Soil moisture and subseasonal forecasts: Lessons from GLACE-2 and beyond

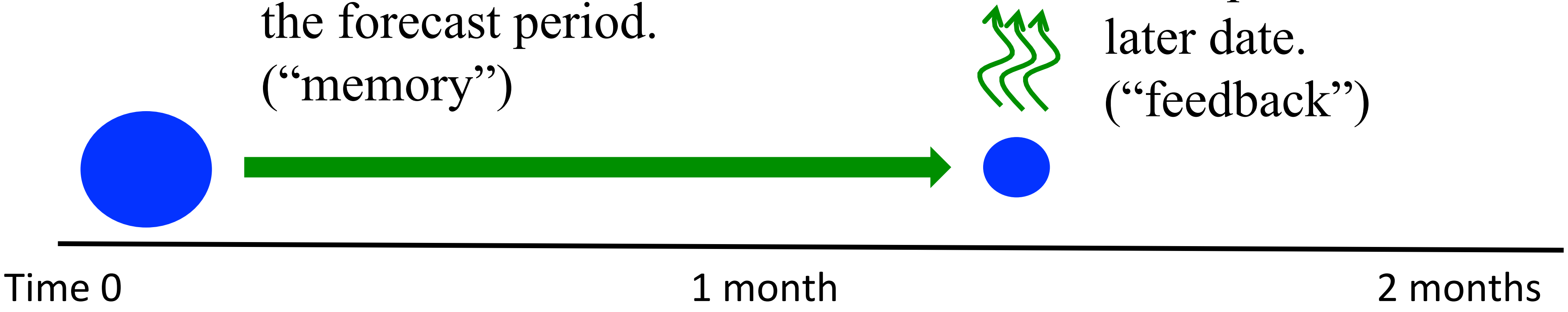
Randal Koster

Theoretical Underpinning

For an initialized land state to affect a forecast, two things must happen:

a. The initialized anomaly must be remembered into the forecast period. (“memory”)

b. The remembered anomaly must be able to affect the atmosphere at the later date. (“feedback”)



1a. Memory. Aspects of the land surface with memory that can contribute to forecasts include (NRC 2010):

-- Soil moisture

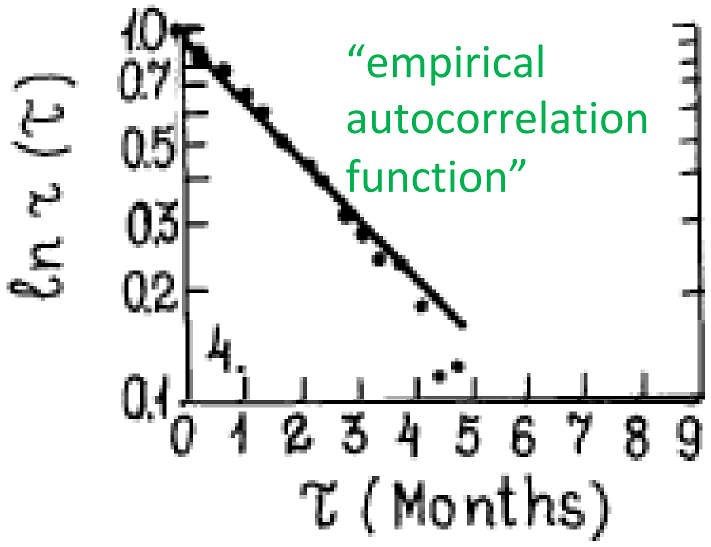
-- Snow cover

-- Vegetation state

-- Water table depth

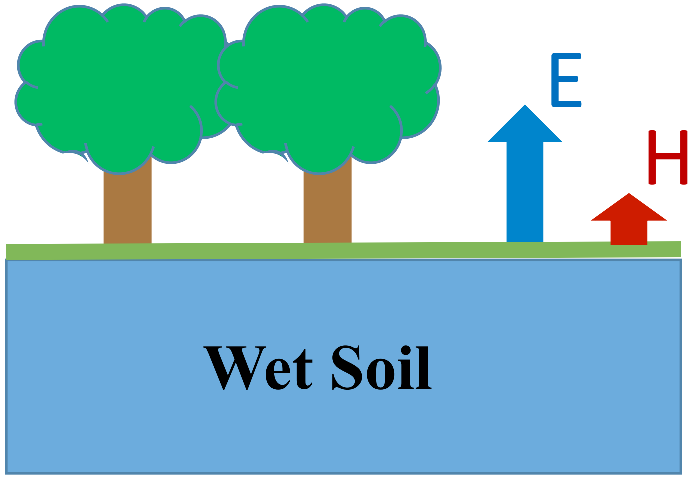
-- Land heat content

Studied the most



Vinnekov and Yeserkepova, J. Climate, 4, 66-79, 1991

1b. Feedback. How this might work for soil moisture:



Wet soil ➪ higher evap., lower sensible heat flux

This can affect local air temperature:

➪ more evaporative cooling

➪ lower air temperature

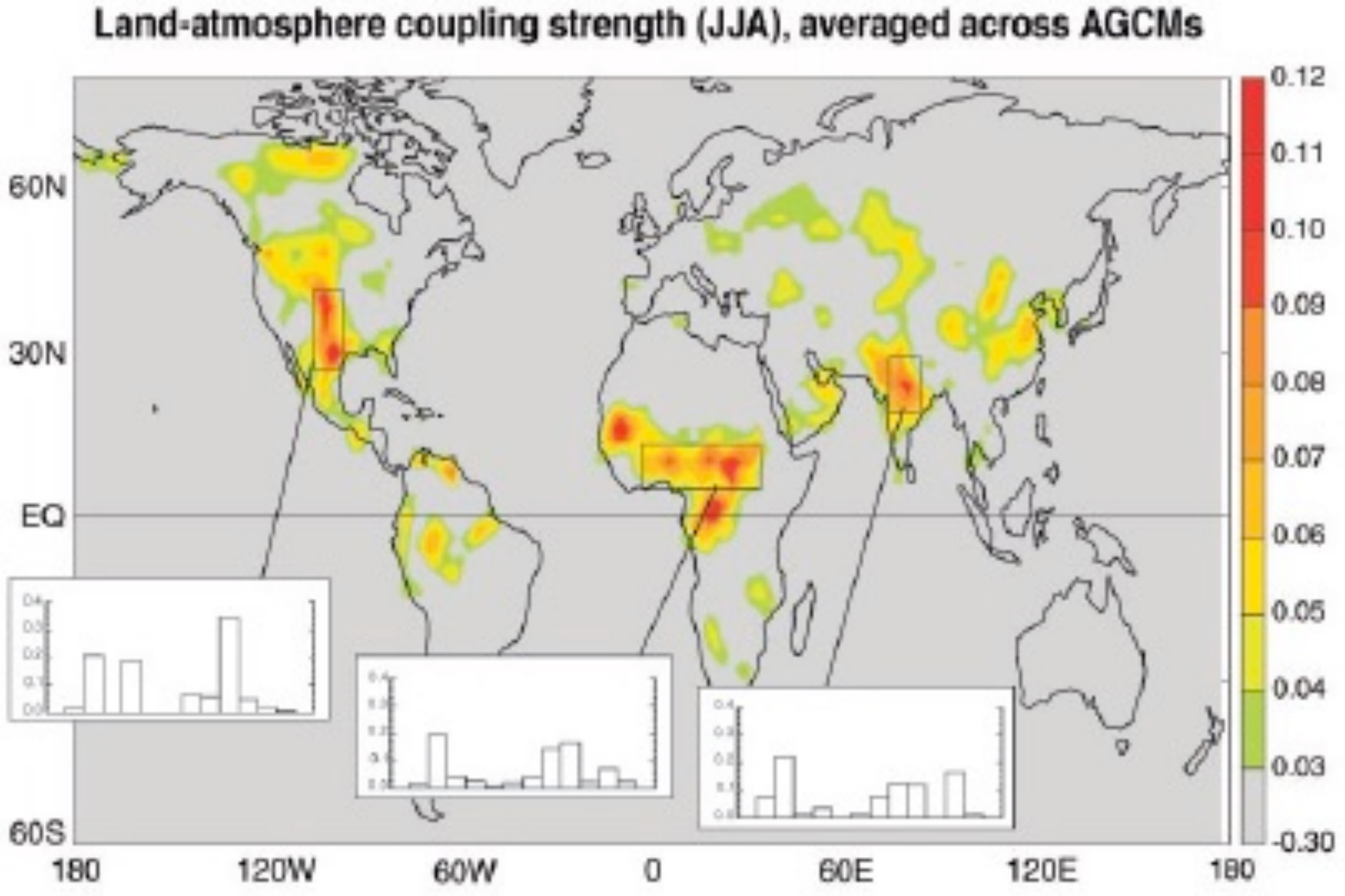
It can also affect local precipitation:

➪ boundary layer modification

➪ conditions more conducive
(or perhaps less conducive)
to onset of moist convection

Where is soil moisture/atmosphere feedback the strongest? In the transition zones between dry and wet areas.

From the GLACE experiment: Multi-model estimate of where soil moisture variability affects (short-term) rainfall variability



Koster et al., Science, 305, 1138-1140, 2004

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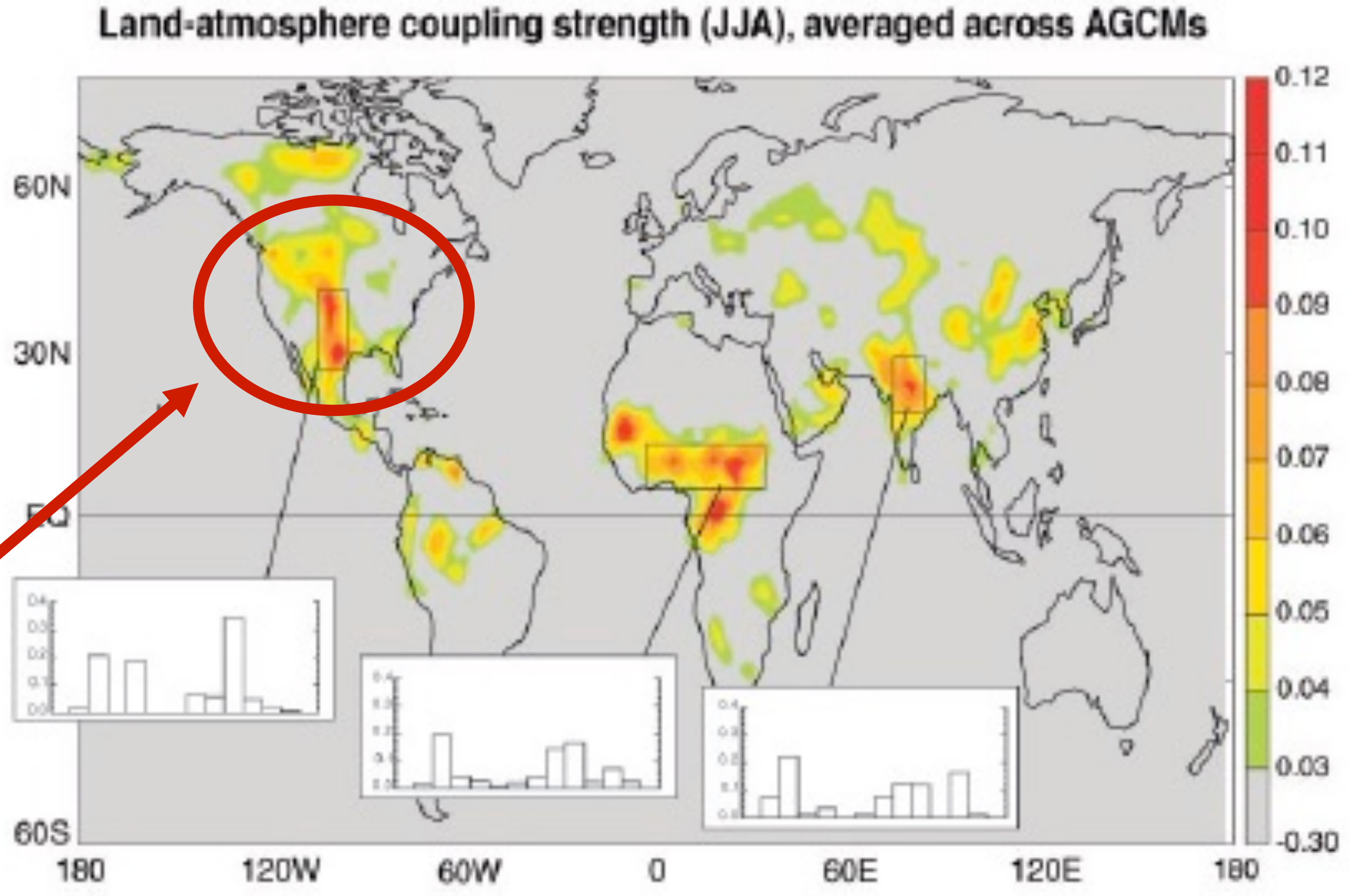
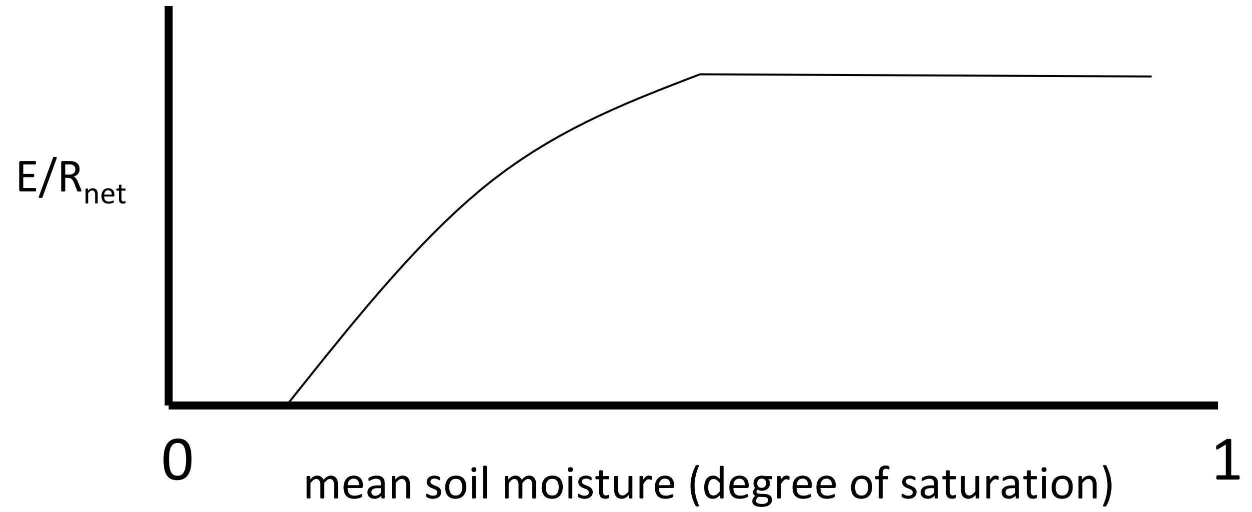


This pattern here will be discussed in later slides

Koster et al., Science, 305, 1138-1140, 2004

Why does land moisture have an effect where it does? For a large impact, need two things:

- a large enough evaporation signal
- a coherent evaporation signal – for a given soil moisture anomaly, the resulting evaporation anomaly must be predictable.



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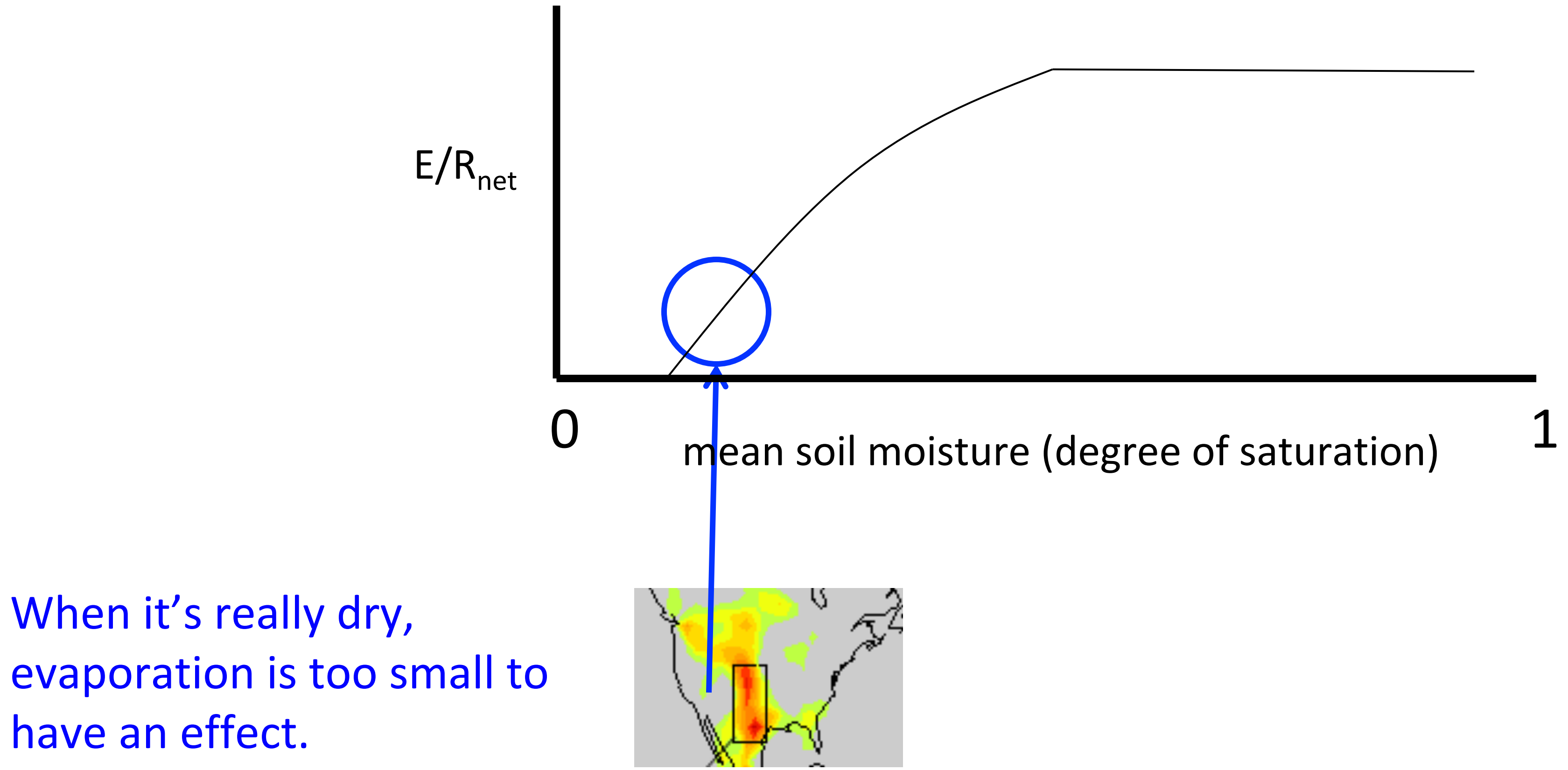

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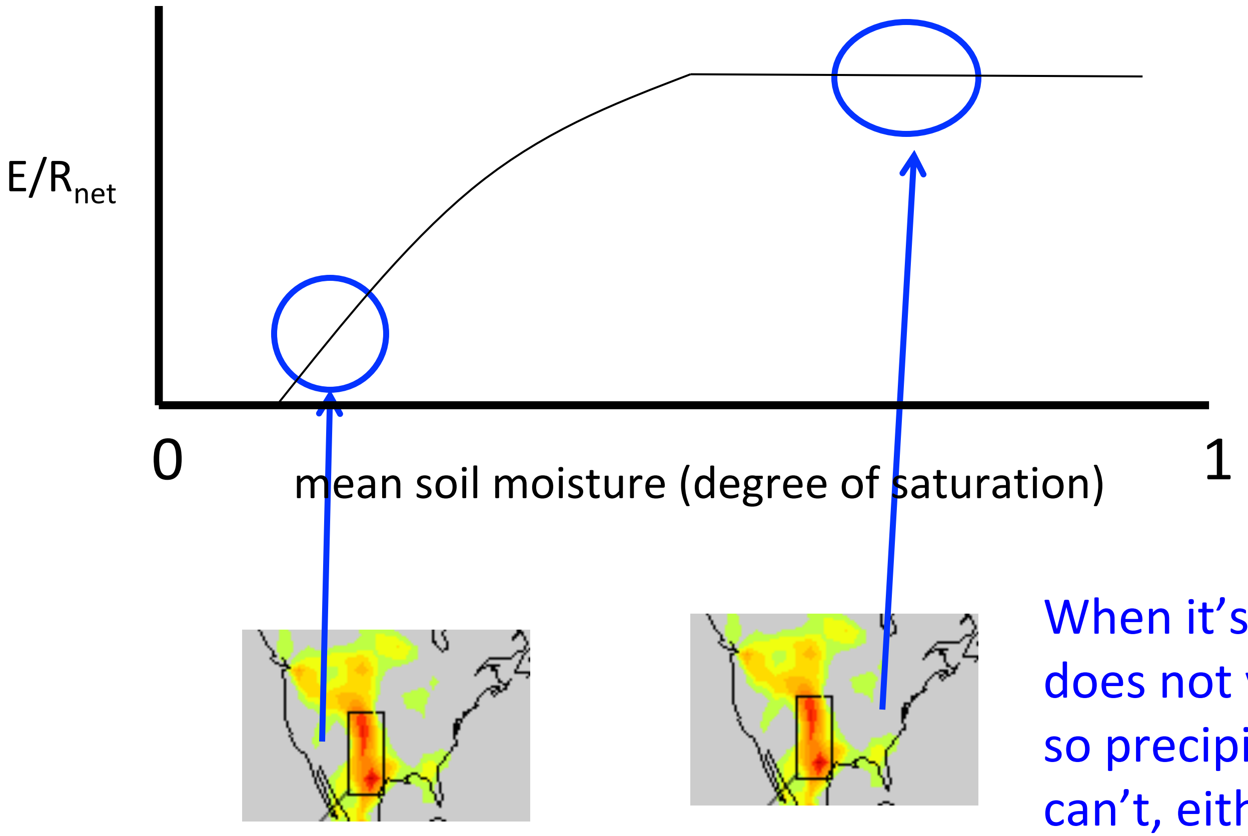

When it's really wet, evaporation does not vary with soil moisture, so precipitation and temperature can't, either.

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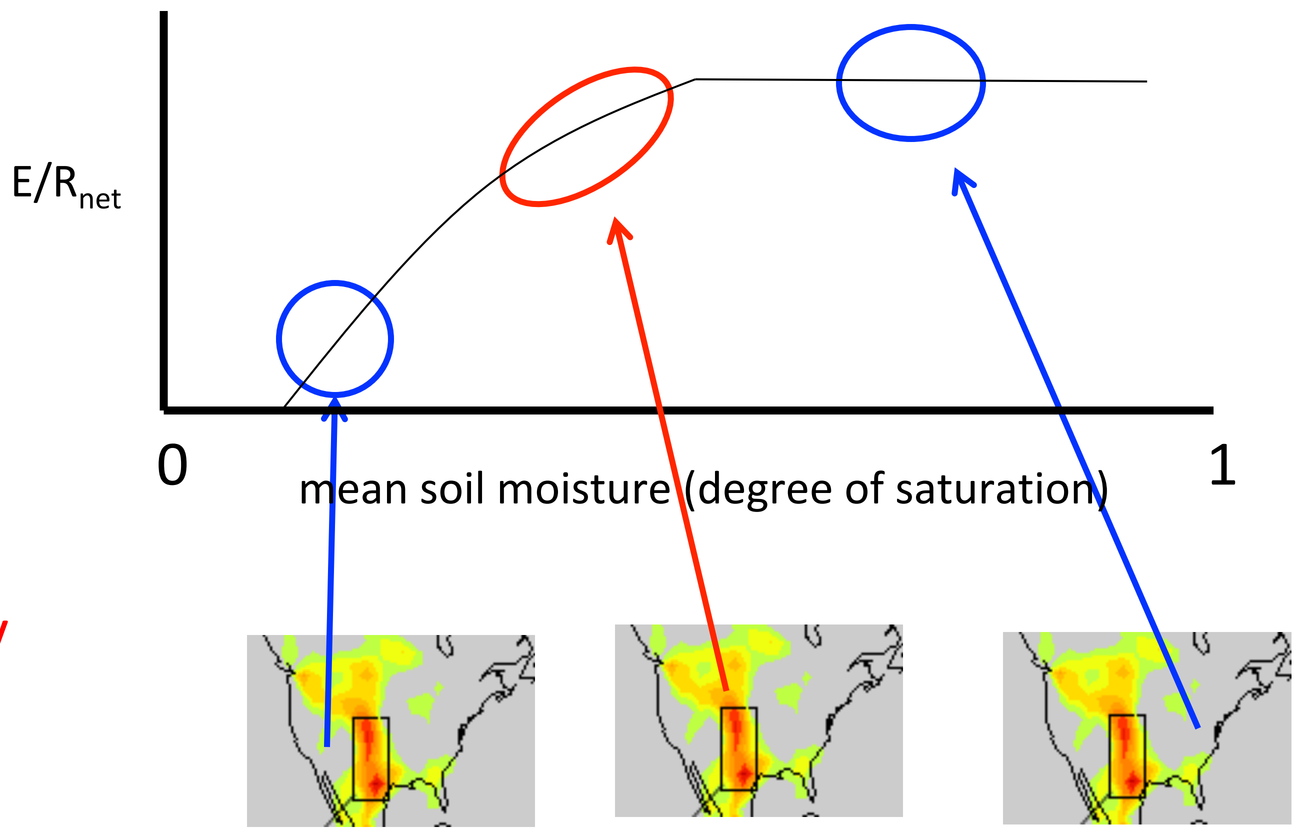
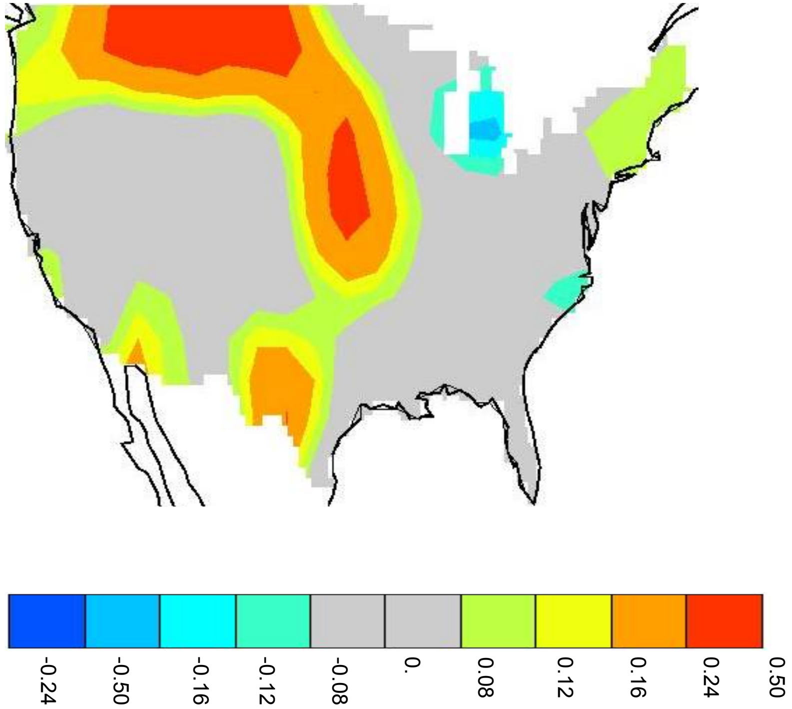


You mainly get an impact in the "sweet spot" in between: in the transition zone, where it's not too dry and not too wet.

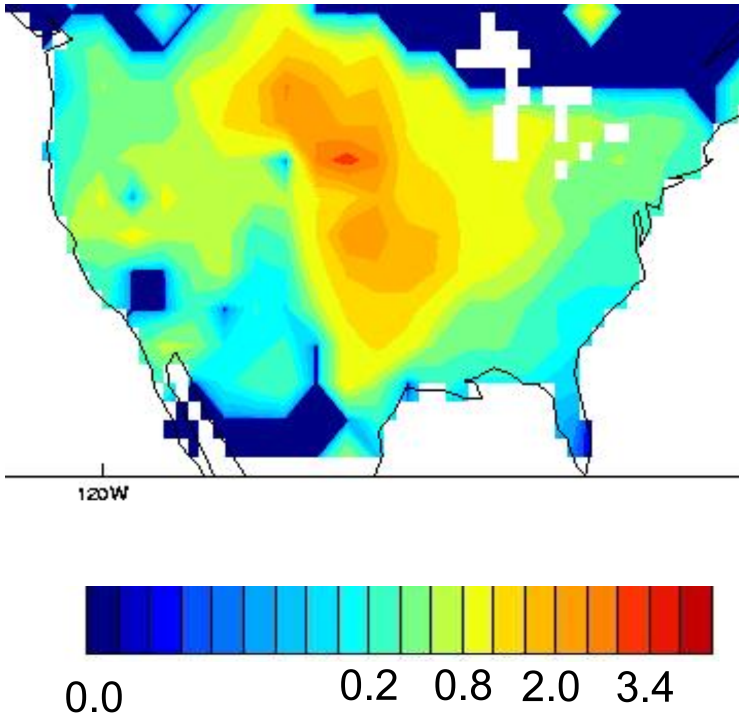
The impacts within the transition zone can be seen in the observations, as well…

July precipitation autocorrelations (pentads, twice removed)

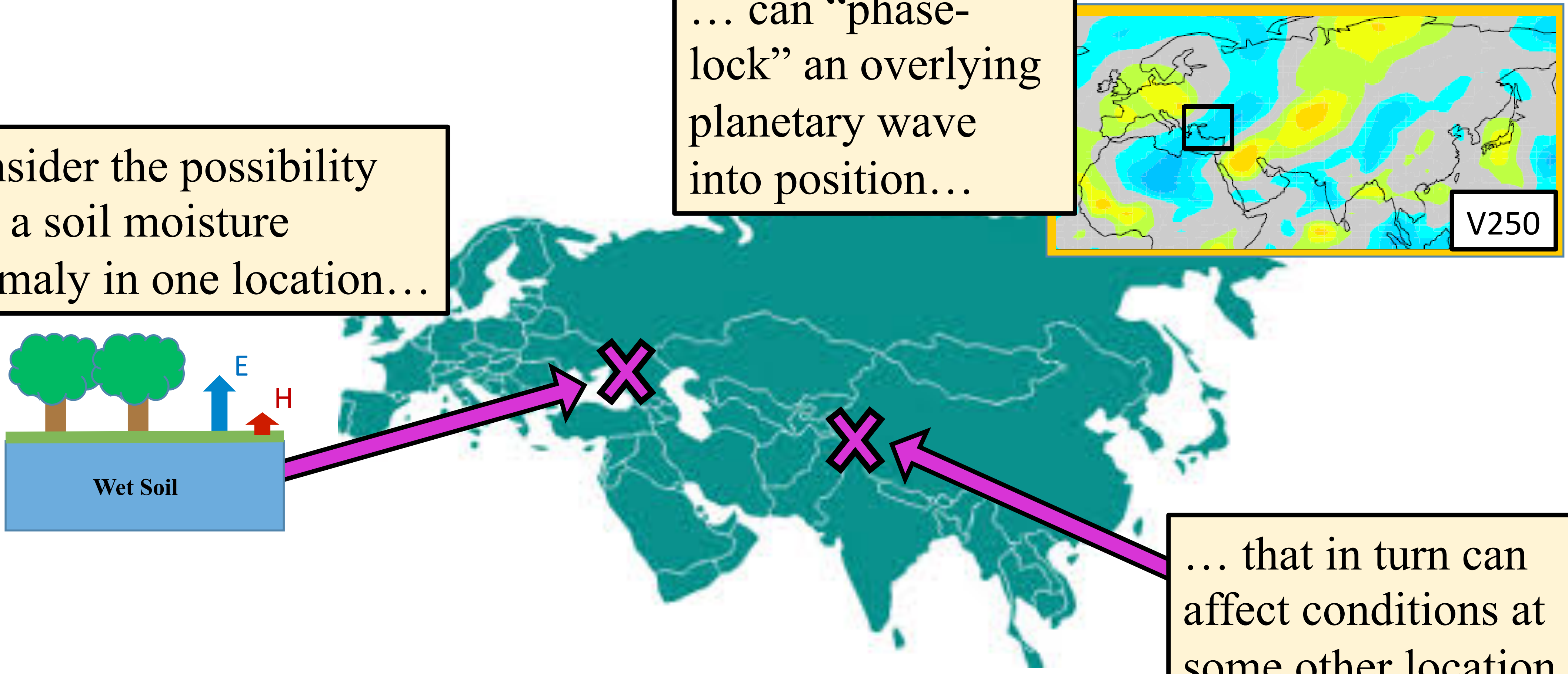


(Higgins, 50-yr P dataset)

Interannual variance of JJA temperature



Now consider potential remote effects:



Consider the possibility that a soil moisture anomaly in one location…

… can “phase-lock” an overlying planetary wave into position…

… that in turn can affect conditions at some other location.

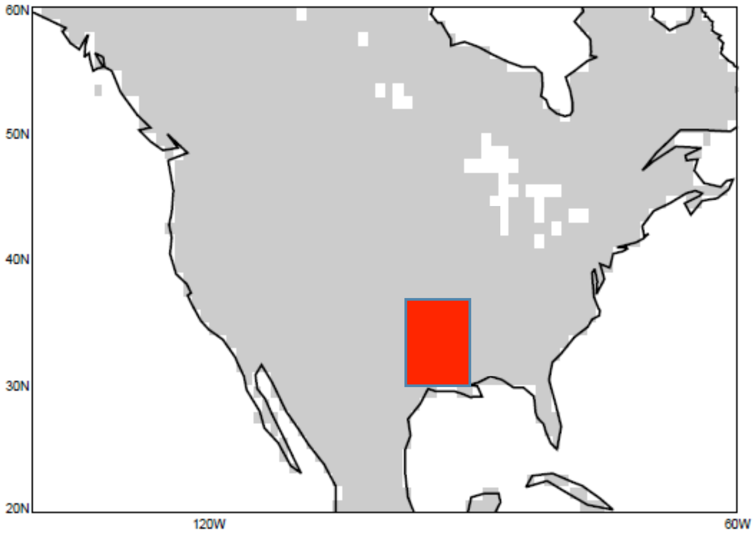
Experimental Design

Control: Ensemble (768 members) of April-July simulations using atmosphere-land components of the GEOS-5 system, at 1°×1° resolution.

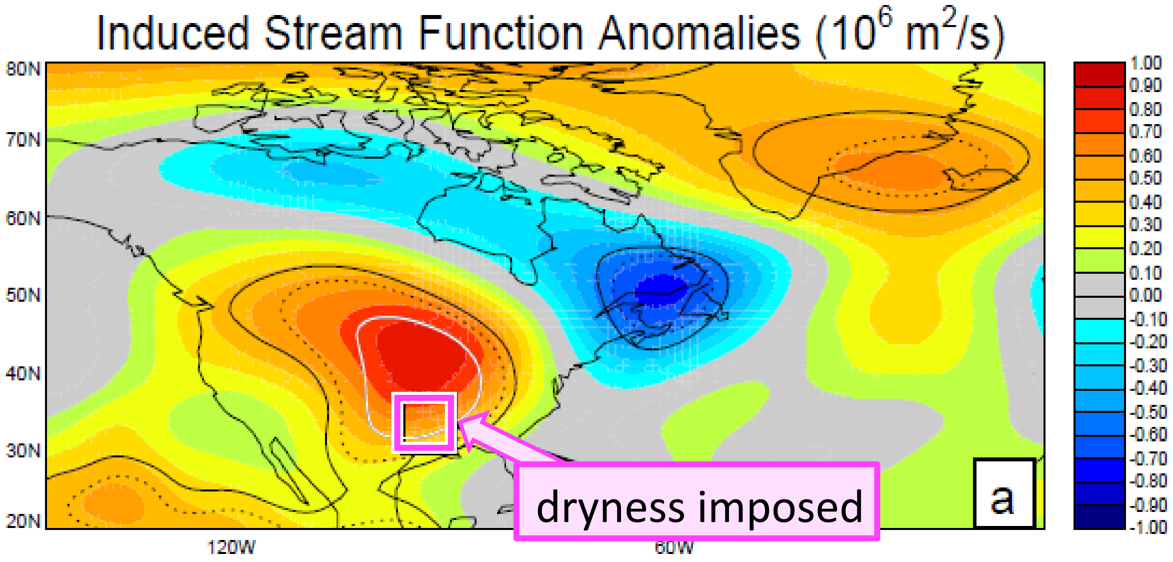
Experiment: Same as control, except:

(a) Smaller ensemble size (192 or 96 members)

(b) Precipitation in a selected region is not allowed to hit the surface during April-June, *forcing the surface to become dry there*.



The dry surface anomaly does (on average) induce a wave pattern in June-July…



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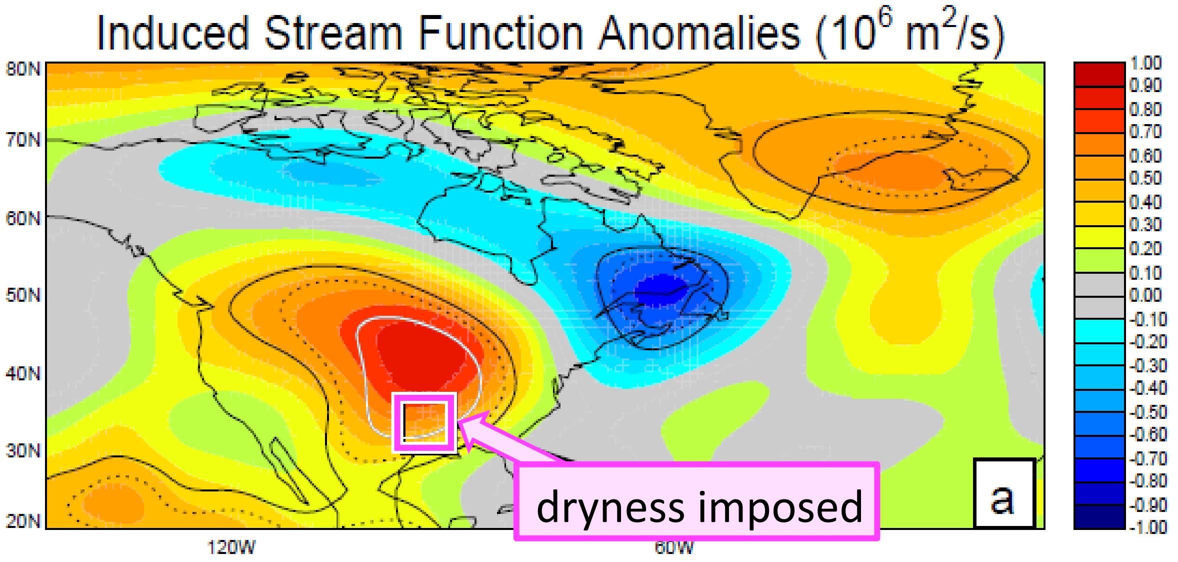
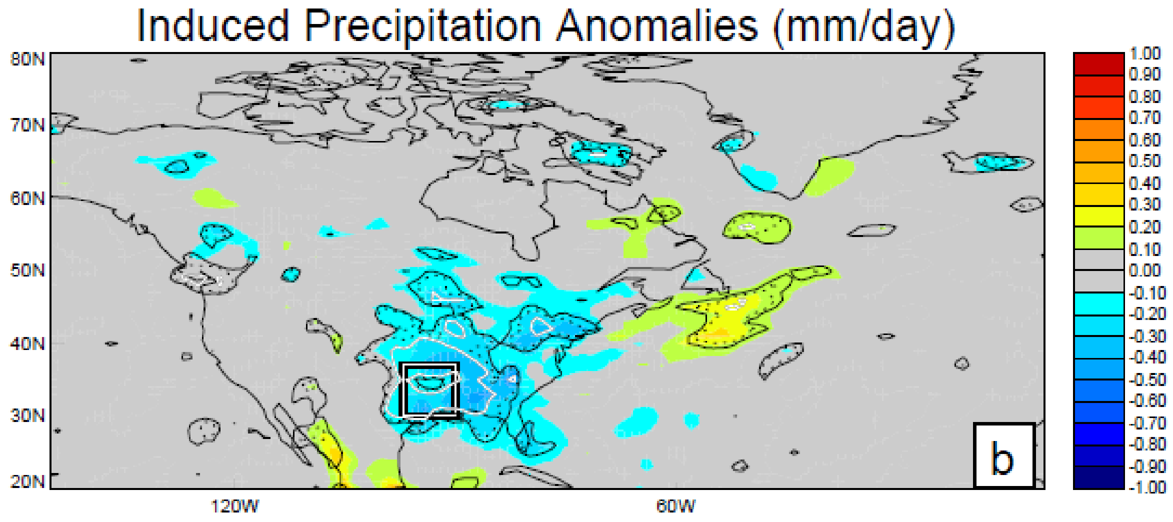
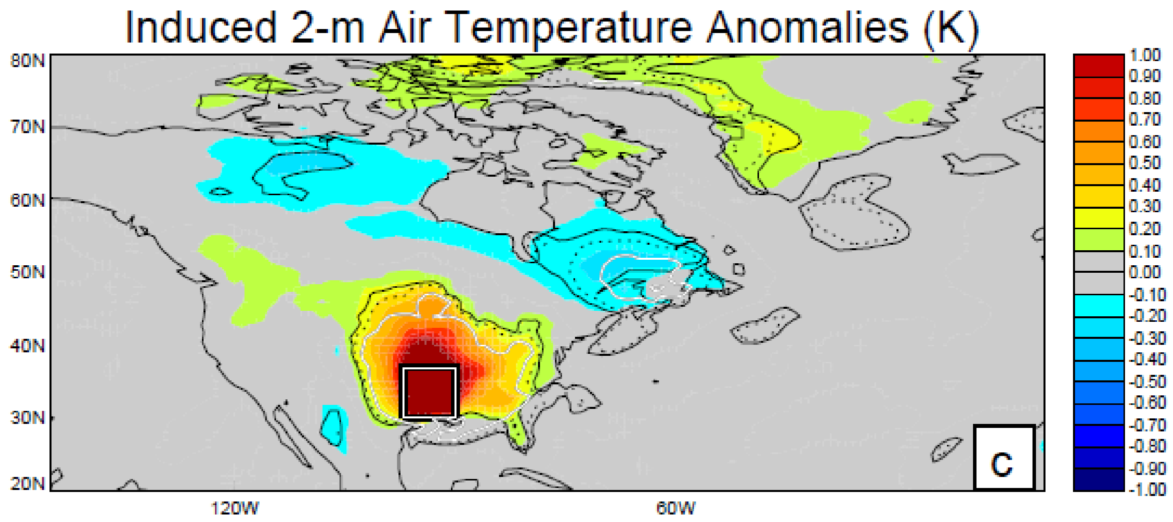
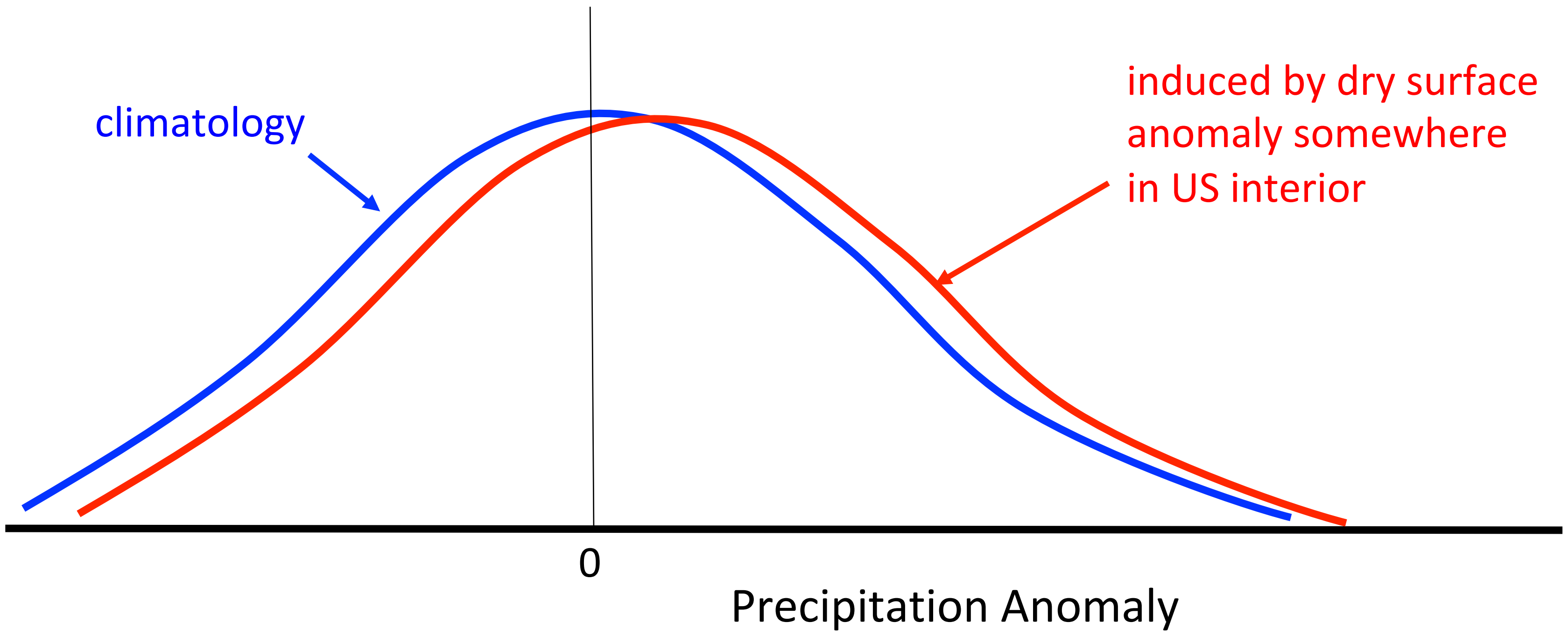






… that does lead to remote, wavelike patterns in T2M and precipitation anomalies.

Important consideration: Given the large number of ensemble members needed to extract the signals of interest from the AGCM, we are talking here about shifts in PDFs. These shifts are subtle, and their relevance (e.g.) to forecasting large-scale dryness are yet to be demonstrated.

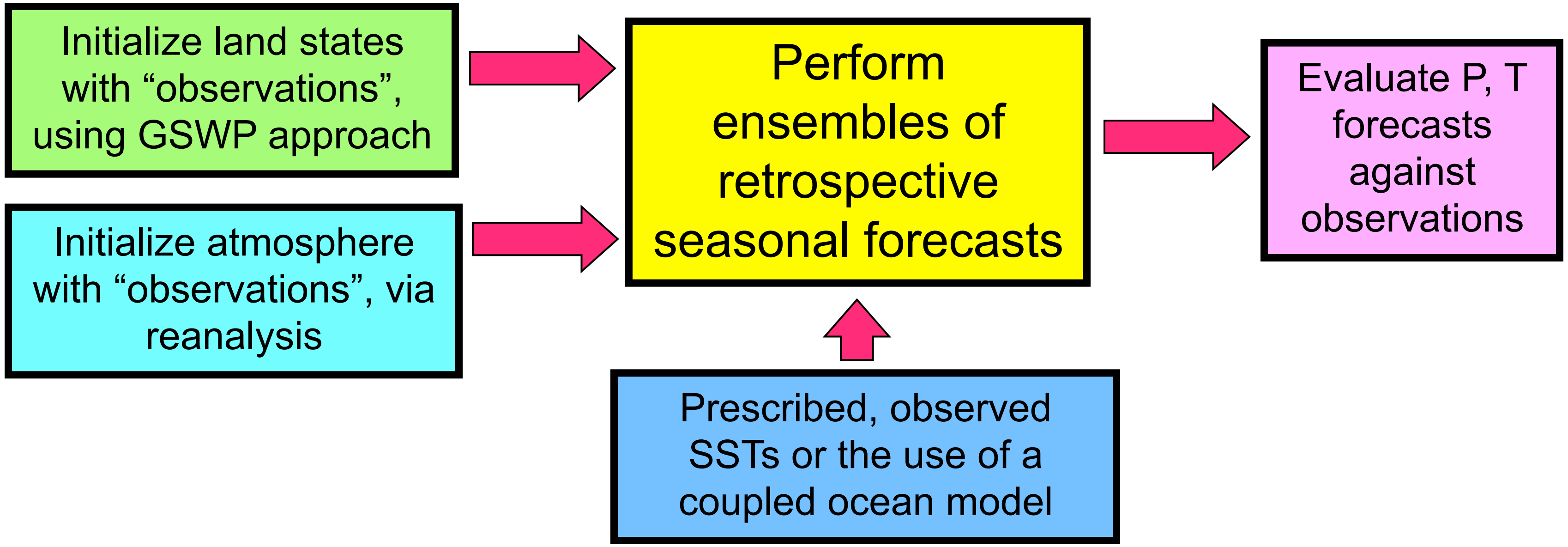


Multi-model Subseasonal Forecast Experiment: GLACE-2

Overall goal of GLACE-2: Determine the degree to which realistic land surface (soil moisture) initialization contributes to forecast skill (rainfall, temperature) at 1-2 month leads, using a wide array of state-of-the-art forecast systems.

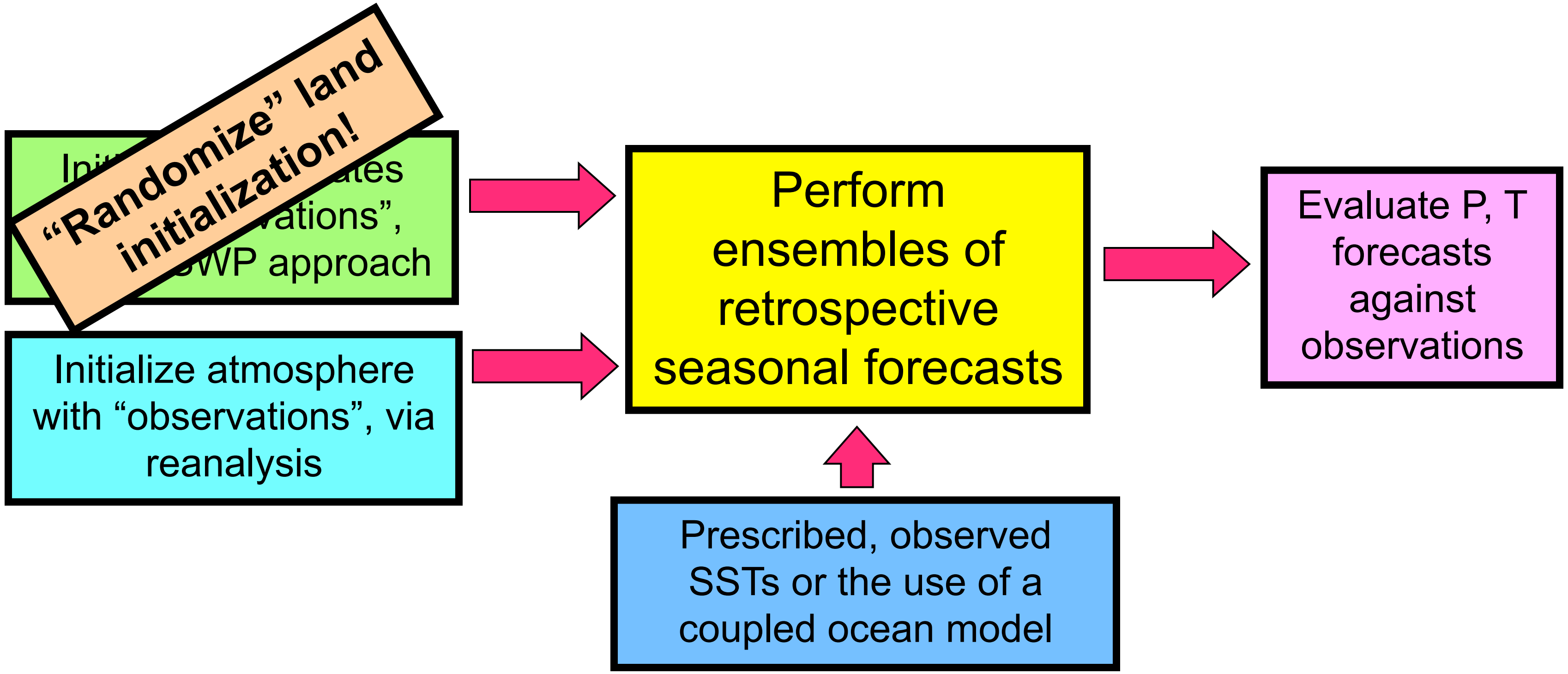
GLACE-2:
Experiment Overview

Series 1:



GLACE-2:
Experiment Overview

Series 2:



GLACE-2:
Experiment Overview

Step 3: Compare skill in two sets of forecasts; isolate contribution of realistic land initialization.

Forecast skill, Series 1 − Forecast skill, Series 2 = Forecast skill due to land initialization

Baseline: 100 Forecast Start Dates

	Apr 1	Apr 15	May 1	May 15	Jun 1	Jun 15	Jul 1	Jul 15	Aug 1	Aug 15
1986	●	●	●	●	●	●	●	●	●	●
1987	●	●	●	●	●	●	●	●	●	●
1988	●	●	●	●	●	●	●	●	●	●
1989	●	●	●	●	●	●	●	●	●	●
1990	●	●	●	●	●	●	●	●	●	●
1991	●	●	●	●	●	●	●	●	●	●
1992	●	●	●	●	●	●	●	●	●	●
1993	●	●	●	●	●	●	●	●	●	●
1994	●	●	●	●	●	●	●	●	●	●
1995	●	●	●	●	●	●	●	●	●	●

Each ensemble consists of 10 simulations, each running for 2 months.

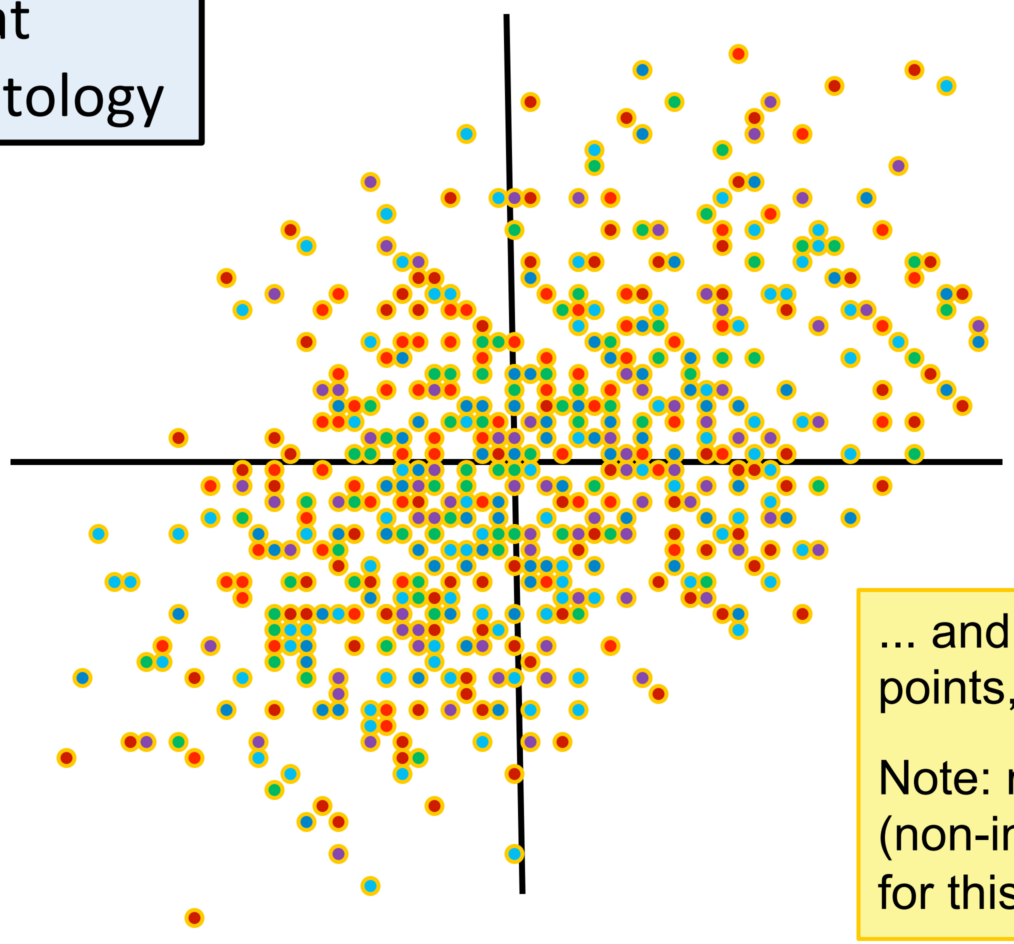
→ 1000 2-month simulations.

Participant List

Group/Model	# models	Points of Contact
1. NASA/GSFC (USA): GMAO seasonal forecast system (old and new)	2	R. Koster, S. Mahanama
2. COLA (USA): COLA GCM, NCAR/CAM GCM	2	P. Dirmeyer, Z. Guo
3. Princeton (USA): NCEP GCM	1	E. Wood, L. Luo
4. IACS (Switzerland): ECHAM GCM	1	S. Seneviratne, E. Davin
5. KNMI (Netherlands): ECMWF	1	B. van den Hurk
6. ECMWF	1	G. Balsamo, F. Doblas-Reyes
7. GFDL (USA): GFDL system	1	T. Gordon
8. U. Gothenburg (Sweden): NCAR	1	J.-H. Jeong
9. CCSR/NIES/FRCGC (Japan): CCSR GCM	1	T. Yamada
10. FSU/COAPS	1	M. Boisserie
11. CCCma	1	B. Merryfield
	13 models	

Multi-model "consensus" measure of skill: a prerequisite to a conditional skill analysis

Compute Z-scores for each model relative to that model's climatology



... and then compute r^2 from 6MN points, N forecasts from each model.

Note: models may behave similarly (non-independently); must account for this in significance testing.

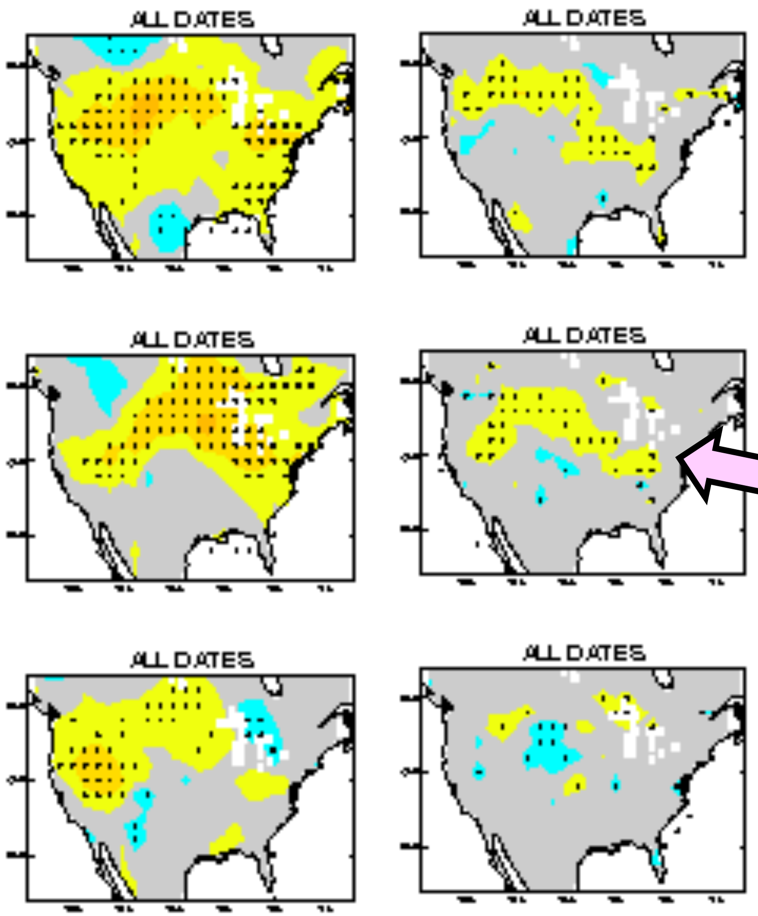
Forecasts: “Consensus” skill due to land initialization (JJA)

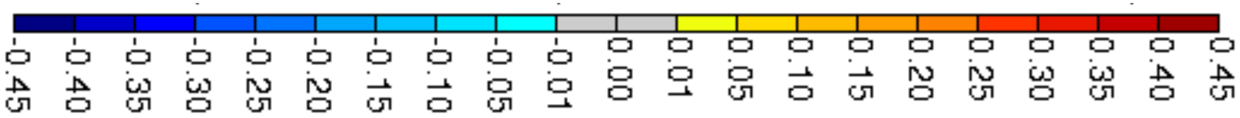
temperature **precipitation**

16-30 days

31-45 days

46-60 days



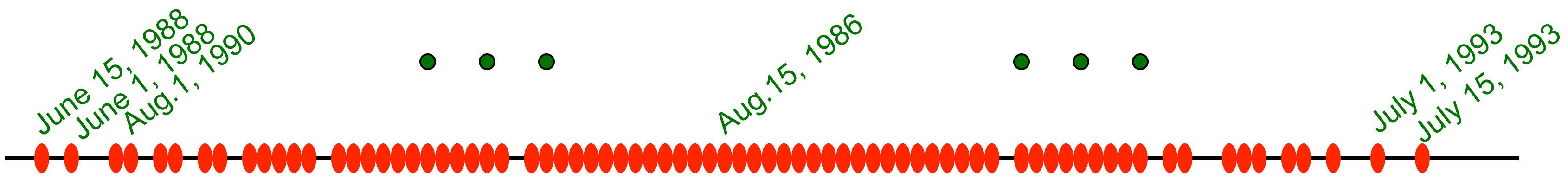


Some small contribution to precipitation forecast skill even beyond 1 month!

(“Weaker” models are averaged in with “stronger” ones.)

Conditional skill: **Suppose we know at the start of a forecast that the initial soil moisture anomaly, W_i, is relatively large...**

Step 1: At each grid cell, rank the forecast periods from lowest initial soil moisture to highest initial soil moisture:

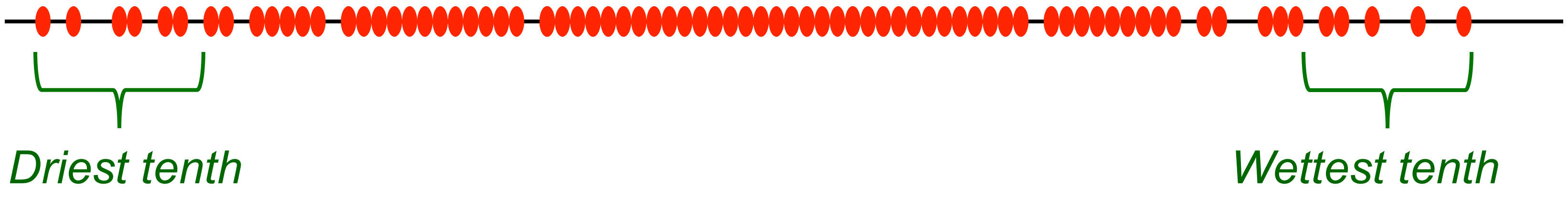


Step 2: Separate into terciles:

<u>Conditional skill:</u> Suppose we know at the start of a forecast that the initial soil moisture anomaly, W_i, is relatively large...

Step 2: Separate into quintiles:

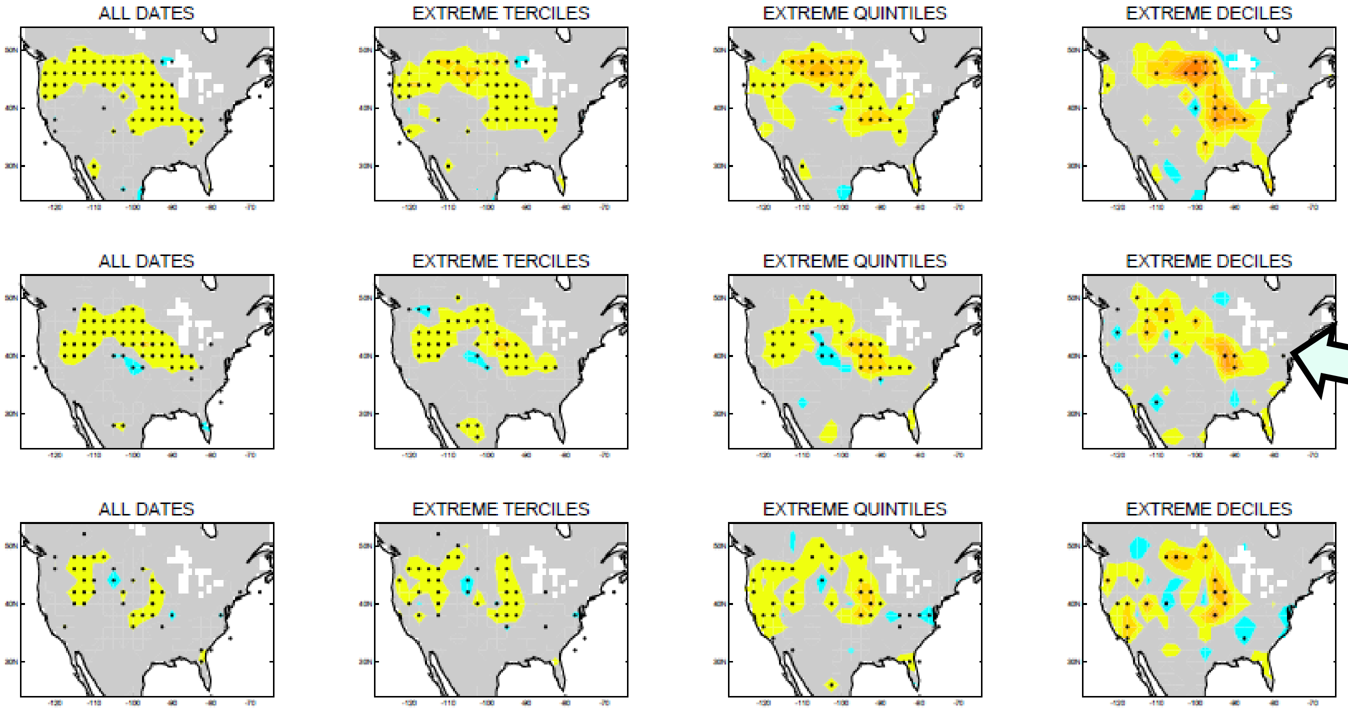
Step 3: Separate into deciles:



Precipitation forecasts: Increase in skill due to land initialization (JJA)

(conditioned on strength of local initial soil moisture anomaly)

	all points	Extreme terciles	Extreme quintiles	Extreme deciles
16-30 days				
31-45 days				
46-60 days				



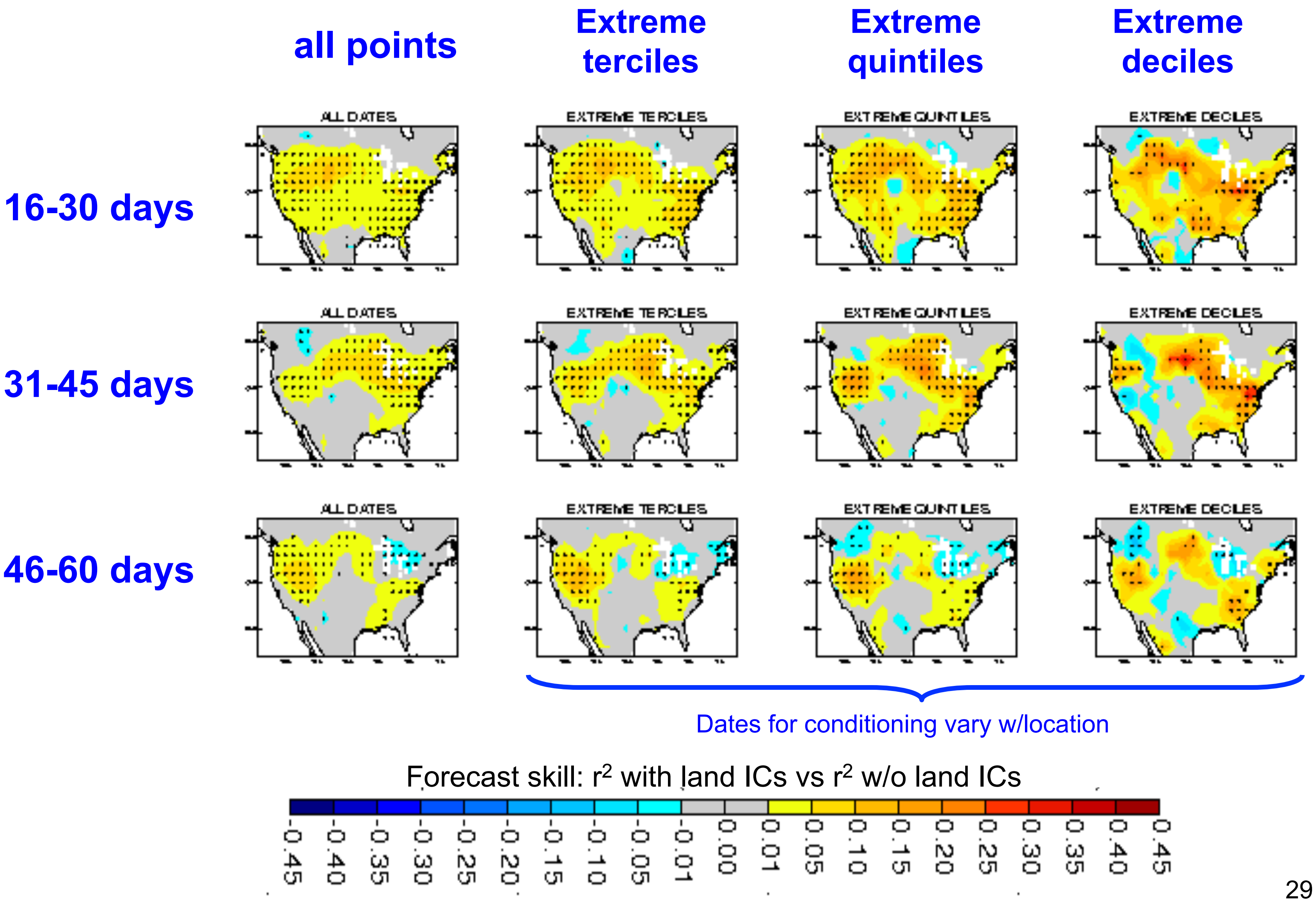
Dates for conditioning vary w/location

Contributions to forecast skill increase when only larger initial soil moisture anomalies are considered.

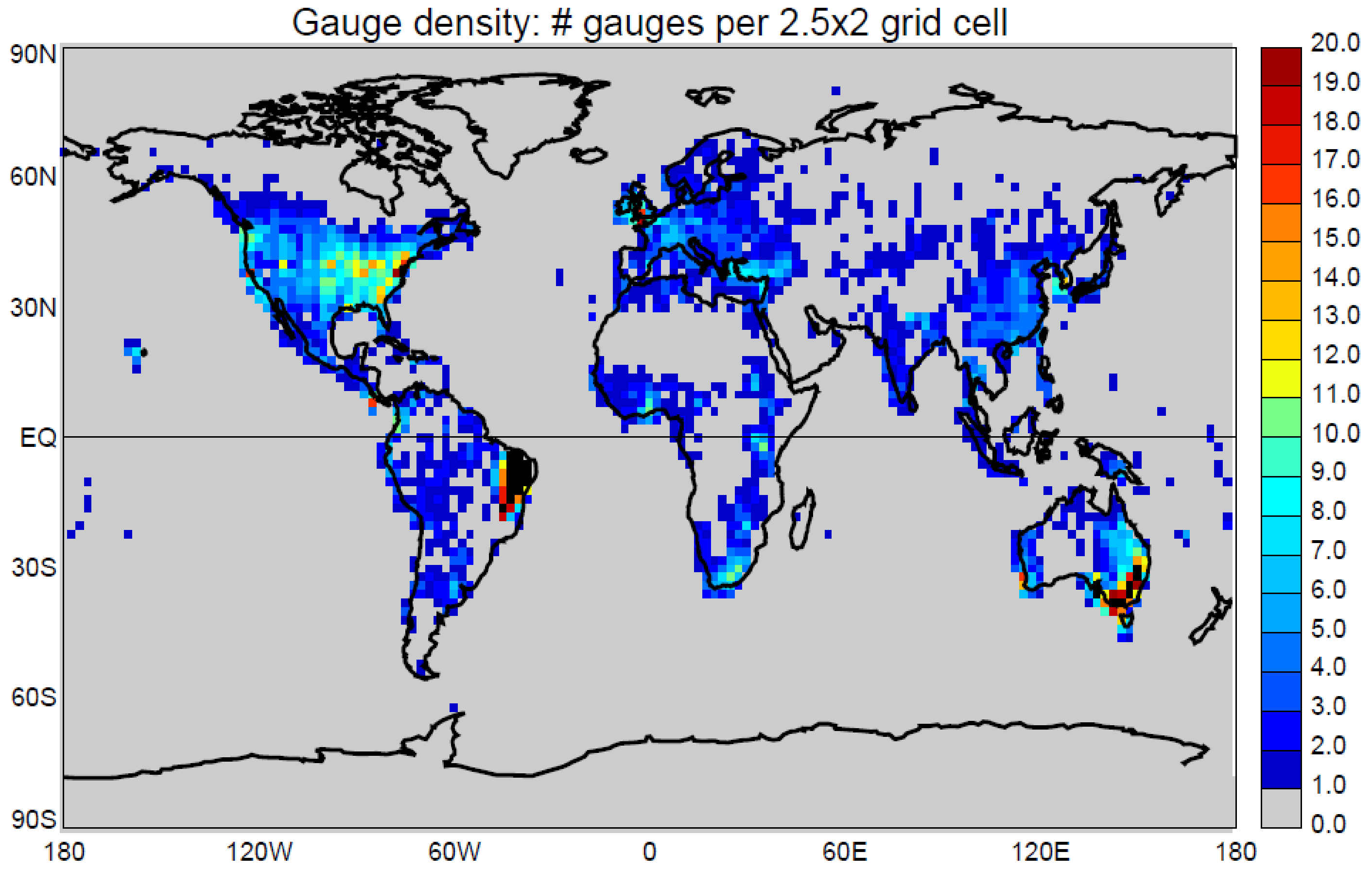
Forecast skill: r^2 with land ICs vs r^2 w/o land ICs

Temperature forecasts: Increase in skill due to land initialization (JJA)

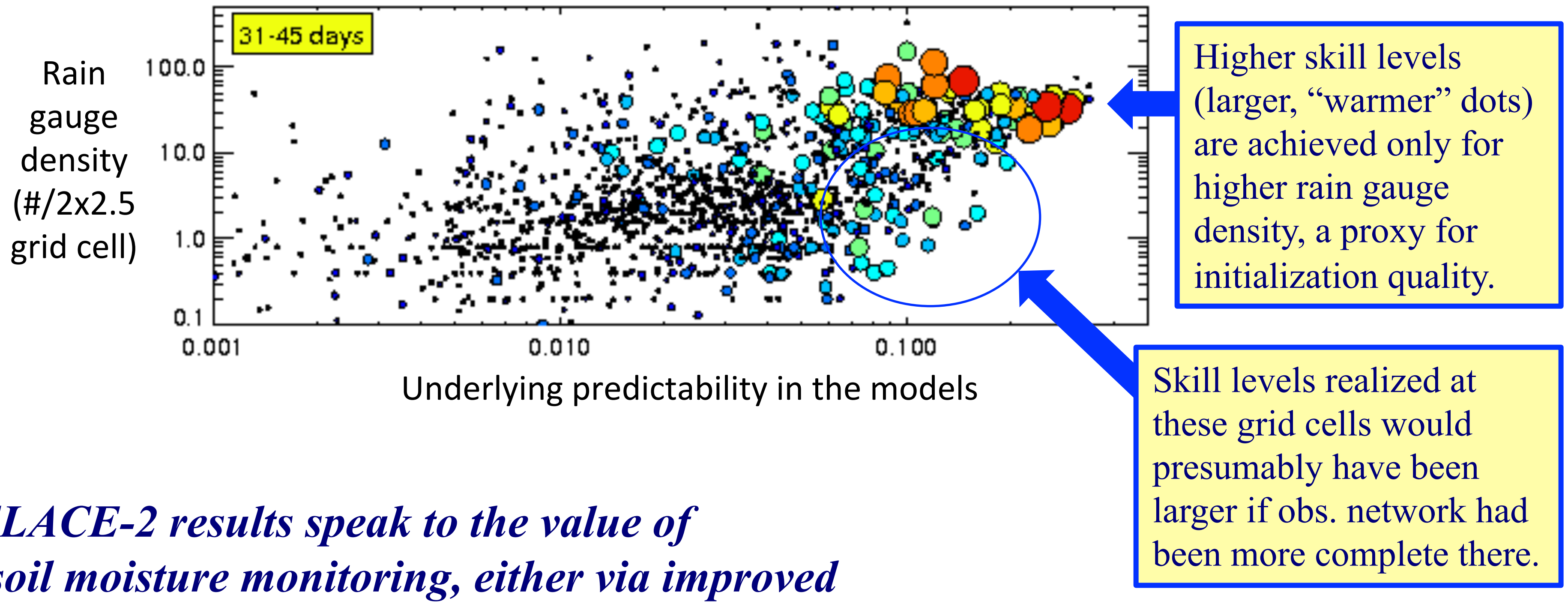
(conditioned on strength of local initial soil moisture anomaly)



Note also: the skill levels achieved are related to the <u>quality</u> of the observation networks underlying the initialization.



Air Temperature Forecast Skill at 31-45 Days Derived from Soil Moisture Initialization. (Each dot represents a location; size of dot represents skill achieved there.)



➡ ***The GLACE-2 results speak to the value of improved soil moisture monitoring, either via improved rain measurement or via soil moisture sampling from space.***

Conclusions of GLACE-2 Analysis

1. The individual models vary in their ability to extract forecast skill from land initialization.

In general:

-- Low skill for precipitation

-- Moderate skill (in places) for temperature, even out to two months.

2. Land initialization impacts on skill increase dramatically when conditioned on the size of the initial local soil moisture anomaly.

→ If you know the local soil moisture anomaly at time 0 is large, you can expect (in places) that initializing the land correctly will improve your temperature forecast significantly, and your precipitation forecast slightly, even out to 2 months.

Lessons learned from GLACE-2

1. A clean experiment (every center performs their simulations in exactly the same way) is desirable but is simply not practical:
   -- Different centers have different capabilities.
   -- Because participation is voluntary, individual centers may need to tailor their designs slightly to make them relevant to their own institution's needs.

⇨ Some flexibility on the part of organizers is required to make the experiment a success.

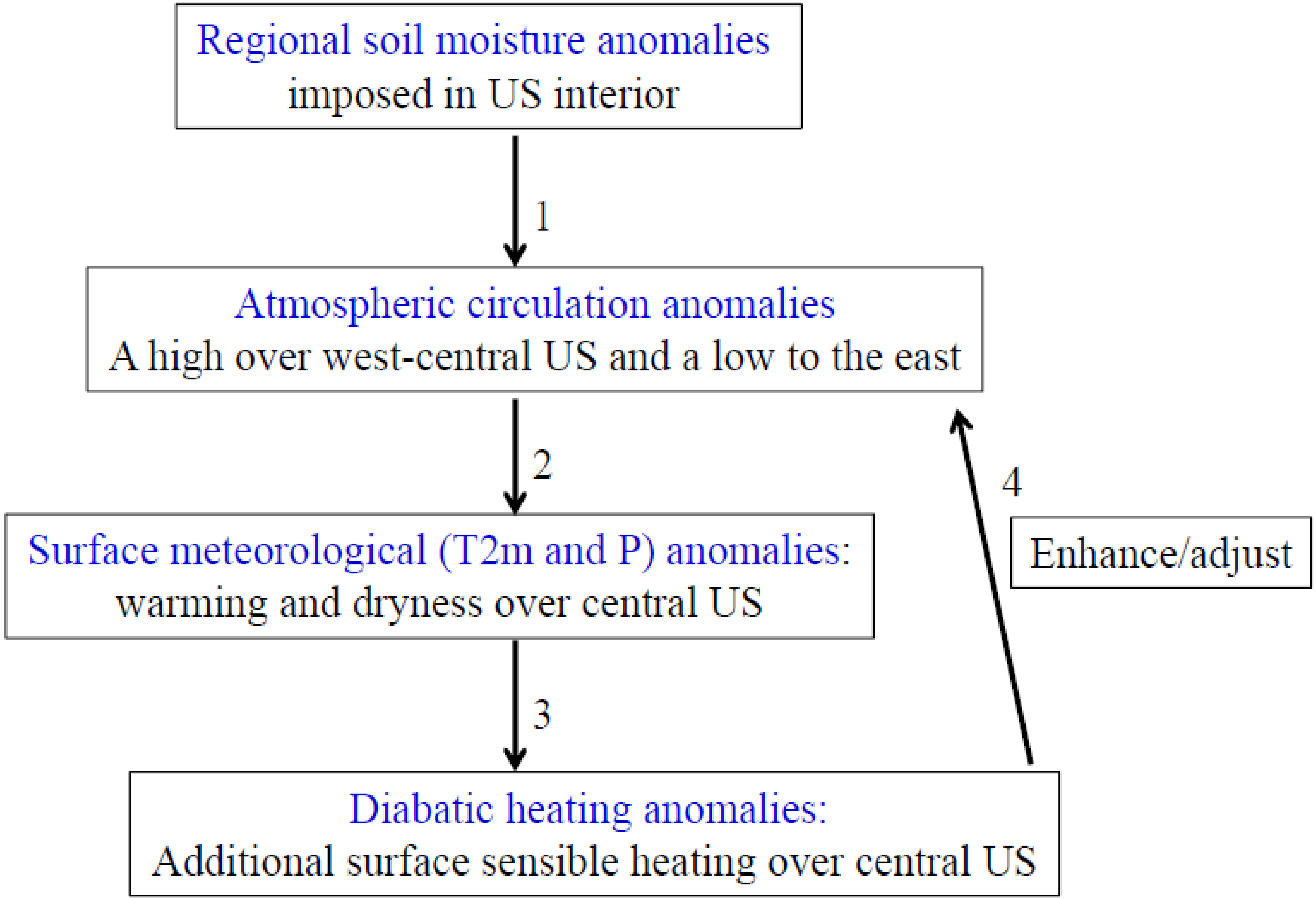
2. Be reasonably complete in the diagnostics requested, but do not be unnecessarily comprehensive.

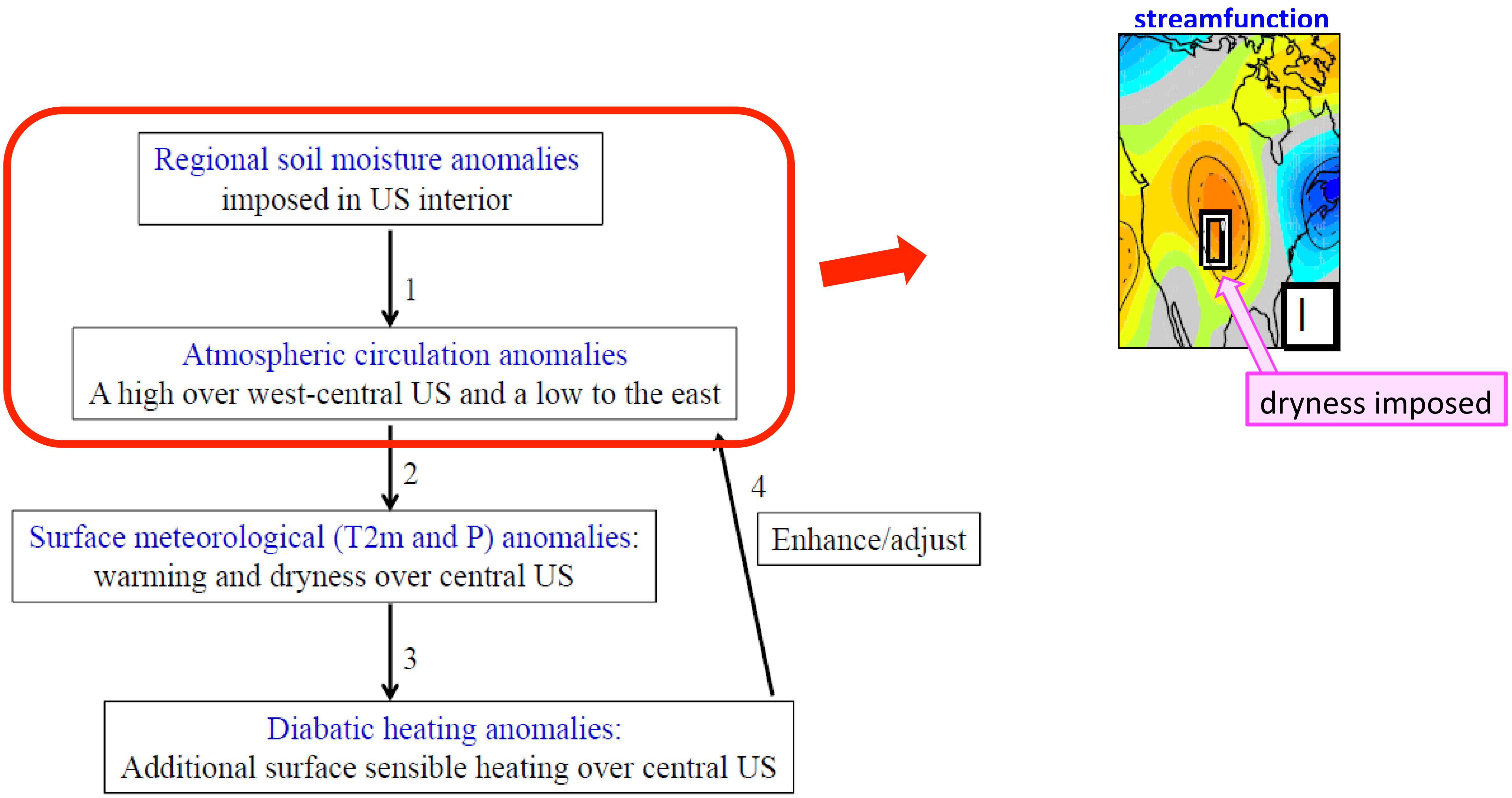
⇨ Know what data you will need before asking for it; don't ask for things "because we might need them, and we should have them just in case".

3. (Obvious!) Validation will only be possible if both the forecasted meteorological variables and the relevant (upstream?) initialization variables are well measured.

Thank you!

This, along with a suite of additional "dry surface" experiments, suggests a feedback loop:




Regional soil moisture anomalies
imposed in US interior
1
Atmospheric circulation anomalies
A high over west-central US and a low to the east
2
Surface meteorological (T2m and P) anomalies:
warming and dryness over central US
3
Diabatic heating anomalies:
Additional surface sensible heating over central US
4
Enhance/adjust
streamfunction
dryness imposed

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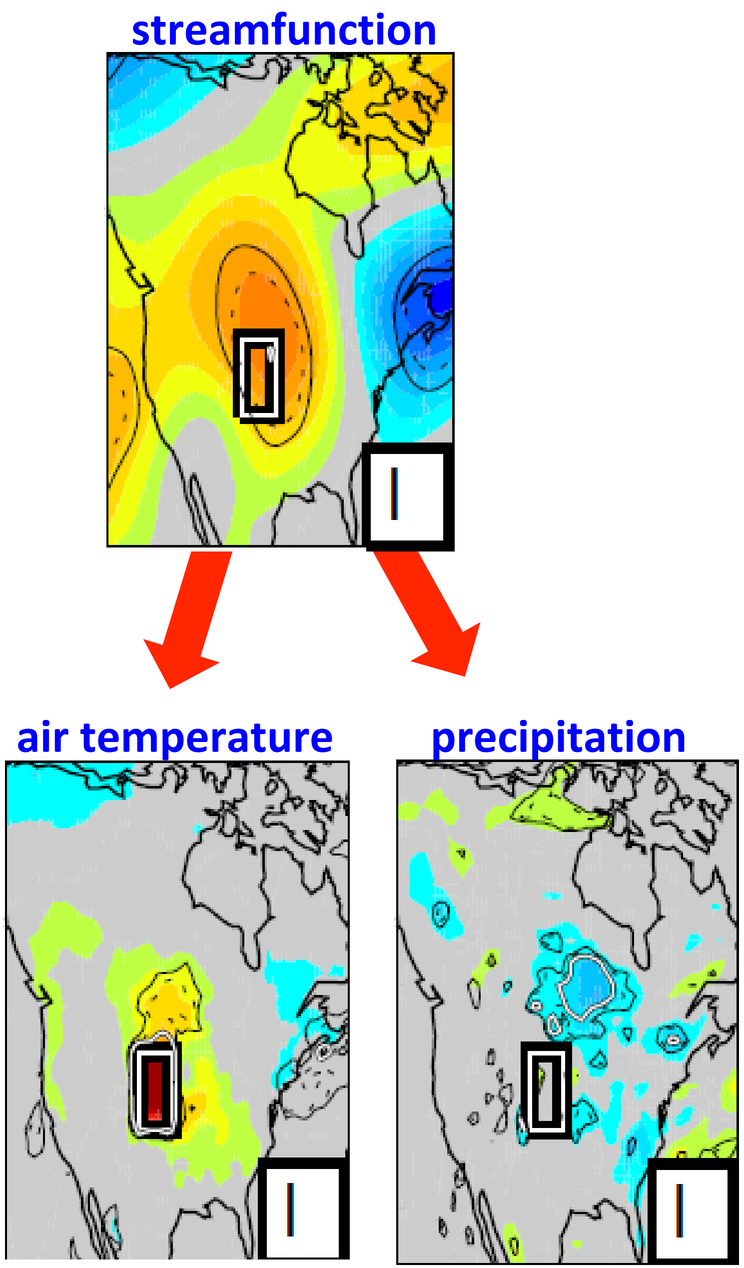

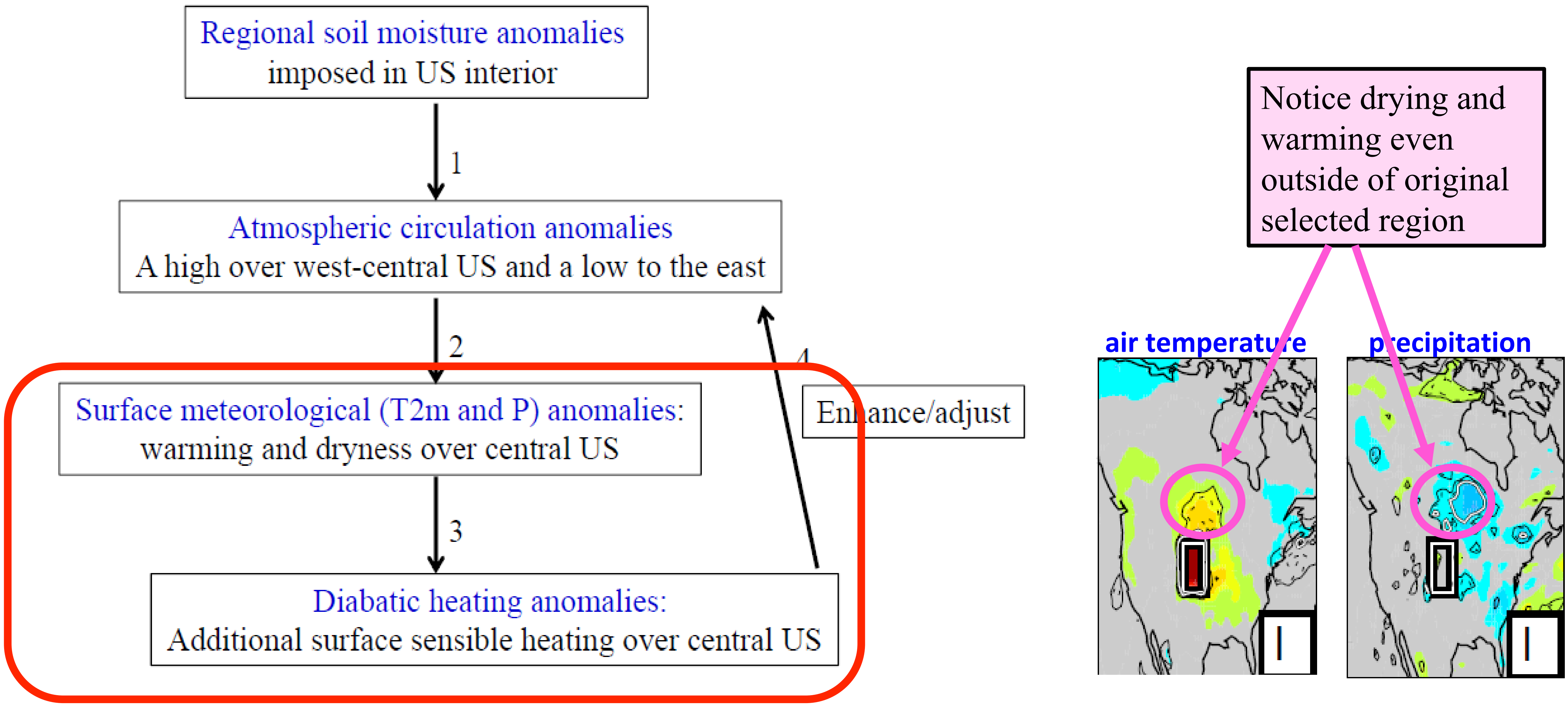
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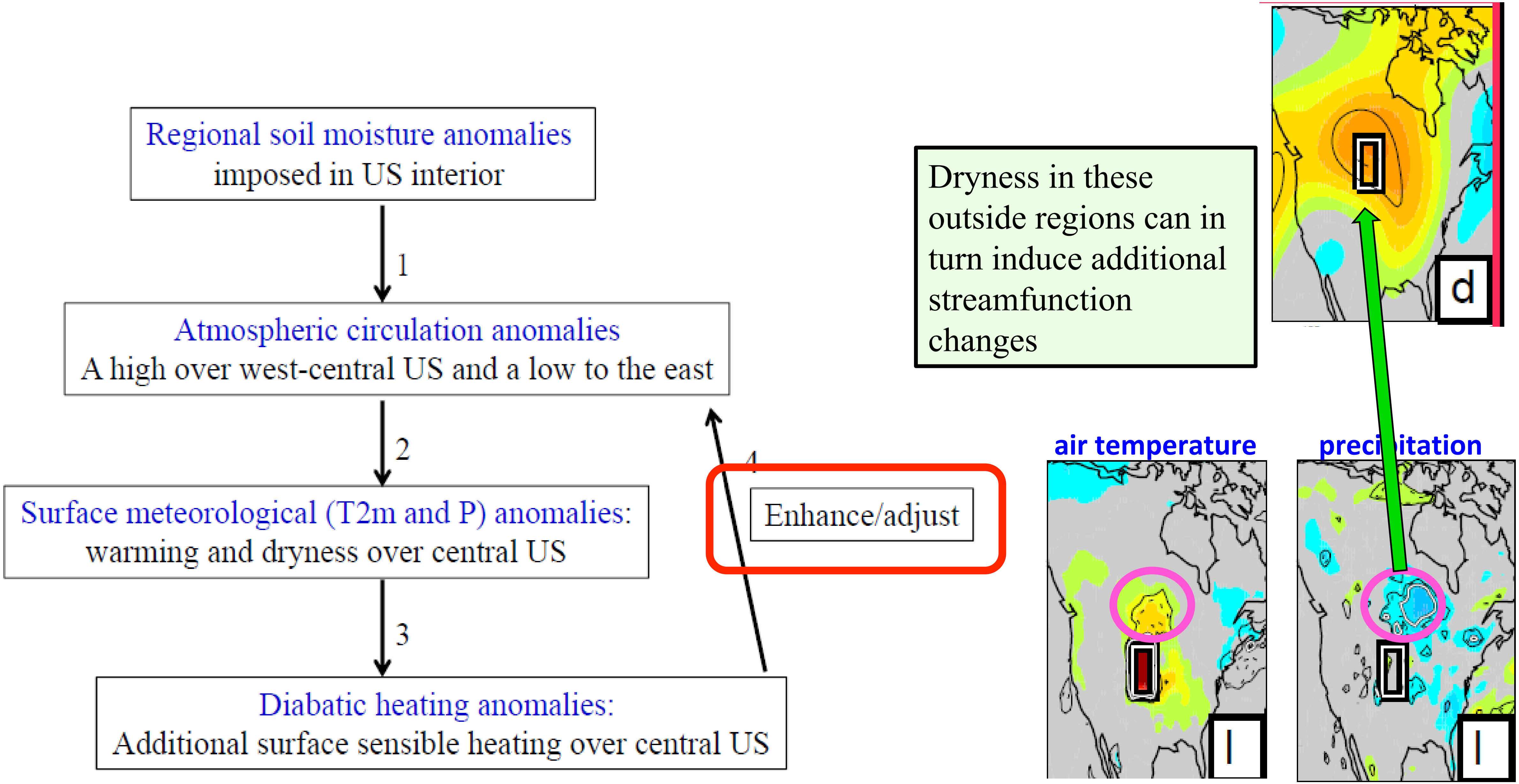
Enhance/adjust
Notice drying and warming even outside of original selected region
air temperature
precipitation



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Enhance/adjust
Dryness in these outside regions can in turn induce additional streamfunction changes
d
air temperature
precipitation