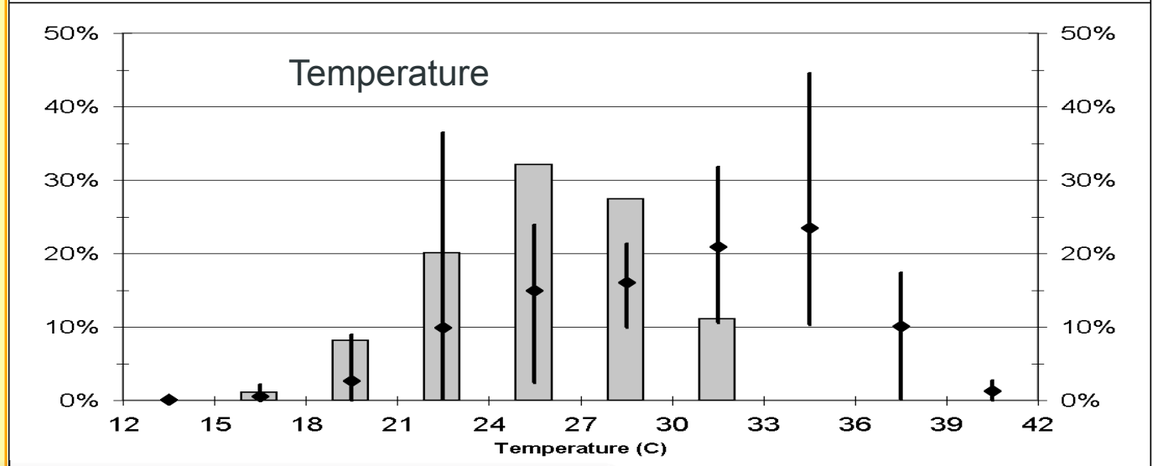
Excessive downward radiation (systematic cloud errors) at surface in all models lead to a drying (LSMs first allocate extra energy to evapotrans-piration) and then warming (as soil moisture is depleted, energy goes to sensible and ground heat flux instead). Positive feedbacks exacerbate errors.







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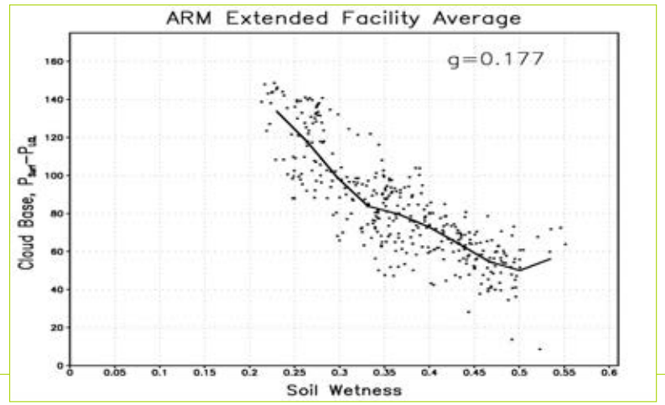
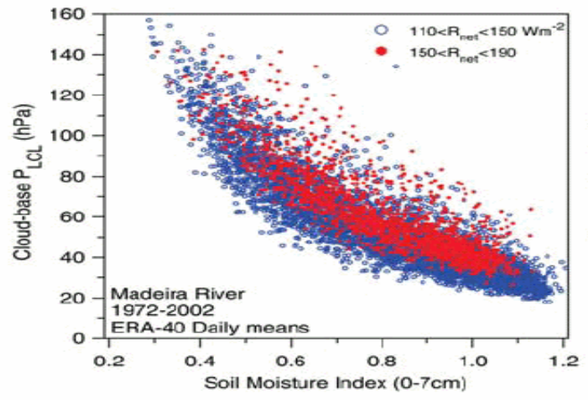
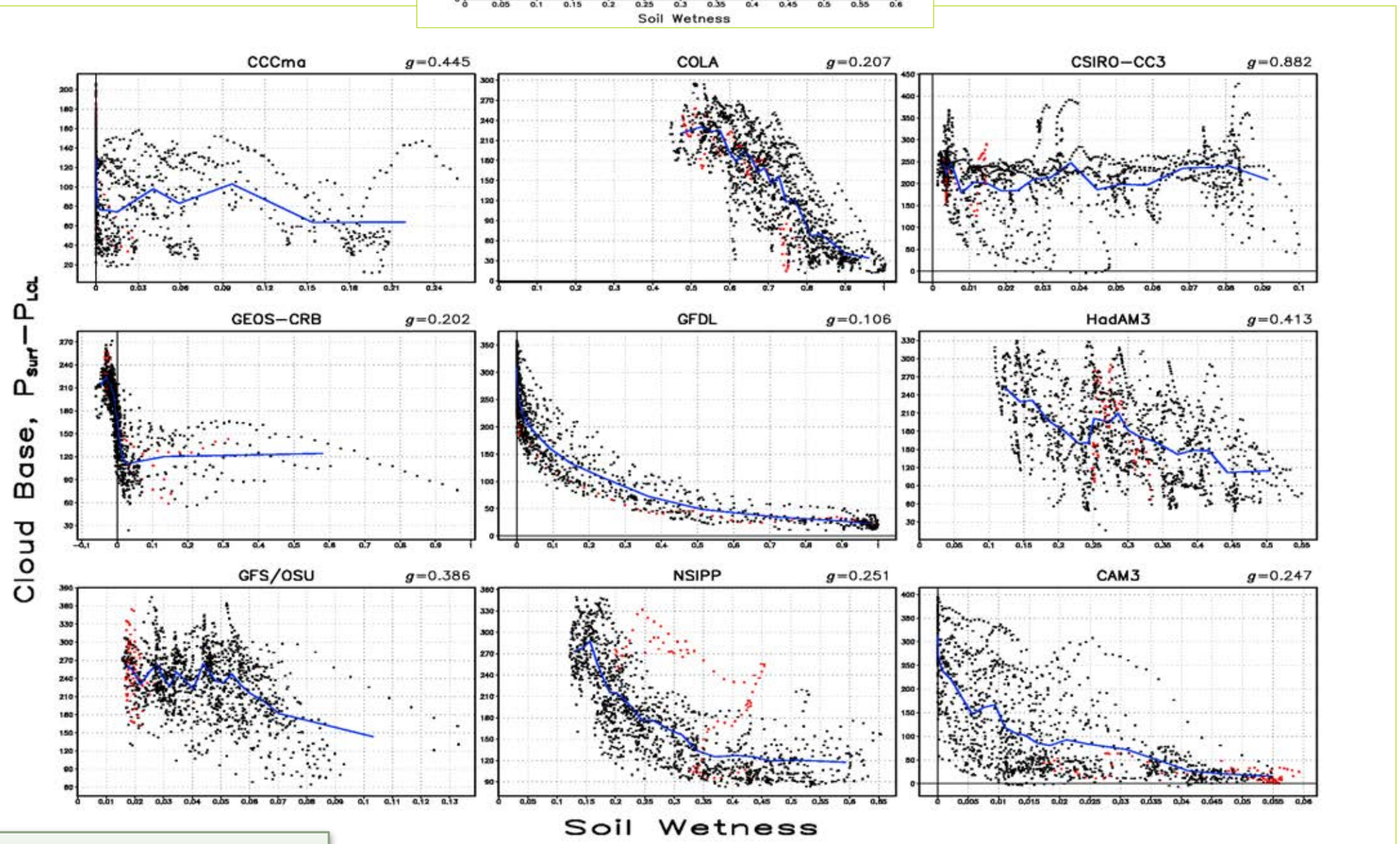
LCL vs. Soil Wetness

Observed ARM relationship agrees with Betts' theory of soil wetness controls on SHF, PBL depth.

The models are all over the place.







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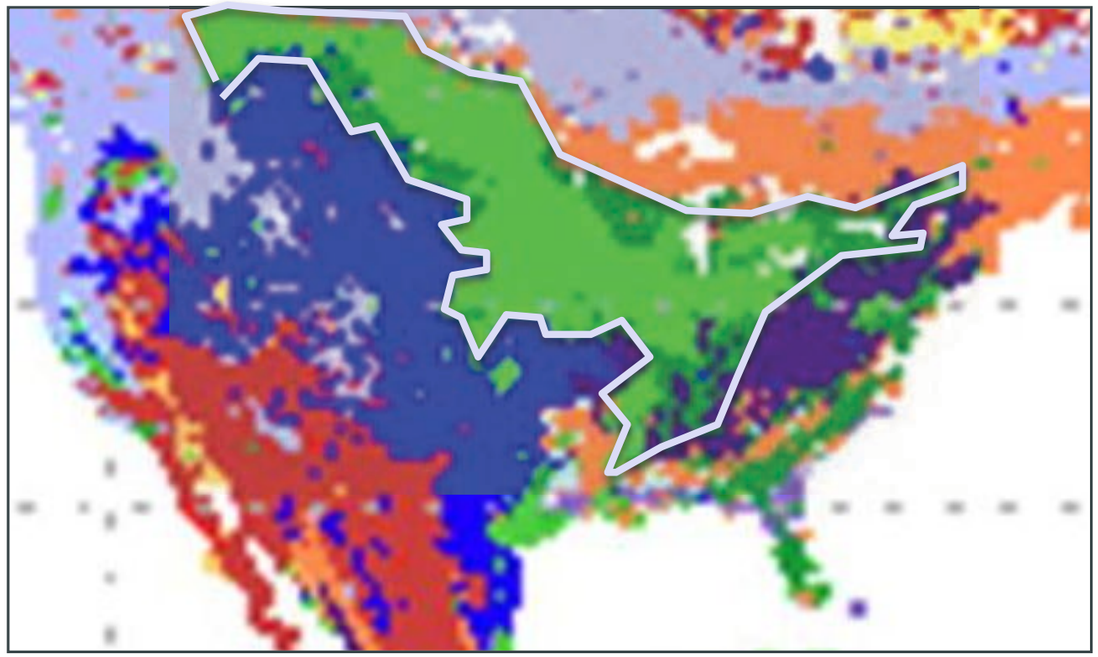
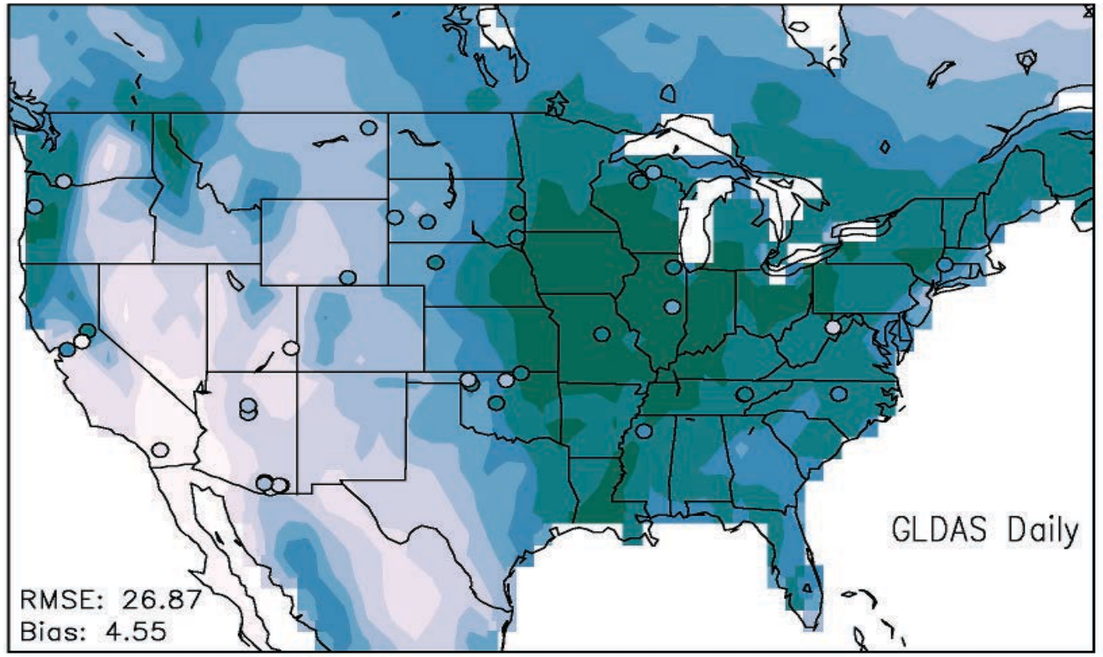
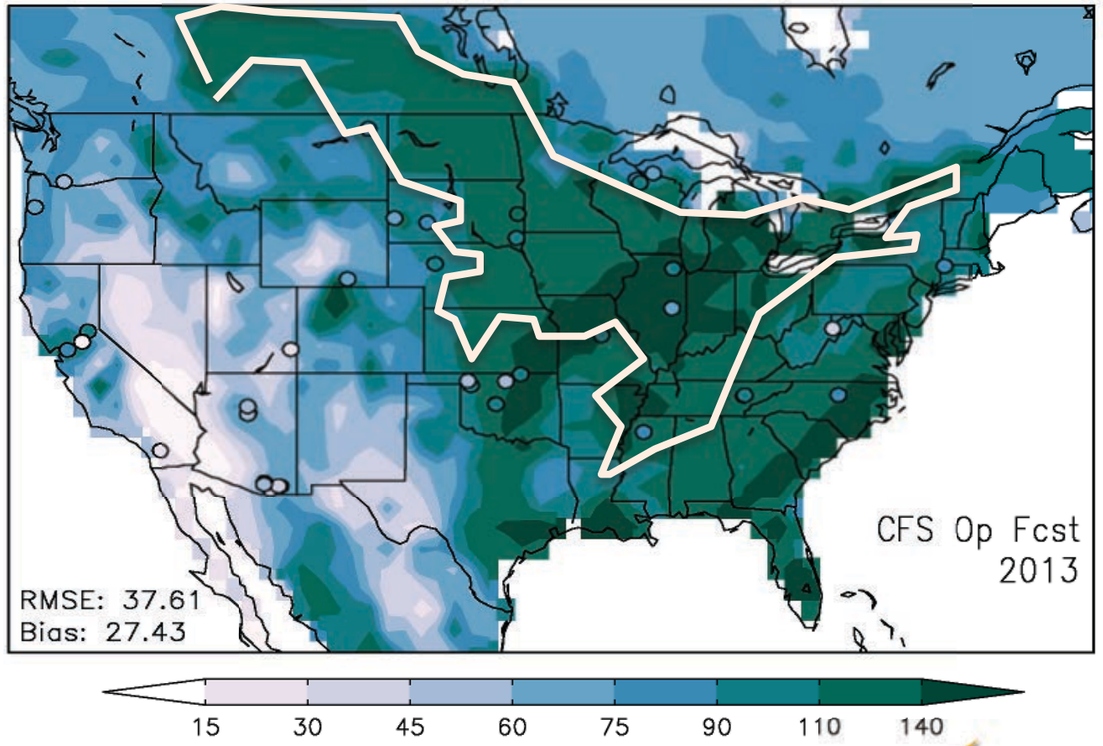
The Quick Fix

- To correct warm biases in CFSR, roots for Noah crop vegetation type were extended to all 4 soil layers; it transpires freely.



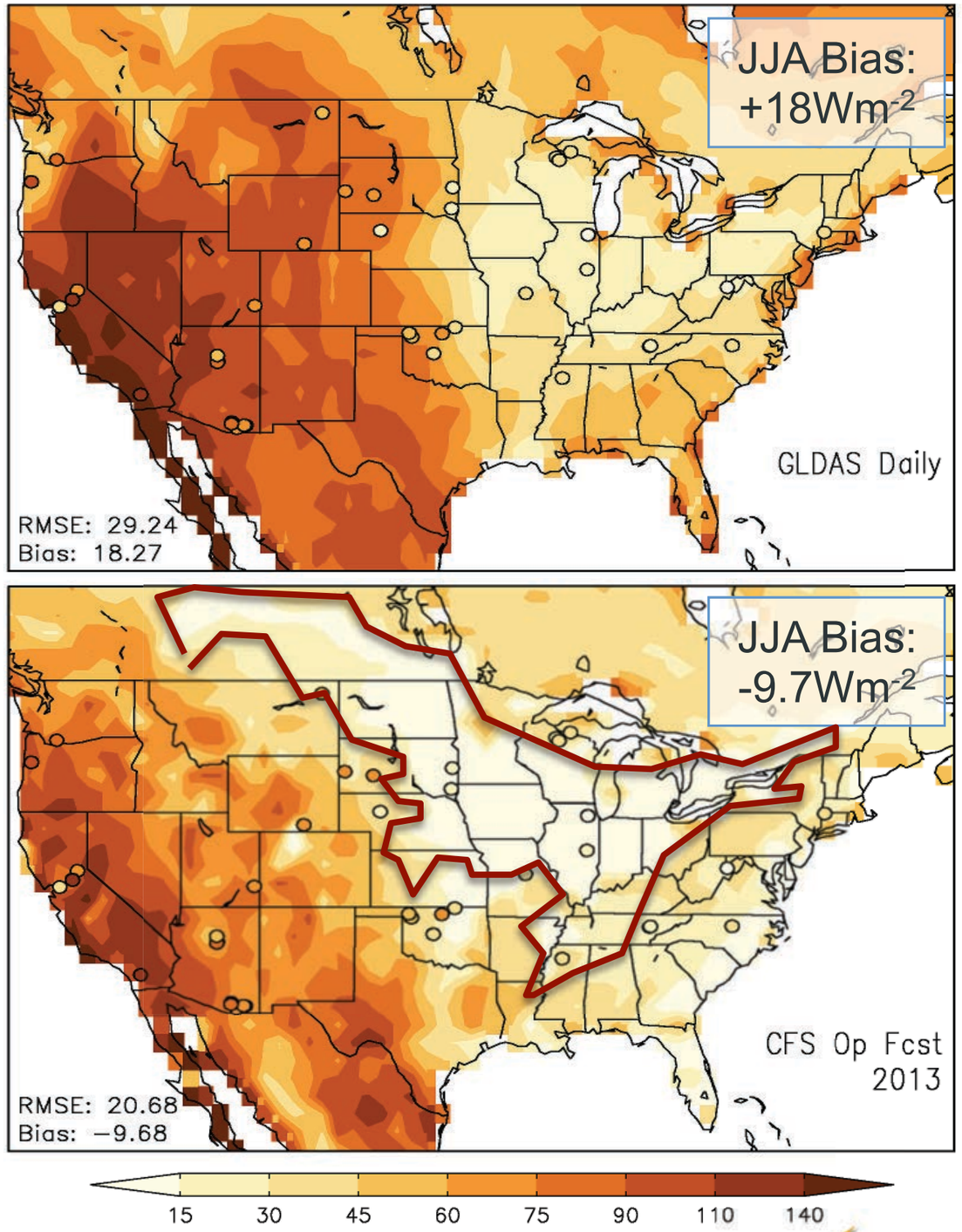
Green: Total and partial cropland





Sensible heat fluxes

- Essentially zero over much of Midwest in CFS over crop vegetation type.
- This seems to cause problems for boundary layer simulation (essentially there is none)… perpetual fog.
- But hey, the temperature error was reduced! Right result for wrong reason.



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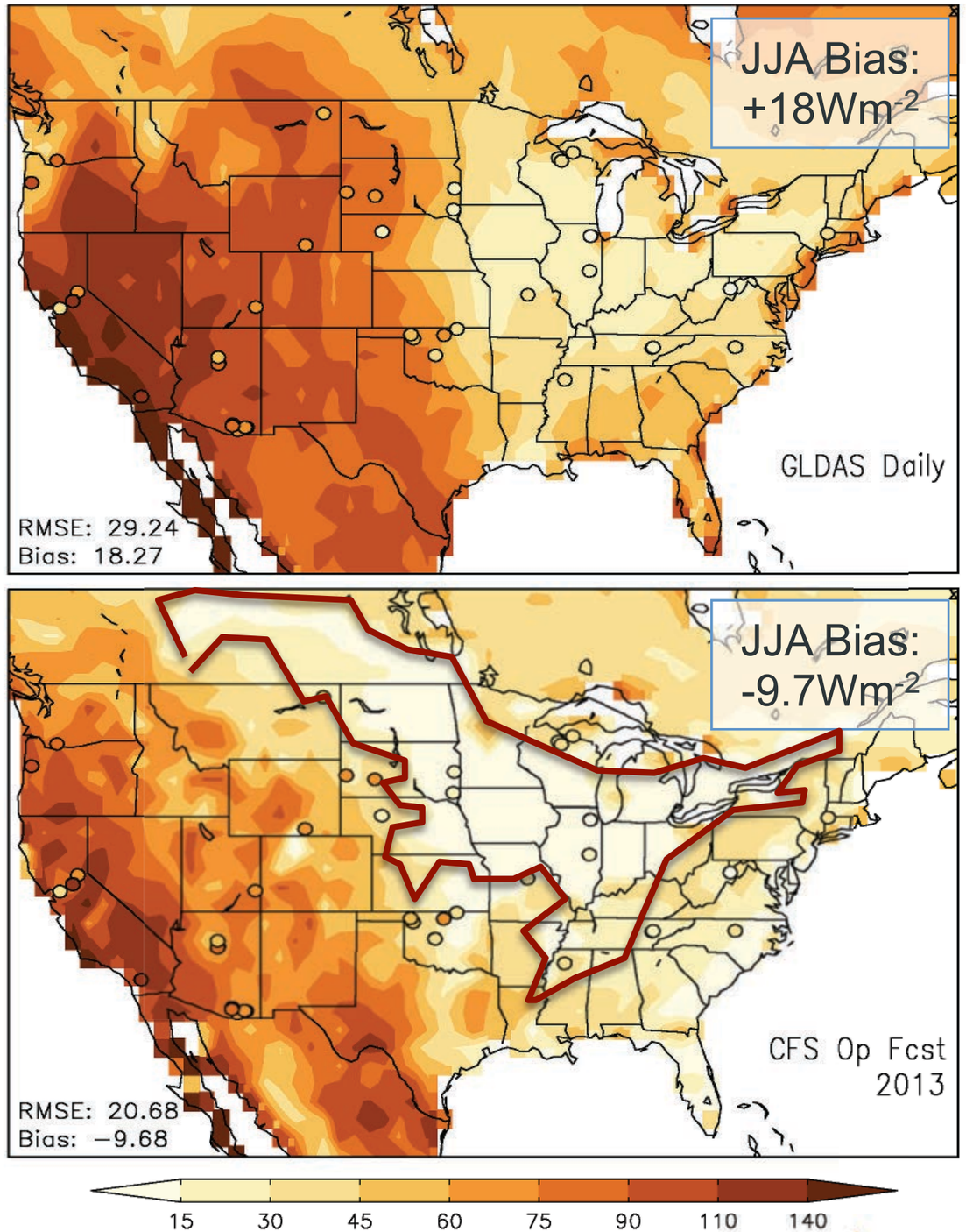

- Global Energy and Water Exchanges (GEWEX) program, Global Land/Atmosphere System Study (GLASS) project: Accurately understand, model, and predict the role of Local Land-Atmosphere Coupling "LoCo" in water and energy cycles in weather and climate models.

Courtesy: Michael Ek (NOAA/NCEP/EMC)

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- All land-atmosphere coupling is local…
  …*at least initially*…

Courtesy: Michael Ek (NOAA/NCEP/EMC)

Benchmarking and Metrics

- Benchmarking LSM performance against regression models and flux tower data: PLUMBER (PALS Land sUrface Model Benchmarking Evaluation pRoject) Best et al. (2015; *J. Hydromet.*)
  - where PALS = Protocol for the Analysis of Land Surface models (PALS; *pals.unsw.edu.au*) Abramowitz (2012; GMD)

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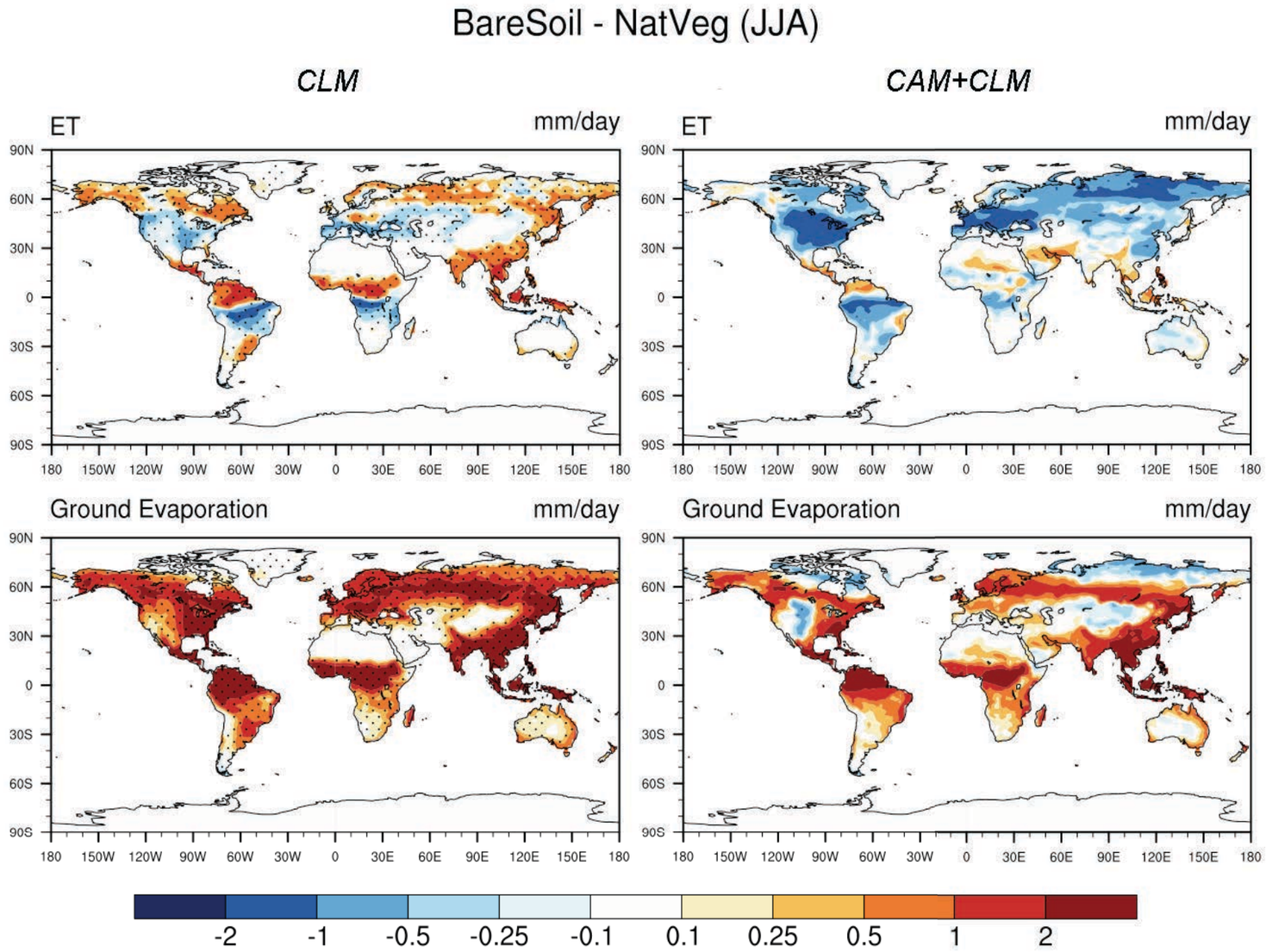
- Such benchmarking needs to be extended to coupled AGCM-LSMs.
- GLASS scientists are compiling a suite of metrics to diagnose coupled land-atmosphere processes in observations and validate them in models (cf. *www.ahmedbtawfik.com/comet/*).

Coupled processes matter!

- Uncoupled LSM – global removal of vegetation leads to an <u>increase</u> in ET over many areas.
- When LSM is coupled to AGCM so that feedbacks occur, ET decreases over most areas.



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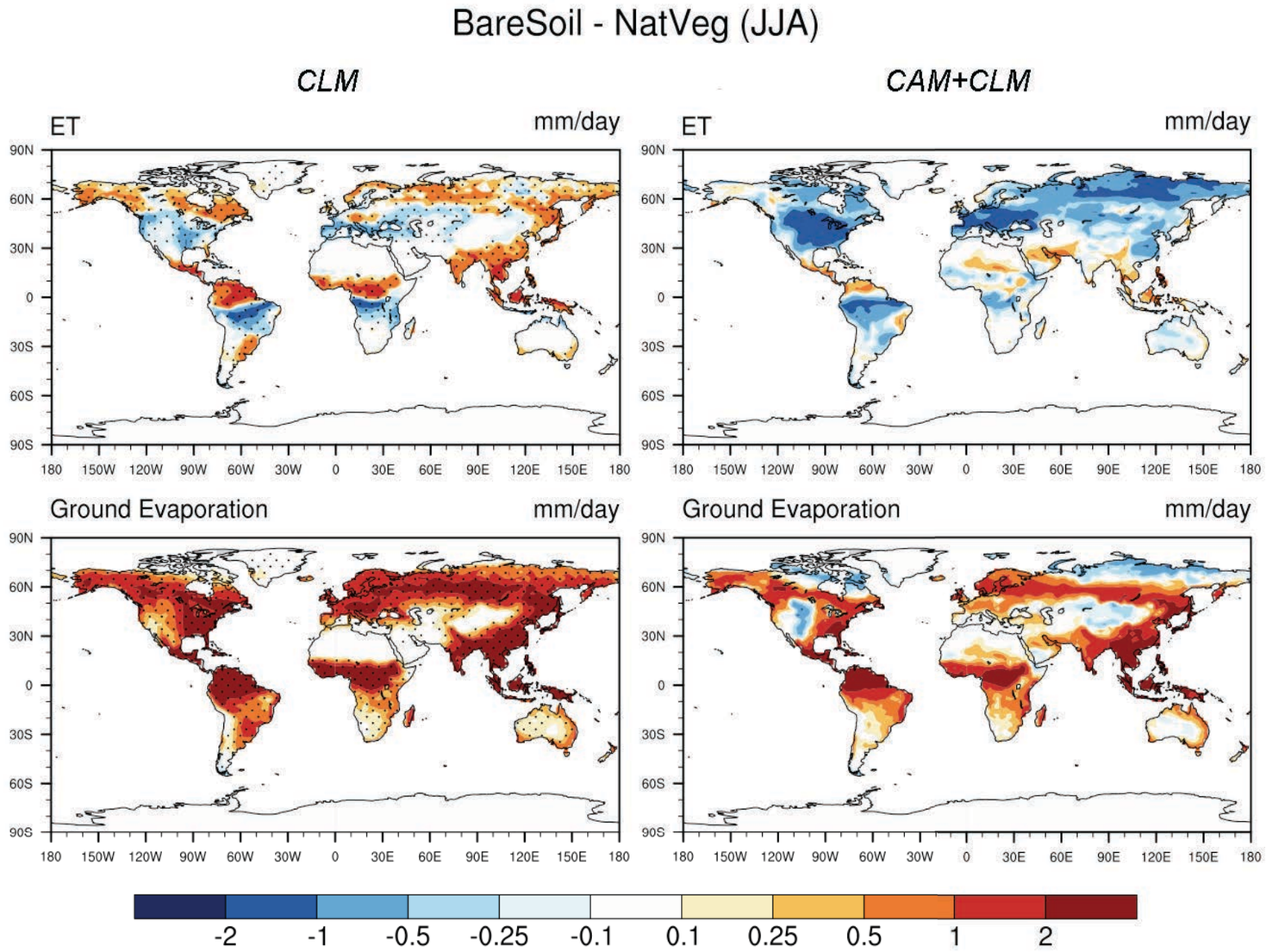
- **Model development is also a <u>coupled problem</u>!**



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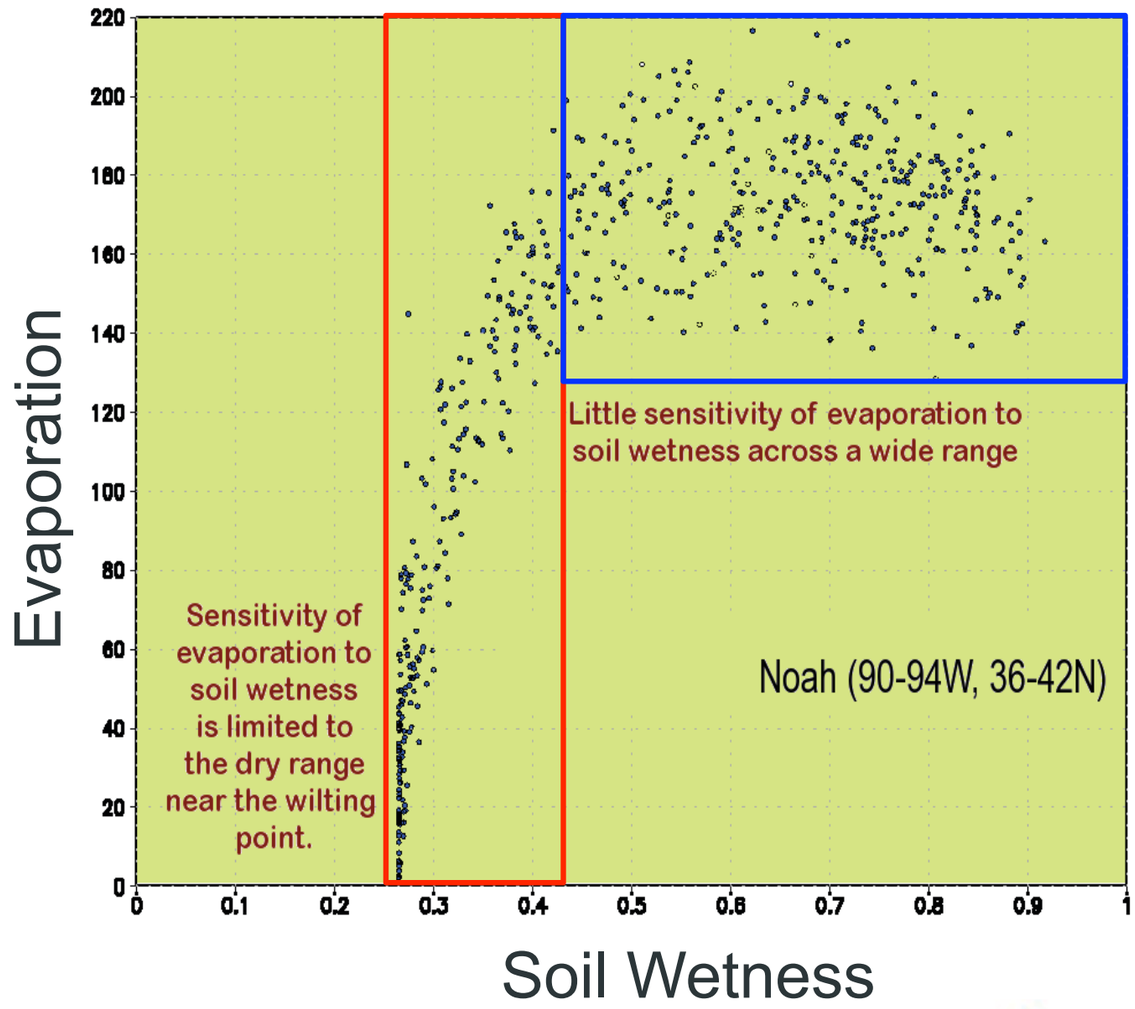
- Process-based coupled land-atmosphere metrics have been developed to understand nature, "confront" models.
- The observational data to validate models is reaching a useful mass in many regards.

Extra Slides…

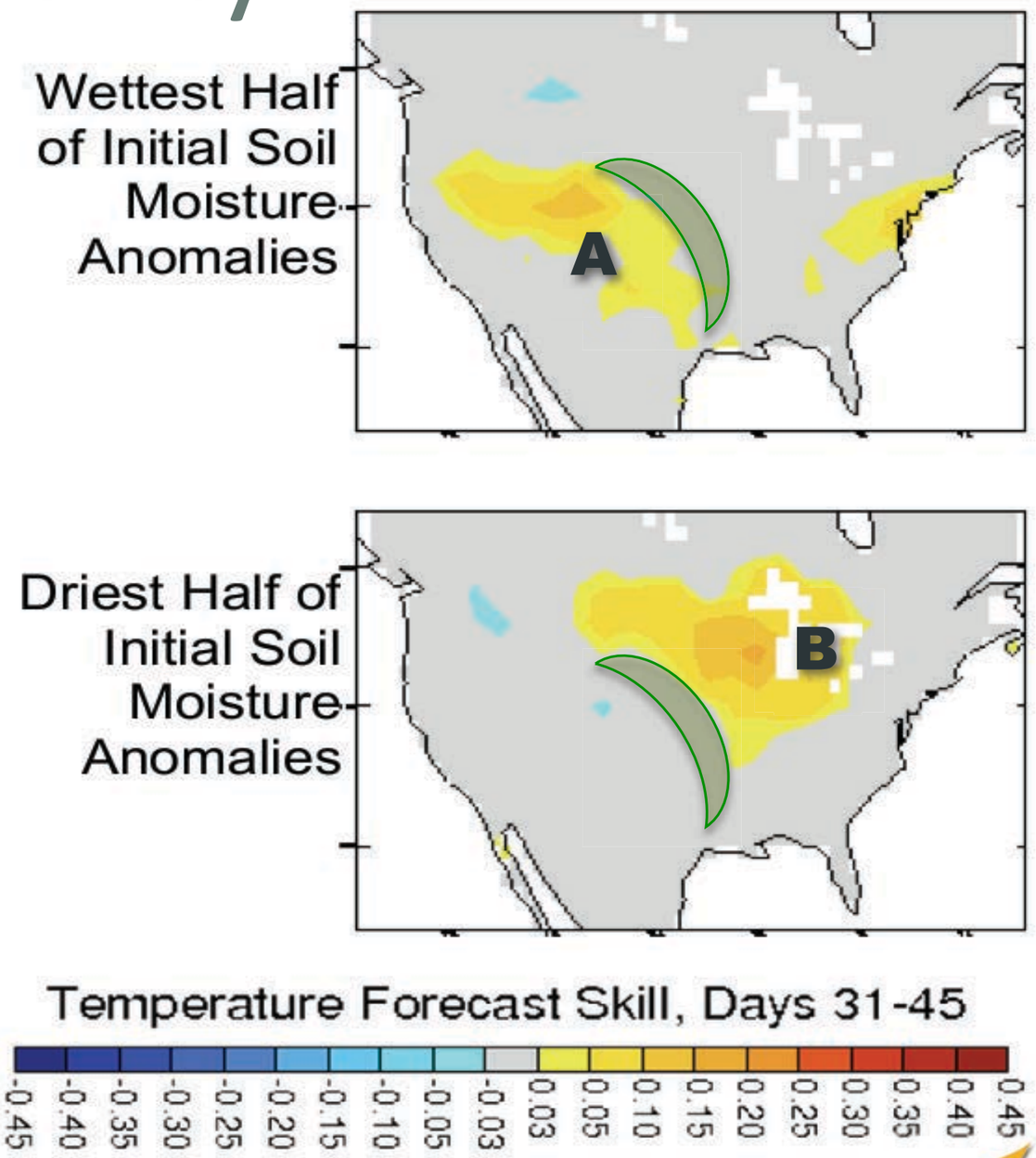
Soil Moisture Controls on Evaporation

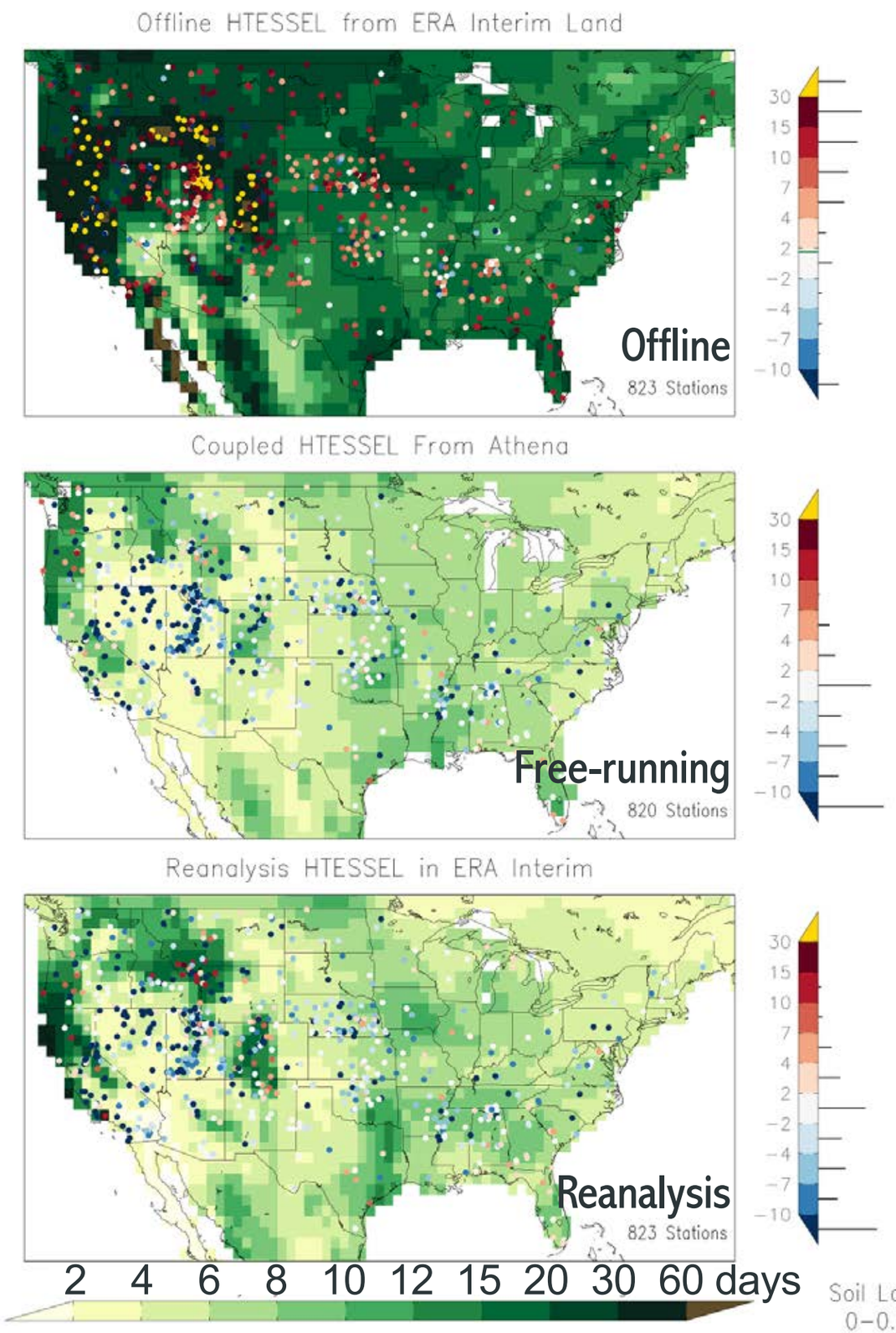
- Over many parts of the world, there is a range of SM over which evaporation rates in(de)crease as soil moisture in(de)creases (soil moisture is a limiting factor – moisture controlled).
- Above some amount of moisture in the soil, evaporation levels off.
- In that wet range, moisture is plentiful, and is no longer controlling the partitioning of fluxes (it's energy controlled).



This Affects Predictability in GLACE-2

- Soil moisture anomalies that push the local L-A system toward the regime of greatest sensitivity generate biggest improvements.
- When a desert area becomes moist (**A**), it gains predictability, and thus skill.
- When a humid area becomes dry (**B**), it gains predictability, and thus skill.



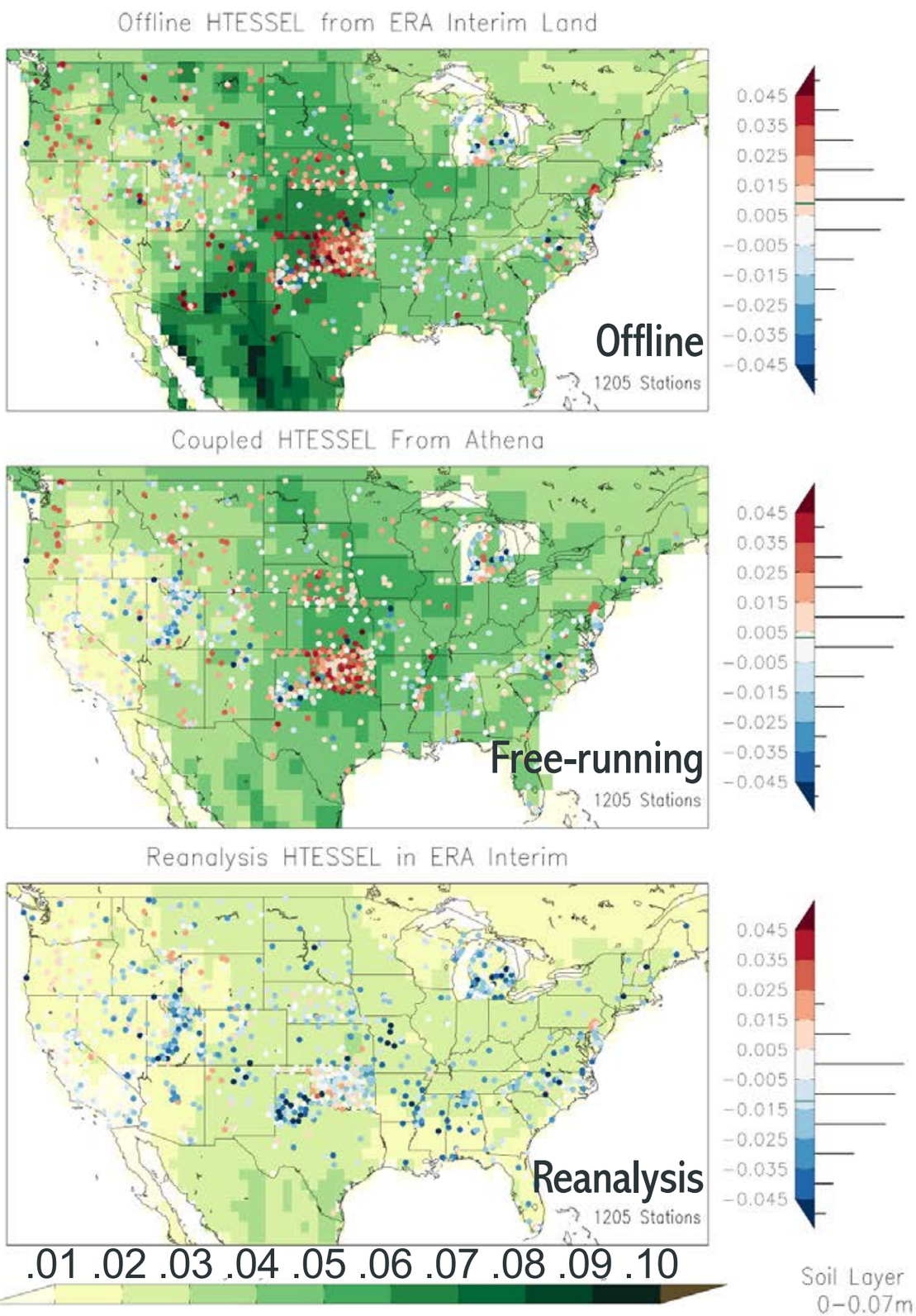


Memory: model vs obs

ECMWF Models - $\tau_{0\text{-}7cm}$

- Offline HTESSEL has <u>too much memory</u> – because no feedback??
- When coupled to IFS, HTESSEL has <u>too little memory</u> – problem with IFS rainfall spectrum?
- Data assimilation helps a little.
- Spatial patterns consistent – strongly determined by LSM parameter maps.

Shading = model τ, dots are errors relative to each station (ISMN networks shown here)



Variability (Std. Dev.)

ECMWF Models - $\sigma_{0\text{-}7cm}$

- Offline HTESSEL seems to have too much day-to-day variability of volumetric SM in most locations
- Free-running IFS has small overall bias, still has regional errors
- ERA-Interim has <u>way too little</u> variability (*Mahfoufery?*)
- This only intra-seasonal variability of daily SM – interannual σ removed!

Shading = model σ, dots are errors relative to each station (ISMN and NASMDB networks combined)

World Meteorological Organization
Working together in weather, climate and water

World Weather Research Programme

WWRP WORLD WEATHER RESEARCH PROGRAMME

"...improve accuracy, lead time and utilization of weather prediction."

WCRP World Climate Research Programme

WMO IOC ICSU International Council for Science

"Determine the predictability of climate and effect of human activities on climate."

Global Energy and Water Cycle Experiment GEWEX WCRP

"Weather, Water, Climate"

COLA Center for Ocean-Land-Atmosphere Studies GEORGE MASON UNIVERSITY

PLUMBER

- PALS Land sUrface Model Benchmarking Evaluation pRoject (PLUMBER)
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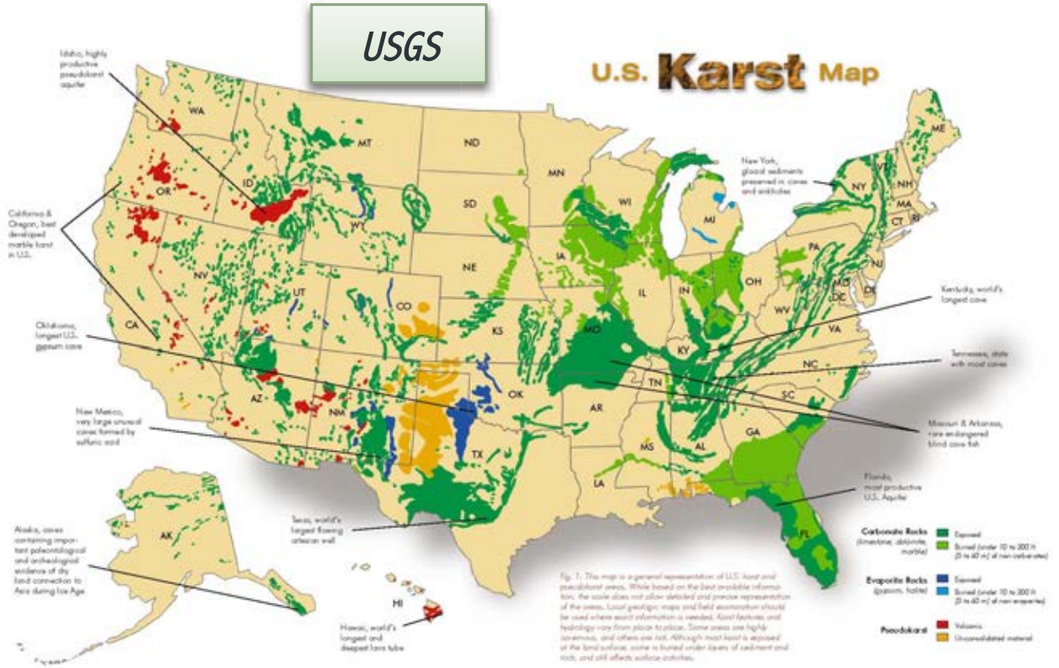
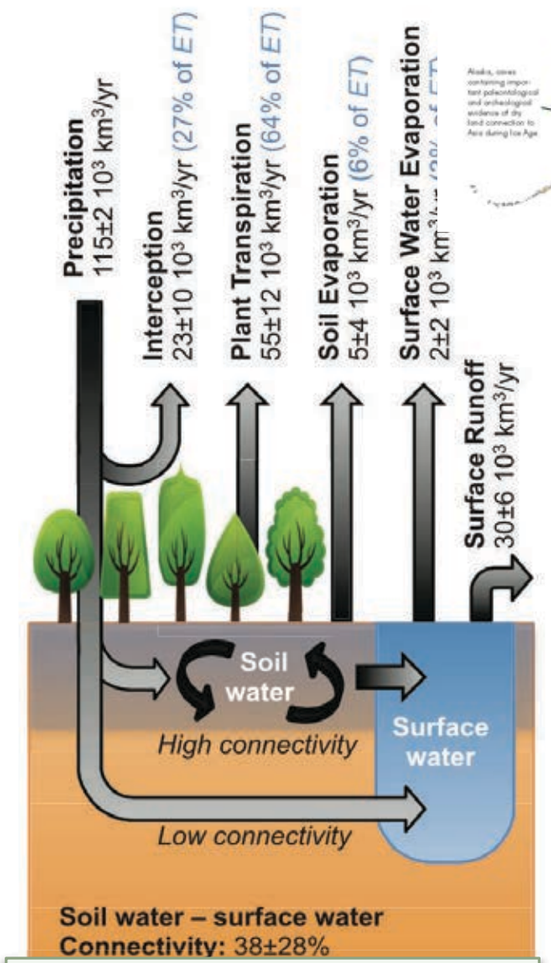
- Compare today's LSMs to some very basic statistical regressions (against SW_{DOWN} ($+T_2$ ($NL+q_2$))) for estimating surface fluxes – who validates better?
- This is a "no-brainer", right? It must be the physically-based, complex land surface models. Right?
- Wrong – especially for daily sensible heat flux regressions win!

Best et al. (2015; *J. Hydromet.*)

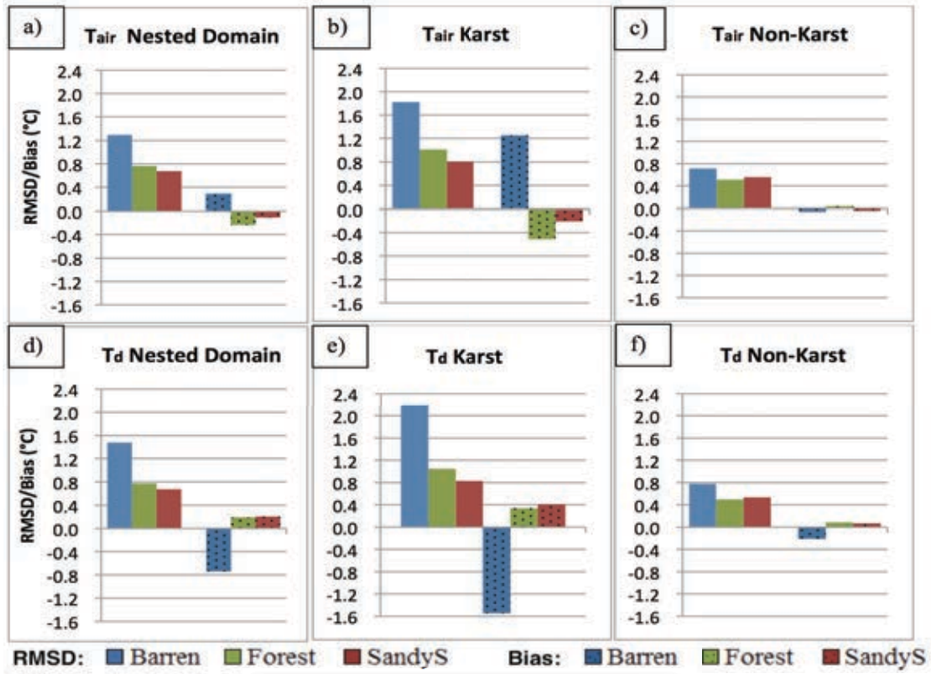
Missing Processes

- One example: hydrology with "low connectivity"
  - Many locations have fractured soils, permeable subsurface (karst)
  - Isotope studies suggest much infiltration bypasses root zone, drains straight to water table.
  - Modeling studies show errors larger over karst, sfc. flux differences affect convection, circulation.





Good et al. (2015; *Science*)



Courtesy: Xingang Fan